KANE
ENVIRONMENTAL INC

Engineering and Remedial Design Report

Bothell Service Center Simon & Sons
18107 Bothell Way NE
Bothell, Washington
FSID # 33215922

Prepared For:

City of Bothell
18415 101st Avenue NE
Bothell, Washington

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Kane Environmental, Inc. Project No. 82302

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1.0 INTRODUCTION

This Engineering and Remedial Design Report (ERDR) was prepared by Dailey Engineering, LLC and Kane Environmental, Inc. on behalf of the City of Bothell (the City) for the Bothell Service Center Simon & Sons (BSCSS) Site located in Bothell, Washington (the Site). A vicinity map and Site location are shown on **Figure 1**. A draft Remedial Investigation/Feasibility Study (dRI/FS) was prepared and submitted to the Washington Department of Ecology (Ecology) in July 2017 to characterize the Site and evaluate proposed remedial actions to address the contamination and based on that evaluation, propose the most appropriate remedial alternative to clean up the Site. Subsequently, in September 2017, a draft Cleanup Action Plan (dCAP) was prepared for Ecology to describe the proposed cleanup action and to set forth the requirements that the cleanup must meet. The CAP and RI/FS report was issued as final by the Department of Ecology on December 27, 2017.

1.1 Purpose

This document is the ERDR for the BSCSS Site located Bothell, Washington. The general location of the Site is shown in **Figure 1**. An ERDR is required as part of the site cleanup process under Chapter 173-340 WAC, Model Toxics Control Act (MTCA) Cleanup Regulations. The purpose of the ERDR is to provide sufficient information for the development and review of construction plans and specifications. More specifically, this report:

- Identifies who will own, operate, and maintain the cleanup action during and following construction
- Shows existing site conditions and proposed location of the cleanup action
- Describes engineering justification for design and operation parameters, including
    - Design criteria, assumptions and calculations for all components of the cleanup action
    - Expected treatment, destruction, immobilization, or containment efficiencies and documentation on how that degree of effectiveness is determined
    - Demonstration that the cleanup action will achieve compliance with cleanup requirements by citing pilot or treatability test data, results from similar operations, or scientific evidence from the literature
- Identifies design features for control of hazardous materials spills and accidental discharges (for example, containment structures, leak detection devices, run-on and runoff controls)

- Identifies design features to assure long-term safety of workers and local residences (for example, hazardous substances monitoring devices, pressure valves, bypass systems, safety cutoffs)

- Discusses methods for management or disposal of any treatment residual and other waste materials containing hazardous substances generated as a result of the cleanup action

- Discusses facility specific characteristics that may affect design, construction, or operation of the selected cleanup action, including

    - Relationship of the proposed cleanup action to existing facility operations

    - Probability of flooding, probability of seismic activity, temperature extremes, local planning and development issues

    - Soil characteristics and groundwater system characteristics

- Describes compliance monitoring that will be performed during and after construction to meet the requirements of WAC 173-340-410

- Describes construction procedures proposed to assure that the safety and health requirements of WAC 173-340-810 are met

1.2 Authorization / Scope of Work

Kane Environmental's work for this project was authorized under an On-Call Hazardous Materials Services Consultant Agreement with the City dated June 2016. Kane Environmental's scope of work for this portion of the project included:

- Prepare and submit to Ecology a draft RI/FS;

- Prepare and submit to Ecology a draft CAP; and

- Prepare and submit to Ecology a draft ERDR

1.3 Regulatory Framework

The Site is listed in Ecology's database as Bothell Service Center Simon & Sons (BSCSS). The Site is assigned Facility Site ID number 33215922 for dry cleaning solvent contamination in soil and groundwater. The Cleanup Site ID number is 427. The Site is currently under a Consent Decree between the Washington State Department of Ecology, the City of Bothell, and former owners of the Simon & Sons Dry Cleaning property to implement a Cleanup Action Plan for the Site.

2.0 BACKGROUND

The property containing the source of contamination was previously owned by Bothell Service Center Associates (BSCA) and managed by NLO Property Management. The City of Bothell is the current owner of the BSCSS property and the City owns roadways and other parcels adjacent to the BSCSS property (Wexler property and Former Hertz property), which are also part of the Site. The City has a Consent Decree to implement a Cleanup Action Plan for the Site with Ecology and the Attorney General's Office.

A discussion of the physical characteristics of the Site are discussed in the subsections below.

2.1 Location

The BSCSS property address is 18107 Bothell Way NE, Bothell, WA 98011, located at 47.760 degrees north and -122.209 degrees west in Section 7 of Township 26 north, Range 5 east. The King County Assessor's Office lists the parcel number as 237420-0065, which is 0.62 acres in size. The BSCSS property previously included a one-story, masonry, commercial building approximately 8,410 square feet in area, containing five tenant suites. The former building on the BSCSS property and associated aboveground features were demolished in August 2016. The BSCSS property currently contains the concrete at-grade floor of the former building, and the asphalt paving is also still present. Stormwater drains and piping are still functional on the BSCSS property while the sanitary sewer and water lines were disconnected in August 2016. This BSCSS property is located on the northeast comer of the intersection of 98^{th} Avenue Northeast and the former State Route 522. The Site also includes a portion of the vacated State Route 522, and a portion of a parcel south of that. Vacant properties located to the east, south, and southeast of the BSCSS property are owned by the City, and are in the process of being redeveloped. Private residential properties are located to the west and north of the Site. General location of the Site is shown on **Figure 1**. A Site plan is shown on **Figure 2**.

2.2 Historical Uses of Site

According to available information, the former building on the BSCSS property was constructed in 1988, and Simon and Son Drycleaning, a dry cleaning facility, operated in the westernmost tenant suite from approximately 1989 through 1999. In 1999, a release of the dry cleaning solvent tetrachloroethene (PCE) was detected in subsurface soils beneath the former building on the BSCSS property. The detected release of PCE was reported to Ecology by NLO Property Management in a letter dated August 22, 2000. The corresponding and subsequent subsurface investigations and remedial activities conducted on the BSCSS property and vicinity are discussed in Section 1.5 of the RI/FS.

2.3 RI/FS Summary

The BSCSS Site previously contained a former dry cleaners which caused a release of PCE into the soil and groundwater some time prior to 2000. Remedial investigation activities have defined the nature and extent of soil and ground water impacts, which include PCE and its breakdown products TCE, DCE, and vinyl chloride.

Site cleanup levels for soil and ground water are selected as MTCA Method A, or B for COCs with no established Method A value. Points of compliance are as follows:

- Soil

  In accordance with WAC 173-340-740(6), the point of compliance for soil is all soil to 15 feet bgs within the boundaries of the Site.

- Ground water

  In accordance with WAC 173- 340-720(8), the point of compliance for groundwater is all groundwater within the boundaries of the Site.

Based on the results of the remedial investigation and feasibility study conducted under MTCA and the application of the selection of remedy criteria, the preferred alternative, Alternative 2 at the Site (developed in accordance with WAC 173-340-350 through 173-340-390) includes:

- Design and Installation of ERH System and accompanying Bioremediation/Recirculation
- Installation of SVE system
- Limited soil excavation and contingency-based soil excavation
- Engineering controls – depends on building construction schedule
- Institutional controls, if necessary.

2.4 SEPA Information

Information needed to fulfill the applicable requirements of the State Environmental Policy Act (chapter 43.21C RCW) was provided in the remedial investigation/feasibility study. A Determination of Non-Significance was issued by Ecology on November 8, 2017.

2.5 Additional Information

This project is funded by the City of Bothell and with a remedial action grant 50% match by the Washington State Department of Ecology.

3.0 CLEANUP ACTION

Based on the results of the remedial investigation and feasibility study conducted under MTCA (Kane Environmental, 2017a) and the application of the selection of remedy criteria in a Cleanup Action Plan (Kane Environmental, 2017b), the selected remedy is Electrical Resistive Heating/Bioremediation with Groundwater Recirculation, augmented by targeted soil excavation and soil vapor extraction, developed in accordance with WAC 173-340-350 through 173-340-390. The selected remedy will be implemented as the primary alternative for source control and plume remediation.

3.1 Description

During the ERH process, electrodes are inserted across the treatment volume in a triangular 3-phase pattern. Separate phases of electrical power are applied to the three electrodes making up each array, such that electricity flow is directed between each electrode, and a current is fluxed across that volume of subsurface. As site soil resists this flow of electricity, electrical energy is converted to heat energy through an exothermic process, and the treatment volume is brought to the boiling point of the water/contaminant mixture (approximately 100 degrees Centigrade) in a safe and controlled manner.

At a typical ERH site, electrodes are placed on 15 to 18-foot centers and extend to the depth of contaminant impact. Electrodes are constructed in 12-inch diameter borings using 4-inch diameter slotted steel casings. The annulus space in the top 3-feet of each electrode is sealed with Portland cement while the bottom of the electrode is filled with either drilling sand or an electrically conductive backfill of graphite and steel shot. Sand is used in depth intervals where heating is not desired, while conductive backfill is used where subsurface heating will take place.

Electrodes are connected to a vacuum blower and a negative pressure is applied to each electrode wellhead. The particles comprising the conductive backfill are sized so that water, steam, and air move through it in a manner identical to drilling sand. Thus, each electrode acts as a 4-inch diameter vapor recovery well. Because the electrode field extends to the edges of the treatment area, ERH systems provide a very effective vapor and steam recovery mechanism with extraction wells placed on a conservative 15-foot spacing. This arrangement not only allows for the aggressive recovery of contaminant vapors and steam from the subsurface, it also cools the surface of the treatment area during heating.

Installation of the ERH system includes; drilling boreholes, installing electrodes and slotted vapor recovery components in 12-inch boreholes, installation of temperature monitoring probes in 6-in borings placed throughout the treatment volume, as well as equipment staging and the physical connection of all operating equipment (power control unit, transformer, power cables, vapor recovery lines, activated carbon, steam condenser, blower, and cooling tower). Once the electrode and vapor recovery system is constructed, including connection of all electrical and vapor lines at the surface, the system will undergo a two-week testing, shake-down and start-up period, to ensure that the system is constructed to design, and will run properly. Following this shake-down period, the system is slowly brought to full power. Electrical power is supplied continuously to the electrodes through the above grade Power Control Unit (PCU), in order to heat the subsurface at a controlled rate of approximately 1 to 1.5 degrees Centigrade/day. After the target temperatures are achieved during the initial heating period of approximately 45 to 60 days , boiling conditions are maintained throughout the treatment volume for approximately 70 to 90 days, to give a total operational period of approximately 160 to 180 days.

During the entire heating period, the vapor extraction system would be operating continuously. As the soil is heated, contaminant vapor flow in the recovery system would progressively increase as the volatility of the contaminants increases. When the soil temperatures get close to the target, a significant amount of water would start to vaporize, which creates a steam-stripping effect for the volatiles. This steam is subsequently condensed in the steam condenser. Because of the heat and the steam-stripping effect, the removal of volatile contaminants from low-permeability silty soils is much more effective than standard air sparging and soil vapor extraction.

The progress of treatment with ERH is monitored through soil temperature monitoring of the subsurface, periodic collection and analysis of extracted vapors, and soil sampling for treatment confirmation. Thermocouples located at 5-foot intervals spanning the vertical target treatment zone would be used to track the subsurface soil temperature profile as it approaches and attains the target temperature. Air samples collected weekly from the vapor recovery line, after the condenser and before the activated carbon treatment, would be used along with vapor recovery stream flow-rate readings, to track the total amount of volatile contaminants removed from the subsurface as thermal treatment progresses. The soil samples, typically collected at 60, 90, and 100 percent of the thermal treatment cycle, would be used to verify the extent of contaminant removal indicated by the air sampling results. The Soil Compliance Monitoring Plan is further discussed in Section 3.12 and is included in the Engineering and Remedial Design Report as Attachment A.

Remediation of other areas of contamination outside of the electrical resistive heating (ERH) remediation zone and Bioremediation/Groundwater Recirculation will be addressed by targeted soil excavation and disposal, and soil vapor extraction in the vadose zone. Use of additional vadose soil excavation and removal in the source area (ERH treatment zone), engineering controls and institutional controls are included on a contingency basis if the MTCA Method A soil cleanup levels in the vadose zone soils are not met. Furthermore, as a contingency, if groundwater concentrations goals are not met, a vapor barrier, or other vapor mitigation measures, will be implemented in the areas of the building development.

3.2 Parties Involved

Cascade Technical Services Thermal Division (Cascade) was contracted by Kane Environmental to remediate the Source Area at this Site using in-situ thermal remediation (ISTR) through electrical resistance heating. Cascade's scope of work includes installation of wells necessary to implement ISTR. Cascade Drilling was contracted by Kane Environmental for installation of the ERH electrode wells and bioremediation extraction and injection wells. ETEC Advanced Bioremediation Solutions was contracted to install and operate the bioremediation and groundwater recirculation system.

3.3 Existing Conditions

Per MTCA, a "Site" is "any site or area where a hazardous substance…has been deposited, stored, disposed of, or placed, or otherwise come to be located." The RI provides information about the location of hazardous substances from which an informed estimate of the Site boundaries can be made. **Figure 2** shows the approximate extent of the Site as defined by the extent of HVOC in groundwater, primarily the dry cleaning solvent PCE, at concentrations greater than Washington's Model Toxics Control Act (MTCA) Method A groundwater cleanup levels. The HVOC plume originating from the BSCSS property is known to exist beneath the BSCSS property and extend onto adjacent and downgradient properties, including (from up- to down-gradient):

- 98th Avenue NE, located to the west and southwest of the BSCSS property;
- The vacated portion of State Route 522 located immediately south of the BSCSS property;
- The adjoining former Al's Auto Bothell Wexler property to the east, now owned by the City;
- The location of the Bothell Former Hertz Facility (former Hertz property) south of the vacated portion of SR522, now vacant, undeveloped, and also owned by the City.

The results of prior subsurface investigations conducted indicated the following:

- A release of an unknown quantity of PCE occurred at the Site between 1989 and 1999 during operation of Simon & Son Fine Drycleaning, and a residual source of PCE remains beneath the northwest corner of the former structure on the BSCSS property,
- The PCE release(s) affected the soil above and below the water table as well as groundwater at the Site,
- PCE as DNAPL has been encountered on the Site at depths of approximately 45 to 50 feet bgs.

- Groundwater is affected to a depth of at least 50 feet where a silty stratum occurs in the source area, and at a depth of 30 to 40 feet down-gradient and across much of the Site, and

- The groundwater plume migrated across the Site via east and east-southeasterly flowing groundwater across city rights-of-way, and as far as the City-owned Al's Auto Bothell Wexler property and the former Hertz property parcel.

3.3.1 Flooding

According to a map retrieved from the FEMA website, the site is in Zone X, determined to be outside the area of the 500-year floodplain.

3.3.2 Seismic Activity

According to an earthquake hazard map found on the FEMA web site, the site, like the rest of the Seattle metropolitan area, lies in Seismic Design Category D2, corresponding to high seismic vulnerability.

3.3.3 Temperature Extremes

Temperature data are available from the Seattle (Sand Point) weather station, the closet weather station to the site, from 1986 to 2012. During this period, the highest temperature recorded was 105°F, and the lowest temperature recorded was 10°F.

3.3.4 Local Planning and Development

According to data available on the City of Bothell's website, the site is zoned DC (Downtown Core district) and DN (Downtown Neighborhood district).

3.3.5 Soil and Groundwater Characteristics

The Site is located within the Puget Sound Lowland, a north-south trending structural and topographic depression bordered on the west by the Olympic Mountains and on the east by the Cascade Mountains. The area is characterized by gently rolling glacial drift plains covered with small ridges, hills, and depressions formed by the continental ice sheet that covered the area during the Pleistocene Epoch and retreated approximately 12,500 years ago. Most of northwestern King County is mantled by glacial deposits (including gravel, sand, silt, clay, boulders), which are commonly up to and over 150 feet thick (Liesch and others, 1963).

The vacated portion of SR522 immediately south of the Site is located at the mapped contact between alluvial soils associated with the Sammamish River to the south, and glacial soils to the north (HWA, 2012).

Past subsurface assessment work at the Bothell Service Center identified sand and gravel fill with minor silt to a depth of four to ten feet bgs, with native soil consisting of silt and fine sand below the fill. Although these silts and sands are texturally similar to alluvial soils found on the former Hertz property to the south, the higher densities suggest these may be glacially consolidated deposits (HWA, 2012).

Generally, the geology can be described as glacio-fluvial deposits overlain by varying depths of fill material. Additionally, a consistent glacial till unit was present throughout the Site at depths ranging from 46 to 55 feet bgs. The maximum thickness of the till unit was not determined at the Site, but is at least 50 feet thick based on Site borings.

Farallon (Farallon, 2008a) characterized the Site as being underlain by three groundwater zones – Shallow (5-25 feet bgs), Intermediate (25-35 feet bgs), and Deep (35-55 feet bgs). However, the strata containing these zones are discontinuous over short distances and are not separated by confining units; thus, on a local scale, groundwater occurs as a single aquifer flowing southeasterly to discharge points along the Sammamish River.

Horizontal groundwater flow: Horizontal groundwater flow in all zones is generally to the east-southeast, at gradients of around 0.03 feet/foot. Based on a calculated gradient of 0.03 feet/foot across the Site (all aquifers), and hydraulic conductivities calculated from the pumping test analyses, the calculated Shallow aquifer average linear velocity is 0.03 feet per day, and Intermediate/Deep velocity is 1.14 feet per day.

Vertical gradient: The vertical gradient was found to be downward in most areas, except for upward gradients measured at MW-7/MW-12/MW-22; MW-15/MW-20; and MW-6/MW-8/MW-11.

Seasonal trends: Most wells exhibit 2 to 3 feet of seasonal or yearly variation, with higher groundwater levels generally in the spring, and lower groundwater levels in late summer or fall, as typical for this region.

3.3.6 Current Facility Operations

The site is currently vacant, undergoing redevelopment. The proposed remedy is therefore not expected to affect current facility operations.

3.4 ERH System Design Criteria and Engineering Calculations

The overall treatment strategy for the Site is to heat the subsurface to a temperature between 85°C & 100 °C or greater in order to facilitate the reduction of the Contaminants of Concern (COC) mass in soil and groundwater throughout the entire 5,660-sf source zone thermal treatment area and 4,759-cy source zone treatment volume. Energy will be input to the subsurface at thirty-six (36) co-located electrode/VR wells. Spaced at 16-feet on center, these electrodes cover the two Thermal Treatment Zones (TTZs) as shown on **Figure 3**. Subsurface temperatures will be monitored at three Temperature Monitoring Points (TMPs) located across the Treatment Area. Each TMP contains a thermocouple string with sensors set at 5-foot depth intervals. The system components required to implement this strategy include:

- 36 co-located electrode/Vapor Recovery (VR) wells, including an additional northern well.
- Six (6) Temperature Monitoring Points (TMPs) to verify subsurface temperatures. Five of the TMPs are placed at 25 feet bgs within the shallow ERH electrode array and one in placed at 55 feet bgs in the source area.
- An above grade treatment system composed of Cascade containerized equipment, including:
    - A 500-kVA PDS unit
    - A 500-scfm extraction and treatment system comprised of:
        - Skid mounted vacuum blower
        - Condenser skid with an air-to-water heat exchanger and cooling tower
        - Two in-line vapor phase granular activated carbon vessels for vapor stream treatment prior to discharge
        - Liquid phase granular activated carbon for liquid waste treatment
    - Equipment control and data acquisition systems
    - Automated site security and observations systems

The proposed ERH system operating strategy will involve the following steps:

<u>Pre-design Sampling</u>: Prior to finalizing the ERH system design and layout, supplemental soil sampling was conducted just north of MW-9 to ensure performance of the system. The results of this sampling are included in Attachment B. An additional ERH electrode was placed as a contingency to ensure electrode distribution in this area of the Site.

Startup & Commissioning: A two-week period that includes one week of VR operation and one week of joint ERH and VR systems operations.

Operations & Maintenance: Once hydraulic and vapor control have been established, the treatment volume will be heated to the target temperatures within 45-60 days. Assuming a starting temperature of approximately 20°C, this will require a heating rate of approximately 1°C /day, a rate that has been achieved using ERH at Sites featuring similar conditions. Subsurface temperature will then be held at temperature for 70 to 90 days, producing 160 to 180 days of total operations.

- During the operations period, COC mass is reduced through a combination of five remedial processes: vapor phase extraction, steam stripping, heat-enhanced evaporation, thermally enhanced *in-situ* hydrolysis, and thermally enhanced *in situ* biodegradation.
- The first three processes result in the direct extraction of COCs. During the last two processes, COCs are degraded *in situ* to non-toxic daughter products, which will then be removed through vapor phase extraction.
- Ultimately, these five remedial mechanisms will work in concert to reduce the starting concentrations of chlorinated solvents to the Site clean-up goals.

Post Operations: Following the Operations & Maintenance (O&M) period, the Soil Vapor Extraction (SVE) system will be operated for additional 7-days after which time closure sampling will be performed. The SVE system will include at least 12 SVE wells that will be installed in the northeastern portion of the BSCSS property, near the Wexler property where dissolved gasoline contamination has been confirmed to be comingled with the BSCSS HVOC plume (Kane, 2018) at a location adjacent to the east of the BSCSS property and included within the BSCSS Site. The wells will consist of screen from approximately 2 feet bgs to the depth of groundwater, approximately 10 feet bgs. The wells will be placed 15 feet apart in a triangular array to capture PCE previously found in vadose zone soils in this area of the Site. The radius of influence from the SVE wells will extend to address soils located on both the BSCSS and Wexler properties. A combined detailed SVE design, operation and maintenance plan and confirmation sampling plan will be provided in September 2018.

3.4.1 Above Grade Treatment System

Vapor Recovery System Flows

Expected flows from the co-located electrode/VR wells along with the capacity of the vacuum blower for the above grade treatment system are shown in **Table 1**.

Table 1. Flow Rates and Blower Sizing

Electrodes	Flow at Each Wellhead	Estimated Combined Flow (scfm)	Blower Capacity (scfm)
36	10-scfm	360-scfm	500-scfm @ 10"- Hg Vacuum

Anticipated total flow rates are based on the following:

- Applied wellhead vacuum of 2-inches of mercury (Hg) vacuum
- 10-scfm from each electrode/VR wellhead (0.5-scfm/ft of slotted VR well screen)

Flow rates account for the presence of steam expressed as a liquid. The selected blower can provide up to 500-scfm of flow at vacuums up to 10-inches of Hg. We estimate about 5 to 10 SCFM per well with a total flow rate of 180-360 SCFM. Multiplying by the number of minutes in 90 days (129,600 minutes) would give us a volume range of 23,328,000 to 46,656,000 cubic feet of total vapor recovered.

With the treatment volume estimated at 4,944 cubic yards (133,488 cubic ft), this would equate to approximately 175 to 350 total volumes of the entire treatment volumes (including soil, water, pore space).

Power Drop and Energy Demand

Electrical Service requirements for the proposed ERH system are provided in **Table 4**.

Table 2. Electrical Service Requirements

PDS Size	Electrical Service requirements
500-kVA	800 Amps of 480 volt, 3-phase power

The amount of energy (expressed in kWh) that can be input (fluxed) into a given treatment volume over a given time period is a function of the power that can be fluxed through the electrodes (expressed in kW/ft^2 of electrodes) over that time period.

Both the effective surface area of the electrodes and the electrical conductivity of the surrounding subsurface material define the achievable power flux at each electrode. If too much power is fluxed through an electrode in an attempt to achieve a faster heat-up rate, it will experience dry-out, decreasing the conductivity of the surrounding subsurface, and ultimately causing a significant decrease in the electrode's overall efficiency.

Cascade's operational strategy and resulting ERH system design for the Site is based on a heat-up rate of 1°C per day. While it may be possible to achieve a faster heating rate, Cascade has consistently met this heating rate at all of our ERH sites without developing dry-out issues.

The amount of energy required to achieve a given clean-up goal at a specific site is a function of multiple parameters, including; the treatment volume, site hydrology and lithology, contaminant type and concentrations, required clean-up percentage, groundwater flow, and the presence of significant organic materials (sorption effects). All of these factors converge to define the energy density (expressed as kWh/cy of treatment volume) required to reach the set clean-up goals on a given site.

Based on a historic dataset of over 100 completed ISTR projects, along with extensive datasets of Site-specific data, and advanced heat-balance modelling calculations, the advanced Site model algorithm developed for this project has generated a total energy input requirement of 1,829,979-kWh to bring the treatment volume to temperature and achieve Site remediation goals for the source zone. This load of energy will be applied to the subsurface throughout the duration of the ERH project, providing a total energy density of 385 kWh/cy of energy per cubic yard of treatment volume to achieve the clean-up goals for the Site. These numbers are not subjective, but rather a function of site subsurface conditions, physical removal mechanisms, and complex contaminant chemistry, defined by the site specific conditions and overall project goals.

The projected energy requirements for the entire Site ERH system are presented in **Table 3.**

Table 3. Expected Energy Use Rates

Days of Operation	Projected Energy Input (kWh)	Auxiliary Equipment (kWh)	Total Energy (kWh)
158	1,829,979	221,426	2,051,405

<u>Condensate Production and Disposal</u>

About 50% of the condensate produced during ERH is recycled back into the electrodes as electrode saturation water, while the remainder is treated, and subsequently discharged to the Publically Owned Treatment Works (POTW).

The production of condensate will start as the average subsurface temperatures approaches 80°C and will continue through the remainder of the remediation. The expected condensate production and disposal rates for the overall ERH treatment duration are shown in **Table 4.** Depending on Site hydrogeologic conditions and fluctuations in seasonal climatic conditions, total water disposal rates and volumes may vary significantly.

Table 4. Wastewater Disposal Rates and Total Volume

Treated Wastewater Production (gpm)	Electrode Saturation Rate (gpm)	Condensate Disposal (gal)
2.0	1.0	226,671

3.4.2 ERH System Components

ERH systems are composed of three major sub-systems

1. Power Delivery
2. Vapor extraction and treatment
3. Liquid extraction and treatment

Power to the electrode field will be provided by a 500-kVA PDS. A vapor and liquid extraction and treatment system will treat the combined process flow from the 36-electrode/VR wellfield. A generalized process flow diagram for the above grade vapor and liquid extraction and treatment system is shown on **Figure 4.**

The following system components are included in the treatment system:

- Office trailer and sanitation center for use by Cascade Thermal, Kane Environmental, and staff
- Temporary power service from the local utility
- 4-inch diameter conduit for underground electrical cables from power pole
- PDS with climate controlled office spaces
- Utility connections for potable water and condensate disposal
- Fenced equipment compound with gates and proper signage
- Perimeter fencing with gates, including pedestrian barrier topped with chain link fence

- Vehicle barriers consisting of concrete or plastic water-filled jersey barriers
- An automated security system with motion detection and closed circuit TV cameras
- Telemetry systems for process monitoring and control, site data, and site security
- Cloud-Based Graphical User Interface for on-site and remote control
- Dedicated areas for decontamination facilities and waste storage
- Secure storage for materials, supplies, and tools
- Certification that all aboveground electrical equipment is UL listed/labelled
- Certification that all equipment meets 70E Arc Flash requirements

The electrode field for each TTZ will contain the following:

- Electrodes with co-located vapor recovery wells
- Flow control valves at each electrode wellhead
- Instrumented sampling runs at each electrode wellhead
- Electrical cables and fused cable field boxes to reduce cable runs and protect electrodes
- TMPs containing down-hole thermocouples
- Thermocouple field boxes to reduce wiring runs
- Vacuum Monitoring Points (VMPs)
- Automated electrode saturation system
- Vapor conveyance piping with strategic sampling ports

The vapor and liquid extraction and treatment system for the combined wellfield is comprised of:

- A large primary knockout tank for liquid, NAPL, and vapor separation
- Secondary knockout tanks with capacity for liquid, condensate, and vapor separation

- Primary air-to-water heat exchanger with a cooling tower
- A 25-hp process blower, with a design flow of 500-scfm at 10-inches of mercury
- Vapor Phase GAC system capable of handling process flow rate and contaminant load
- Liquid Phase GAC system for waste water treatment
- Secondary containment on all liquid-handling equipment

Cascade Thermal, the ERH contractor, will mobilize, install, operate, and maintain each ERH system component. At the conclusion of the project, Cascade will dismantle and demobilize all system components and return the Site to pre-existing conditions.

Power Delivery Systems

Power to the subsurface, and all auxiliary treatment equipment, is provided by the Cascade PDS. Rated for 100% duty cycle, Cascade's lightweight PDS' weigh less than 20,000 pounds. Manufactured by Cascade, PDS units are contained inside secure, weather tight, and temperature regulated 40-foot ISO boxes that provide ample office space for on-site staff. They are UL Listed and meet National Fire Prevention Association (NFPA) Arc-Flash 70E requirements. Each PDS unit is monitored and controlled by the on-site operations computer, or remotely by staff using computers, tablets, or smart phones.

The 500- kVA PDS selected for this Site can provide independently controlled power input to four (4) separate electrode groupings. This permits the treatment area to be sub-divided into four (4) sub-volumes that can be heated at varying voltages depending on how they react to ERH over the course of the remediation.

Controlled power input to separate sub-regions of the electrode field permits:

- Distribution of power to the different sub-volumes at levels that match their unique electrical conductivity. This is important, because there can be significant changes in electrical conductivity across a large treatment area.
- Balance power input to ensure that each sub-volume is heated evenly without one part of the treatment volume taking more power per cubic yard than the other parts.
- Adjust power input as the treatment sub-volumes dry out and subsurface electrical conductivity changes.

Backup Power System and Protocols

In the case of a Site-wide power failure, application of power to the subsurface stops and the creation of steam in the subsurface will cease almost instantly. Operations staffs are automatically notified with the alarms and commands being accomplished using energy from the redundant uninterruptable power supplies in the PDS.

A backup diesel generator, with an automatic transfer switch, will keep the liquid and vapor extraction and treatment systems, the security and Site camera systems, the data collection, and the telemetry-communication systems operational until Site power is restored.

Site Communications

Site communication systems include a dedicated high-speed Internet service and a secure Ethernet hub. The management of heating, security, auxiliary equipment, and data collection is run through the Programmable Logic Controller (PLC) located in the PDS. System components communicate with the PLC using either Ethernet net cable or high-speed Internet. From the PLC, Site data is available to project staff over secure Internet connections to their computers, tablets, and smart phones

Graphical User Interface

The Supervisory Control and Data Acquisition (SCADA) system on each PDS allows automated monitoring and control of the entire treatment system, including auxiliary equipment and Site security. A dedicated and secure ACP Thin Client server houses a customizable Graphical User Interface (GUI) for each PDS. A Virtual Private Network (VPN) tunnel provides direct and secure communication between the PDS and the Thin Client server.

Built on a Rockwell Automation backbone, this GUI set-up allows increased capabilities, reliability, security, and speed compared to the configurations typically utilized in the environmental remediation industry. A Certified Rockwell System Integration team maintains the Cascade SCADA and GUI systems.

System Controls and Interlocks

Equipment diagnostics, controls, and alerts for the entire remediation system are processed through the PDS computers. Remote operators can turn the PDS on or off, monitor and change applied power levels at the electrodes, adjust pump and blower speeds, check and adjust tank levels, view subsurface temperatures, and reset system and security alerts.

Automated system alerts are provided for condenser and vacuum blower shut downs, transfer pump failures, excessive phase currents, overheating of components, open doors, and high or low tank levels.

Automated system controls turn off power to the electrodes, while maintaining vapor recovery operations, if a shutdown condition occurs. Project staff receives these notifications 24/7 by computer, tablet, and smart phone. Once sent, alerts continue every 30-second until they are acknowledged.

Most system alert issues can be corrected remotely by altering operating parameters or can be addressed by on-site staff during their next scheduled work shift. More severe system faults may require that portions, or all, of an electrode field be shutdown. In this case, operations staff defaults to critical response mode to ensure that subsurface heating is restarted as soon as reasonably possible.

3.4.3 Expected Effectiveness

Although the ERH treatment is expected to attain MTCA cleanup levels for groundwater and soil under optimal conditions, a remediation level of 1 ppm PCE in soil will be set as a targeted remediation goal for this component of the cleanup. If this is not met at the end of the treatment schedule, a decision can be made to either extend the duration of thermal treatment for a limited time or implement a contingency involving targeted vadose soil excavation in the ERH treatment area. Following this step, residual soil and groundwater contamination in the ERH treatment area will be addressed by engineered and institutional controls using an environmental covenant. Similarly, other areas of the site containing residual contamination not in compliance with cleanup levels despite remediation efforts in the CAP (bioremediation, groundwater treatment and recirculation, SVE) will also have engineered and institutional controls (environmental covenant) in order to be protective.

3.4.3 Compliance with Cleanup Requirements

ERH is a proven technology capable of achieving tremendous contaminant mass removal in a relatively short duration when compared to other remedial techniques. Since the technology was brought out of Battelle and into commercialization in the late 1990’s, hundreds of Sites have been successfully remediated using this ISTR technology, ranging from relatively easy chlorinated solvent sites to complex sites featuring recalcitrant compounds and demanding site features. When applied correctly, this technology has a 100% success rate, and is capable of reaching even the most stringent clean-up goals.

3.5 Materials to be Treated

The characteristics, quantity, and location of soil and groundwater to be treated are discussed in this section.

3.5.1 Chemicals of Concern

As identified in the RI/FS, chemicals of concern (COCs) in Site soil and groundwater are halogenated volatile organic compounds (HVOCs), primarily:

- Tetrachloroethene (PCE)
- Trichloroethene (TCE)
- Cis-1,2 Dichloroethene (cis-1,2 DCE), and
- Vinyl Chloride (VC)

3.5.2 Impacts to Soil

HVOCs in concentrations exceeding MTCA Method A and B cleanup levels occur in soil beneath, and to the west, southwest, south, east, and southeast of the former structure on the BSCSS property as shown on **Figure 2**. Impact to soil is discussed in greater detail in the RI/FS.

HVOC concentrations generally decrease with depth and distance from the source. The volume of soil, including porewater, to be treated is estimated to be 4,759 cubic yards.

3.5.3 Impacts to Groundwater

To assess impacts to the Site and determine the extent of impacts requiring remedial action, groundwater sample analytical results were evaluated with respect to the following criteria:

- MTCA Method A Cleanup Levels for Groundwater (MTCA Table 720-1);
- MTCA Method B Non-carcinogenic Groundwater Cleanup Levels.

HVOC contaminated groundwater extends to depths up to 55 feet bgs beneath the BSCSS property, horizontally to the south and southwest beneath 98th Avenue, to the southeast and east-southeast beneath the vacated SR522 roadway onto the former Hertz property, and east onto the former Wexler/Schucks property, as shown on **Figure 2**. Impact to groundwater is discussed in greater detail in the RI/FS. The volume of groundwater to be treated is estimated to be 224,864-gallons, assuming an average sediment porosity of 0.3 and a static groundwater level of approximately 10-ft bg.

3.6 Proposed Construction ERH, BioRemediation and SVE Systems

An array of ERH wells will be installed in the area of the former dry cleaning operation, and will extend to the west along the east side of 98th Avenue NE, south beyond the former BSCSS building footprint, and east to approximately half the distance of the former BSCSS building footprint. The proposed locations of wells and other ERH equipment are shown in **Figure 3 and Figure 5**. A diagram of the shallow ERH electrodes is included as **Figure 6**, a diagram of the deep ERH electrodes is included as **Figure 7**, and a diagram of the ERH temperature monitoring probes is included as **Figure 8**. The ERH system will operate for approximately six months.

Concurrently, injection and extraction wells will be installed in the remaining area of the PCE plume. The injection wells will place a bioremediation product into the subsurface groundwater, and at the same time, remove groundwater from edge of the plume **(Figure 10).** This will create groundwater recirculation cycle will be controlled by pumps located in an aboveground trailer. The extracted groundwater will be run through activated carbon, and then this clean groundwater will be amended with the bioremediation product, and re-injected into the groundwater. The installation of the bioremediation/recirculation system will occur approximately one month after startup of the ERH system. **Figure 10** shows the well installations locations and Attachment C provides the equipment diagram for the bioremediation/groundwater recirculation system.

Groundwater performance monitoring will be conducted during both activities (ERH and Bioremediation). There is also an area of PCE contaminated soil in the eastern portion and adjacent to the east perimeter of the former BSCSS building (along the western portion of the Wexler property), that will be removed by soil vapor extraction (SVE). The SVE system will be installed in September 2018. **Figure 11** showing the SVE well installations and equipment layout for the SVE system prior to its installation is provided. The SVE system will operate for approximately six months. Also, localized, targeted soil excavation of PCE contaminated soil will be conducted in near-surface soil in the eastern area of the former BSCSS building footprint that was identified during site characterization. Limited soil excavation will occur at the time of the SVE installation.

3.6.1 Design Features – Hazardous Materials

All Cascade thermal treatment equipment is containerized and built with secondary containment on all liquid handling equipment. Secondary containment also features sensors to trigger alarm commands if any liquid spills are detected. Operations staffs are automatically notified with the alarms and commands being accomplished using energy from the redundant uninterruptable power supplies in the PDS.

3.6.2 Design Features – Safety

The project site is fenced along the road and property/Site boundaries. During site activities, Cascade Thermal will comply with federal and state laws and regulations when handling, storing, or transporting hazardous and non-hazardous wastes. All site personnel involved with operating, constructing or sampling the treatment system will be 40-hour Hazardous Waste Operations Response trained in compliance with Occupational Safety & Health Administration (OSHA) 29 Code of Federal Regulations (CFR) 1910.120, and possess a valid annual certificate to perform on-site activities. A copy of these certificates for project personnel will be maintained on-site.

Site personnel will also be trained in all phases of environmental protection and pollution control. The Cascade Site Manager and Cascade Project Manager will conduct a review meeting and awareness debriefing discussing the Spill Prevention and Containment Plan and site pollution control with the field crew prior to initiating site work for system installation activities, and again prior to initiating system operations. The ERH system Spill Prevention and Containment Plan is included, along with the ERH HASP, in Attachment E. Monitoring for fugitive air emissions will be performed at selected sites along the site boundary and at the exhaust stack of the air/vapor treatment system.

Monitoring will be conducted to assess the concentrations being released, determine the potential for measurable COCs to reach the project perimeter, and ensure that the air emissions are meeting the project air discharge permit requirements in accordance with the terms of the substantive requirements of the Puget Sound Clean Air Agency (PSCAA). The ambient source impact levels (ASILs) are presented in Table 5 below.

Table 5. Ambient Source Impact Levels

Chemical Name	ASIL (µg/m^3)*	Averaging Time
TCE	0.59	Annual Mean
DCE	2,600	24-hour Mean
PCE	1.1	Annual Mean
TCA	6,400	24-hour Mean
VC	0.012	Annual Mean

* - micrograms per cubic meter

Further descriptions of ERH System components and safety features can be found in Section 3.4.2 of this document.

3.6.3 Design Features – Seismic

ERH System Engineering Controls to Address Potential For Seismic Events

During an earthquake it is impossible to determine the type and extent of damage the ERH Site would receive. However, in the event of regional seismic activity with large enough impacts to disturb operations, Cascade has operational and engineering controls in place to mitigate health and safety concerns as well as help prevent unnecessary damages.

Engineering Controls

In case of a Site-wide power failure during a seismic event, application of power to the subsurface stops and the creation of steam in the subsurface will cease almost instantly. Operations staffs are automatically notified with the alarms and commands being accomplished using energy from the redundant uninterruptable power supplies in the PDS. A backup diesel generator, with an automatic transfer switch, will keep the liquid and vapor extraction and treatment systems, the security and Site camera systems, the data collection, and the telemetry-communication systems operational until power is restored.

Equipment diagnostics, controls, and alerts for the entire remediation system are processed through the PDS computers. Remote operators can turn the PDS' on or off, monitor and change applied power levels, adjust pump speeds, check tank levels, view subsurface temperatures, and reset system and security alerts.

Automated system alerts are provided for condenser and vacuum blower shut downs, transfer pump failures, excessive phase currents, overheating of components, open doors, and high or low tank levels. Automated system controls turn off power to the electrodes, while maintaining vapor recovery operations, if a shutdown condition occurs. Project staff receives these notifications 24/7 by computer, tablet, and smart phone. Once sent, alerts continue every 30-second until they are acknowledged.

Most system alert issues can be corrected remotely by altering operating parameters or can be addressed by on-site staff during their next scheduled work shift. More severe system faults may require that portions, or all, of an electrode field be shutdown. In this case, operations staff defaults to critical response mode to ensure that subsurface heating is restarted as soon as reasonably possible.

In the case of an unforeseen seismic event, the electrode field can be de-energized and all operating systems can be controlled remotely to shut down unnecessary functions, and ensure that all necessary activities such as vapor recovery continue to operate.

Furthermore, Cascade routinely constructs its ISTR systems using tie-downs and secure fasteners to help mitigate any unnecessary risks associated with taller equipment being able to fall. For the Bothell Service Center Simon & Son ERH project, an equipment with the potential to fall over during seismic events will be securely fastened using a network of robust tie-downs, securely connecting the equipment to the ground surface.

Health and Safety

Cascade has designed, built and operated numerous ISTR systems in areas at high risk for Seismic events. Cascade routinely incorporates an earthquake and seismic event specific section in the project

Health and Safety Plan (HASP) to mitigate potential risks to our staff and all personnel who could potentially be on-site during an event. The intent of these specific sections in the Site HASP are to provide a preconceived plan of action and an educational resource for all project personnel.

3.6.4 Construction Health and Safety

Environmental protection is the prevention and control of environmental pollution and the reduction of habitat disruption that may occur to soil, groundwater, biological, and air resources during the remedial activities. Site personnel to the extent possible will manage or reduce the impact to visual aesthetics, noise, solid, chemical, gaseous, and liquid wastes.

Site equipment, the remediation system and its components proposed to be operated for this contract will be operated to the extent possible to have a minimal impact on the environmental resources within the project boundaries. Cascade will confine work activities to the project and treatment areas as defined by contract specifications. The specific treatment areas and associated work areas will be clearly marked by Cascade. Project tasks will not require disturbance of areas outside the site boundaries.

Cascade's project management team will hold daily on-Site safety meetings at the beginning of each work day for all project personnel to ensure the continued protection of health and safety throughout the project duration. A HASP for the ERH system installation and construction is included as Attachment E.

3.6.5 Waste Management and Disposal

Waste Management Areas

Non-hazardous solid waste will be placed in dumpsters or other appropriate containers with lids. Dumpsters will be emptied on a regular basis. Cardboard, paper, and plastics will be segregated from other debris and disposed at the base recycling facility. Construction debris and other non-hazardous debris generated during site operations will be disposed accordingly and recycled to the extent possible. Handling and disposal of site debris and waste will be conducted to prevent further or additional contamination of the soil and groundwater at the site.

Additional segregation and handling procedures will be implemented so that hazardous or toxic waste will not be co-mingled with non-hazardous wastes. The containers of hazardous wastes will be labeled and stored in a designated location for transport to an appropriate disposal/recycling facility.

Non-hazardous solid waste hauling and disposal will be performed in accordance with applicable Washington State regulations. Disposal of any undefined or questionable waste stream will not be conducted until the appropriate analysis and characterization are completed.

Three waste management areas will be established for the project:

- A decontamination pad
- A drilling waste storage area
- A sanitation center

Kane will need to designate a flat area for waste storage. It should be large enough to hold at least one 20-yard tip bins for soil and five (5) 55-gallon DOT drums holding decontamination water, which will be provided by Cascade.

Sediment and Erosion Control

Soils

Most of the remediation area is currently covered by either concrete, foundations, or asphalt.

Planned Erosion and Sedimentation Control Practices

Disturbance to the existing surface cover during ERH system installation, operations and demobilization will be limited to:

- Placement of ERH system electrodes and wells using standard drilling practices
- Trenching for project-specific water, wastewater, natural gas, and electrical utility lines

Because disturbance to the existing surface covering will be limited to subsurface drilling and shallow trenching, the project will not affect existing erosion and sedimentation rates at the Site. Drilling and trenching activities in the TTZs could cause a temporary disturbance to the surface cover. However, these disturbances will be almost immediately re-covered to match the surrounding surfacing materials. The net result will be no changes to current Site drainage or erosion patterns.

Proper controls will be put in place to minimize the release of sediments during field activities. At a minimum, Cascade will:

- Contain excavated non-hazardous material to prevent run-off and spread of sediments
- Contain any materials used for re-surfacing to prevent run-off and spread of sediments
- Containerize all potentially hazardous materials in covered tip bins and DOT drums

Erosion and sedimentation control systems will be inspected daily and any issues will be resolved in a timely manner.

Noise Control

Cascade's Site equipment is contained in metal enclosures for security, weather protection, and noise abatement. Enclosures are designed and constructed to ensure that the Occupational Safety and Health Administration (OSHA) levels for 8-hour noise exposure without hearing protection (85 dBA from a distance closer than or equal to 5-ft from the source) is not exceeded at their immediate exteriors. It is Cascade's long-standing practice that all of the *in situ* thermal treatment equipment produced and used in Cascade ISTR projects adheres strictly to these noise specifications. To help minimize noise at the fence line, equipment is staged so that low noise skids are used to shield possible receptor locations from higher noise skids.

Dust Control

Standard practices to minimize spreading dust and debris beyond the work areas include:

- Wet open soil and roadways, as necessary
- Keep soil stockpiles covered
- Remove excavated soil and drilling cuttings from the work area on a daily basis and either:
    - Properly stockpile them
    - Place them in covered tip-bins
    - Place them in DOT drums
- Collect trash for sorting into recyclables throughout the day
- Place trash and recyclable in proper collection bins
- Use vegetation and mulch to temporally cover open areas, as needed
- Use barriers and fencing, such as wattles, to contain wind-blown dust, as needed

3.7 Quality Control

Prior to the ERH system start-up and operations, a series of quality assurance and quality control (QA/QC) checks are completed known as commissioning. Commissioning is a process used to test that systems components have been installed properly and can perform according to design intent. During construction and prior to commissioning, checklists are completed for proper operation of the following equipment:

- In-situ thermal heating
- Groundwater treatment
- Vapor, steam, and air treatment
- Process control and monitoring
- Site security systems
- Permitting and regulatory compliance

The commissioning process will be considered incomplete if deficiencies in component operations, permitting, or regulatory compliance prevent the team from agreeing on acceptance.

3.8 Bioremediation and Groundwater Recirculation System Approach

3.8.1 Process Overview

The groundwater recirculation system is an automated, programmable treatment process to extract contaminated groundwater, run the groundwater through activated carbon to remove HVOCs, add a remedial substrate (bioremediation), and reinject the groundwater/substrate mixture back into the aquifer (Attachment C). This recirculation provides a continuous supply of remedial substrate to be utilized by the established microbial community responsible for the Reductive Dechlorination (RD) process. Through operating injection vertical wells in conjunction with vertical extraction wells, artificial groundwater gradients can be produced within a groundwater plume to induce the cycling of biologically-active and remedial substrate-rich treatment water uniformly throughout the contaminated zone. In addition, the substrate injections promote desorption of the majority contaminant mass present on the soil matrix, thereby dissolving this mass into the groundwater and furthering the overall RD remedial process. The microbial community responsible for RD requires dissolved contamination as mass adsorbed to the soil matrix is not readily bioavailable to these microbes. The recirculation loop has the added benefit of providing a degree of hydraulic control to mitigate downgradient migration of the contaminated groundwater plume.

One groundwater recirculation system will be installed and used to operate in the Shallow, Intermediate and Deep portion of the aquifer at the same time. In addition, when the system is initially turned on and the extraction pumps are all extracting, groundwater elevations will be collected to evaluate the degree of communication with key monitoring locations and radius of influence.

The ultimate goal is to obtain contact between the substrate and the >95% chlorinated solvent mass sorbed to the organic fraction of the soil matrix in order to stimulate ERD where the bulk of the contaminant are sorbed. Without contact there is no reaction. Therefore, delivery of the substrate to the subsurface is paramount, which is why a groundwater recirculation approach was selected. Slug injections fail to achieve effective contact due to the generation of preferential flow pathways, while a long-term recirculation approach minimizes this problem. By inducing hydraulic gradients via injection/extraction, a user can push/pull the amended groundwater to any location desired, even under existing buildings/roads. The most transmissive zones in the saturated zone will be the first to receive the amended groundwater, which will cause microbes to grow in the effective pore space. As they grow in the pore space they foul it with biomass, reducing the effective porosity in that zone, and facilitating fluid transport to the less transmissive zones.

The initial substrate, Carbstrate product, initiates the ERD process and causes the bulk of the pore space to be lightly fouled with biomass. Prior to any remedial activity on site, a round of groundwater bio-sampling was conducted to determine the baseline concentrations of bacteria present at the Site. Results of the bio-sampling reported relatively low concentrations of bacteria and are included in Attachment B. After three months of system operation, groundwater analytical samples will be collected, and a second round of bio-sampling and analyses of quantitative polymerase chain reaction (qPCR) and key functional genes using the **QuantArray®-Chlor Approach** will be conducted to compare the bacteria concentration relative to the baseline results. A 1×10^4 cells/mL or lower Dhc criterion will be used to assess if bioaugmentation is needed or not. Dhc concentrations higher than 10^4 cells/mL will be interpreted to indicate moderate to high concentrations of *Dehalococcoides* exist that can be associated with observable or significant dechlorination activity. Based on analytical results, bioaugmentation of the Carbstrate with bacteria will be conducted. An enhanced in situ bioaugmentation work plan will be submitted to Ecology for approval before implementation. A professional microbiologist with experience in bioremediation will be involved in deciding if bioaugmenation is needed and in writing and executing the work plan for bioaugmentation. At the end of the system operation, substrate addition ceases, causing the microbial death rate to increase, and the dead biomass begins to decay. This biomass then becomes a secondary, long-term substrate that sustains ERD for at least 1.5 - 2 years due to the rotting/decaying biomass generated from the substrate (behaves like an electron donor). Academic literature (Yang and McCarty, 2004) supports this concept that decaying biomass yields better ethene/ethane generation rates than primary substrates like lactate or soybean oil. It should be noted that dead/rotting biomass is not the source of substrate. The carbohydrate (i.e. sugar, lactate, etc.) is the primary substrate, which is converted into biomass over time as the bacteria grow/reproduce on the primary substrate. Once the primary substrate is completely consumed, the bacteria begin to die off due to the lack of a carbon/energy source. The bacteria can actually utilize some of this dying cell mass as a secondary substrate. Almost all natural subsurface saturated zones have very low foc/organic carbon fractions. It is extremely rare to have a high enough foc in a saturated zone to stimulate any effective anaerobic dechlorination. The chlorinated solvent plume typically has to be co-mingled with a highly soluble carbon/energy source, like a TPH plume or sewage/wastewater from a septic field before significant dechlorination can occur. Sorbed foc mass isn't readily bioavailable, unlike a highly soluble TPH or sewage plume.

Chlorinated solvent retardation rates decrease from PCE to VC, so there will be varying rates of contaminant migration towards the extraction wells. Typically, cis-DCE and VC are observed at higher concentrations at the extraction well locations due to their higher solubility values and lower sorption coefficients. Each location is going to have its own unique baseline conditions, and we will be plotting the VOC data over time to evaluate contaminant transport/breakthrough and biotransformation at all locations. The main benefit of anaerobic dechlorination is that it enhances the desorption of the VOCs, making them more soluble and bioavailable.

One potential risk with this method is the possibility for biofouling, which occurs when bacteria, supported by the injected substrate, accumulate and grow around the well screen, inhibiting the productivity and function of the well. However, the proposed recirculation system is designed with precautionary measures and operational procedures in place to prevent biofouling, by adding the substrate using weekly injections, not on an on-going basis.

3.8.2 Substrate

Carbstrate™, a nutrient-amended carbohydrate amendment, will be applied as the electron donor substrate. Its qualities include high water solubility, no particulate matter, low viscosity, and a low retardation factor in order to ensure mobility within the target treatment zone. If the substrate has a low solubility or significant retardation factor, then delivery via induced hydraulic gradients would require multiple pore volumes of recirculation prior to achieving site-wide delivery. In addition to its solubility and low-retardation factor, it is a non-toxic, food-grade product that includes the macro-nutrients that will be necessary for effective microbial growth (i.e. nitrogen and phosphate) as well as a specific suite of trace metals that have been shown to be critical for active anaerobic microbial activity. It is also a dry substrate, which helps prevent fouling of injection points and equipment components.

3.8.3 Substrate Concentrations

The proposed remedial approach is to pulse-inject a nutrient-amended carbohydrate to a re-circulating groundwater system to overcome the terminal electron acceptor (TEA) sinks (i.e. dissolved oxygen, nitrate, sulfate, etc.) and create sulfate-reducing and/or methanogenic conditions throughout the desired saturated zone. Either of these conditions will promote the transfer of electrons to the chlorinated solvents, which will reduce their concentrations and remediate the target area. The Site-wide delivery of the substrate throughout the saturated zone will be optimized via groundwater recirculation facilitated by the automated system.

The proposed system will *pulse-inject* a higher concentration of nutrient/carbohydrate-amended groundwater throughout the target zone (saturated and smear zones) to achieve a 50-200 mg/L TOC concentration. This concentration of TOC has been shown to be the effective concentration to achieve robust anaerobic dechlorination. The goal is to not only fully dechlorinate the minor mass of chlorinated solvents dissolved in groundwater, but also fully dechlorinate the majority of the chlorinated solvent mass sorbed onto the organic fraction in the soil as it partitions into the groundwater.

3.8.4 Groundwater Recirculation System

This section describes the groundwater recirculation pilot system to be installed and operated at the Site. This full-scale system will include: a remediation equipment enclosure; vertical injection wells; vertical extraction wells; monitoring wells; and conveyance/conduit lines.

The drawdowns observed during the aquifer tests indicate that hydraulic control at the BSCA property is feasible at modest pumping rates. The proposed remedial approach will utilize six extraction wells in the Shallow zone, four extraction wells for the Intermediate zone, and four extraction wells for the Deep zone (Figure 11). The remedial approach uses hydraulic control/capture to primarily distribute the substrate across a large area via displacement and advective flow at very low flow rates (<10 gpm total combined flow). The low system flow rate, and programmed injection timeframes in the system, keep injection wells only receiving flow for a limited time (usually a few minutes) before it ceases injection and allows the well to pressurize and sit idle for 15 to 20 minutes. This pulsed, low flow delivery approach is more a volumetric approach that needs to recirculate at least 3 to 6 pore volumes in order to achieve effective distribution/contact of the substrate across the bulk of the impacted soil matrix (where the bulk of the solvents are sorbed) to achieve remedial goals. For the Shallow aquifer zone (dimensions of 150 feet x 100 feet x 10 feet saturated thickness, 0.15 effective porosity), there are approximately 170,000 gallons of groundwater in one pore volume. A recirculation system operating at 3 to 6 gpm will recirculate one pore volume in 0.65 to 1.3 months. Over the anticipated bioremediation remedial timeframe of an estimated 2 to 3 years, the system will recirculate dozens of pore volumes, obtaining a high degree of contact/distribution, without generating significant hydraulic head to drive the plume offsite. Lower groundwater extraction rates in the Shallow zone will not inhibit the remedial process, and will help remediate that upper solvent mass without pulling it deeper (or causing short-circuiting) into the Intermediate zone. Heated water flushing may not be prevented, but it is not considered a major concern. The concern is substrate distribution across a large area under slow flow conditions in the pore space, and active displacement is the only way obtain mixing/contact with the substrate can be achieved.

All extraction wells will be four-inch diameter wells, which will increase the yield and hydraulic control at the BSCA property during full-scale remediation. The bulk of the contaminant mass resides in the Shallow zone, where the groundwater extraction rates were the lowest (<0.2 to 0.6 gpm) and the drawdown was the highest. As mentioned, MW-06 is screened deeper than the other Shallow wells, which is why it had a higher sustainable yield. MW-25 did not yield a sustainable extraction rate at less than 2 gpm (only operated for 4 minutes, yielding 7 to 8 gallons), but it did recharge 6.5 feet in one minute during the recovery phase, showing groundwater extraction at that location with a programmable submersible pump is feasible. A programmable pump will have a dwell time entry to pulse the extraction wells on and off, which could be set at 1 to 5 minutes for this site. If the wells recharge that quickly, they will yield a moderate extraction rate with a fixed system. The larger diameter extraction wells will likely yield at least 0.5 to 1 gpm sustainable pumping rates, and a large radius of influence (ROI) as it is pumped on over a large timeframe. The placement of the three extraction wells on Figure 4 are approximately on 50 foot centers along the western BSCA property line between MW-9 to MW-39, which will provide a high degree of hydraulic control on this end of the plume. The 50-foot centers were chosen based on the lithology and drawdown information. The Shallow zone test showed an influence of at least a 50-foot ROI using a 2-inch diameter well. Based on this data, the hydraulic control in this area will be very high. The extraction wells at 25 feet away will come into competition with the other well, reducing their yields, but providing a higher degree of hydraulic control. If the extraction wells are moved too close together they will start to dewater each other. Therefore, the three proposed extraction wells and their placement are appropriate. These three wells pumping at the same time will create a larger ROI, that will extend beyond the known VOC impacts in the Shallow zone, based on the total observed ROI during pumping tests. In addition, there are three extraction wells distributed to the east and south of the BSCA property to provide hydraulic control and substrate distribution at the distal end of the plume. Both the Intermediate and Deep zones have four extraction wells that are placed in accordance with the contaminant plumes onsite to provide a high degree of hydraulic control/capture. We expect these extraction wells to yield a much higher pumping rate (4 to 6 gpm), and maintain a high degree of hydraulic control/capture. The injection and extraction wells will be secured with fencing. Furthermore, injection and extraction wells located outside the fenced area, to the south of former State Route 522 will be placed below ground with access from at-grade vaults. A project specific Health & Safety plan will be prepared prior to starting the installation of the Bioremediation/Groundwater Recirculation system.

Remedial product injection into the vertical injection wells will be feasible due to the sufficient hydraulic conductivity and medium dense nature of the soils. The ability to extract groundwater at sustainable rates, and then re-inject that groundwater containing the amendments is implementable and appropriate for this site.

The placement of the extraction wells surrounding the injection wells is done in a manner that will provide a high degree of plume containment. With these low flow rates and the highly sorbed nature of the chlorinated solvents, chlorinated solvent mass will not migrate beyond the extraction wells. Extraction wells will be monitored for VOC concentrations. In addition, selected monitoring wells downgradient of the extraction wells will be used as performance monitoring wells for off-property plume migration and treatment. The groundwater compliance monitoring plan is attached with this document, included with the soil compliance monitoring plan (Attachment A).

3.8.5 Remediation Equipment Enclosure

The groundwater recirculation system will be operated using aboveground equipment housed in a secure weatherproof enclosure. The remediation equipment enclosure will be situated on the Site. Equipment contained within this enclosure will include: a 200-gallon poly tank to contain the concentrated Substrate injection solution ("solution tank"); an air compressor; a programmable logic controller (PLC) system; and injection and extraction manifolds, with their respective pressure gauges, ball valves, flow meters and sampling ports. In addition, a 1,000-gallon poly tank to hold the extracted groundwater ("holding tank") and a 150-gallon activated carbon drum will be located immediately outside the enclosure.

The groundwater extraction pumps located in an aboveground trailer, approximately 10 feet long, 8 feet wide, and 8 feet high, will send groundwater from the extraction wells to the pre-treatment holding tank. The pre-treatment holding tank will contain a high/high, high, and low float for logic control. A transfer pump will pump the groundwater from the pre-treatment tank through GAC vessels (in series), and into the post-treatment holding tank (also containing three floats for logic control). The in-situ delivery (ISD) system will pull treated groundwater from the post-treatment holding tank, and amend it automatically using a metering peristaltic pump connected to a small substrate solution/mixing 50-gallon tank located inside the aboveground trailer. The concentrated substrate solution will be metered into the injection header at a specified rate when the system is in the injection mode. The ISD system will inject the groundwater containing the substrate to the desired injection wells, based on set times and rates dictated by the operator.

Drilling and installation of the injection and extraction wells will commence in July 2018. Investigation derived waste (IDW) will be addressed the same as previous sampling at the Site, with most of the soil designated as Contained-In. Documentation for Contained-In soils will be obtained from Ecology prior to removal of any IDW from the Site. The injection schedule, and the performance and confirmation monitoring plans will start in September 2018. Groundwater samples from selected existing wells will be collected in July/August 2018 to establish a current baseline of groundwater conditions prior to implementation in the Bioremediation/Groundwater Recirculation treatment area. The Ecology Site Manager will be contacted prior to any baseline sampling, and notified of any changes in schedules.

When the system is fully operational, the remediation substrate will be added one time per week to the solution/mixing tank via field technicians during their weekly site visits. Based on current activities at the Site, we expect the system to be operational during the Fall 2018. At this time, there are no specific development plans for the Site.

Attachment C provides the general layout of the bioremediation equipment enclosure and presents the process and instrumentation diagram of this bioremediation system.

3.8.6 Well Installations

The bioremediation system will include the installation of vertical injection wells and vertical extraction wells. These wells will be installed by a Washington state licensed well driller. Prior to conducting the well installations, Underground Service Alert (USA) will be notified as required by Washington law at least 48 hours in advance of the field activities.

3.8.7 Vertical Injection and Extraction Wells

Vertical injection wells will be used for the Shallow, Intermediate and Deep portion of the aquifer. The wells will be installed in an array that will provide substrate throughout the entire Shallow, Intermediate and Deep HVOC plume.

Because the existing monitoring wells on Site are either not the proper diameter, or not screened to the target pilot system depths, or not strategically located in the most optimal location, a series of new Shallow, Intermediate, and Deep extraction wells will be installed for the remedial approach. An estimated six new 4-inch diameter Shallow extraction wells (SEWs) will be installed and screened from 5-25 ft bgs. An estimated six 4-inch diameter Intermediate extraction wells (IEWs) will also be installed and screened from 25-35 ft bgs. An estimated four 4-inch diameter Deep extraction wells (DEWs) will be installed and screened from 40-55 ft bgs. Alternatively, intermediate and deep wells may be combined and screened from 25 to 55 feet bgs. The injection and extraction well locations will be sent to the Ecology Site Manager showing actual well locations and depths of screen intervals prior to implementation of the Bioremediation/Groundwater Recirculation system. Injection and extraction wells will not be used for compliance groundwater monitoring. The vertical extraction well locations were selected to correspond for the Shallow portion of the aquifer, and are spaced based on the observed ROIs for each zone during the 2017 pump tests.

The vertical extraction wells will be installed using sonic drilling technology, which advances a non-perforated steel conductor casing, thereby mitigating potential cross-contamination of the aquifer zones. In addition, sonic drilling will limit the exposure of vapors emanating from the open borehole and generated from the soil cuttings. The vertical extraction wells will be constructed in 8-inch diameter borings using 4-inch diameter, Schedule 40 PVC. The screened sections for all zones will be constructed using 0.010-inch machine slotting. Each well will be hung within the center of the borehole, with sand filter pack (#2/12 sand, or equivalent) placed within the annular space as the conductor casing is removed. The sand filter pack will extend 1 ft. above the screen intervals, followed by 1 foot of hydrated bentonite, and then cement to the ground surface. Wells may be completed in a concrete vault depending on location, with camlock fittings installed on the wellheads for connecting with the remediation system's conveyance lines.

The down-hole drilling equipment will be decontaminated following each well installation using a high-pressure rinse. The used decontamination rinse water will be stored within 55-gallon steel drums or a poly tank pending offsite disposal.

Development of the extraction wells will proceed no sooner than 48 hours following the well installation activities to allow time for the cement surface seal to set. Each well will be developed using a surge block to remove the fines from the filter pack. Following the surging, groundwater within each well will be pumped out and monitored for pH, turbidity, electrical conductivity (EC) and temperature. The pumping will continue until these parameters stabilize to within a 10 percent fluctuation or until a maximum of 10 well casing volumes are purged.

Following the completion of the development activities, each well head will be retrofitted to support the extraction equipment. For the pilot system, this equipment will include: a 3-inch diameter, stainless steel submersible pump (Grunfos Redi-Flo3, or equivalent); electrical line; and 1-inch diameter discharge hose.

Furthermore, the soil contamination found in 98th Avenue in the southwestern portion of the site will be remediated using bioremediation injection well.

3.8.8 Groundwater Monitoring Wells

Groundwater compliance wells will be sampled for MNA parameters and VOCs to assess the performance of the remedial action. Groundwater performance samples will be collected from all key monitoring locations throughout the ERH and bioremediation remedial action. Groundwater performance and compliance monitoring is further discussed in Section 3.12.

3.8.9 Conveyance Lines

Below ground conveyance lines will be installed connecting to the injection and extraction wells. The lines will be installed in trenches approximately 16-inches wide by 2 feet deep. The conveyance lines will merge into a common trench near the treatment system compound that will be approximately 3 feet wide by 2 feet deep. These conveyance lines will be constructed using 1-inch diameter PVC pipe electrical conduit for the extraction well pumps will also be included within the conveyance line trenches. Waste material associated with trenching activity, including concrete and soil, will be assumed to be investigation derived waste (IDW). The handling and disposal of IDW is discussed below.

3.9 IDW

Investigation derived waste (IDW) generated from the installation of the remediation system trenching and drilling activities will include drill cuttings from extraction and injection well installation, soil and concrete excavated from the construction of the directional drilling entry pits and the injection trenches, well development water, and decontamination rinse water. This IDW will be stored in either water-proof roll-off containers or 55-gallon drums that will be labeled, and sampled for waste characterization and profiling, and stored on Site pending receipt of the analytical data. It is assumed that the generated IDW may be disposed as Contained-In designation, and some IDW may potentially require disposal as RCRA hazardous waste.

3.10 Permitting

The installation of the ERH and groundwater Bioremediation/Recirculation system will be properly permitted through the appropriate regulatory agencies. An electrical permit will be obtained by from the City of Bothell to install the 100 amp 120/240v single-phase temporary service required for the operation of this system. A right of way permit will be obtained from the City of Bothell to drill and install the electrode wells in 98^{th} Ave NE. In addition, a UIC permit from the Washington State Department of Ecology will be required to re-inject extracted and treated groundwater containing Carbstrate. Completed permits are included as Attachment D.

3.11 Targeted Soil Excavation and SVE System

Limited soil excavation will be conducted during the installation of the remediation systems on the BSCSS property. Limited Soil Excavation has been included in the Preferred Alternative to address any potential additional HVOC soil that may be found during system installations. Soils will be sampled and designated for disposal following Ecology requirements. These limited vadose zone soil excavation locations are the PCE hot spots discussed in the RI/FS report and are shown on Figure 11.

Following thermal (ERH) treatment, confirmation vadose zone soil samples will be collected in the ERH treatment and Bioremediation/Groundwater Recirculation areas to confirm if remediation levels and/or cleanup standards were met in the soil vadose zone source area. This hot soil sampling will be completed following a specific health & safety protocol for hot soil sampling (included as an attachment in the Soil and Groundwater Compliance Monitoring Plan - Attachment A). As a contingency, if soil cleanup standards and/or remediation levels were not attained, targeted vadose zone soil excavation and removal will be carried out to achieve cleanup standards in the ERH treatment area as much as practicable and following a work plan to be approved by Ecology.

A Soil Vapor Extraction system will be installed in the eastern portion of the BSCA property to remediate vadose zone soils contaminated and impacted by PCE, found in proximity to the former BSC sewer line near the sewer manhole to the east of the former building. The SVE wells will be 2-inch diameter PVC to the depth of groundwater. Each SVE well will have an air sampling port to collect air samples either by photoionization detector or Tedlar bags for laboratory analysis. The proposed location of the SVE array is shown in Figure 11, and the actual locations of the SVE wells is dependent on the presence and location underground utility lines, including sewer, fire hydrants, and water lines. No underground natural gas lines are located in the area of the SVE well array.

The SVE system installation will occur following the installation of the Bioremediation system, and air blowers will be connected to electrical power for the Bioremediation system. Health and Safety Plan used for the Bioremediation and Groundwater Recirculation activity will be used. All IDW soils will be disposed of following the same protocol as previous investigations from the Site. Compliance air sampling will be conducted on at a minimum monthly basis until concentrations are synoptic, then confirmation soil sampling will be conducted.

3.12 Compliance Monitoring

Groundwater performance monitoring will be conducted in selected wells during the ERH system operation (see Attachment A). Hot water sampling procedures will be followed. Approximately 4 weeks after the ERH system is disconnected, up to two groundwater performance wells will be installed within the ERH treatment zone to monitoring PCE and its breakdown products concentrations during the treatment activity. The wells will not have to be designed to withstand the heated water or have special surface completions for sampling if installed 4 weeks after system shutdown.

Soil performance monitoring will only be conducted in the area of the ERH system approximately 2 to 3 months after ERH startup and approximately 1 month before estimated ERH system shutdown. Soil samples will be collected in selected areas in the ERH treatment area to determine if the ERH system has reduced PCE, and its breakdown products, to concentrations below their cleanup levels. The soil sampling will be conducted using hot soil sampling techniques following health and safety requirements (included as an attachment in the Soil and Groundwater Compliance Monitoring Plan - Attachment A). Soil samples will be collected and sent to an Ecology-approved environmental laboratory for analysis of Halogenated VOCs by EPA Method 8260. Results at the end of thermal treatment will be evaluated according to whether the remediation level and/or cleanup standards are achieved by the thermal remediation. Contingent soil excavation and removal will be conducted at the soil source area based on the results, based on a work plan to be approved by Ecology. The Soil and Groundwater Compliance Monitoring Plan is included as Attachment A.

As discussed in Section 3.8.8, performance groundwater monitoring will be continued during the Bioremediation system operation until PCE, and its breakdown products, concentrations in groundwater are below their applicable cleanup levels. Based on current activities at the Site, it is anticipated that groundwater performance monitoring will commence in September 2018. An Operations & Maintenance Plan for the Bioremediation/Groundwater Recirculation will be provided prior to system startup.

Groundwater compliance monitoring will start at the time when PCE, and its breakdown products, groundwater concentrations have reached their applicable cleanup levels in the selected performance monitoring wells. Groundwater compliance monitoring will be conducted quarterly for 2 years. A groundwater compliance monitoring contingency will be prepared in case groundwater compliance monitoring is continued after 2 years. The City of Bothell and Ecology will have with long-term access to the extent necessary to operate, maintain and monitor remedial systems and the cleanup, and compliance groundwater monitoring. Furthermore, potential vapor intrusion, associated with future development, will be mitigated by the installation of vapor barriers, or other vapor intrusion mitigation methods.

For baseline and system performance monitoring data, groundwater samples will be collected from the key monitoring wells proposed herein. All key monitoring wells will be analyzed for the following:

- VOCs (limited chlorinated solvent suite, EPA 8260B).
- Ammonia-nitrogen (EPA 350.1).
- Chloride (EPA 300.0)
- Sulfate-sulfur (EPA 375.4 MOD).
- Methane/ethene/ethane (low level analysis via Microseeps, Inc.).
- Total organic carbon (TOC, multiple methods).

- Dissolved iron

In addition, groundwater quality parameters (i.e. Conductivity, ORP and pH) should be taken during sampling events. These parameters will be sampled and analyzed every month the first quarter, followed by quarterly collection. The key groundwater monitoring wells to be sampled, shown on **Figure 9**, will include:

- Shallow Zone: MW-3, MW-21, MW-30, MW-37, HZ-MW-16, HZ-MW-19 and HZ-MW-22
- Intermediate Zone: MW-12, MW-20, MW-36, HZ-MW-23, and HZ-MW-29
- Deep Zone: MW-31, MW-32, MW-35, MW-38, and HZ-MW-25
- 3 Extraction Wells from different aquifer depths

Some of the wells required decommissioning (MW-30, MW-31, MW-36, MW-37, and MW-38) due to their location within the ERH heating zone. The wells will be re-installed or replaced with other existing wells for compliance sampling with review and approval by Ecology.

Extraction wells will be sampled in a manner to minimize any aeration of groundwater samples. The extraction pumps can be operated manually using the PLC of the system by the field technicians. Each extraction well conveyance line will have its own flow meter and gate valve to control the extraction flow rate. In addition, each line will have its own sample port and tubing to collect samples from. Once the pump is turned on, the conveyance line will be evacuated/filled and the pump flow rate will be reduced using the gate valve (to about 1-2 gpm). Once the flow rate is reduced, the sample port will be opened to flush the line and check for air bubbles. If no air bubbles are observed, then a sample will be collected. If bubbles are observed, the flow rate will be reduced until no bubbles are observed. All extraction wells will be sampled for baseline conditions prior to system startup.

3.13 Institutional Controls

If residual contamination will remain on the BSCSS property after cleanup, or any of the other criteria for triggering an institutional control under WAC 173-340-440 are met, institutional controls will be implemented, including an environmental covenant. The draft environmental covenant(s) will be included in the draft Institutional Control Plan submitted to Ecology within 60 days after the decommission of the ERH and SVE systems. Vapor intrusion risks at the site will be addressed by the active remediation of contaminated soil and groundwater at the site. Engineering controls, such as vapor barriers, or other vapor intrusion mitigation methods, will be implemented for the new development structures. The anticipated schedule for placing controls may be after the completion of the bioremediation task.

4.0 SUMMARY & CONCLUSIONS

The Bothell Service Center Site previously contained a former dry cleaners, which caused a release of PCE into the soil and groundwater some time prior to 2000. Remedial investigation activities have defined the nature and extent of soil and ground water impacts, which include PCE and its breakdown products TCE, DCE, and vinyl chloride.

Site cleanup levels for soil and ground water are selected as MTCA Method A or B for COCs with no established Method A value. Points of compliance are as follows:

- Soil

  In accordance with WAC 173-340-740(6), the point of compliance for soil is all soil to 15 feet bgs within the boundaries of the Site.

- Ground water

  In accordance with WAC 173- 340-720(8), the point of compliance for groundwater is all groundwater within the boundaries of the Site.

Based on the results of the remedial investigation and feasibility study conducted under MTCA and the application of the selection of remedy criteria, the preferred alternative, Alternative 2 at the Site (developed in accordance with WAC 173-340-350 through 173-340-390) includes:

- Design and Installation of ERH System and Bioremediation/Recirculation
- Installation of SVE system in all areas where it is applied
- Limited soil excavation and contingency-based soil excavation
- Engineering controls – depends on building construction schedule
- Institutional controls.

5.0 REFERENCES

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Figures

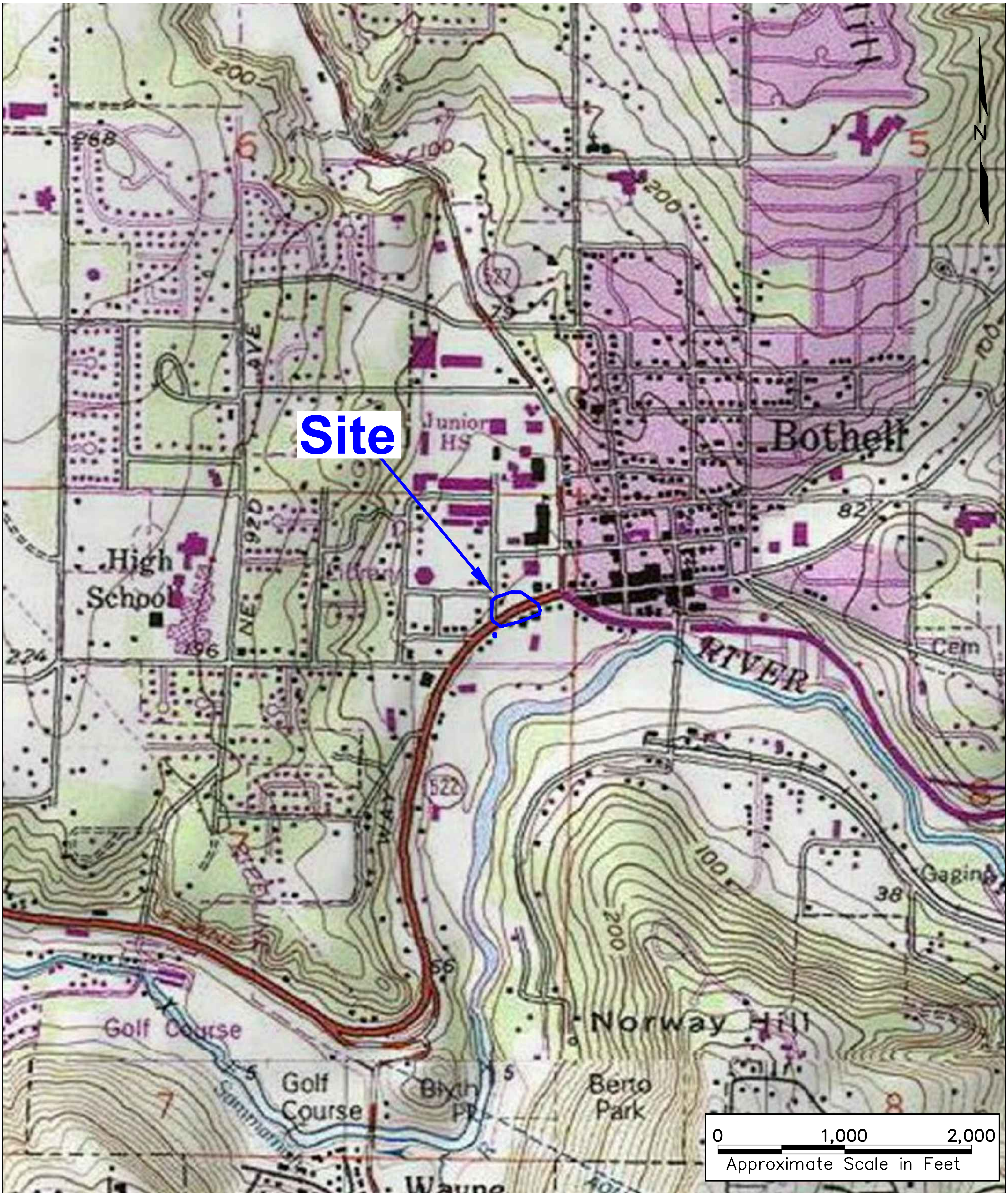

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Figure 1
Vicinity Map

Aerial Photo Source: Google Earth Pro
Aerial Photo Date: June 27, 2016

LEGEND

Approximate Location of Site Boundary

Various Property Boundaries

0 60 120
Approximate Scale in Feet

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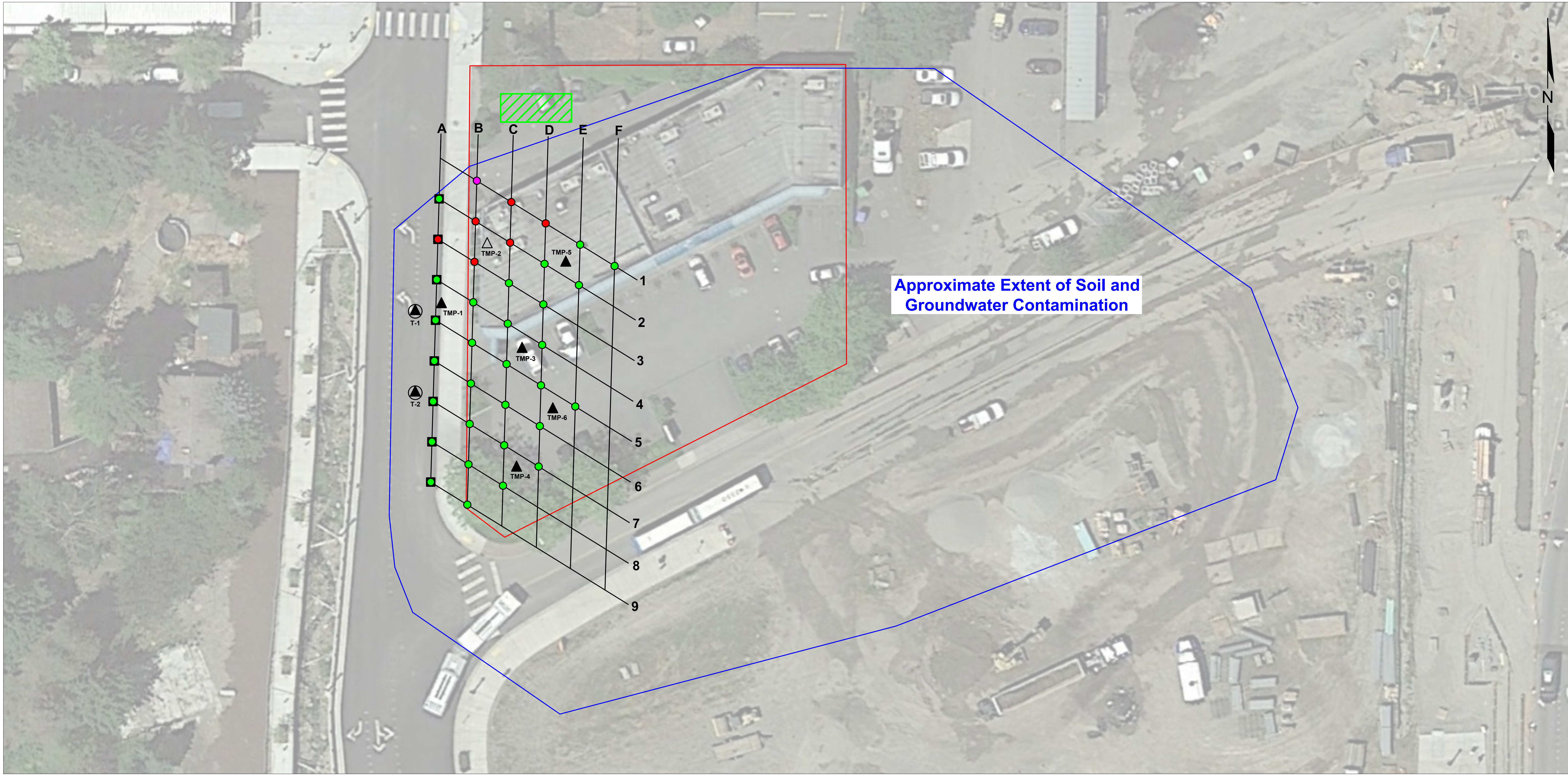
Figure 2
Site Plan



LEGEND

- Site Boundary
- BSCA Property Boundary
- Location of Above Grade Electrode (5-25 ft bgs)
- Location of Above Grade Electrode (5-55 ft bgs)
- Location of Above Grade Electrode (5-35 ft bgs)
- Location of Below Grade Electrode (5-25 ft bgs)
- Location of Below Grade Electrode (5-55 ft bgs)
- TMP-1 Location of Shallow Temperature Monitoring Probe (TMP)
- TMP-2 Location of Deep Temperature Monitoring Probe (TMP)
- T-1 Location of Storm Sewer Thermocouple
- ERH Equipment Location

Aerial Photo Source: Google Earth Pro
Aerial Photo Date: June 27, 2016

0 40 80
Approximate Scale in Feet

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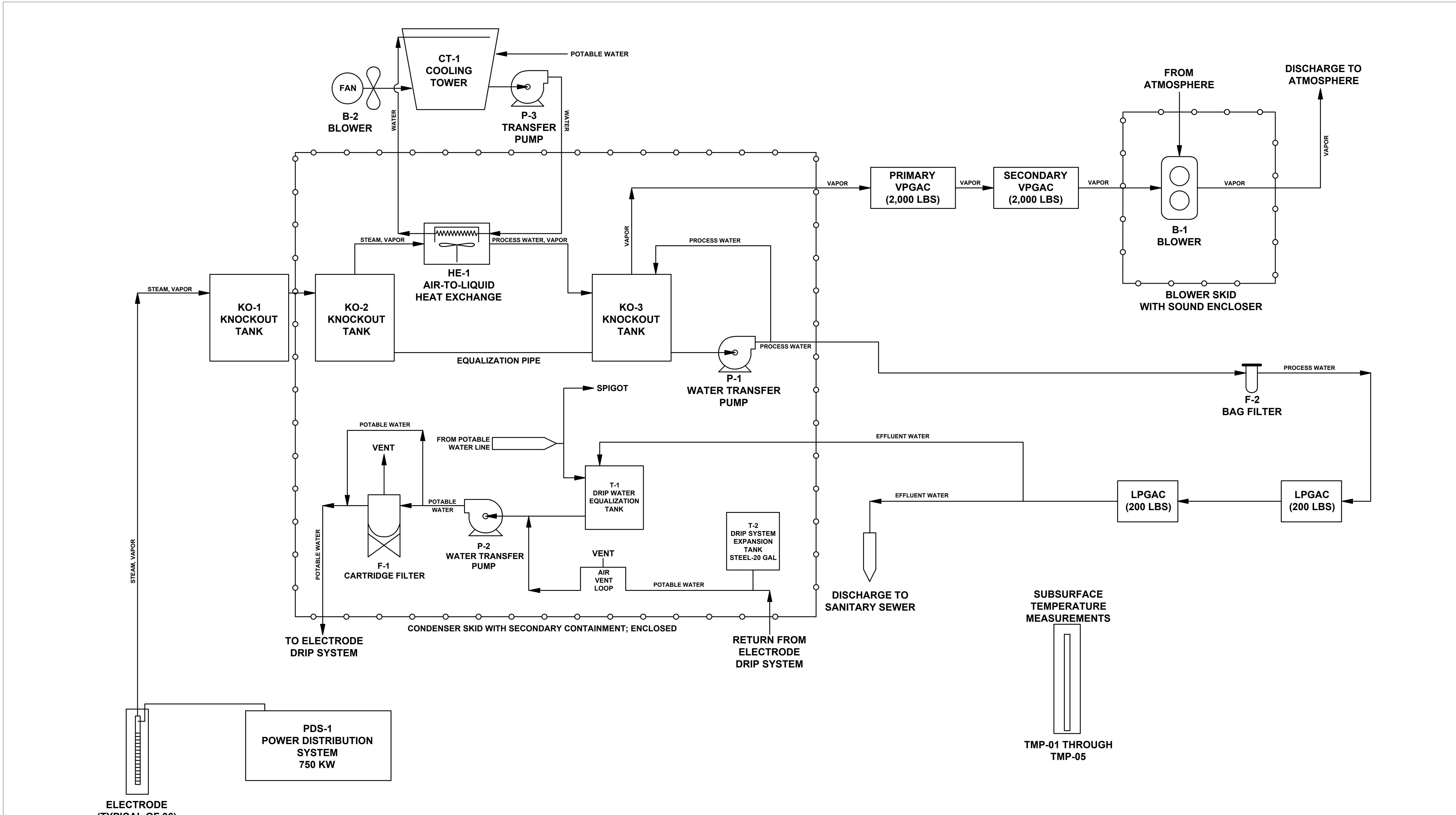
Figure 3
Electrode and Equipment Layout



Process Flow Diagram created by Cascade Environmental

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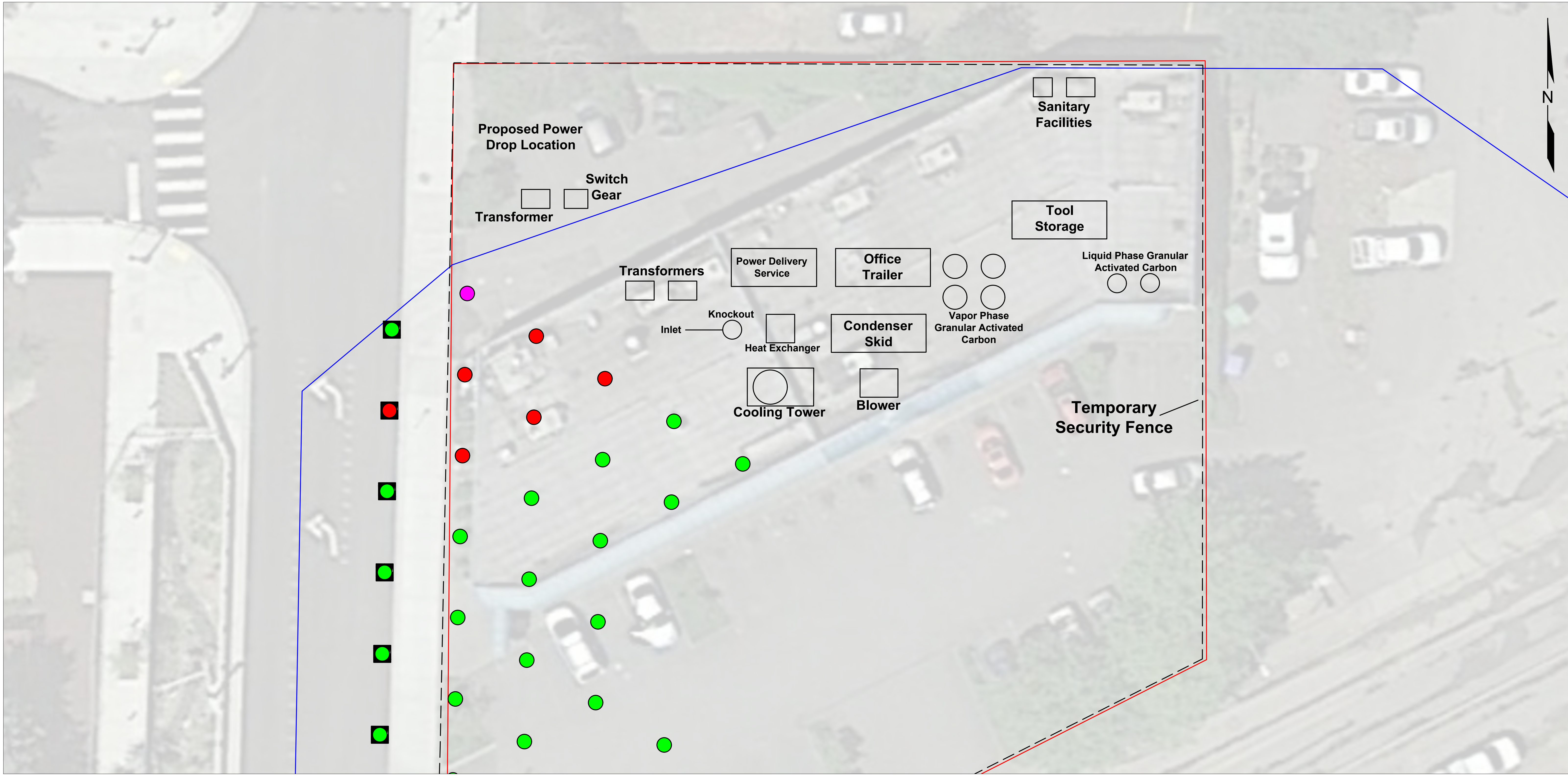
Figure 4
Process Flow Diagram



LEGEND

- Site Boundary
- BSCA Property Boundary
- Location of Above Grade Electrode (5-25 ft bgs)
- Location of Above Grade Electrode (5-55 ft bgs)
- Location of Above Grade Electrode (5-35 ft bgs)
- Location of Below Grade Electrode (5-25 ft bgs)
- Location of Below Grade Electrode (5-55 ft bgs)

Aerial Photo Source: Google Earth Pro
Aerial Photo Date: June 27, 2016

0 20 40
Approximate Scale in Feet

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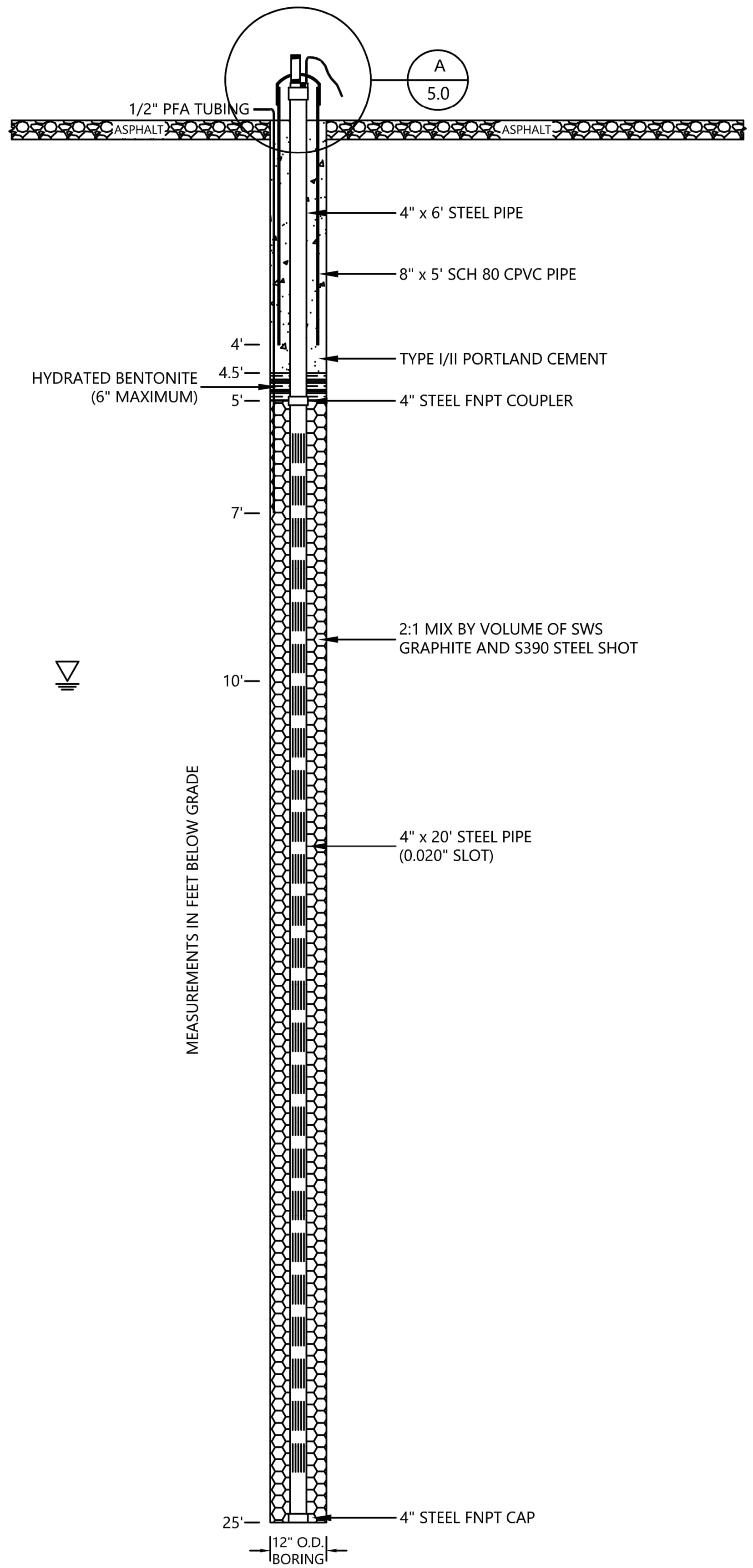
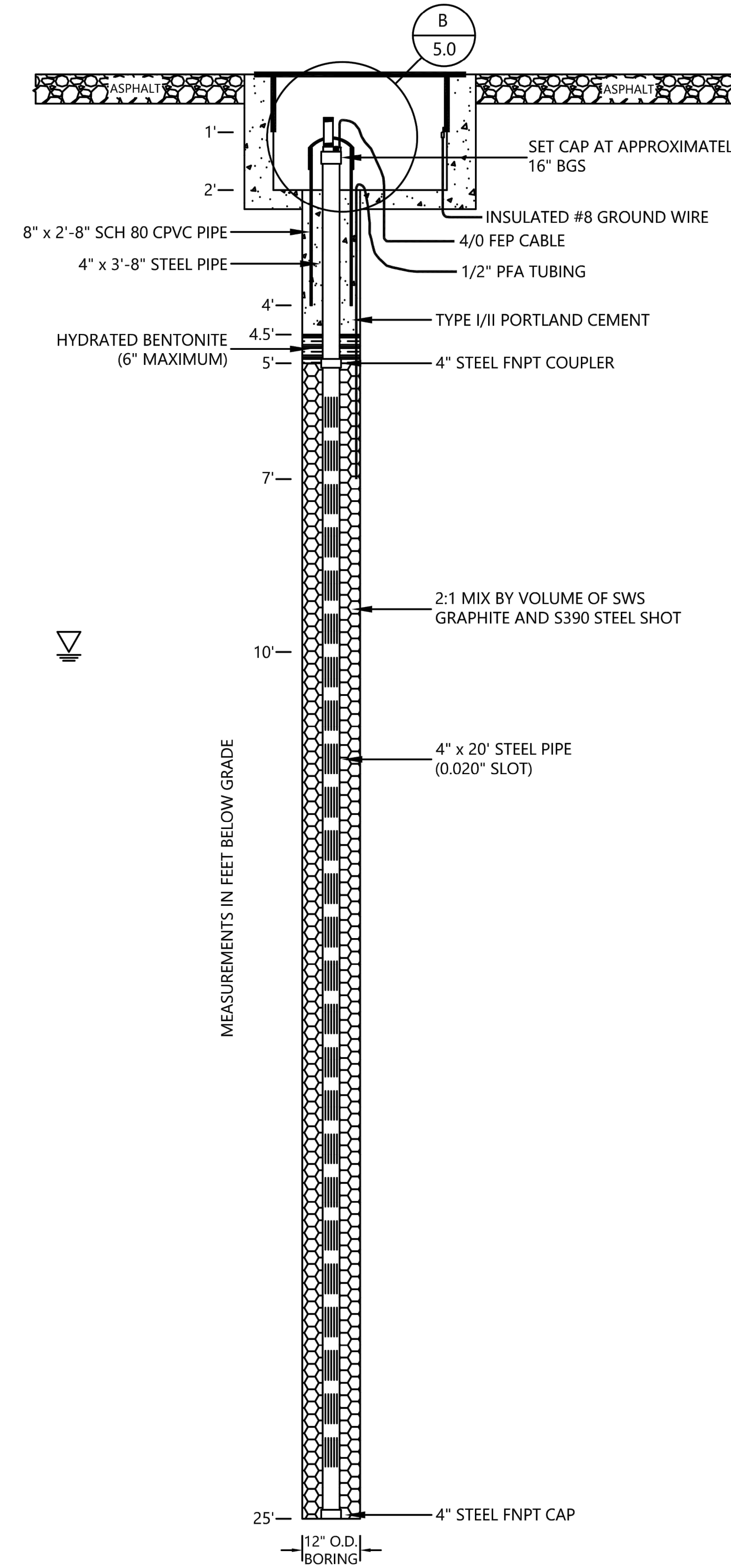
Figure 5
Equipment Layout Detail



SHALLOW ABOVE GRADE ELECTRODE
TYPICAL OF 23



SHALLOW BELOW GRADE ELECTRODE
TYPICAL OF 7

Shallow Electrode Diagram created by Cascade Environmental

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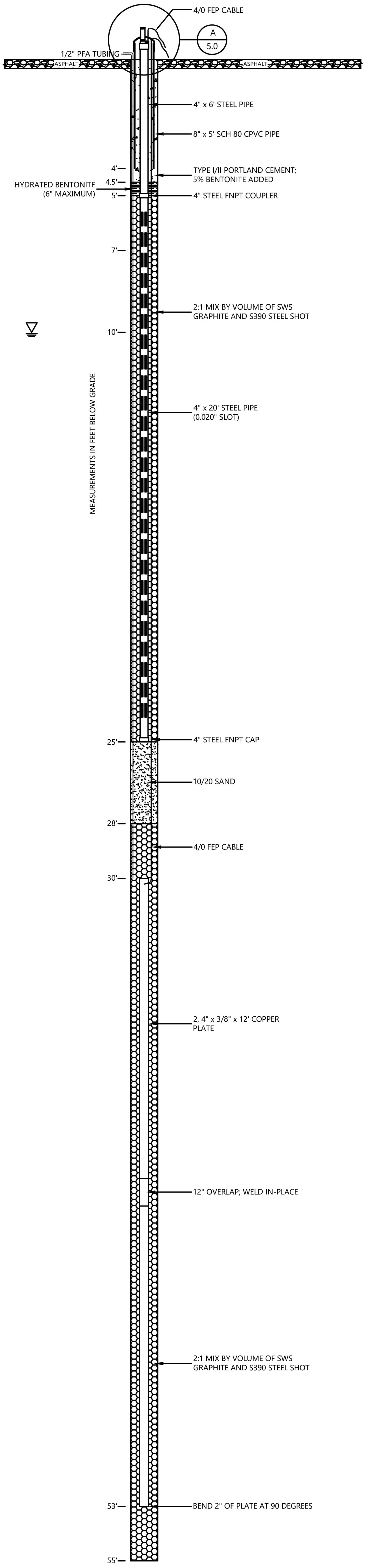
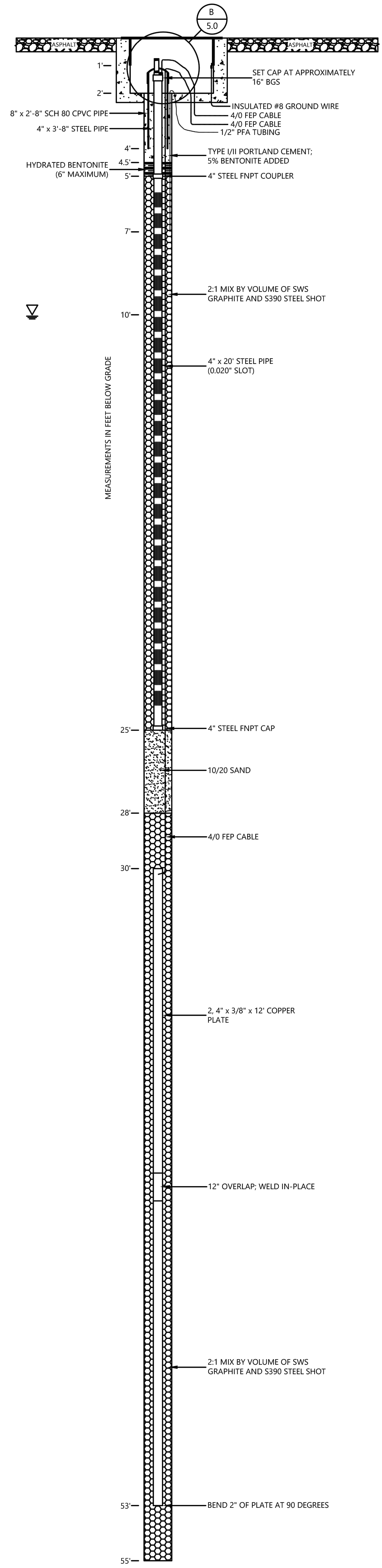
Figure 6
Shallow Electrode Details



DEEP ABOVE GRADE ELECTRODE
TYPICAL OF 5



DEEP BELOW GRADE ELECTRODE
TYPICAL OF 1

Deep Electrode Diagram created by Cascade Environmental

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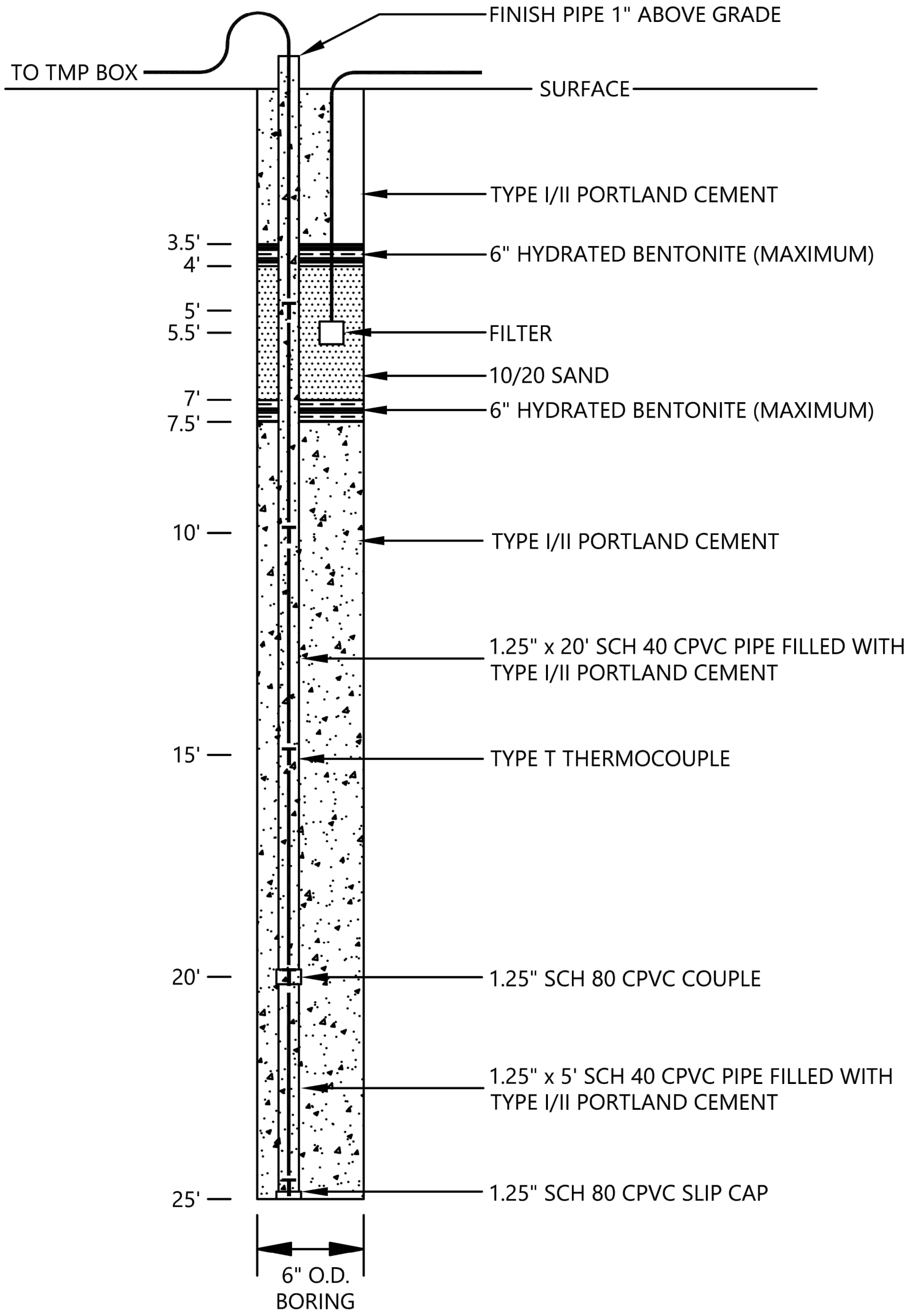
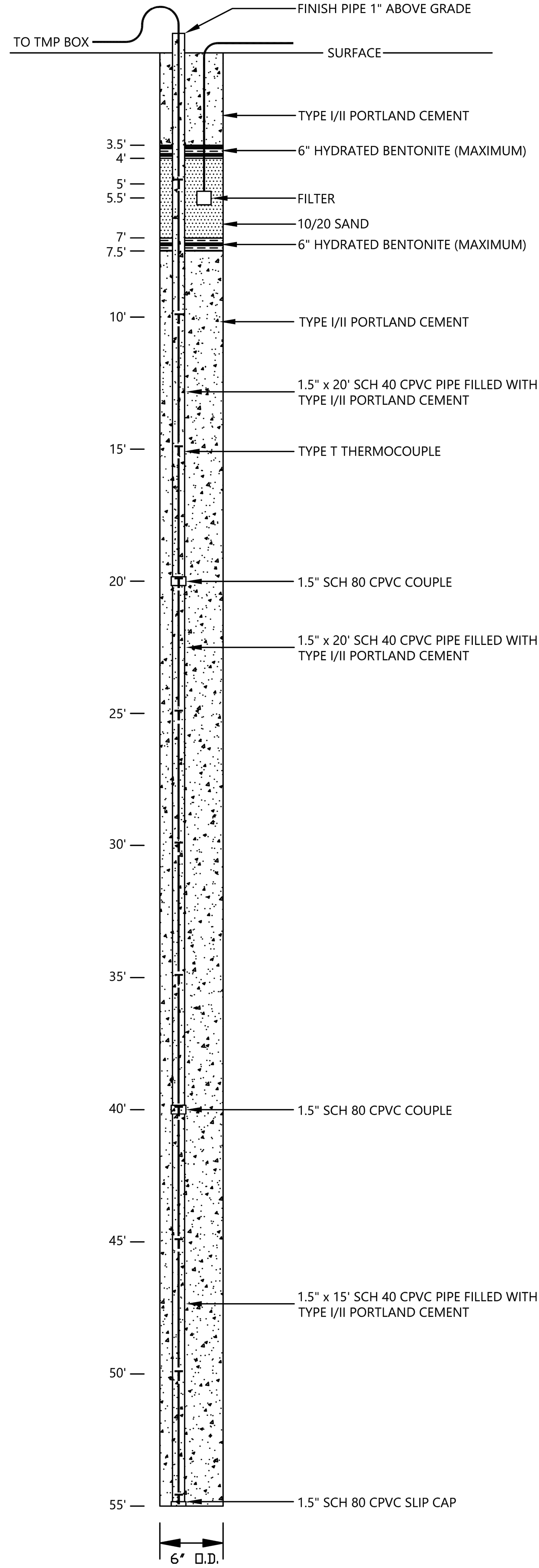
Figure 7
Deep Electrode Details



SHALLOW TEMPERATURE MONITORING PROBE - 5 THERMOCOUPLES (TYPICAL OF 4)



DEEP TEMPERATURE MONITORING PROBE - 11 THERMOCOUPLES (TYPICAL OF 1)

Temperature Monitoring Probe Diagram created by Cascade Environmental

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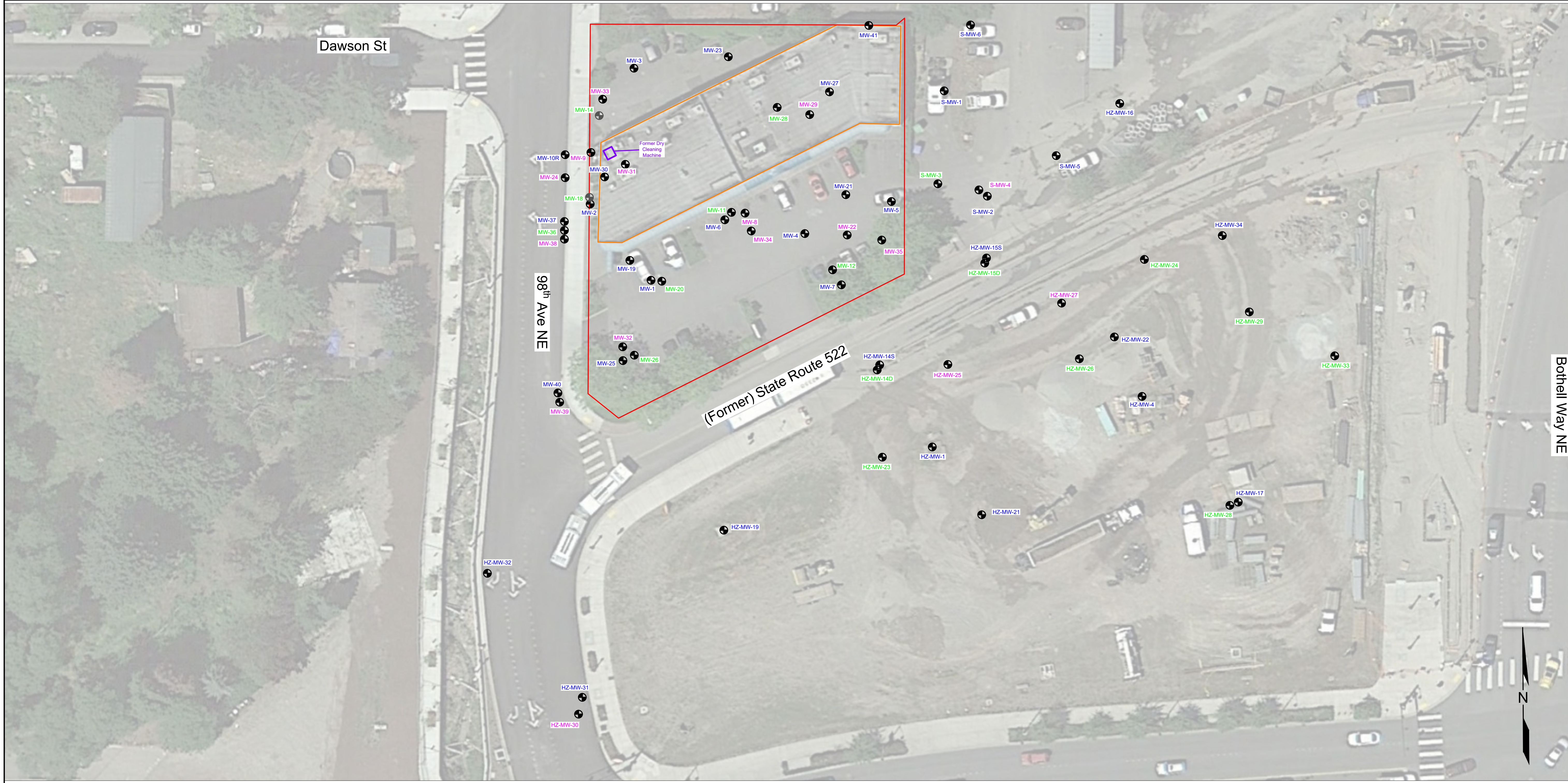
Figure 8
Temperature Monitoring Probe Details



LEGEND

BSCA Property Boundary

Former Dry Cleaning Machine

MW-1 Monitoring Well, Shallow (5-25ft)

MW-2 Monitoring Well, Intermediate (25-35 ft)

MW-3 Monitoring Well, Deep (35-55 ft)

Aerial Photo Source: Google Earth Pro
Aerial Photo Date: June 27, 2016

0 50 100
Approximate Scale in Feet

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Figure 9
Groundwater Monitoring Well Locations

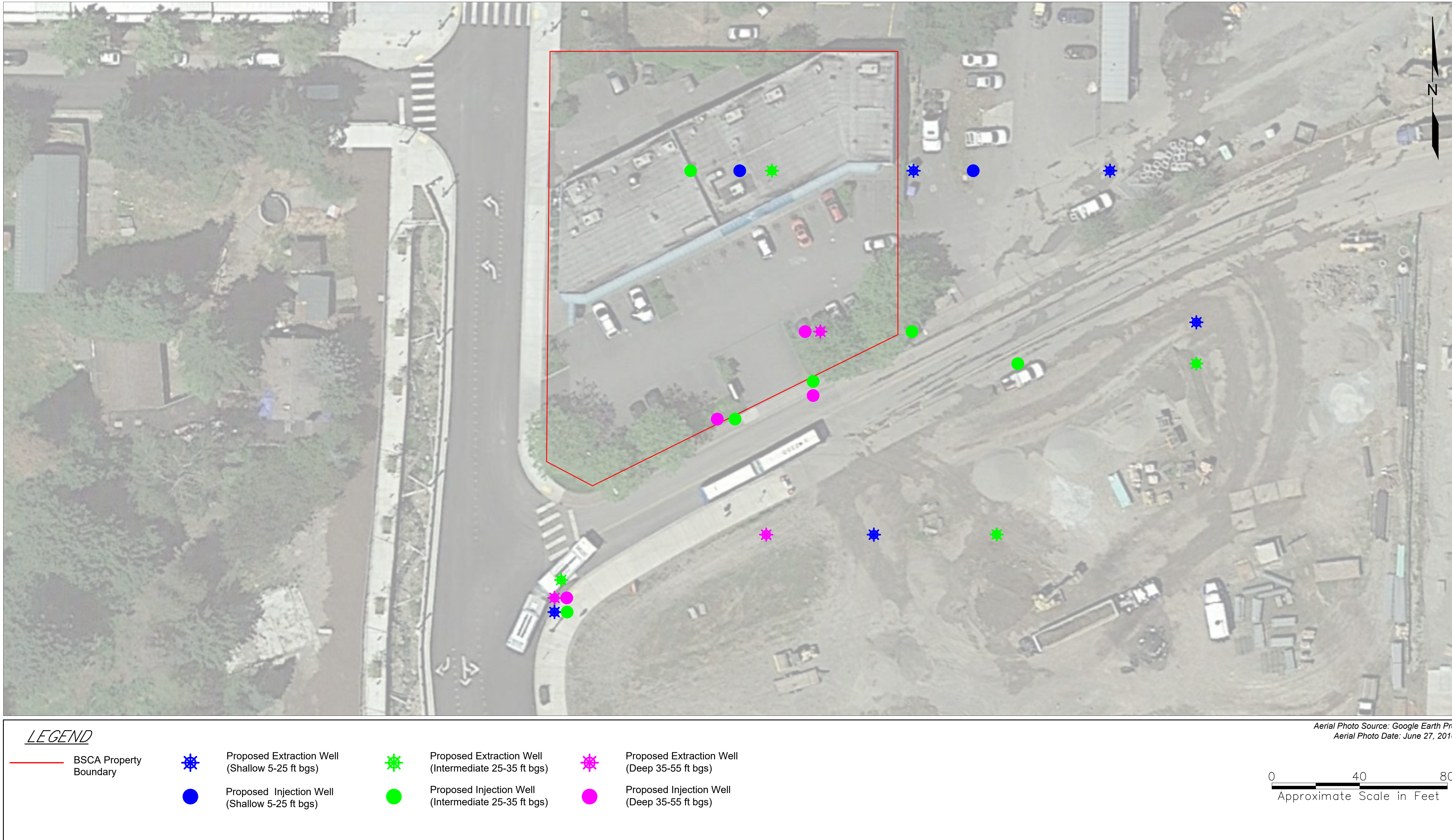

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Figure 10
Proposed Bioremediation/Grondwater Recirculation Well Locations

LEGEND

BSCA Property Boundary

Approximate Location of Soil Excavation

Approximate Location of Soil Vapor Extraction (SVE) Well

Aerial Photo Source: Google Earth Pro
Aerial Photo Date: June 27, 2016

0 20 40
Approximate Scale in Feet

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Figure 11
Proposed SVE Well and Soil Excavation Locations

Attachment A

Soil and Groundwater Compliance Monitoring Plan

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Soil and Groundwater Compliance Monitoring Plan

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Prepared For:

City of Bothell
18415 101st Avenue NE
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March 12, 2018

Kane Environmental, Inc. Project Number: 82302

Prepared By:

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FIGURES

ATTACHMENTS

1.0 INTRODUCTION

This Soil and Groundwater Compliance Monitoring Plan (CMP) was prepared by Kane Environmental, Inc. on behalf of the City of Bothell (the City) for the Bothell Service Center Simon & Sons (BSCSS) Site located in Bothell, Washington (the Site). A vicinity map and Site location are shown on Figure 1. A draft Remedial Investigation/Feasibility Study (dRI/FS) was prepared and submitted to the Washington Department of Ecology (Ecology) in July 2017 to characterize the Site and evaluate proposed remedial actions to address the contamination and based on that evaluation, propose the most appropriate remedial alternative to clean up the Site. Subsequently, in September 2017, a draft Cleanup Action Plan (dCAP) was prepared for Ecology to describe the proposed cleanup action and to set forth the requirements that the cleanup must meet. The CAP and RI/FS report was issued as final by the Department of Ecology on December 27, 2017. This CMP was prepared in concurrence with the Engineering and Remedial Design Report (ERDR), also dated March 12, 2018.

2.0 BACKGROUND

The property containing the source of contamination was previously owned by Bothell Service Center Associates (BSCA) and managed by NLO Property Management. The City of Bothell is the current owner of the BSCSS property and the City owns roadways and other parcels adjacent to the BSCSS property, which are also part of the Site. The City has a Consent Decree to implement a Cleanup Action Plan for the Site with Ecology and the Attorney General's Office.

The Site is listed in Ecology's database as Bothell Service Center Simon & Sons (BSCSS). The Site is assigned Facility Site ID number 33215922 for dry cleaning solvent contamination, specifically tetrachloroethylene (PCE) and its breakdown products TCE, DCE, and vinyl chloride in soil and groundwater. The Cleanup Site ID number is 427. The Site is currently under a Consent Decree between the Washington State Department of Ecology, the City of Bothell, and former owners of the Simon & Sons Dry Cleaning property to implement a Cleanup Action Plan for the Site.

Based on the results of the dRI/FS conducted under MTCA (Kane Environmental, 2017a) and the application of the selection of remedy criteria in a CAP (Kane Environmental, 2017b), the selected remedy is Electrical Resistive Heating/Bioremediation with Groundwater Recirculation, augmented by targeted soil excavation and soil vapor extraction, developed in accordance with WAC 173-340-350 through 173-340-390. The selected remedy will be implemented as the primary alternative for source control and plume remediation

The progress of treatment with ERH will be monitored through soil temperature monitoring of the subsurface, periodic collection and analysis of extracted vapors, and soil and groundwater sampling for treatment confirmation. Soil performance monitoring will only be conducted in the area of the ERH system, approximately 2 to 3 months after ERH startup and approximately 1 month before estimated ERH system shutdown. Soil samples will be collected in selected areas in the ERH treatment area to determine if the ERH system has reduced PCE, and its breakdown products, to concentrations below their cleanup levels. Groundwater performance monitoring will also be conducted in selected wells during the ERH system operation. Performance groundwater monitoring will be continued during the bioremediation system operation until PCE, and its breakdown products, concentrations in groundwater are below their applicable cleanup levels. Groundwater compliance monitoring will follow, and continue on a quarterly basis for two years.

3.0 SOIL SAMPLING WORK PLAN

The following sections describe the tasks to be carried out to complete the soil CMP during and following the completion of ERH remedial activities.

3. 1 Utility Locate

Private and public underground utility surveys will be conducted at the Site prior to the drilling activity. Washington State law requires that the area being drilled needs to be marked in white paint prior the public utility locate.

3. 2 Soil Borings

Drilling activities will be conducted in three events, the first two conducted at approximately 2 to 3 months after ERH startup and approximately 1 month before estimated ERH system shutdown. A final third sampling event will be conducted following the ERH system shutdown. Each drilling event, Kane Environmental will contract a licensed drilling company to advance six soil borings on the Site by limited access direct push or direct push (by hand) methods. The exact drilling method will depend on the accessibility and the locations of ERH equipment located on site. Borings will be completed to a maximum depth of 10 feet below ground surface (bgs), or drilling refusal. Proposed borings will be advanced in six consistent areas between ERH electrodes. Proposed boring locations may be modified depending upon the findings of the utility locate and accessibility near the ERH equipment located on site. All borings will be closed following local regulatory guidelines. No permanent groundwater monitoring wells will be installed.

See Figure 1 for the proposed locations of the six areas where borings will be advanced throughout the three sampling events.

3. 3 Soil Sampling

Due to the increased subsurface temperatures from the ERH system and volatile nature of contaminants present on the Site, specific sampling methodology will be observed. Kane Environmental will follow the sampling methodology outlined in the Cascade *Hot Soil Sampling for Organic Compounds, SOP-SA-100* (included as Attachment 1).

The soil sampling scope of work as proposed will be completed by a Kane Environmental Staff Geologist or Environmental Scientist. Soil samples will be logged for physical properties and will be screened by a photoionization detector (PID).

During each sampling event, up to two soil samples will be collected from each boring. Samples will be collected from the vadose zone, at depths ranging between 0 and 10 feet bgs, or above field indications of saturated soil. Soil samples will be obtained utilizing the collection, preparation and preservation methods outlined in EPA Method 5035A, as required by Washington Department of Ecology (Ecology).

Soil sampling nomenclature will identify each soil sample with the sampling event number, boring location identification number, followed by a number designating the sample depth. For example, soil sample “2-

ERH-2: 5ft" was collected during the second sampling event, from the first ERH soil boring area, and the sample was collected at 5 feet bgs. Soil sample locations will be noted in associated figures.

All samples will be immediately placed into ice-filled coolers and delivered to OnSite Environmental in Redmond, Washington, an Ecology accredited laboratory, under standard chain-of-custody procedures.

3. 4 Analytical

Kane Environmental proposes that select soil samples be analyzed by OnSite Environmental for the following chemical constituents:

- Halogenated Volatile Organic Compounds by EPA Method 8260.

Internal test methods run by the laboratory to ensure data accuracy and reproducibility will include method blanks, laboratory control standards, sample duplicates, matrix spikes, and matrix spike duplicates.

Analytical data will be received from the laboratory five to seven business days following sample submission.

Soil cuttings and equipment decontamination water will be collected and temporarily stored in 55-gallon or 16-gallon drums. The drums will be labeled and stored on the Site in an area that does not impede daily activities. The drums will be removed and disposed of following results from the analytical laboratory.

3. 5 Health and Safety

As discussed in Cascade's *Hot Soil Sampling for Organic Compounds, SOP-SA-100,* Kane Environmental will coordinate with the Cascade ERH project managers, as well as health and safety personnel, to develop specific health and safety procedures prior to any sampling activity on site.

4.0 GROUNDWATER SAMPLING WORK PLAN

The following sections describe the tasks to be carried out to complete the groundwater CMP during and following the completion of ERH and bioremediation remedial activities.

4. 1 Groundwater Sampling

Groundwater performance monitoring will be conducted in selected wells during the ERH system operation. Approximately four weeks after the ERH system is disconnected, up to two groundwater performance wells will be installed within the ERH treatment zone to monitor concentrations PCE and its breakdown products following the ERH treatment activity. The wells will not have to be designed to withstand the heated water or have special surface completions for sampling if installed 4 weeks after system shutdown.

Performance groundwater monitoring will be continued during the bioremediation/recirculation system operation until PCE, and its breakdown products, concentrations in groundwater are below their applicable cleanup levels throughout the Site.

Groundwater compliance monitoring will start at the time when groundwater concentrations of PCE, and its breakdown products, have reached their applicable cleanup levels in the selected performance monitoring wells. Groundwater compliance monitoring will be conducted quarterly for 2 years.

The key groundwater monitoring wells to be sampled, shown on Figure 2, will include:

- Shallow Zone: MW-3, MW-21, HZ-MW-16, HZ-MW-19 and HZ-MW-22;
- Intermediate Zone: MW-12, MW-20, HZ-MW-23, and HZ-MW-29;
- Deep Zone: MW-35, and HZ-MW-25;
- 2 monitoring wells to be installed post-ERH operations;
- 3 Extraction Wells from different aquifer depths.

Prior to each sampling event, depth to groundwater in each well will be measured with a decontaminated electric water interface probe. The probe will be cleaned with Alconox® detergent and rinsed with distilled water between locations.

During the ERH groundwater performance monitoring activities, Kane Environmental will follow the sampling methodology outlined in the Cascade *Hot Groundwater Sampling, SOP-SA-101* (Attachment 2). Only one performance monitoring well (MW-21) is located within proximity to the ERH system layout which will require the conditions outlined in the *Hot Groundwater Sampling, SOP-SA-101.* All other performance monitoring wells are located at a sufficient distance (greater than 10 feet) from the ERH system layout and can be sampled following standard procedure. With the exception of MW-21, during groundwater performance and compliance monitoring activities, Shallow groundwater monitoring wells will be sampled using a peristaltic pump with disposable polyethylene tubing, and Intermediate and Deep groundwater monitoring wells will be sampled using a submersible pump with disposable PVC tubing. The tubing, or submersible pump, will be lowered to approximately one foot above the bottom of the well screen.

Low-flow sampling methodologies per United States Environmental Protection Agency (USEPA) guidelines will be utilized. Field parameters, including pH, temperature, conductivity, and total dissolved solids (TDS), will be measured during purging, and allowed to stabilize for the last three readings prior to sampling.

Groundwater sampling nomenclature will identify each groundwater sample with the corresponding monitoring well identification.

Unfiltered groundwater will be placed into appropriate laboratory-supplied, pre-cleaned and preserved containers for analysis. The groundwater samples will be immediately placed into ice-filled coolers and subsequently transported to OnSite Environmental under standard chain-of-custody procedures.

4. 2 Analytical

Kane Environmental proposes that select groundwater samples be analyzed by OnSite Environmental for the following chemical constituents:

- Halogenated Volatile Organic Compounds by EPA Method 8260;
- Ammonia-nitrogen by EPA 350.1;
- Chloride (EPA 300.0);
- Sulfate-sulfur by EPA 375.4 MOD;
- Methane/ethene/ethane by low level analysis via Microseeps, Inc.;
- Total organic carbon (TOC, multiple methods); and,
- Dissolved iron.

Internal test methods run by the laboratory to ensure data accuracy and reproducibility will include method blanks, laboratory control standards, sample duplicates, matrix spikes, and matrix spike duplicates.

Analytical data will be received from the laboratory five to seven business days following sample submission.

Purged groundwater will be collected and temporarily stored in 55-gallon or 16-gallon drums. The drums will be labeled and stored on the Site in an area that does not impede daily activities. The drums will be removed and disposed of following results from the analytical laboratory.

4. 3 Health and Safety

As discussed in Cascade's *Hot Groundwater Sampling, SOP-SA-101,* Kane Environmental will coordinate with the Cascade ERH project managers, as well as health and safety personnel, to develop specific health and safety procedures prior to any sampling activity on site.

5.0 REFERENCES

Cascade Technical Services, 2017, *Hot Soil Sampling for Organic Compounds, No. SOP-SA-100,* July 24, 2017.

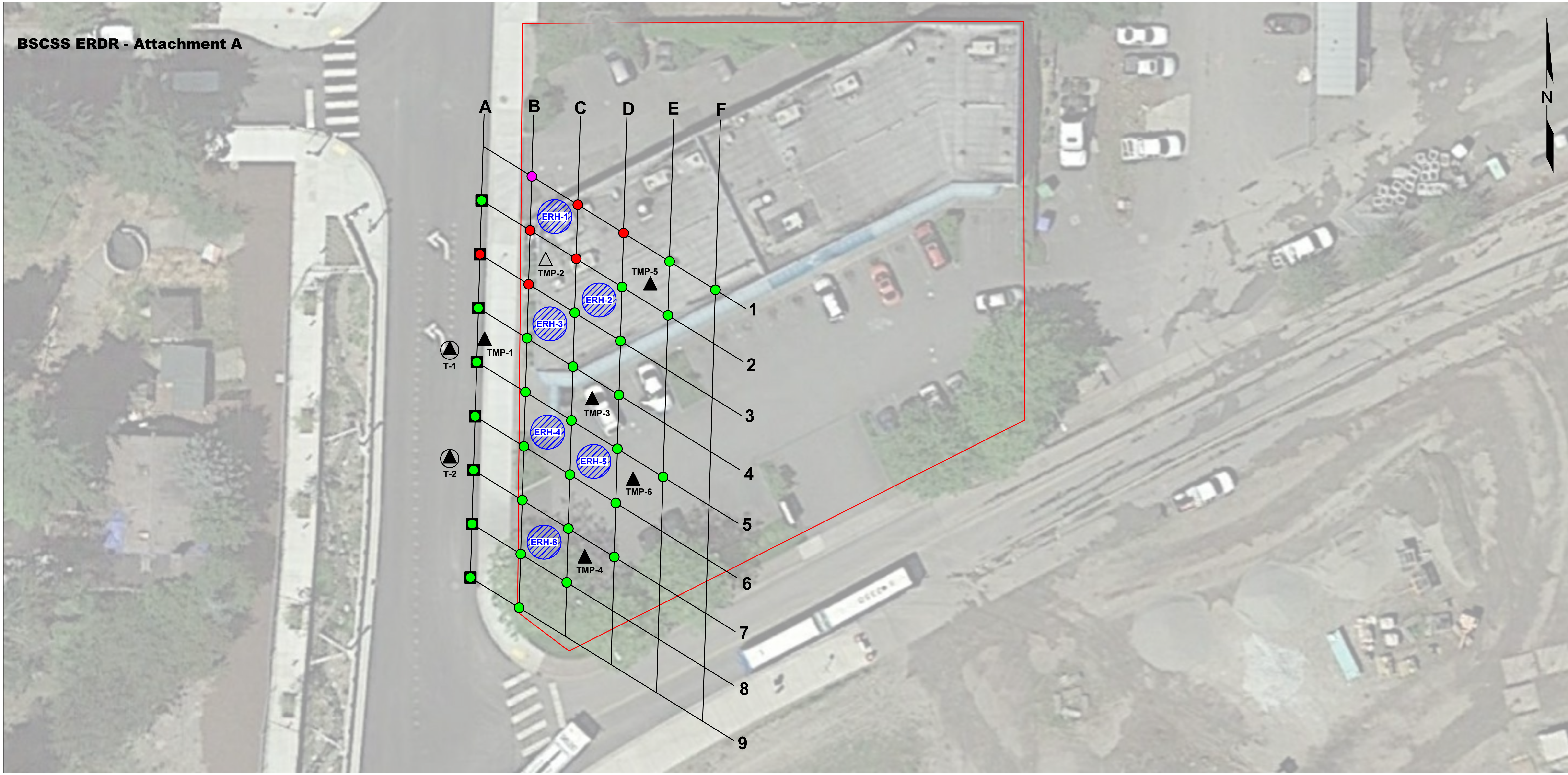
Cascade Technical Services, 2018, *Hot Groundwater Sampling, No. SOP-SA-101,* March 2018.

Kane Environmental, 2017a, *Draft Remedial Investigation & Feasibility Study*, Bothell Service Center, Bothell, Washington, October 4, 2017.

Kane Environmental, 2017b, *Cleanup Action Plan*, Bothell Service Center, Bothell, Washington, December 27, 2017.

CMP FIGURES

BSCSS ERDR - Attachment A



Aerial Photo Source: Google Earth Pro
Aerial Photo Date: June 27, 2016

LEGEND

- BSCA Property Boundary
- Location of Above Grade Electrode (5-25 ft bgs)
- Location of Above Grade Electrode (5-55 ft bgs)
- Location of Above Grade Electrode (5-35 ft bgs)
- Location of Below Grade Electrode (5-25 ft bgs)
- Location of Below Grade Electrode (5-55 ft bgs)
- TMP-1 Location of Shallow Temperature Monitoring Probe (TMP)
- TMP-2 Location of Deep Temperature Monitoring Probe (TMP)
- T-1 Location of Storm Sewer Thermocouple
- ERH-1 Location of Proposed Soil Compliance Moinitoring Sample Area

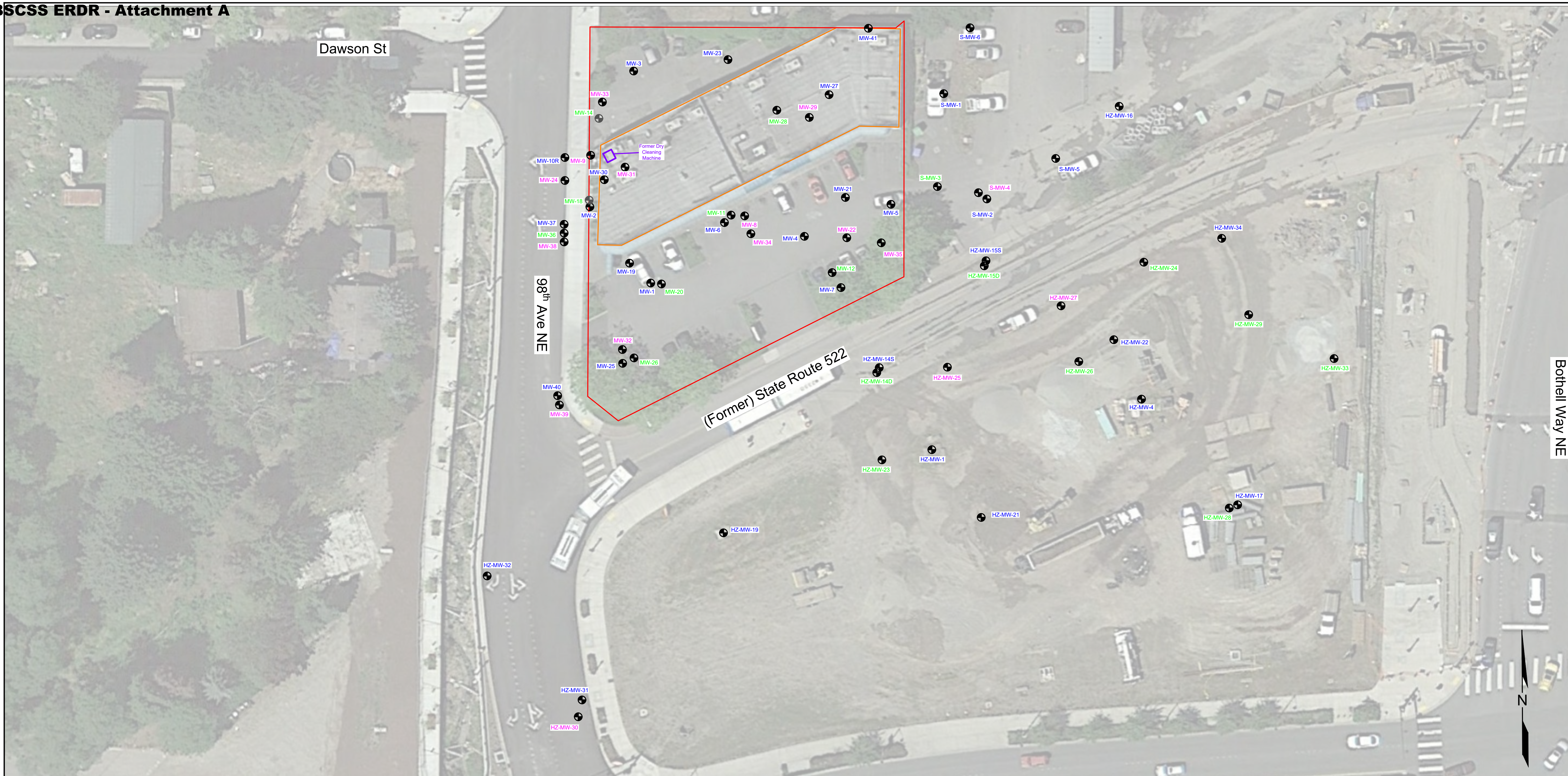
0 30 60
Approximate Scale in Feet

KANE ENVIRONMENTAL INC
3815 Woodland Park Avenue North, Suite 102
Seattle, WA - 206-691-0476
www.kane-environmental.com

Soil and Groundwater Compliance Monitoring Plan
Bothell Service Center Simon & Son
18107 Bothell Way NE
Bothell, Washington

Figure 1
Proposed Soil Sample Locations

BSCSS ERDR - Attachment A



LEGEND

BSCA Property Boundary

Former Dry Cleaning Machine

MW-1 Monitoring Well, Shallow (5-25ft)

MW-2 Monitoring Well, Intermediate (25-35 ft)

MW-3 Monitoring Well, Deep (35-55 ft)

Aerial Photo Source: Google Earth Pro
Aerial Photo Date: June 27, 2016

0 50 100
Approximate Scale in Feet

KANE ENVIRONMENTAL INC
3815 Woodland Park Avenue North, Suite 102
Seattle, WA - 206-691-0476
www.kane-environmental.com

Soil and Groundwater Compliance Monitoring Plan
Bothell Service Center Simon & Son
18107 Bothell Way NE
Bothell, Washington

Figure 2
Groundwater Monitoring Well Locations

CMP ATTACHMENT 1

HOT SOIL SAMPLING FOR ORGANIC COMPOUNDS

No. SOP-SA-100

1. PURPOSE AND APPLICABILITY

The purpose of this Standard Operating Procedure (SOP) is to ensure that Cascade Technical Services (Cascade) follows a consistent program in performance of hot soil sampling. This SOP is specifically intended for sampling of soils to be submitted for volatile organic (VOC)/semi-volatile organic compound (SVOC)/hydrocarbon analysis. Such soils are heated in excess of 100°C and this SOP establishes a set of procedures to ensure collection of soil samples that are representative of field conditions and to minimize the potential for loss of volatile organic compounds during sample collection.

Cascade is typically responsible for overseeing or performing a soil sampling program for each major project. Sampling may be performed as progress sampling during In Situ Thermal Remediation (ISTR) operation or as confirmatory sampling at the conclusion of ISTR operation. This SOP outlines the methodology of such sampling, to help ensure consistency from one project to the next, and to ensure that sampling is performed in accordance with industry standard methods (Gaberell *et al*., 2002). It is recognized, however, that project specific goals may differ, and that sampling methodologies may change accordingly to some degree. It is the ultimate responsibility of the Project Manager (PM) to ensure that the proposed sampling protocols meet both corporate and client requirements prior to sample collection.

This SOP applies to all major Cascade's projects, and to personnel responsible for performing or overseeing soil sampling activities. All work must be done in accordance with the project specific work plan, health and safety plan, sampling and analysis plan, and/or quality assurance project plan procedures.

2. RESPONSIBILITY

The Site Supervisor, or his designee, will conduct periodic inspections of the sampling procedures established by this SOP. The purpose of the inspection is to verify that the procedures and the requirements of the SOP are being followed. Any deviations or inadequacies that are identified during the inspection will be documented and immediately corrected.

It is also the responsibility of the party conducting the sampling to ensure appropriate coverage of wiring and cables within the wellfield to allow for drill rig access. It is required that plywood, or other appropriate form of protection, be placed over the wiring while the drill rig is moving to the specified drilling location. If covering the wires will not be sufficient to protect them from being damaged, a Cascade operator shall be asked to unplug any necessary cables while the drill rig is moving into place, and plug all wires back in once the drill rig is in place. No wires or cables shall be disconnected or reconnected by either the sampling party or the drill rig operators.

3. SAFETY

A Cascade operator or employee must be present at all times while the drill rig is moving within the wellfield. This ensures the safety of all project personnel and prevents damage to any equipment within the wellfield. Prior to any sampling personnel or equipment entering the wellfield, or moving from one sampling location to another, a Cascade operator must shut down all active heater circuits (TCH sites only) in the vicinity of the sampling location, lock out/tag out all affected circuits, and verify that the heaters in those circuits are no longer live.

At ERH sites, the entire wellfield must be de-energized and locked out/tagged out prior to entering the wellfield and during all drilling activities.

At SEE sites, steam has to be shut off several days in advance of the drilling, and it must be confirmed based on available data that no live steam is present in the subsurface at the drilling locations during sampling.

Exact safety procedures related to sampling in the wellfield is project specific and must be discussed with the Project Manager and/or Cascade's Health and Safety manager prior to all soil sampling activities.

All standard PPE shall be worn by all personnel involved in the sampling process. Standard PPE is listed below:

- Hard hat
- High Visibility Vest or Long Sleeve Shirt
- Safety Glasses
- Steel-Toed Boots
- Temperature rated gloves (when handling hot materials)

Drillers may be required to also wear the following PPE as necessary, depending on project circumstances:

- Hard hat with face shield
- Apron or Tyvek® suit

4. REQUIRED MATERIALS

Cascade has assembled a Soil Sampling Kit that contains the majority of the necessary materials listed below.

- Core barrel type soil sampler (typically provided by driller)
- Alconox® or other biodegradable soap for decontamination
- Scrub brush(es) for decontamination of down-hole equipment
- Distilled water & large buckets for decontamination
- Nitrile Gloves
- Teflon tape or Aluminum Foil
- PVC end caps (Red and black - typically provided by driller)

- Thermometer
- Ice bath (tub(s) with drain holes, dividers, ice)
- Field logbook & sample chain of custody form (typically provided by the laboratory)
- Stainless Steel Spoons / Spatulas
- Stainless Steel Sampling Bowls

5. METHOD

The procedures for performing hot soil sampling are as follows:

Sampling Tool

The length and diameter of the sampling tool may vary depending on the driller used to perform the work and the sampling tool selected. Soil samples will be collected using a core barrel type sampler equipped with four to ten 6-inch stainless steel sleeves. The stainless steel sleeves are also available in un-cut sections of varying lengths. Cascade highly recommends that the sleeves be supplied pre-cut into 6-inch intervals, so that each interval can be sampled individually and to reduce the possibility of cross contamination between cutting tools and the samples. Figure 1 shows a 5-ft core barrel equipped with four 6-inch stainless steel sleeves.

Figure 1. Typical 5-foot Long Core Barrel

Decontamination

All down-hole equipment (augers, core barrel, drive rods) must be decontaminated prior to use, between sampling locations, and at the end of each day. Sampling sleeves and end caps, which may be used more than once, must be decontaminated prior to each use. Decontamination will consist of the following:

1. Removal of any gross contamination (e.g., wet soils stuck to the auger) by steam cleaning or other appropriate method;
2. Cleaning with a biodegradable soap (e.g., Alconox®) and water solution using a scrub brush;
3. Rinsing off the soapy solution with clean water; and,
4. Rinsing with distilled water.

Sample Collection

There are two different basic methods described for sample collection below. The sample collection method shall be approved by the PM prior to sample collection to ensure that data results meet project goals.

Sample Collection Method 1

1. The decontaminated core barrel sampler and sample sleeve will be assembled and advanced to the desired depth.
2. Once removed from the borehole, the core barrel will be disassembled, and the sample sleeves will be removed sequentially, one-by-one. Temperature rated Person Protective Equipment (PPE) (heat resistant gloves, sleeves, bib apron, hardhat with face shield) should be worn while handling hot materials.
3. The ends of each 6-inch sample sleeve will be immediately covered with sections of Teflon® tape or Aluminum Foil and then capped with PVC end caps (Figure 2).
4. Black and red endcaps are typically used to differentiate between the top and the bottom of each sample sleeve. The red endcap is typically labeled with the sampling depth interval (e.g., 1 ft to 1.5 ft.).
5. One of the sleeves will be selected and a thermometer will be inserted through the end cap into the soil sample for temperature monitoring (Figure 2).
6. The capped and sealed sleeves will then be placed into an ice bath for cooling. The ice bath will contain drain holes to allow melt water to freely drain rather than accumulate around the sample holder. Water shall be collected and containerized for proper disposal. A picture of an ice bath is included as Figure 3. The sample identification (ID) information will be marked on each ice bath for reference when processing the cooled samples for labeling and shipping.
7. Once cooled to a temperature no higher than 50^{o}F (10°C), the sample sleeve will be removed from the ice bath, labeled and sealed tightly in a plastic bag for shipment to the laboratory on ice in an insulated cooler. The laboratory will open and extrude the appropriate amount of soil (typically five grams for VOC samples) from the middle of the sleeve and placing the extruded soil in containers of the appropriate size and preservation.

8. The following information for each sample will be documented in a Field Logbook: brief soil description, depth interval of sample, temperature of sample collected at time of collection, time and date of sample collection, name of sampler/s. A photographic record of each sample collected, with identification label, is desirable. Figure 5 shows a typical setup for processing hot soil samples.
9. Excess soil should either be drummed or disposed of using another appropriate disposal technique.

Sample Collection Method 2

1. Follow steps 1-6 of Method 1.
2. Sampling methods may vary depending on the general purpose of the soil sampling event. For the purposes of this document the sampling methods will be divided into two categories: Interim and Confirmatory Sampling.

2.1 Interim Soil Sampling – Interim soil sample depths are typically selected based on the highest headspace PID reading collected at each 6-inch sleeve. Once cooled to a temperature no higher than 50°F (10°C), remove the cap on one end, gently scoop out a small portion of soil into a bowl to expose fresh soil within the sleeve. Place the PID sample probe into the headspace within the sleeve and record the reading. Once the headspace PID reading has been taken, replace the endcap and return the sample sleeve to the ice bath while this is repeated for all sample sleeves for the selected interval.

It is imperative that all spoons and spatulas be decontaminated prior to use and in between readings of each 6-inch sleeve.

Once all of the PID readings have been collected and used to determine the ideal depth to sample, the cooled sleeves may be processed in the field by extruding the appropriate amount of soil from the middle of the sleeve, and placing the extruded soil directly into containers of the appropriate size and preservation, as dictated by the analytical laboratory and project sampling plan/quality assurance plan. Typically, for VOC samples, five grams of soil will be placed in pre-cleaned, pre-preserved vials (preserved either with deionized water or sodium bisulfate for low level samples, or preserved with methanol for high level samples). Typically, for SVOC samples, a 2 oz. or 4 oz. unpreserved amber jar is filled with the extruded soil. Alternately, if appropriate, volatile organic compounds may be collected in commercially available systems such as EnCore®. Figure 4 shows the typical EnCore® sampling technique. Vials will be properly labeled and stored on ice in an insulated cooler.

2.2 Confirmatory Soil Sampling – Confirmatory sampling generally has discrete sampling locations selected prior to the sampling event; however, headspace PID readings, as described above, may be required for documentation purposes. Otherwise, once cooled to a temperature no higher than 50°F (10°C), the cooled sleeves may be processed as described above in section 2.1.

3. The following information for each sample will be documented in a Field Logbook: brief soil description, depth interval of sample, headspace PID reading (if required), temperature of sample collected at time of collection, time and date of sample collection, name of sampler/s. A photographic record of each sample collected, with identification label, is desirable. Figure 5 shows a typical setup for processing hot soil samples.

QA/QC Samples

Trip blanks, equipment blanks, duplicates and any other Quality Assurance/Quality Control (QA/QC) samples, if required, will be collected in accordance with the project specific Quality Assurance Project Plan, or the Sample Analysis Plan (SAP).

Analytical Methods

The analytical methods followed by the laboratory will vary depending on the contaminants of concern at the site, as well as the required detection limits and other data quality objectives. Examples of common volatile organic/semi-volatile organic analytical methods are shown below:

Analytical Method	Compounds of Interest	Notes
SW846 8260B	Volatile organic compounds (VOCs), including chlorinated VOCs	Options include: Requesting Tentatively Identified Compounds (TICs) for a library search of compounds, or requesting Selected Ion Monitoring (SIM) for lower detection limits if needed
SW846 8270C	Semi-volatile organic compounds (SVOCs), including polycyclic aromatic hydrocarbons (PAHs)	
SW846 8015	Total Petroleum Hydrocarbons (TPH) as Gasoline Range Organics (GRO)	Approximately C6-C12
SW846 8015	Total Petroleum Hydrocarbons (TPH) as Diesel Range Organics (DRO)	Approximately C10-C28

Figure 2. Removal and Capping of Sleeved Samples

Figure 3. Ice Bath for Cooling Samples

Figure 4. EnCore® Sampling Method

Figure 5. Typical Sample Processing Setup

6. SAMPLE RELATED FORMS

Chain of Custody form, from analytical laboratory, as appropriate
Field logbook & photographic log, as applicable

7. REFERENCES

Gaberell, M., A. Gavaskar, E. Drescher, J. Sminchak, L. Cumming, W.-S. Yoon, and S. De Silva. 2002. "Soil Core Characterization Strategy at DNAPL Sites Subjected to Strong Thermal or Chemical Remediation." in: A.R. Gavaskar and A.S.C. Chen (Eds.), *Remediation of Chlorinated and Recalcitrant Compounds—2002. Proceedings of the Third International Conference on Remediation of Chlorinated and Recalcitrant Compounds* (Monterey, CA; May 2002). ISBN 1-57477-132-9. Battelle Press, Columbus, OH.

Cascade Technical Services 17270 Woodinville Redmond Rd NE Ste 777 Bldg. A Woodinville, WA 98072 425.527.9700			
Procedure #	SOG- SA-100	Revision #	2
Review #1	Nikole Stone	Review #2	Alyson Fortune
Effective Date	7/24-2017	Approved By:	Stefan Cnophe Nielsen

CMP ATTACHMENT 2

Hot Groundwater Sampling

No. SOP-SA-101

1. PURPOSE AND APPLICABILITY

The purpose of this Standard Operating Procedure (SOP) is to ensure that TerraTherm, Inc. (TerraTherm) follows a consistent program to collect hot groundwater samples. For the purpose of this SOP, groundwater will be at or above ambient temperature conditions; as such, it is extremely important to follow established sampling methods including any health and safety protocols.

The preferred sampling method will be defined in the project specific work plan, sampling and analysis plan, and/or quality assurance project plan, but should be confirmed by the Project Manager (PM) and/or Project Engineer (PE) prior to sample collection.

For the purpose of this SOP, hot groundwater sampling refers to the collection of water, whether extracted from the ground or processed through the treatment system. Data collected in the field is used to identify any potential safety hazards; as well as evaluate the efficiency and progress of the remediation effort; therefore, it is extremely important that these data be reliable and accurate. This SOP, although maybe not in its entirety, applies to most TerraTherm projects and the personnel responsible for groundwater collection.

2. RESPONSIBILITY

The Site Supervisor, or his/her designee, will conduct periodic inspections of the sampling procedures established by this SOP. The purpose of the inspection is to verify that the procedures and the requirements of the SOP are being followed. Any deviations or inadequacies that are identified during the inspection will be immediately corrected.

3. SAFETY

Due to the high temperatures of the groundwater being collected, specific safety gear is required during the hot groundwater sampling process, aside from the standard personal protective equipment (PPE). Groundwater temperatures collected during hot groundwater sampling events are typically less than 90-95 °C (194-203 °F) but can approach boiling point temperatures (100 °C /212 °F) depending on in what phase of the thermal remedy the samples are collected. Steam pressure may build up inside wells and should be purged appropriately before sampling commences. The sampler should position him/herself away from the line of fire of any pressure/hot liquids, as much as is practical. Sampling crews should have a pre-task meeting with the appropriate engineering staff/data manager to review subsurface temperatures in the areas of sampling. All required PPE is listed below.

Although not common, steam pressure in the subsurface may result in a forceful ejection of hot (boiling) water/steam from the well. Steam pressure build up could also result in the forceful ejection of installed well caps/plugs. All wells within the radius of influence treatment have the potential to be affected by this.

Standard PPE:

- Hard hat
- High visibility vest
- Long sleeve shirt
- Safety glasses
- Steel-toed boots
- Nitrile gloves (for sampling purposes—should wear under the temperature rated gloves listed below. For work after cooling the sample, nitrile only may be worn)

Hot Groundwater Sampling PPE:

- Face shield (required)
- Temperature-rated gloves (required), examples:
  - TEMP-DEX Heat Resistant Gloves, Nitrile, 250°F Max. Temp https://www.grainger.com/product/TEMP-DEX-Heat-Resistant-Gloves-49Y254
  - Daymark Steam Resistant Gloves, Rubber, 225˚F Max. Temp https://www.grainger.com/product/DAYMARK-Steam-Resistant-Gloves-6GVA4
- Temperature-rated sleeves (as necessary)
- Apron or Tyvek® suit (as necessary)

4. REQUIRED MATERIALS

The following sampling materials may be needed, depending on the specific needs of the sampling program:

- ¼” outer diameter Teflon® tubing
- ¼” outer diameter stainless steel or copper tubing
- Stainless steel compression fittings and/or ¼” inner diameter flexible tubing (e.g. silicone)
- 5 gallon buckets
- Ice and cold water
- Unpreserved glass jars (typically 1L)
- Sampling containers, provided by the laboratory, specific to the parameters to be measured
- High temperature rated pump (if sampling from a monitoring well without a dedicated pump)
- Water level meter and/or interface probe (Solinst or equivalent)—if water levels are desired
- Flow through cell, multi-parameter sampling sonde (e.g. YSI), and turbidity meter—only required if groundwater parameters need to be recorded (typically for wells that are not constantly purged)
- Associated calibration supplies for multi-parameter sonde/turbidity meter

5. METHOD

Hot groundwater samples at thermal sites can be obtained from two different well types.

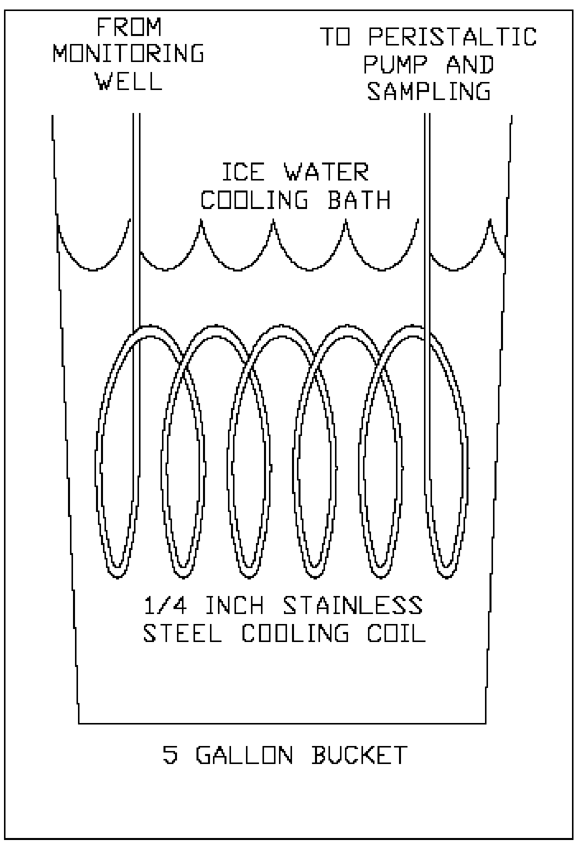
1. Samples collected from multi-phase extraction wells (MPE wells) installed and operated as a part of the thermal remedy to maintain hydraulic and/or pneumatic control.
2. Dedicated groundwater monitoring wells installed between the heaters/electrodes or steam injection and extraction wells.

The MPE wells include a high temperature down-hole pump that is used for hydraulic control within the thermal treatment zone (TTZ). When samples are collected from MPE wells, the already installed pump is typically used to bring the sample to the surface.

The dedicated groundwater monitoring wells do not typically have a permanently installed pump. Due to the elevated temperatures of groundwater within the wellfield, standard sampling pumps such as a peristaltic and/or bladder pumps, typically cannot be used for the collection of groundwater. These pumps typically do not contain heat resistant materials necessary to support the elevated temperatures of the groundwater. Therefore special high temperature rated (~90-100°C (194-212 °F)) pumps may be required for sampling at the dedicated groundwater monitoring wells.

The following groundwater sampling procedure applies for sampling from both well types. The use of a cooling coil was adapted from the methods provided in the B&R Environmental, Technical Memorandum for Purging and Groundwater Sampling Using Low Flow Purging and Sampling Techniques (B&R Environmental, 1998). The apparatus used to perform sample cooling is shown in **Figure 1** below.

Figure 1. Sample Cooling Apparatus



Hot Groundwater Sampling

No. SOP-SA-101

The following outlines the procedures of the hot groundwater sampling process.

1. Prior to initial sampling, a cooling coil is formed by wrapping a ~10-ft length of ¼-inch copper (or stainless steel) tubing around a 4-inch diameter pipe until four to six full turns have been made. The ends of the tubing are fashioned such that both ends of the tubing extend upward. See **Figure 2** below.

Figure *2. Copper Cooling Coil*

2. Connect a ¼-inch Teflon® sample tubing from the sample port of the MPE well or from the pump tubing of the monitoring well to the cooling coil using the compression fittings on either end of the tubing and place the coil in a bucket or cooler with ice water to form the ice bath. Connect a second piece of ¼-inch Teflon® sample tubing on the discharge side of the cooling coil using a compression coupling to allow for easy transfer of groundwater into the sample collection jar (typically 1L unpreserved glass). Note, due to the temperature, sample tubing may soften during sampling. Therefore, caution should be used to check all connections prior to opening any MPE wellhead valves and also throughout the sampling event.

3. For sampling from MPE wells, open the sample port valve on the wellhead and collect groundwater (after the cooling coil) directly into a clean, unpreserved 1L glass jar, and immediately transfer the liquid to appropriate laboratory (preserved) containers. Due to the pumping force associated with the high temperature downhole pumps, it is extremely difficult to collect groundwater directly into laboratory supplied containers, specifically smaller containers that contain preservative.

CAUTION – Sampling materials and jars may be hot even after the cooling loop! Wear appropriate PPE. Often, nitrile gloves (single or doubled up) provide enough temperature protection for the cooled sample.

- When sampling directly from a typical operating MPE well, it may not be necessary to purge the well prior to sampling collection. The thermal groundwater pumps may be in continuous operation during the project operations period and will therefore already be purged. Note that if the pump is in continuous operations, once the sample tubing from the monitoring well is connected to the cooling coil, liquid will immediately flow into the unpreserved jar. If hot groundwater samples are being collected from an MPE well that is not in continuous operation (i.e. pump cycles on and off) or are being collected from dedicated groundwater wells, the wells should be purged such that the groundwater sample sent to the lab for analysis is representative of in situ water quality.

- When sampling from a dedicated groundwater monitoring well, same procedure as described above is adapted, except that the sampling setup is connected to the sample tube from the sampling pumps, instead of the MPE sample port. Depending on the monitoring well setup, purging of the well may be required. Purge volume is typically two times the static saturated well volume. Care should be taken when removing the monitoring well cap to release any steam pressure that may have built up from boiling water in the subsurface. It may be advantageous to have the wells equipped with dedicated downhole tubing/fittings.

- For low yield wells, the well should be purged dry and allowed to recover. Sampling commences as soon as the well has recovered sufficiently to collect the appropriate volume for the anticipated sample analysis.

- If required, water quality parameters including temperature, turbidity, specific conductance, pH, and dissolved oxygen (DO) can be measured during the sample collection from both well types using a multi-parameter meter with a flow through cell such as a YSI (or equivalent).

- After sample collection, the coil and unpreserved jar should be thoroughly decontaminated with a non-abrasive soap, such as Alconox® or Simple Green, and deionized water. A new coil, sample tubing, and jar should be used for each sample location in order to minimize cross-contamination between samples.

6. SAMPLE RELATED FORMS

Groundwater sample chain of custody (COC) form, provided by laboratory

Record any relevant information about the groundwater sampling (e.g. color of liquid, amount of suspended particles, water depth if recorded, any field parameters recorded, any NAPL present, flow rate, purge volume, etc.) in a field logbook.

7. REFERENCES

B&R Environmental, Technical Memo for Purging and Groundwater Sampling Using Low Flow Purging and Sampling Techniques (B&R Environmental, 1998).

Hot Groundwater Sampling

No. SOP-SA-101

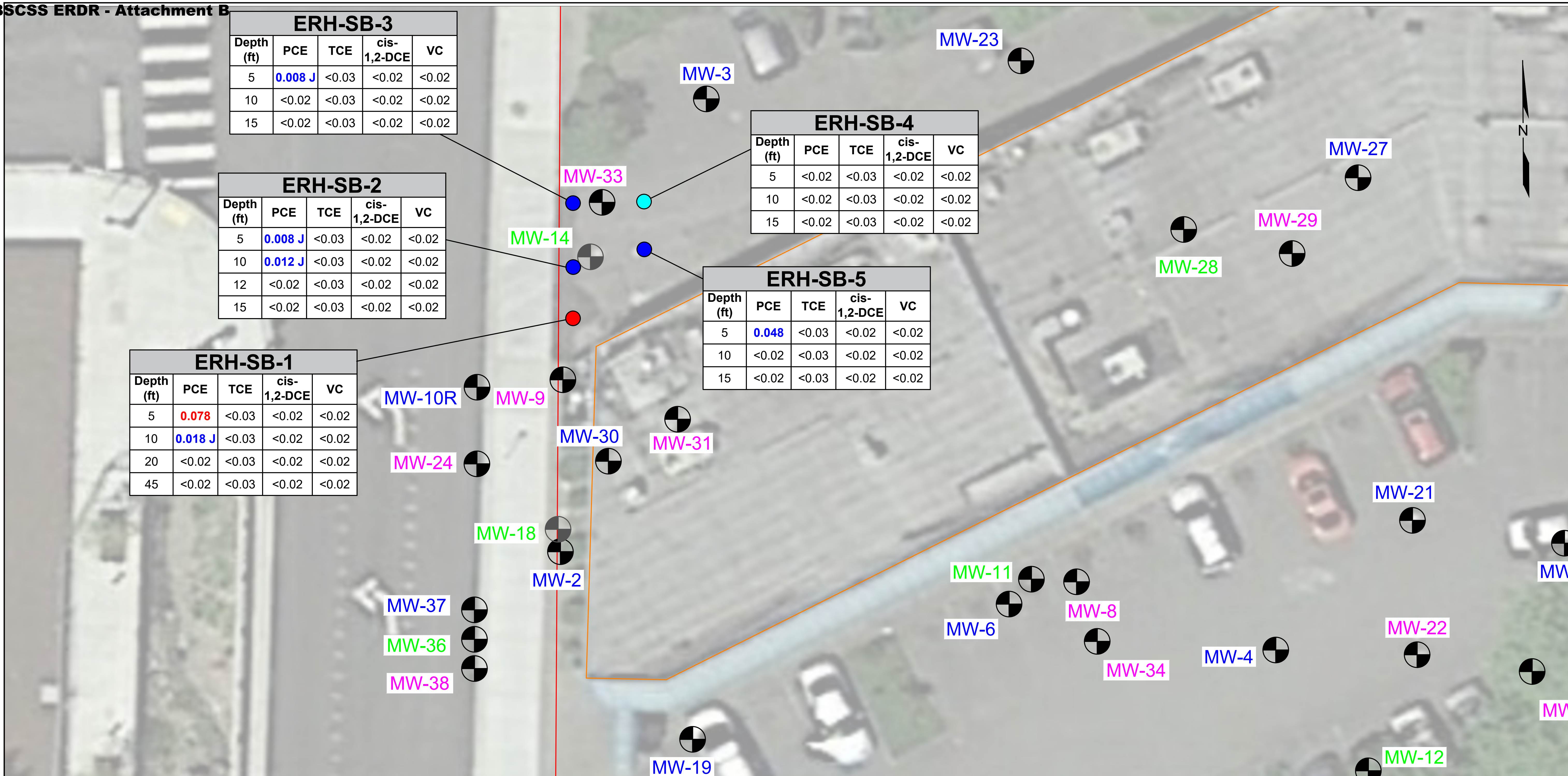
TerraTherm, Inc.
151 Suffolk Lane
Gardner, MA 01440
978.343.1200

Guidance #	**SOP- SA-101**	**Revision #**	**5**
Review #1	Nikole Stone	**Review #2**	Alyson Fortune
Effective Date	**March 2018**	**Approved By:**	Steffen Griepke Nielsen

Attachment B

Pre-Design Soil Sampling and Groundwater Bio-Sampling Results

BSCSS ERDR - Attachment B



ERH-SB-3

Depth (ft)	PCE	TCE	cis-1,2-DCE	VC
5	0.008 J	<0.03	<0.02	<0.02
10	<0.02	<0.03	<0.02	<0.02
15	<0.02	<0.03	<0.02	<0.02

ERH-SB-4

Depth (ft)	PCE	TCE	cis-1,2-DCE	VC
5	<0.02	<0.03	<0.02	<0.02
10	<0.02	<0.03	<0.02	<0.02
15	<0.02	<0.03	<0.02	<0.02

ERH-SB-2

Depth (ft)	PCE	TCE	cis-1,2-DCE	VC
5	0.008 J	<0.03	<0.02	<0.02
10	0.012 J	<0.03	<0.02	<0.02
12	<0.02	<0.03	<0.02	<0.02
15	<0.02	<0.03	<0.02	<0.02

ERH-SB-5

Depth (ft)	PCE	TCE	cis-1,2-DCE	VC
5	0.048	<0.03	<0.02	<0.02
10	<0.02	<0.03	<0.02	<0.02
15	<0.02	<0.03	<0.02	<0.02

ERH-SB-1

Depth (ft)	PCE	TCE	cis-1,2-DCE	VC
5	0.078	<0.03	<0.02	<0.02
10	0.018 J	<0.03	<0.02	<0.02
20	<0.02	<0.03	<0.02	<0.02
45	<0.02	<0.03	<0.02	<0.02

Aerial Photo Source: Google Earth Pro
Aerial Photo Date: June 27, 2016

LEGEND

- BSCA Property Boundary
- MW-1 Monitoring Well, Shallow (5-25ft)
- MW-2 Monitoring Well, Intermediate (25-35 ft)
- MW-3 Monitoring Well, Deep (35-55 ft)
- Soil boring location with concentrations greater than MTCA Method A cleanup levels
- Soil boring location with detectable concentrations below MTCA Method A cleanup levels
- Soil boring location with no detectable concentrations

MTCA Method A Cleanup Levels

PCE = Tetrachloroethylene	(0.05 ppm)
TCE = Trichloroethylene	(0.03 ppm)
cis-1,2 DCE = cis-1,2 Dichloroethene	(160 ppm*)
VC = Vinyl Chloride	(240 ppm*)

All results in ppm = parts per million (equivalent to mg/kg)
* - MTCA Method B Cleanup Level
J = Analyte detected below reporting limit, result is an estimate

0 15 30
Approximate Scale in Feet

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18107 Bothell Way NE
Bothell, Washington

Figure 1
Soil Analytical Results - January 2018

KANE ENVIRONMENTAL INC

SEATTLE ▪ PHOENIX▪ SAN FRANCISCO

April 5, 2018

Mr. Jerome Cruz, Ph.D.
Toxics Cleanup Program, Northwest Regional Office
Washington State Department of Ecology
Northwest Regional Office
3190 160th Ave SE
Bellevue, Washington 98008-5452

RE: Baseline Microbial Groundwater Sampling Results

Mr. Cruz:

Groundwater samples were collected from eight groundwater monitoring wells (MW-31, MW-30, MW-5, MW-21, MW-35, MW-12, MW-11, and MW-8) on February 12, 2018. The groundwater samples were collected to aid in the evaluation of the types of bacteria present in the areas where future in situ bioremediation is going to be conducted. The groundwater samples were submitted to Microbial Insights, Inc. (MI) of Nashville, Tennessee, for analyses of quantitative polymerase chain reaction (qPCR) to identify the concentration of Dehalococcoides (DHC) and other relevant bacteria present in the three groundwater bearing zones (shallow, intermediate, and deep) where in situ anaerobic bioremediation is being proposed as the remedial approach. In addition to qPCR, MI analyzed each groundwater sample for key functional genes responsible for the reductive dechlorination process.

These eight groundwater samples represent baseline conditions in these zones prior to biostimulation (i.e. addition of substrate/nutrients). Without the presence of a readily available carbon/energy source (i.e. substrate), the indigenous bacterial population will be at low concentrations in the aquifer. In addition, areas that contain low concentrations of chlorinated solvents (i.e. electron acceptors) may inhibit certain microbial growth. Upon biostimulation, these bacterial communities will likely reach higher concentrations during active remediation. These laboratory results are being used to initially evaluate the type of microbial community that can be detected in these three zones, and if biostimulation alone will be sufficient in the remedial process. If biostimulation isn't effective, then bioaugmentation (i.e. addition of specific bacteria or consortiums) will be required during full scale remediation.

Each sampling/well location results are discussed herein as presented in the attached laboratory report from MI. These biological/microbial results are compared to the historical groundwater data from each location to present the correlating solvent concentrations and associated biodegradation analysis.
MW-31: MW-31 has a screened interval from 40 to 50 ft bgs, which is within the deep zone. The concentrations of chlorinated solvents in MW-31 are low level detections of PCE (8-11 µg/L) and TCE (<

1 ug/L). There are no significant detections of TCE, cis-DCE, and/or VC at MW-31 that indicate any significant dechlorination is occurring in this area. This is likely due to the lack of a carbon/energy source in the deep zone, which is expected. The MI report (Table 1) presents the results obtained from MW-31. Despite the lack of any significant chlorinated solvent mass or carbon/energy source, this location has a low detection of DHC (4.0E+00 cell/mL) and low to moderate detections of other key anaerobic bacteria ranging from 1.25E+02 to 4.48E+03 cells/mL. In addition, there was a high detection of sulfate reducing bacteria (APS) at 7.02E+04 cells/mL, and a low detection of methanogens (MGN) at 9.90E+00 cells/mL. These anaerobic bacteria are also indications of a robust and healthy microbial consortium around MW-31.

MW-30: MW-30 has a screened interval from 9 to 19 ft bgs, which is within the shallow zone. The concentrations of chlorinated solvents in MW-30 are high detections of PCE (92,000-130,000 µg/L), and no significant detections of TCE (BDL). There was only one significant detection of cis-DCE (1,300 µg/L), and no detections of VC at MW-30, which indicates very limited dechlorination is occurring in this area. This is likely due to the lack of a carbon/energy source in this part of the shallow zone, which is expected. The MI report (Table 1) presents the results obtained from MW-30. This location has no detection of DHC (<2.50+00 cell/mL) and moderate detections of other key anaerobic bacteria ranging from 6.71E+01 to 5.79E+03 cells/mL. While PCE doesn't appear to be dechlorinating to any significant degree at MW-30, there was a low-level detection of PCE Reductase (PCE-1) at 2.02E+01 (J) indicating the presence of some PCE dechlorinating bacteria. In addition, there was a high detection of sulfate reducing bacteria (APS) at 7.81E+04 cells/mL, and no significant detection of methanogens (MGN) at <2.50E+01 cells/mL (note: higher detection limit than MW-31 and others). The detections of these reductive dechlorinating and other bacteria are indications of a robust and healthy microbial consortium around MW-30, despite the lack of any dechlorination occurring in this area. Without a soluble and biodegradable substrate, no significant anaerobic dechlorination will occur and these bacteria will remain at suppressed concentrations.

MW-5: MW-5 has a screened interval from 10 to 25 ft bgs, which is within the shallow zone. The concentrations of chlorinated solvents in MW-5 are high detections of PCE (590-21,000 µg/L), and significant detections of TCE (15-660 µg/L), cis-DCE (20-630 µg/L), and one low-level detection of VC (4/4/14 sampling event, which also shows of negative ORP), which indicates significant anaerobic dechlorination is occurring in this area. This is likely due to the presence of a carbon/energy source in this part of the shallow zone. The MI report (Table 1) presents the results obtained from MW-5. This location has a low-level detection of DHC (1.54+01 cell/mL) and moderate detections of other key anaerobic bacteria ranging from 2.37E+02 to 2.45E+03 cells/mL. There were also low-level detections of PCE Reductase 1 and 2 (PCE-1 and PCE-2) at 2.0E-01 to 9.0E-01 cells/mL indicating the presence of some PCE dechlorinating bacteria. In addition, there was a high detection of sulfate reducing bacteria (APS) at 2.09E+04 cells/mL, and no significant detection of methanogens (MGN) at <5.00E+00 cells/mL.

The detections of these reductive dechlorinating and other bacteria are indications of a robust and healthy microbial consortium around MW-5, which correlates strongly with the dechlorination occurring in this area. The addition of a soluble and biodegradable substrate in this area would likely speed up the anaerobic dechlorination process.

MW-21: MW-21 has a screened interval from 10 to 15 ft bgs, which is within the shallow zone. The concentrations of chlorinated solvents in MW-21 are high detections of PCE (8,400-27,000 µg/L), and significant detections of TCE (210-540 µg/L), cis-DCE (190-360 µg/L), but no detections of VC, which indicates significant anaerobic dechlorination is occurring in this area. This is likely due to the presence of a carbon/energy source in this part of the shallow zone. The MI report (Table 1) presents the results obtained from MW-21. Despite the groundwater data showing some anaerobic dechlorination is occurring, this location has no significant detections of DHC (<5.00E-01 cell/mL) and no detections of other key anaerobic bacteria. The only bacteria detected was total Eubacteria (EBAC) at 1.06E+03 cells/mL. The lack of any anaerobic bacteria indicates this part of the site is lacking any significant microbial consortium around MW-21. However, the groundwater data (<u>which is more representative of the microbial community in the subsurface</u>) shows anaerobic dechlorinating bacteria are present around MW-21. The contradiction in the microbial data is likely due to groundwater samples not being as accurate as Bio-Trap samples.

MW-35: MW-35 has a screened interval from 48 to 58 ft bgs, which is within the deep zone. The concentrations of chlorinated solvents in MW-35 are low level detections of PCE (1.4-2.1 µg/L). There have been no significant detections of TCE, cis-DCE, and/or VC at MW-35 that indicate any significant dechlorination is occurring in this area. This is likely due to the lack of a carbon/energy source in the deep zone, which is expected. The MI report (Table 1) presents the results obtained from MW-35. Despite the lack of any significant chlorinated solvent mass or carbon/energy source, this location has a low detection of DHC (3.00E-01 cell/mL) and low to moderate detections of other key anaerobic bacteria ranging from 1.78E+01 to 1.85E+03 cells/mL. In addition, there was a moderate detection of sulfate reducing bacteria (APS) at 7.07E+03 cells/mL, and a low detection of methanogens (MGN) at 3.54E+01 cells/mL. These anaerobic bacteria are also indications of a robust and healthy microbial consortium around MW-35.

MW-12: MW-12 has a screened interval from 25 to 33 ft bgs, which is within the intermediate zone. The concentrations of chlorinated solvents in MW-12 are high detections of PCE (700-5,900 µg/L), and significant detections of TCE (5.1-390 µg/L), cis-DCE (29-1,600 µg/L), and two low-level detections of VC (3/20/13 and 4/4/14 sampling events, which also shows of negative ORPs), which indicates significant anaerobic dechlorination is occurring in this area. This is likely due to the presence of a carbon/energy source in this part of the intermediate zone. The MI report (Table 1) presents the results obtained from MW-12. This location has a low-level detection of DHC (8.06+01 cell/mL) and moderate detections of other key anaerobic bacteria ranging from 2.38E+03 to 2.02E+04 cells/mL. There were also low-level detections of PCE Reductase 1 and 2 (PCE-1 and PCE-2) at 3.00E-01 to 6.69E+02 cells/mL indicating the presence of some PCE dechlorinating bacteria. In addition, there was a high detection of sulfate reducing bacteria (APS) at 1.39+04 cells/mL, and a significant detection of methanogens (MGN) at 5.37E+01 cells/mL. The detections of these reductive dechlorinating and other bacteria are indications of a robust and healthy microbial consortium around MW-12, which correlates strongly with the dechlorination occurring in this area. The addition of a soluble and biodegradable substrate in this area would likely speed up the anaerobic dechlorination process.

MW-11: MW-11 has a screened interval from 25 to 33 ft bgs, which is within the intermediate zone. The concentrations of chlorinated solvents in MW-11 are low detections of PCE (2.0-27 µg/L), and low-level detections of TCE (0.18-0.53 µg/L), cis-DCE (0.26-0.42 µg/L), and no detections of VC, which indicates very limited anaerobic dechlorination is occurring in this area. This is likely due to the lack of a carbon/energy source in this part of the intermediate zone. The MI report (Table 1) presents the results obtained from MW-11. This location has a low-level detection of DHC (6.20E+00 cell/mL) and moderate to high detections of other key anaerobic bacteria ranging from 4.38E+03 to 1.82E+04 cells/mL. In addition, there was a high detection of sulfate reducing bacteria (APS) at 7.14+04 cells/mL, and a moderate detection of methanogens (MGN) at 1.32E+03 cells/mL. The detections of these reductive dechlorinating and other bacteria are indications of the presence of a good microbial consortium around MW-11. If significant chlorinated solvent mass was present in this area, then more TCE, cis-DCE, and VC would be detected. The addition of a soluble and biodegradable substrate in this area would likely speed up the anaerobic dechlorination process of this low-level solvent mass in this area.

MW-8: MW-8 has a screened interval from 45 to 50 ft bgs, which is within the deep zone. The concentrations of chlorinated solvents in MW-8 are low detections of PCE (.0.44-180 µg/L), and low-level detections of TCE (0.98-50 µg/L), cis-DCE (0.88-160 µg/L), and one low-level detection of VC (10/11/14 sampling event), which indicates some low-level anaerobic dechlorination is occurring in this area. This is likely due to the presence of a carbon/energy source in this part of the deep zone. The MI report (Table 1) presents the results obtained from MW-8. This location has a low-level detection of DHC (3.00E-01 cell/mL) and low to moderate detections of other key anaerobic bacteria ranging from 3.26E+01 to 1.06E+03 cells/mL. There was also a low-level detection of PCE Reductase 2 (PCE-2) at 1.50E+00 cells/mL indicating the presence of some PCE dechlorinating bacteria. In addition, there was a high detection of sulfate reducing bacteria (APS) at 1.02+04 cells/mL, but no detection of methanogens (MGN) at <5.00E+00 cells/mL. The detections of these reductive dechlorinating and other bacteria are indications of the presence of a microbial consortium around MW-8, which correlates strongly with the dechlorination occurring in this area. The addition of a soluble and biodegradable substrate in this area would likely speed up the anaerobic dechlorination process.

Overall, the majority of these sampling locations show the presence of DHC and many other bacteria capable of anaerobic dechlorination. These detections of these bacteria in all three zones indicate that biostimulation will be successful, and that bioaugmentation will not be required at this site. In addition, the historical groundwater data collected from MW-2 and MW-6 onsite, show when a substrate is added to this aquifer, robust and complete anaerobic reductive dechlorination of PCE, TCE, etc. occurs at this site.

Sincerely,
KANE ENVIRONMENTAL, INC.

John Kane
CEO / President

cc: Nduta Mbuthia, City of Bothell

ATTACHMENTS:
QuantArray Results
Chain of Custody
How to Use Estimated Percentile Ranks from the Microbial Insights Database
How to Retrieve and Use Estimated Percentile Ranks from the Microbial Insights Database

microbial insights
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SITE LOGIC Report

QuantArray®-Chlor Study

Contact: John Kane

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Suite 102
Seattle, WA 98103

Email: jkane@kane-environmental.com

MI Identifier: 027PB

Report Date: 02/26/2018

Project: BSCSS Task 9.2, 82302-Task 9.2
Comments:

microbialinsights

The QuantArray®-Chlor Approach

Quantification of *Dehalococcoides*, the only known bacterial group capable of complete reductive dechlorination of PCE and TCE to ethene, has become an indispensable component of assessment, remedy selection, and performance monitoring at sites impacted by chlorinated solvents. While undeniably a key group of halorespiring bacteria, *Dehalococcoides* are not the only bacteria of interest in the subsurface because reductive dechlorination is not the only potential biodegradation pathway operative at contaminated sites, and chlorinated ethenes are not always the primary contaminants of concern. The QuantArray®-Chlor not only includes a variety of halorespiring bacteria (*Dehalococcoides*, *Dehalobacter*, *Dehalogenimonas*, etc.) to assess the potential for reductive dechlorination of chloroethenes, chloroethanes, chlorobenzenes, chlorophenols, and chloroform, but also provides quantification of functional genes involved in aerobic (co)metabolic pathways for biodegradation of chlorinated solvents and even competing biological processes. Thus, the QuantArray®-Chlor will give site managers the ability to simultaneously yet economically evaluate the potential for biodegradation of a spectrum of common chlorinated contaminants through a multitude of anaerobic and aerobic (co) metabolic pathways to give a much more clear and comprehensive view of contaminant biodegradation.

The QuantArray®-Chlor is used to quantify specific microorganisms and functional genes to evaluate the following:

Anaerobic Reductive Dechlorination	Quantification of important halorespiring bacteria (e.g. *Dehalococcoides*, *Dehalobacter*, *Dehalogenimonas*, *Desulfitobacterium* spp.) and key functional genes (e.g. vinyl chloride reductases, TCE reductase, chloroform reductase) responsible for reductive dechlorination of a broad spectrum of chlorinated solvents.
Aerobic Cometabolism	Several different types of bacteria including methanotrophs and some toluene/phenol utilizing bacteria can co-oxidize TCE, DCE, and vinyl chloride. The QuantArray®-Chlor quantifies functional genes like soluble methane monooxygenase encoding enzymes capable of co-oxidation of chlorinated ethenes.
Aerobic (Co)metabolism of Vinyl Chloride	Ethene oxidizing bacteria are capable of cometabolism of vinyl chloride. In some cases, ethenotrophs can also utilize vinyl chloride as a growth supporting substrate. The QuantArray®-Chlor targets key functional genes in ethene metabolism.

How do QuantArrays® work?

The QuantArray®-Chlor in many respects is a hybrid technology combining the highly parallel detection of microarrays with the accurate and precise quantification provided by qPCR into a single platform. The key to highly parallel qPCR reactions is the nanoliter fluidics platform for low volume, solution phase qPCR reactions.

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How are QuantArray® results reported?

One of the primary advantages of the QuantArray®-Chlor is the simultaneous quantification of a broad spectrum of different microorganisms and key functional genes involved in a variety of pathways for chlorinated hydrocarbon biodegradation. However, highly parallel quantification combined with the various metabolic and cometabolic capabilities of different target organisms can complicate data presentation. Therefore, in addition to Summary Tables, QuantArray® results will be presented as Microbial Population Summary and Comparison Figures to aid in data interpretation and subsequent evaluation of site management activities.

Types of Tables and Figures:

Microbial Population Summary	Figure presenting the concentrations of QuantArray®-Chlor target populations (e.g. *Dehalococcoides*) and functional genes (e.g. vinyl chloride reductase) relative to typically observed values.
Summary Tables	Tables of target population concentrations grouped by biodegradation pathway and contaminant type.
Comparison Figures	Depending on the project, sample results can be presented to compare changes over time or examine differences in microbial populations along a transect of the dissolved plume.

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Results

Table 1: Summary of the QuantArray®-Chlor results obtained for samples MW-31, MW-30, MW-5, and MW-21.

Sample Name Sample Date	MW-31 02/12/2018	MW-30 02/12/2018	MW-5 02/13/2018	MW-21 02/13/2018
Reductive Dechlorination	cells/mL	cells/mL	cells/mL	cells/mL
Dehalococcoides (DHC)	**4.00E+00**	<2.50E+00	**1.54E+01**	<5.00E-01
tceA Reductase (TCE)	<5.00E-01	<2.50E+00	<5.00E-01	<5.00E-01
BAV1 Vinyl Chloride Reductase (BVC)	<5.00E-01	<2.50E+00	**4.10E+00**	<5.00E-01
Vinyl Chloride Reductase (VCR)	<5.00E-01	<2.50E+00	**6.00E-01**	<5.00E-01
Dehalobacter spp. (DHBt)	**3.05E+03**	**1.92E+03**	<5.00E+00	<5.00E+00
Dehalobacter DCM (DCM)	<5.00E+00	<2.50E+01	<5.00E+00	<5.00E+00
Dehalogenimonas spp. (DHG)	**4.48E+03**	**5.79E+03**	**2.42E+03**	<5.00E+00
Desulfitobacterium spp. (DSB)	**2.70E+03**	<2.50E+01	**2.45E+03**	<5.00E+00
Dehalobium chlorocoercia (DECO)	**2.59E+03**	**1.47E+03**	**9.40E+02**	<5.00E+00
Desulfuromonas spp. (DSM)	**1.25E+02**	**6.71E+01**	**2.37E+02**	<5.00E+00
PCE Reductase (PCE-1)	<5.00E+00	**2.02E+01 (J)**	**2.00E-01 (J)**	<5.00E+00
PCE Reductase (PCE-2)	<5.00E+00	<2.50E+01	**9.00E-01 (J)**	<5.00E+00
Vinyl Chloride Reductase (CER)	<5.00E+00	<2.50E+01	<5.00E+00	<5.00E+00
trans-1,2-DCE Reductase (TDR)	<5.00E+00	<2.50E+01	<5.00E+00	<5.00E+00
Chloroform Reductase (CFR)	<5.00E+00	<2.50E+01	<5.00E+00	<5.00E+00
1,1 DCA Reductase (DCA)	<5.00E+00	<2.50E+01	<5.00E+00	<5.00E+00
1,2 DCA Reductase (DCAR)	<5.00E+00	<2.50E+01	<5.00E+00	<5.00E+00
Aerobic (Co)Metabolic				
Soluble Methane Monooxygenase (SMMO)	**2.13E+02**	<2.50E+01	**6.06E+02**	<5.00E+00
Toluene Dioxygenase (TOD)	**5.27E+02**	**2.01E+03**	<5.00E+00	<5.00E+00
Phenol Hydroxylase (PHE)	**1.93E+02**	**7.36E+02**	**8.97E+01**	<5.00E+00
Trichlorobenzene Dioxygenase (TCBO)	<5.00E+00	<2.50E+01	<5.00E+00	<5.00E+00
Toluene Monooxygenase 2 (RDEG)	**2.04E+02**	**2.17E+03**	<5.00E+00	<5.00E+00
Toluene Monooxygenase (RMO)	**1.48E+02**	<2.50E+01	<5.00E+00	<5.00E+00
Ethene Monooxygenase (EtnC)	**7.76E+01**	<2.50E+01	**2.69E+01**	<5.00E+00
Epoxyalkane Transferase (EtnE)	<5.00E+00	<2.50E+01	**9.13E+01**	<5.00E+00
Dichloromethane Dehalogenase (DCMA)	<5.00E+00	<2.50E+01	<5.00E+00	<5.00E+00
Other				
Total Eubacteria (EBAC)	**3.38E+05**	**3.03E+06**	**1.37E+06**	**1.06E+03**
Sulfate Reducing Bacteria (APS)	**7.02E+04**	**7.81E+04**	**2.09E+04**	<5.00E+00
Methanogens (MGN)	**9.90E+00**	<2.50E+01	<5.00E+00	<5.00E+00

Legend:
NA = Not Analyzed
NS = Not Sampled
J = Estimated Gene Copies Below PQL but Above LQL
I = Inhibited
< = Result Not Detected

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Table 2: Summary of the QuantArray®-Chlor results obtained for samples MW-35, MW-12, MW-11, and MW-8.

Sample Name **Sample Date**	**MW-35** **02/13/2018**	**MW-12** **02/14/2018**	**MW-11** **02/14/2018**	**MW-8** **02/14/2018**
Reductive Dechlorination	cells/mL	cells/mL	cells/mL	cells/mL
Dehalococcoides (DHC)	**3.00E-01 (J)**	**8.06E+01**	**6.20E+00**	**3.00E-01 (J)**
tceA Reductase (TCE)	<5.00E-01	<5.00E-01	<5.00E-01	<5.00E-01
BAV1 Vinyl Chloride Reductase (BVC)	<5.00E-01	<5.00E-01	<5.00E-01	<5.00E-01
Vinyl Chloride Reductase (VCR)	<5.00E-01	**2.50E+00**	<5.00E-01	<5.00E-01
Dehalobacter spp. (DHBt)	**1.85E+03**	<5.00E+00	<5.00E+00	**1.06E+03**
Dehalobacter DCM (DCM)	**1.78E+01**	<5.00E+00	<5.00E+00	<5.00E+00
Dehalogenimonas spp. (DHG)	<5.00E+00	**2.02E+04**	**1.80E+04**	**1.99E+03**
Desulfitobacterium spp. (DSB)	**9.90E+02**	**2.38E+03**	**1.82E+04**	**1.75E+02**
Dehalobium chlorocoercia (DECO)	**5.01E+02**	**2.68E+03**	**1.18E+04**	**3.78E+02**
Desulfuromonas spp. (DSM)	**1.56E+02**	<5.00E+00	**4.38E+03**	**3.26E+01**
PCE Reductase (PCE-1)	<5.00E+00	**3.00E-01 (J)**	<5.00E+00	<5.00E+00
PCE Reductase (PCE-2)	<5.00E+00	**6.69E+02**	<5.00E+00	**1.50E+00 (J)**
Vinyl Chloride Reductase (CER)	<5.00E+00	<5.00E+00	<5.00E+00	<5.00E+00
trans-1,2-DCE Reductase (TDR)	<5.00E+00	<5.00E+00	<5.00E+00	<5.00E+00
Chloroform Reductase (CFR)	<5.00E+00	<5.00E+00	<5.00E+00	<5.00E+00
1,1 DCA Reductase (DCA)	<5.00E+00	<5.00E+00	<5.00E+00	<5.00E+00
1,2 DCA Reductase (DCAR)	<5.00E+00	**9.16E+01**	<5.00E+00	<5.00E+00
Aerobic (Co)Metabolic				
Soluble Methane Monooxygenase (SMMO)	**2.96E+01**	**3.86E+03**	**1.90E+00 (J)**	**7.90E+00**
Toluene Dioxygenase (TOD)	**9.33E+01**	**3.65E+03**	<5.00E+00	**3.44E+02**
Phenol Hydroxylase (PHE)	**3.60E+02**	**4.03E+02**	**2.73E+02**	**3.44E+02**
Trichlorobenzene Dioxygenase (TCBO)	<5.00E+00	<5.00E+00	<5.00E+00	<5.00E+00
Toluene Monooxygenase 2 (RDEG)	**3.71E+02**	**7.33E+02**	**1.79E+03**	**1.81E+03**
Toluene Monooxygenase (RMO)	**2.16E+02**	**2.50E+03**	**1.25E+02**	**2.22E+01**
Ethene Monooxygenase (EtnC)	<5.00E+00	<5.00E+00	**1.09E+01**	**6.84E+01**
Epoxyalkane Transferase (EtnE)	**2.65E+01**	**1.12E+02**	**1.44E+02**	**4.29E+02**
Dichloromethane Dehalogenase (DCMA)	<5.00E+00	<5.00E+00	<5.00E+00	<5.00E+00
Other				
Total Eubacteria (EBAC)	**1.53E+05**	**6.24E+05**	**1.21E+06**	**1.95E+05**
Sulfate Reducing Bacteria (APS)	**7.07E+03**	**1.39E+04**	**7.14E+04**	**1.02E+04**
Methanogens (MGN)	**3.54E+01**	**5.37E+01**	**1.32E+03**	<5.00E+00

Legend:
NA = Not Analyzed
NS = Not Sampled
J = Estimated Gene Copies Below PQL but Above LQL
I = Inhibited
< = Result Not Detected

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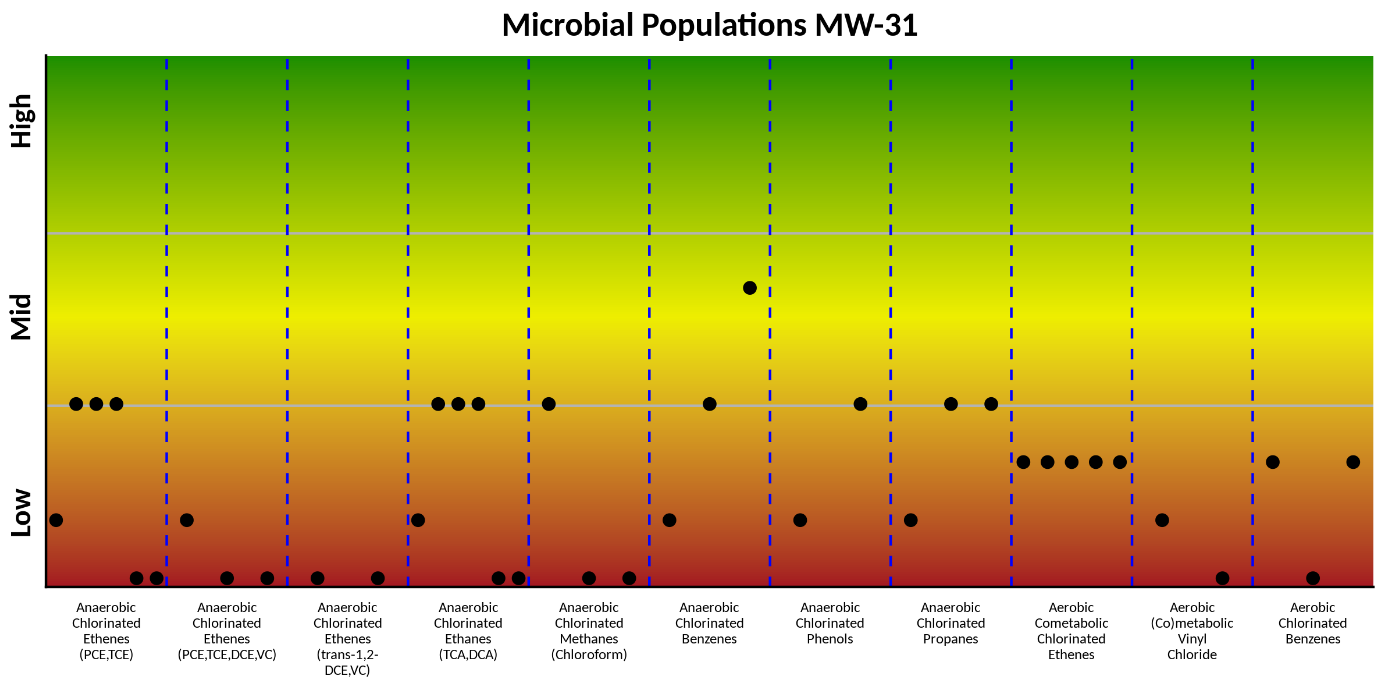

Figure 1: Microbial population summary to aid in evaluating potential pathways and biodegradation of specific contaminants.

Anaerobic - Reductive Dechlorination or Dichloroelimination		Aerobic - (Co)metabolism	
Chlorinated Ethenes (PCE, TCE)	DHC, DHBt, DSB, DSM, PCE-1, PCE-2	Chlorinated Ethenes (TCE,DCE,VC)	sMMO, TOD, PHE, RDEG, RMO
Chlorinated Ethenes (PCE, TCE, DCE, VC)	DHC, BVC, VCR	(Co)metabolic Vinyl Chloride	etnC, etnE
Chlorinated Ethenes (trans-1,2-DCE, VC)	TDR, CER	Chlorinated Benzenes	TOD, TCBO, PHE
Chlorinated Ethanes (TCA and 1,2-DCA)	DHC, DHBt, DHG, DSB[1], DCA, DCAR		
Chlorinated Methanes (Chloroform)	DHBt, DCM, CFR		
Chlorinated Benzenes	DHC, DHBt[2], DECO		
Chlorinated Phenols	DHC, DSB		
Chlorinated Propanes	DHC, DHG, DSB[1]		

[1] *Desulfitobacterium dichloroeliminans* DCA1. [2] Implicated in reductive dechlorination of dichlorobenzene and potentially chlorobenzene.

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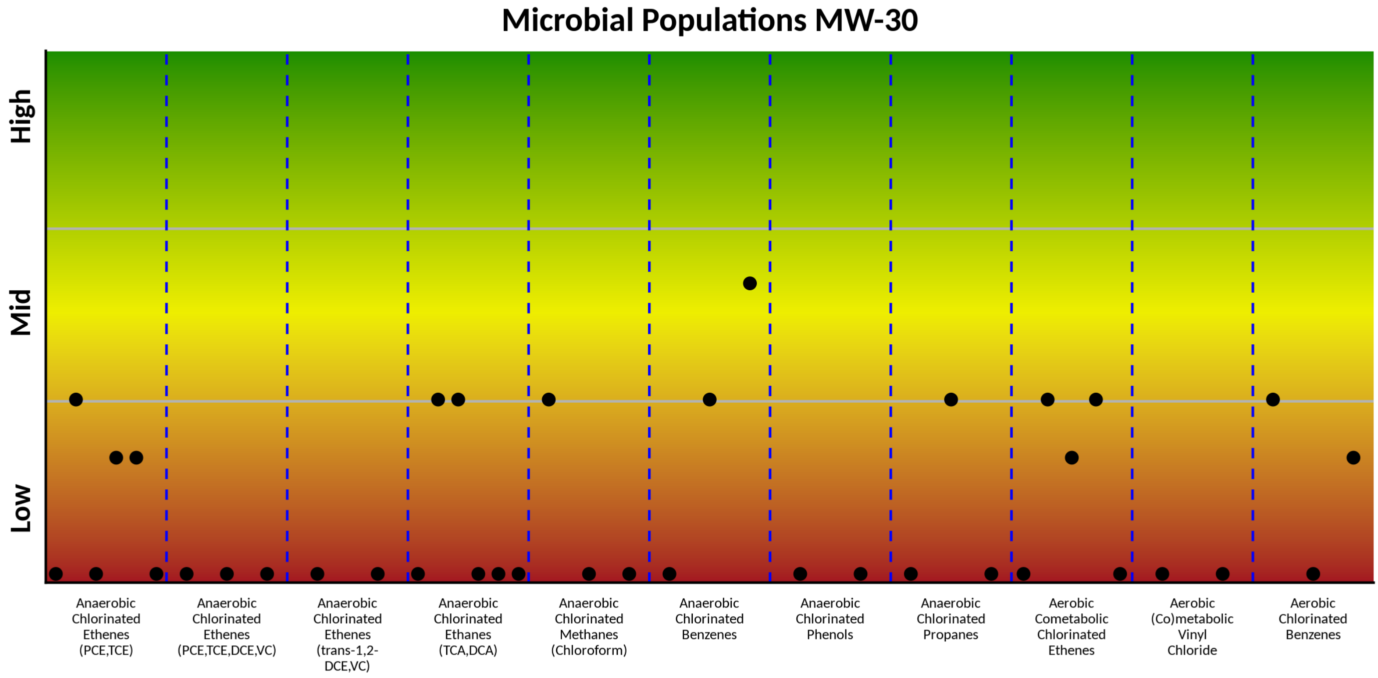

Figure 2: Microbial population summary to aid in evaluating potential pathways and biodegradation of specific contaminants.

Anaerobic - Reductive Dechlorination or Dichloroelimination		Aerobic - (Co)metabolism	
Chlorinated Ethenes (PCE, TCE)	DHC, DHBt, DSB, DSM, PCE-1, PCE-2	Chlorinated Ethenes (TCE,DCE,VC)	sMMO, TOD, PHE, RDEG, RMO
Chlorinated Ethenes (PCE, TCE, DCE, VC)	DHC, BVC, VCR	(Co)metabolic Vinyl Chloride	etnC, etnE
Chlorinated Ethenes (trans-1,2-DCE, VC)	TDR, CER	Chlorinated Benzenes	TOD, TCBO, PHE
Chlorinated Ethanes (TCA and 1,2-DCA)	DHC, DHBt, DHG, DSB[1], DCA, DCAR		
Chlorinated Methanes (Chloroform)	DHBt, DCM, CFR		
Chlorinated Benzenes	DHC, DHBt[2], DECO		
Chlorinated Phenols	DHC, DSB		
Chlorinated Propanes	DHC, DHG, DSB[1]		

[1]*Desulfitobacterium dichloroeliminans* DCA1. [2]Implicated in reductive dechlorination of dichlorobenzene and potentially chlorobenzene.

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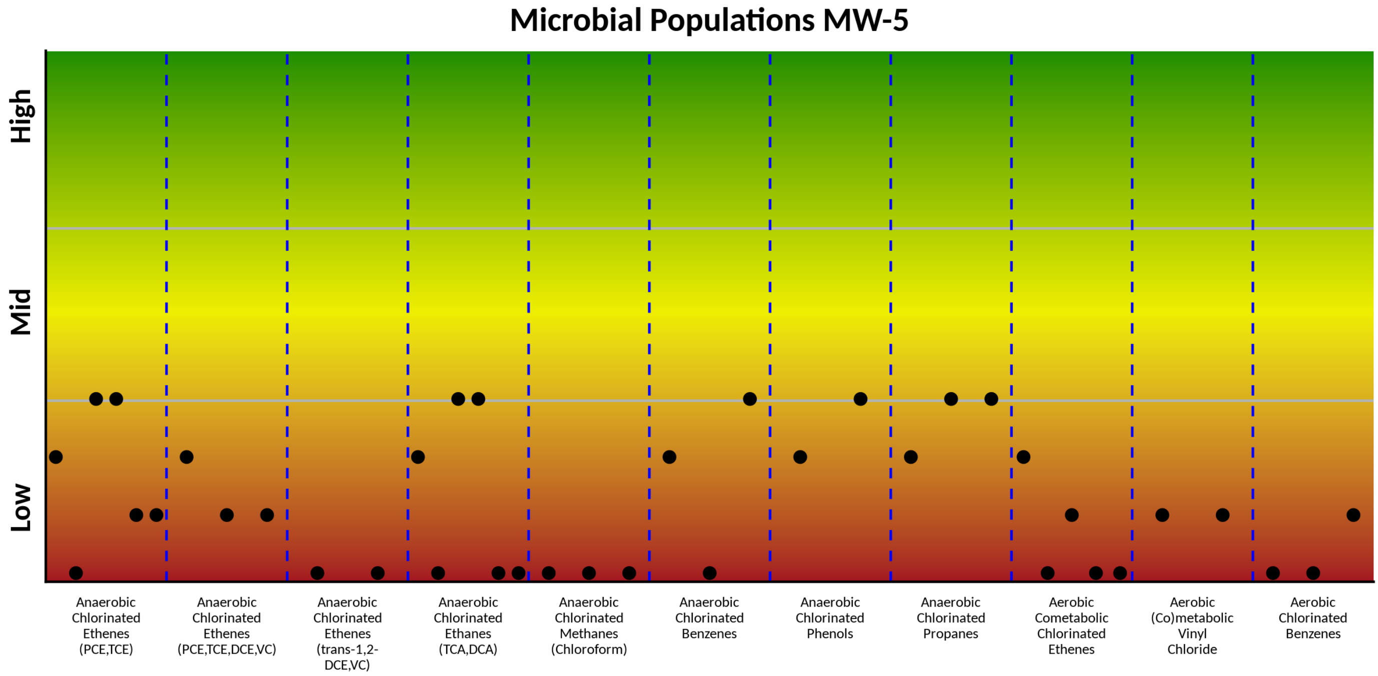

Figure 3: Microbial population summary to aid in evaluating potential pathways and biodegradation of specific contaminants.

Anaerobic - Reductive Dechlorination or Dichloroelimination		Aerobic - (Co)metabolism	
Chlorinated Ethenes (PCE, TCE)	DHC, DHBt, DSB, DSM, PCE-1, PCE-2	Chlorinated Ethenes (TCE,DCE,VC)	sMMO, TOD, PHE, RDEG, RMO
Chlorinated Ethenes (PCE, TCE, DCE, VC)	DHC, BVC, VCR	(Co)metabolic Vinyl Chloride	etnC, etnE
Chlorinated Ethenes (trans-1,2-DCE, VC)	TDR, CER	Chlorinated Benzenes	TOD, TCBO, PHE
Chlorinated Ethanes (TCA and 1,2-DCA)	DHC, DHBt, DHG, DSB[1], DCA, DCAR		
Chlorinated Methanes (Chloroform)	DHBt, DCM, CFR		
Chlorinated Benzenes	DHC, DHBt[2], DECO		
Chlorinated Phenols	DHC, DSB		
Chlorinated Propanes	DHC, DHG, DSB[1]		

[1] *Desulfitobacterium dichloroeliminans* DCA1. [2] Implicated in reductive dechlorination of dichlorobenzene and potentially chlorobenzene.

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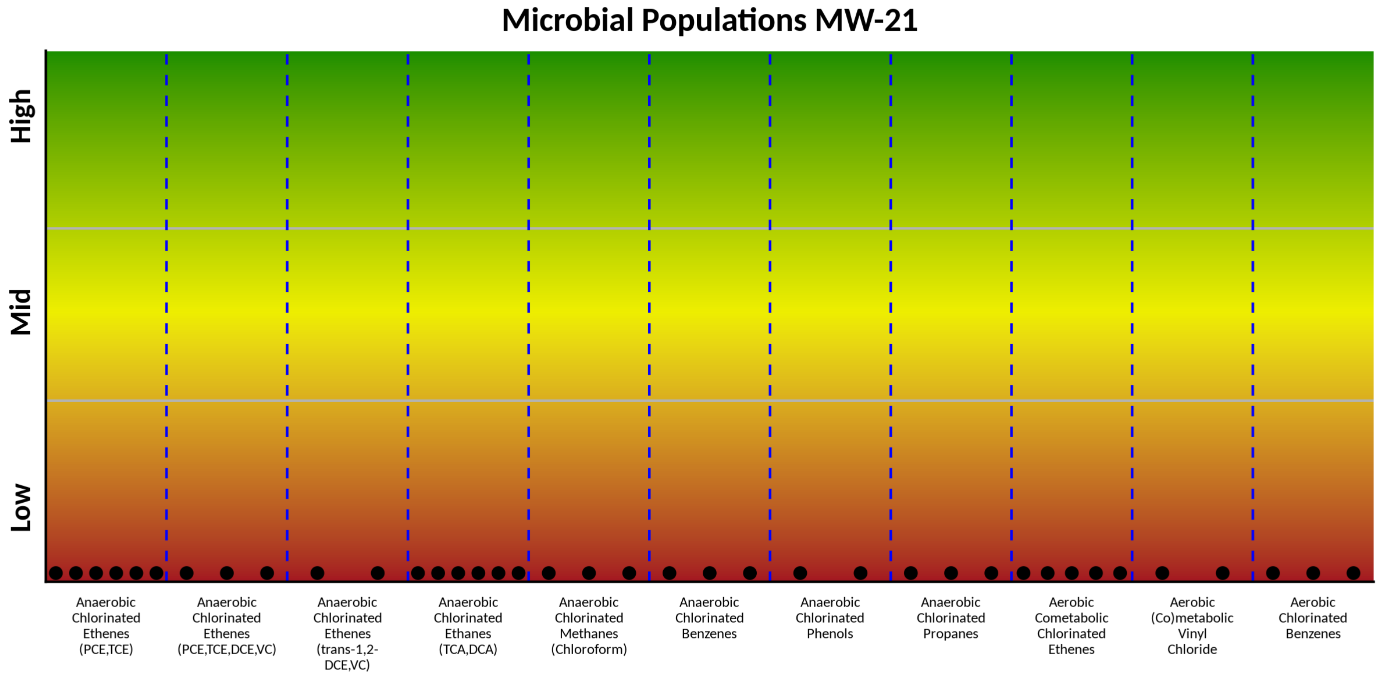

Figure 4: Microbial population summary to aid in evaluating potential pathways and biodegradation of specific contaminants.

Anaerobic - Reductive Dechlorination or Dichloroelimination		Aerobic - (Co)metabolism	
Chlorinated Ethenes (PCE, TCE)	DHC, DHBt, DSB, DSM, PCE-1, PCE-2	Chlorinated Ethenes (TCE,DCE,VC)	sMMO, TOD, PHE, RDEG, RMO
Chlorinated Ethenes (PCE, TCE, DCE, VC)	DHC, BVC, VCR	(Co)metabolic Vinyl Chloride	etnC, etnE
Chlorinated Ethenes (trans-1,2-DCE, VC)	TDR, CER	Chlorinated Benzenes	TOD, TCBO, PHE
Chlorinated Ethanes (TCA and 1,2-DCA)	DHC, DHBt, DHG, DSB[1], DCA, DCAR		
Chlorinated Methanes (Chloroform)	DHBt, DCM, CFR		
Chlorinated Benzenes	DHC, DHBt[2], DECO		
Chlorinated Phenols	DHC, DSB		
Chlorinated Propanes	DHC, DHG, DSB[1]		

[1]*Desulfitobacterium dichloroeliminans* DCA1. [2]Implicated in reductive dechlorination of dichlorobenzene and potentially chlorobenzene.

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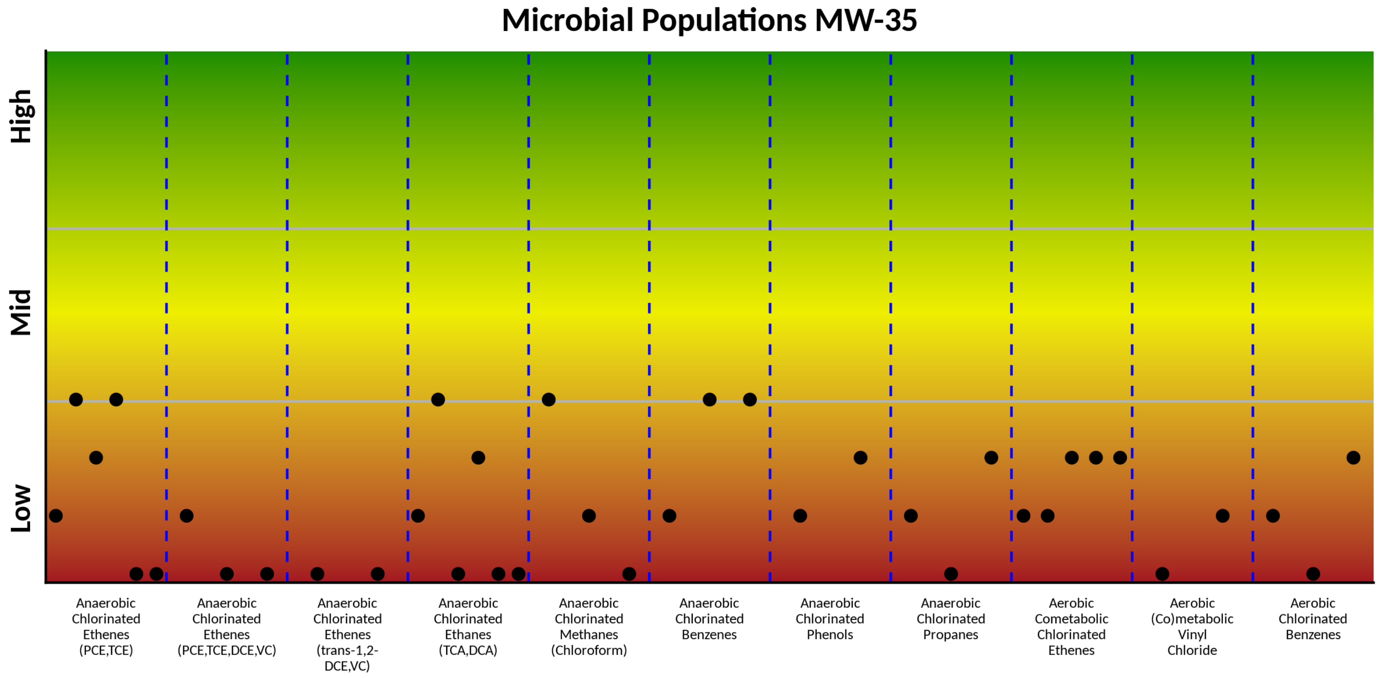

Figure 5: Microbial population summary to aid in evaluating potential pathways and biodegradation of specific contaminants.

Anaerobic - Reductive Dechlorination or Dichloroelimination		Aerobic - (Co)metabolism	
Chlorinated Ethenes (PCE, TCE)	DHC, DHBt, DSB, DSM, PCE-1, PCE-2	Chlorinated Ethenes (TCE,DCE,VC)	sMMO, TOD, PHE, RDEG, RMO
Chlorinated Ethenes (PCE, TCE, DCE, VC)	DHC, BVC, VCR	(Co)metabolic Vinyl Chloride	etnC, etnE
Chlorinated Ethenes (trans-1,2-DCE, VC)	TDR, CER	Chlorinated Benzenes	TOD, TCBO, PHE
Chlorinated Ethanes (TCA and 1,2-DCA)	DHC, DHBt, DHG, DSB[1], DCA, DCAR		
Chlorinated Methanes (Chloroform)	DHBt, DCM, CFR		
Chlorinated Benzenes	DHC, DHBt[2], DECO		
Chlorinated Phenols	DHC, DSB		
Chlorinated Propanes	DHC, DHG, DSB[1]		

[1] *Desulfitobacterium dichloroeliminans* DCA1. [2] Implicated in reductive dechlorination of dichlorobenzene and potentially chlorobenzene.

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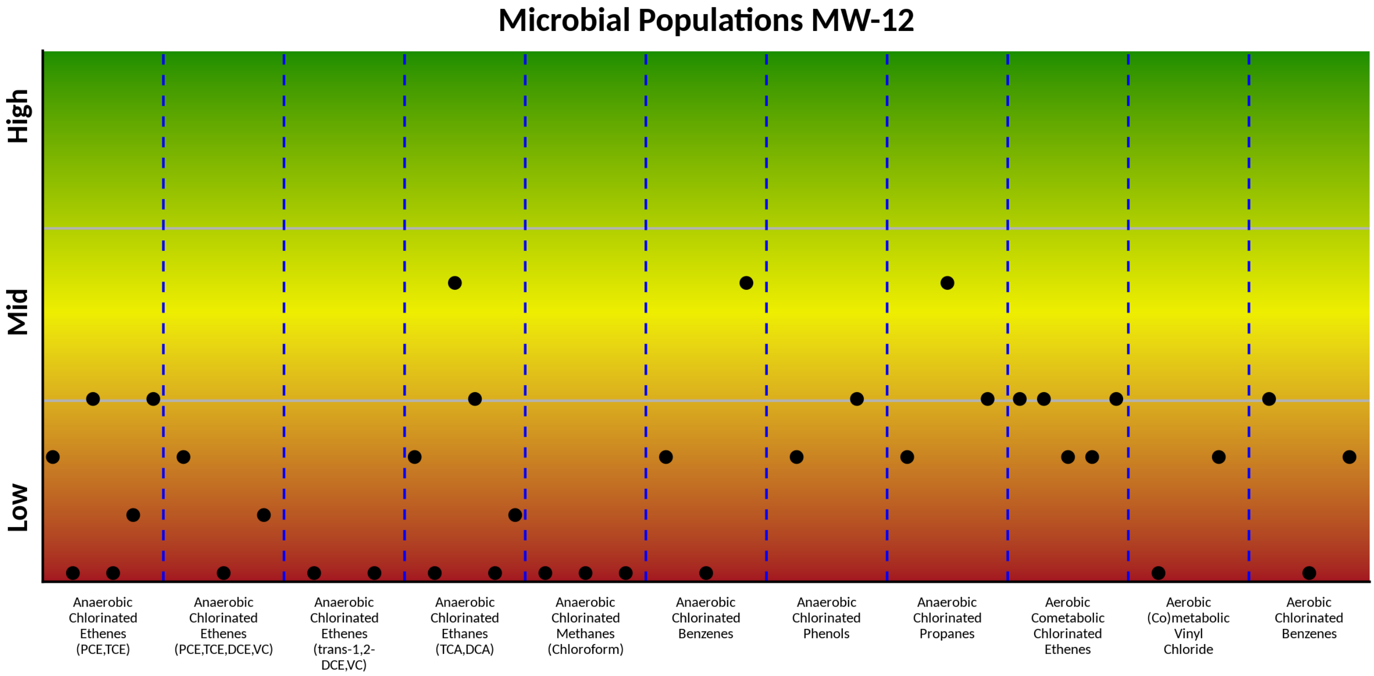

Figure 6: Microbial population summary to aid in evaluating potential pathways and biodegradation of specific contaminants.

Anaerobic - Reductive Dechlorination or Dichloroelimination		Aerobic - (Co)metabolism	
Chlorinated Ethenes (PCE, TCE)	DHC, DHBt, DSB, DSM, PCE-1, PCE-2	Chlorinated Ethenes (TCE,DCE,VC)	sMMO, TOD, PHE, RDEG, RMO
Chlorinated Ethenes (PCE, TCE, DCE, VC)	DHC, BVC, VCR	(Co)metabolic Vinyl Chloride	etnC, etnE
Chlorinated Ethenes (trans-1,2-DCE, VC)	TDR, CER	Chlorinated Benzenes	TOD, TCBO, PHE
Chlorinated Ethanes (TCA and 1,2-DCA)	DHC, DHBt, DHG, DSB[1], DCA, DCAR		
Chlorinated Methanes (Chloroform)	DHBt, DCM, CFR		
Chlorinated Benzenes	DHC, DHBt[2], DECO		
Chlorinated Phenols	DHC, DSB		
Chlorinated Propanes	DHC, DHG, DSB[1]		

[1]*Desulfitobacterium dichloroeliminans* DCA1. [2]Implicated in reductive dechlorination of dichlorobenzene and potentially chlorobenzene.

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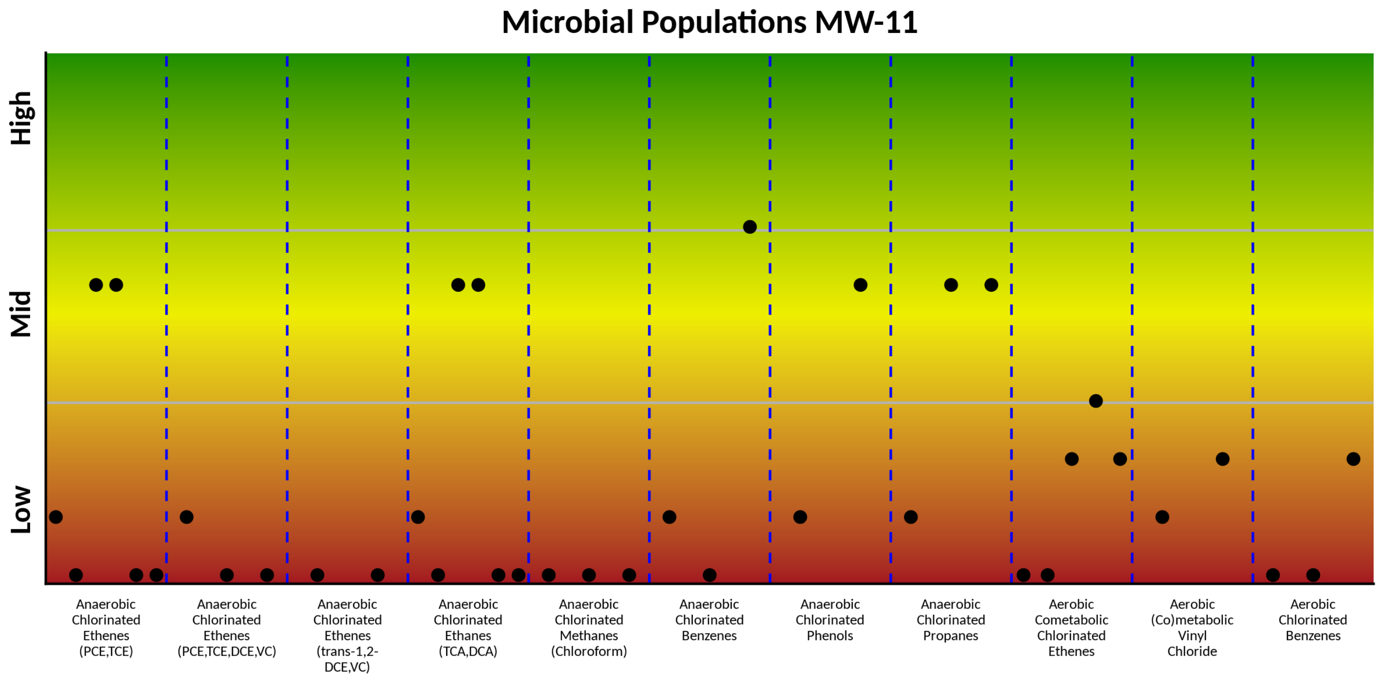

Figure 7: Microbial population summary to aid in evaluating potential pathways and biodegradation of specific contaminants.

Anaerobic - Reductive Dechlorination or Dichloroelimination		Aerobic - (Co)metabolism	
Chlorinated Ethenes (PCE, TCE)	DHC, DHBt, DSB, DSM, PCE-1, PCE-2	Chlorinated Ethenes (TCE,DCE,VC)	sMMO, TOD, PHE, RDEG, RMO
Chlorinated Ethenes (PCE, TCE, DCE, VC)	DHC, BVC, VCR	(Co)metabolic Vinyl Chloride	etnC, etnE
Chlorinated Ethenes (trans-1,2-DCE, VC)	TDR, CER	Chlorinated Benzenes	TOD, TCBO, PHE
Chlorinated Ethanes (TCA and 1,2-DCA)	DHC, DHBt, DHG, DSB[1], DCA, DCAR		
Chlorinated Methanes (Chloroform)	DHBt, DCM, CFR		
Chlorinated Benzenes	DHC, DHBt[2], DECO		
Chlorinated Phenols	DHC, DSB		
Chlorinated Propanes	DHC, DHG, DSB[1]		

[1]*Desulfitobacterium dichloroeliminans* DCA1. [2]Implicated in reductive dechlorination of dichlorobenzene and potentially chlorobenzene.

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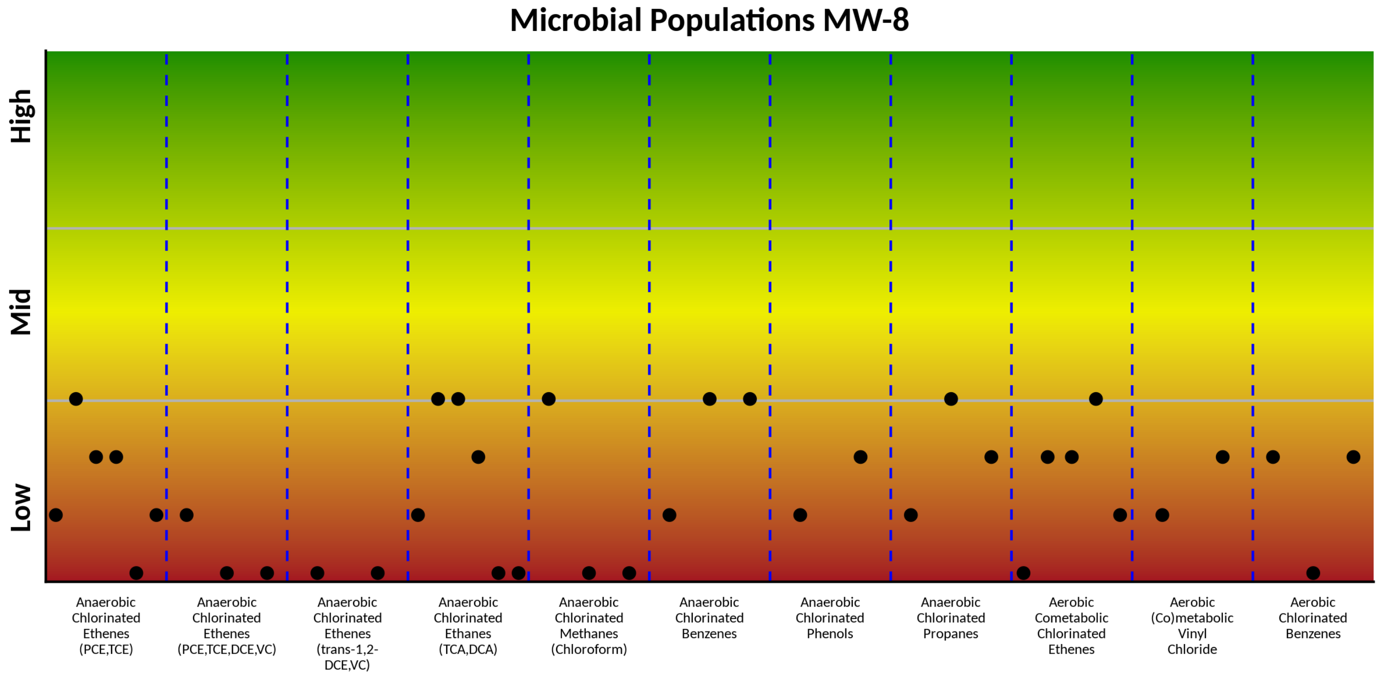

Figure 8: Microbial population summary to aid in evaluating potential pathways and biodegradation of specific contaminants.

Anaerobic - Reductive Dechlorination or Dichloroelimination		Aerobic - (Co)metabolism	
Chlorinated Ethenes (PCE, TCE)	DHC, DHBt, DSB, DSM, PCE-1, PCE-2	Chlorinated Ethenes (TCE,DCE,VC)	sMMO, TOD, PHE, RDEG, RMO
Chlorinated Ethenes (PCE, TCE, DCE, VC)	DHC, BVC, VCR	(Co)metabolic Vinyl Chloride	etnC, etnE
Chlorinated Ethenes (trans-1,2-DCE, VC)	TDR, CER	Chlorinated Benzenes	TOD, TCBO, PHE
Chlorinated Ethanes (TCA and 1,2-DCA)	DHC, DHBt, DHG, DSB[1], DCA, DCAR		
Chlorinated Methanes (Chloroform)	DHBt, DCM, CFR		
Chlorinated Benzenes	DHC, DHBt[2], DECO		
Chlorinated Phenols	DHC, DSB		
Chlorinated Propanes	DHC, DHG, DSB[1]		

[1] *Desulfitobacterium dichloroeliminans* DCA1. [2] Implicated in reductive dechlorination of dichlorobenzene and potentially chlorobenzene.

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Table 3: Summary of the QuantArray®-Chlor results for microorganisms responsible for reductive dechlorination for samples MW-31, MW-30, MW-5, and MW-21.

Sample Name Sample Date	MW-31 02/12/2018	MW-30 02/12/2018	MW-5 02/13/2018	MW-21 02/13/2018
Reductive Dechlorination	cells/mL	cells/mL	cells/mL	cells/mL
Dehalococcoides (DHC)	**4.00E+00**	<2.50E+00	**1.54E+01**	<5.00E-01
tceA Reductase (TCE)	<5.00E-01	<2.50E+00	<5.00E-01	<5.00E-01
BAV1 Vinyl Chloride Reductase (BVC)	<5.00E-01	<2.50E+00	**4.10E+00**	<5.00E-01
Vinyl Chloride Reductase (VCR)	<5.00E-01	<2.50E+00	**6.00E-01**	<5.00E-01
Dehalobacter spp. (DHBt)	**3.05E+03**	**1.92E+03**	<5.00E+00	<5.00E+00
Dehalobacter DCM (DCM)	<5.00E+00	<2.50E+01	<5.00E+00	<5.00E+00
Dehalogenimonas spp. (DHG)	**4.48E+03**	**5.79E+03**	**2.42E+03**	<5.00E+00
Desulfitobacterium spp. (DSB)	**2.70E+03**	<2.50E+01	**2.45E+03**	<5.00E+00
Dehalobium chlorocoercia (DECO)	**2.59E+03**	**1.47E+03**	**9.40E+02**	<5.00E+00
Desulfuromonas spp. (DSM)	**1.25E+02**	**6.71E+01**	**2.37E+02**	<5.00E+00

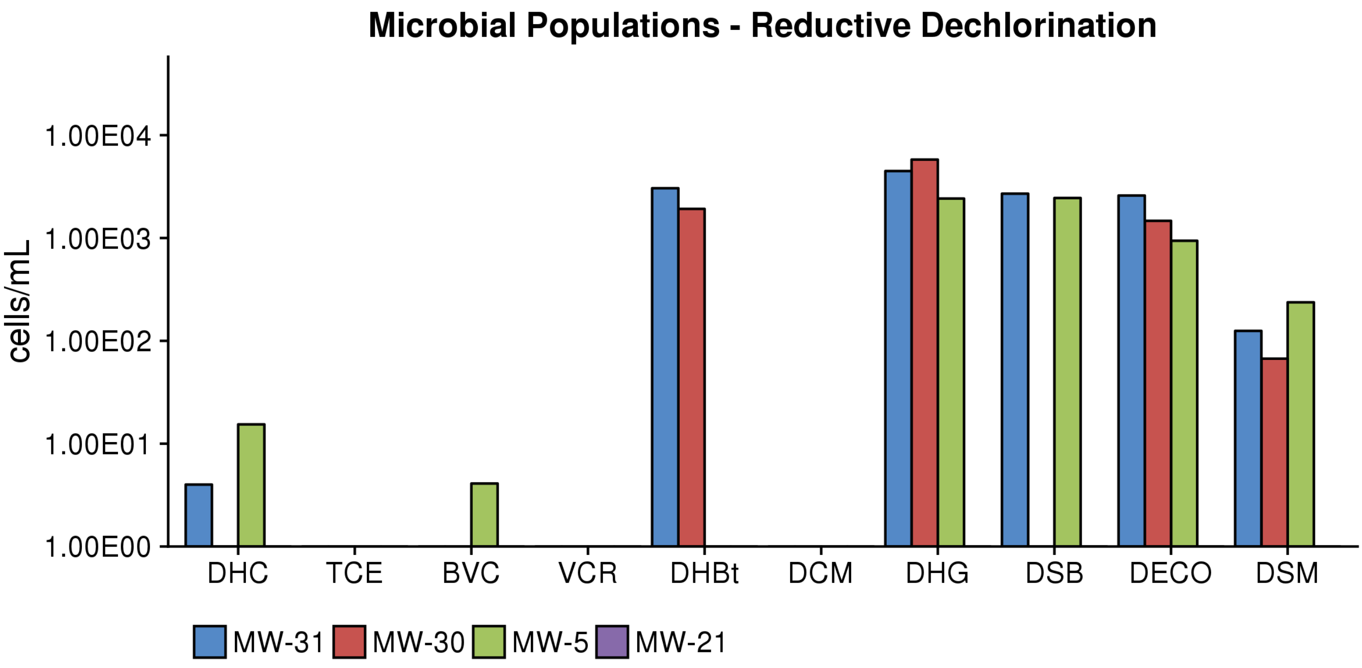

Figure 9: Comparison - microbial populations involved in reductive dechlorination.

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Table 4: Summary of the QuantArray®-Chlor results for microorganisms responsible for reductive dechlorination for samples MW-31, MW-30, MW-5, and MW-21.

Sample Name Sample Date	MW-31 02/12/2018	MW-30 02/12/2018	MW-5 02/13/2018	MW-21 02/13/2018
Reductive Dechlorination	cells/mL	cells/mL	cells/mL	cells/mL
Chloroform Reductase (CFR)	<5.00E+00	<2.50E+01	<5.00E+00	<5.00E+00
1,1 DCA Reductase (DCA)	<5.00E+00	<2.50E+01	<5.00E+00	<5.00E+00
1,2 DCA Reductase (DCAR)	<5.00E+00	<2.50E+01	<5.00E+00	<5.00E+00
PCE Reductase (PCE-1)	<5.00E+00	**2.02E+01 (J)**	**2.00E-01 (J)**	<5.00E+00
PCE Reductase (PCE-2)	<5.00E+00	<2.50E+01	**9.00E-01 (J)**	<5.00E+00
trans-1,2-DCE Reductase (TDR)	<5.00E+00	<2.50E+01	<5.00E+00	<5.00E+00
Vinyl Chloride Reductase (CER)	<5.00E+00	<2.50E+01	<5.00E+00	<5.00E+00

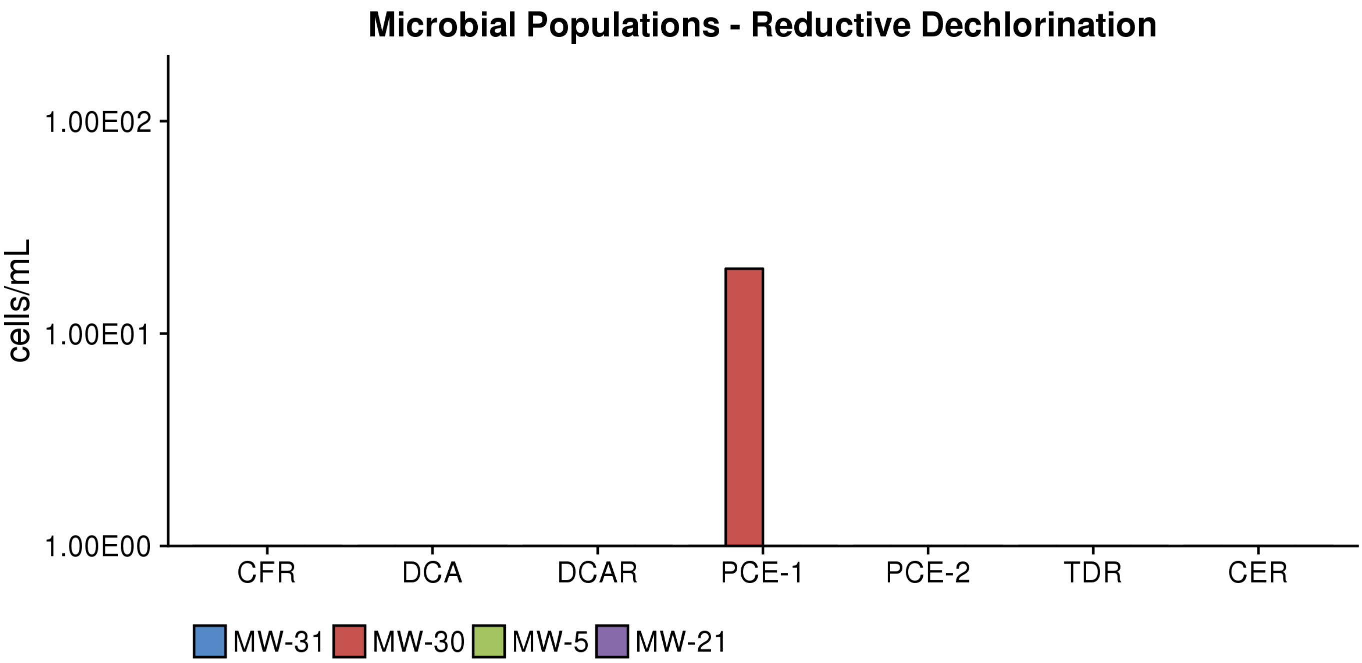

Figure 10: Comparison - microbial populations involved in reductive dechlorination.

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Table 5: Summary of the QuantArray®-Chlor results for microorganisms responsible for reductive dechlorination for samples MW-35, MW-12, MW-11, and MW-8.

Sample Name Sample Date	MW-35 02/13/2018	MW-12 02/14/2018	MW-11 02/14/2018	MW-8 02/14/2018
Reductive Dechlorination	cells/mL	cells/mL	cells/mL	cells/mL
Dehalococcoides (DHC)	**3.00E-01 (J)**	**8.06E+01**	**6.20E+00**	**3.00E-01 (J)**
tceA Reductase (TCE)	<5.00E-01	<5.00E-01	<5.00E-01	<5.00E-01
BAV1 Vinyl Chloride Reductase (BVC)	<5.00E-01	<5.00E-01	<5.00E-01	<5.00E-01
Vinyl Chloride Reductase (VCR)	<5.00E-01	**2.50E+00**	<5.00E-01	<5.00E-01
Dehalobacter spp. (DHBt)	**1.85E+03**	<5.00E+00	<5.00E+00	**1.06E+03**
Dehalobacter DCM (DCM)	**1.78E+01**	<5.00E+00	<5.00E+00	<5.00E+00
Dehalogenimonas spp. (DHG)	<5.00E+00	**2.02E+04**	**1.80E+04**	**1.99E+03**
Desulfitobacterium spp. (DSB)	**9.90E+02**	**2.38E+03**	**1.82E+04**	**1.75E+02**
Dehalobium chlorocoercia (DECO)	**5.01E+02**	**2.68E+03**	**1.18E+04**	**3.78E+02**
Desulfuromonas spp. (DSM)	**1.56E+02**	<5.00E+00	**4.38E+03**	**3.26E+01**

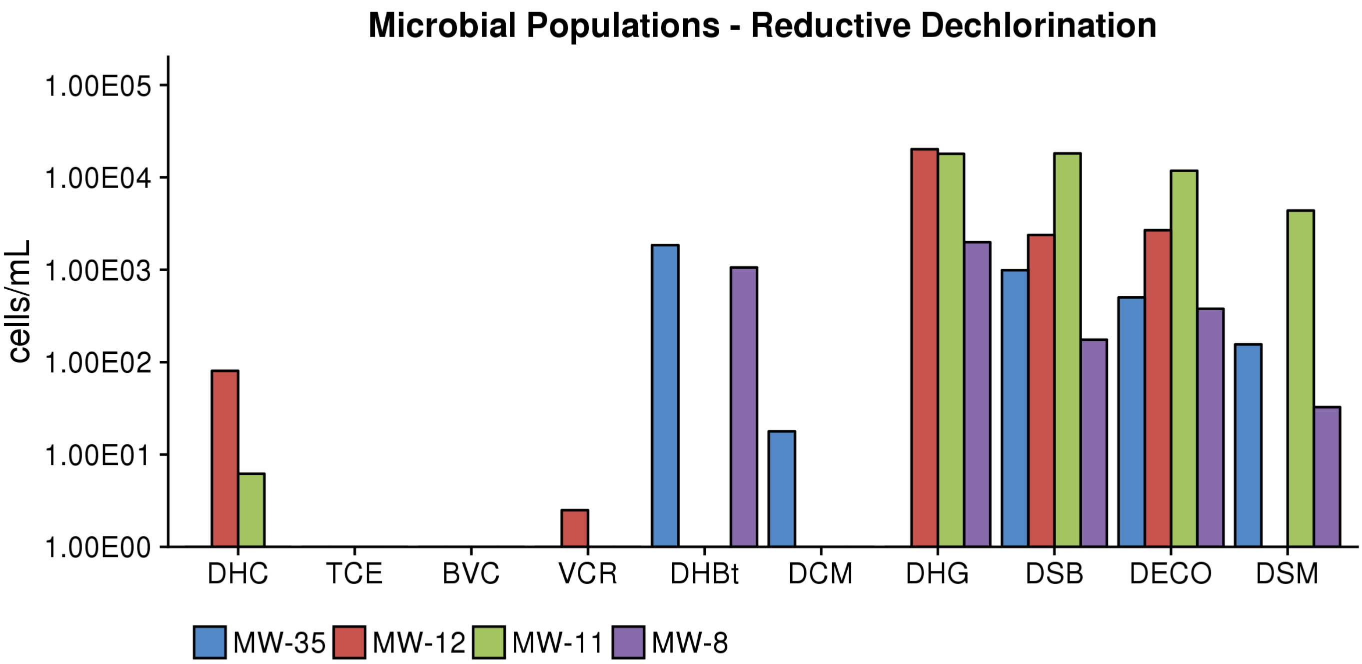

Figure 11: Comparison - microbial populations involved in reductive dechlorination.

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Table 6: Summary of the QuantArray®-Chlor results for microorganisms responsible for reductive dechlorination for samples MW-35, MW-12, MW-11, and MW-8.

Sample Name Sample Date	MW-35 02/13/2018	MW-12 02/14/2018	MW-11 02/14/2018	MW-8 02/14/2018
Reductive Dechlorination	cells/mL	cells/mL	cells/mL	cells/mL
Chloroform Reductase (CFR)	<5.00E+00	<5.00E+00	<5.00E+00	<5.00E+00
1,1 DCA Reductase (DCA)	<5.00E+00	<5.00E+00	<5.00E+00	<5.00E+00
1,2 DCA Reductase (DCAR)	<5.00E+00	**9.16E+01**	<5.00E+00	<5.00E+00
PCE Reductase (PCE-1)	<5.00E+00	**3.00E-01 (J)**	<5.00E+00	<5.00E+00
PCE Reductase (PCE-2)	<5.00E+00	**6.69E+02**	<5.00E+00	**1.50E+00 (J)**
trans-1,2-DCE Reductase (TDR)	<5.00E+00	<5.00E+00	<5.00E+00	<5.00E+00
Vinyl Chloride Reductase (CER)	<5.00E+00	<5.00E+00	<5.00E+00	<5.00E+00

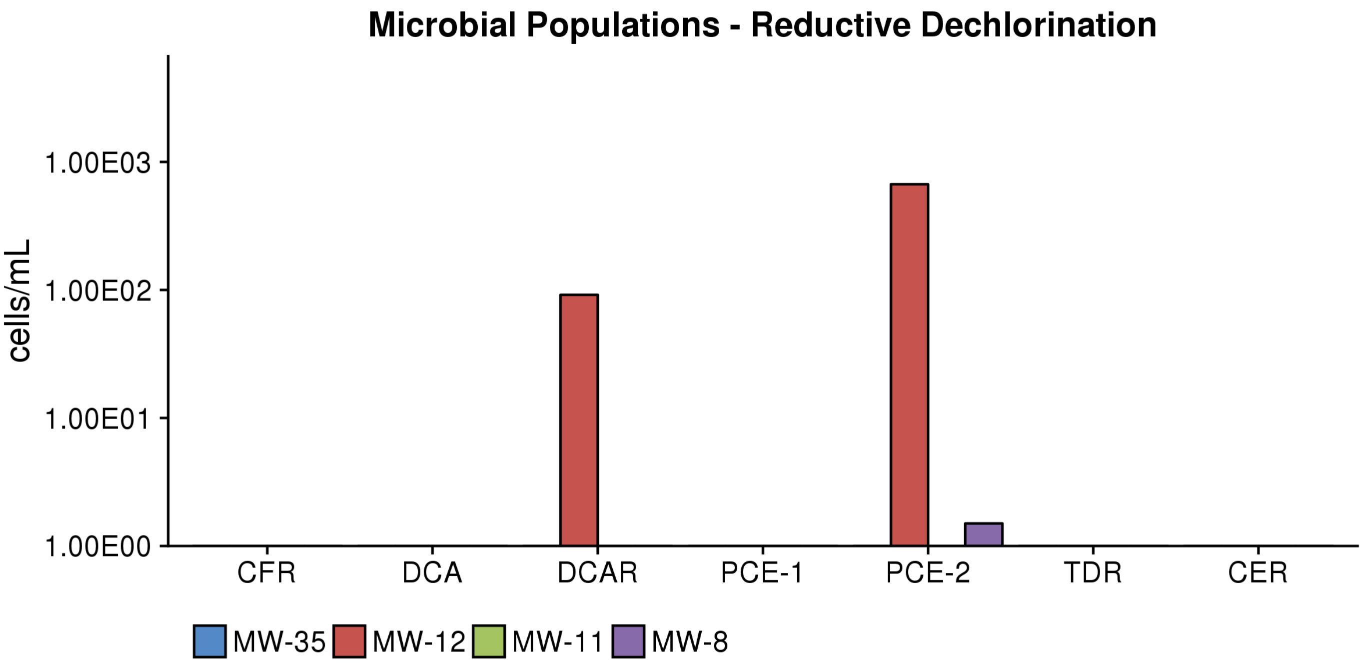

Figure 12: Comparison - microbial populations involved in reductive dechlorination.

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Table 7: Summary of the QuantArray®-Chlor results for microorganisms responsible for aerobic (co)metabolism for samples MW-31, MW-30, MW-5, and MW-21.

Sample Name Sample Date	MW-31 02/12/2018	MW-30 02/12/2018	MW-5 02/13/2018	MW-21 02/13/2018
Aerobic (Co)Metabolic	cells/mL	cells/mL	cells/mL	cells/mL
Soluble Methane Monooxygenase (SMMO)	**2.13E+02**	<2.50E+01	**6.06E+02**	<5.00E+00
Toluene Dioxygenase (TOD)	**5.27E+02**	**2.01E+03**	<5.00E+00	<5.00E+00
Phenol Hydroxylase (PHE)	**1.93E+02**	**7.36E+02**	**8.97E+01**	<5.00E+00
Trichlorobenzene Dioxygenase (TCBO)	<5.00E+00	<2.50E+01	<5.00E+00	<5.00E+00
Toluene Monooxygenase 2 (RDEG)	**2.04E+02**	**2.17E+03**	<5.00E+00	<5.00E+00
Toluene Monooxygenase (RMO)	**1.48E+02**	<2.50E+01	<5.00E+00	<5.00E+00
Ethene Monooxygenase (EtnC)	**7.76E+01**	<2.50E+01	**2.69E+01**	<5.00E+00
Epoxyalkane Transferase (EtnE)	<5.00E+00	<2.50E+01	**9.13E+01**	<5.00E+00
Dichloromethane Dehalogenase (DCMA)	<5.00E+00	<2.50E+01	<5.00E+00	<5.00E+00

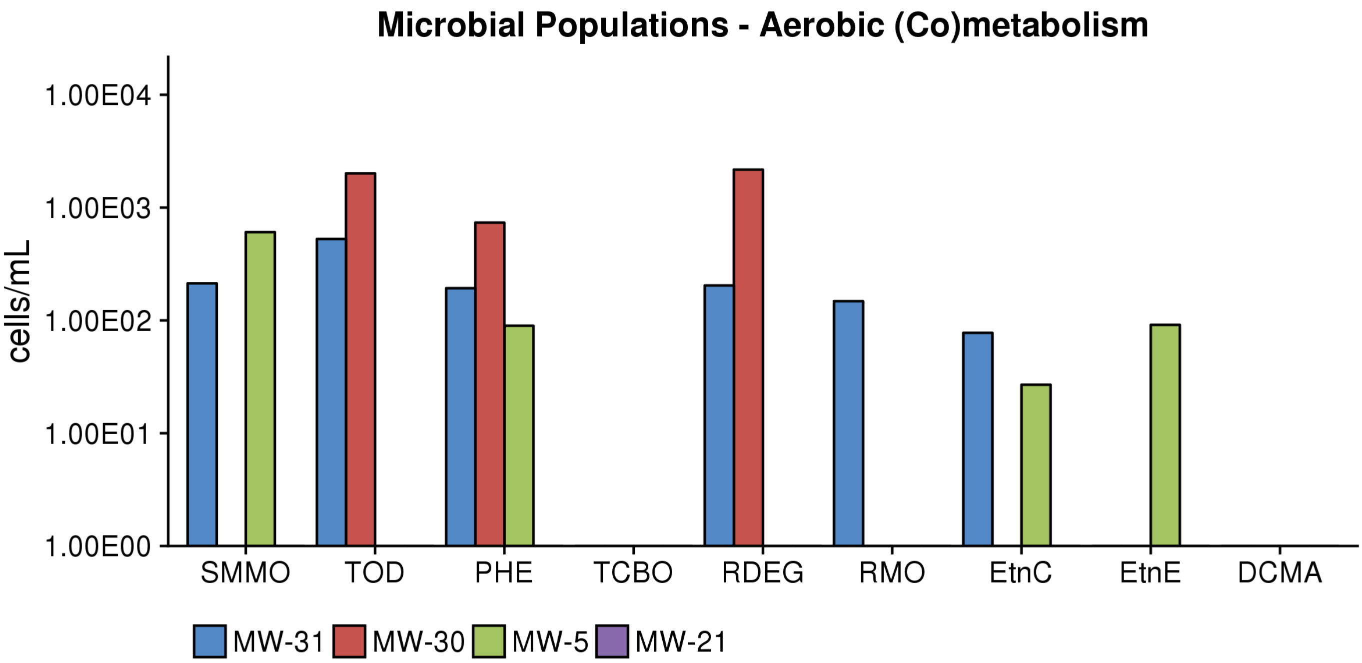

Figure 13: Comparison - microbial populations involved in aerobic (co)metabolism.

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Table 8: Summary of the QuantArray®-Chlor results for microorganisms responsible for aerobic (co)metabolism for samples MW-35, MW-12, MW-11, and MW-8.

Sample Name Sample Date	MW-35 02/13/2018	MW-12 02/14/2018	MW-11 02/14/2018	MW-8 02/14/2018
Aerobic (Co)Metabolic	cells/mL	cells/mL	cells/mL	cells/mL
Soluble Methane Monooxygenase (SMMO)	**2.96E+01**	**3.86E+03**	**1.90E+00 (J)**	**7.90E+00**
Toluene Dioxygenase (TOD)	**9.33E+01**	**3.65E+03**	<5.00E+00	**3.44E+02**
Phenol Hydroxylase (PHE)	**3.60E+02**	**4.03E+02**	**2.73E+02**	**3.44E+02**
Trichlorobenzene Dioxygenase (TCBO)	<5.00E+00	<5.00E+00	<5.00E+00	<5.00E+00
Toluene Monooxygenase 2 (RDEG)	**3.71E+02**	**7.33E+02**	**1.79E+03**	**1.81E+03**
Toluene Monooxygenase (RMO)	**2.16E+02**	**2.50E+03**	**1.25E+02**	**2.22E+01**
Ethene Monooxygenase (EtnC)	<5.00E+00	<5.00E+00	**1.09E+01**	**6.84E+01**
Epoxyalkane Transferase (EtnE)	**2.65E+01**	**1.12E+02**	**1.44E+02**	**4.29E+02**
Dichloromethane Dehalogenase (DCMA)	<5.00E+00	<5.00E+00	<5.00E+00	<5.00E+00

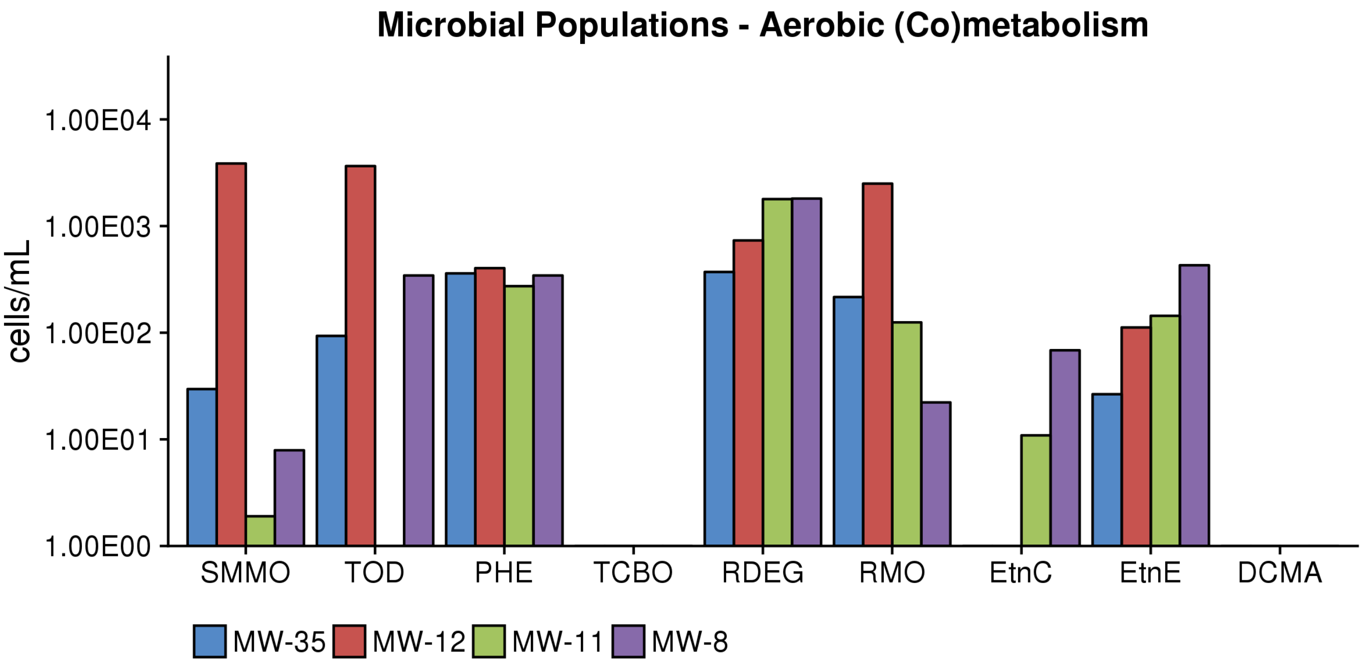

Figure 14: Comparison - microbial populations involved in aerobic (co)metabolism.

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Table 9: Summary of the QuantArray® results for total bacteria and other populations for samples MW-31, MW-30, MW-5, and MW-21.

Sample Name Sample Date	MW-31 02/12/2018	MW-30 02/12/2018	MW-5 02/13/2018	MW-21 02/13/2018
Other	cells/mL	cells/mL	cells/mL	cells/mL
Total Eubacteria (EBAC)	**3.38E+05**	**3.03E+06**	**1.37E+06**	**1.06E+03**
Sulfate Reducing Bacteria (APS)	**7.02E+04**	**7.81E+04**	**2.09E+04**	<5.00E+00
Methanogens (MGN)	**9.90E+00**	<2.50E+01	<5.00E+00	<5.00E+00

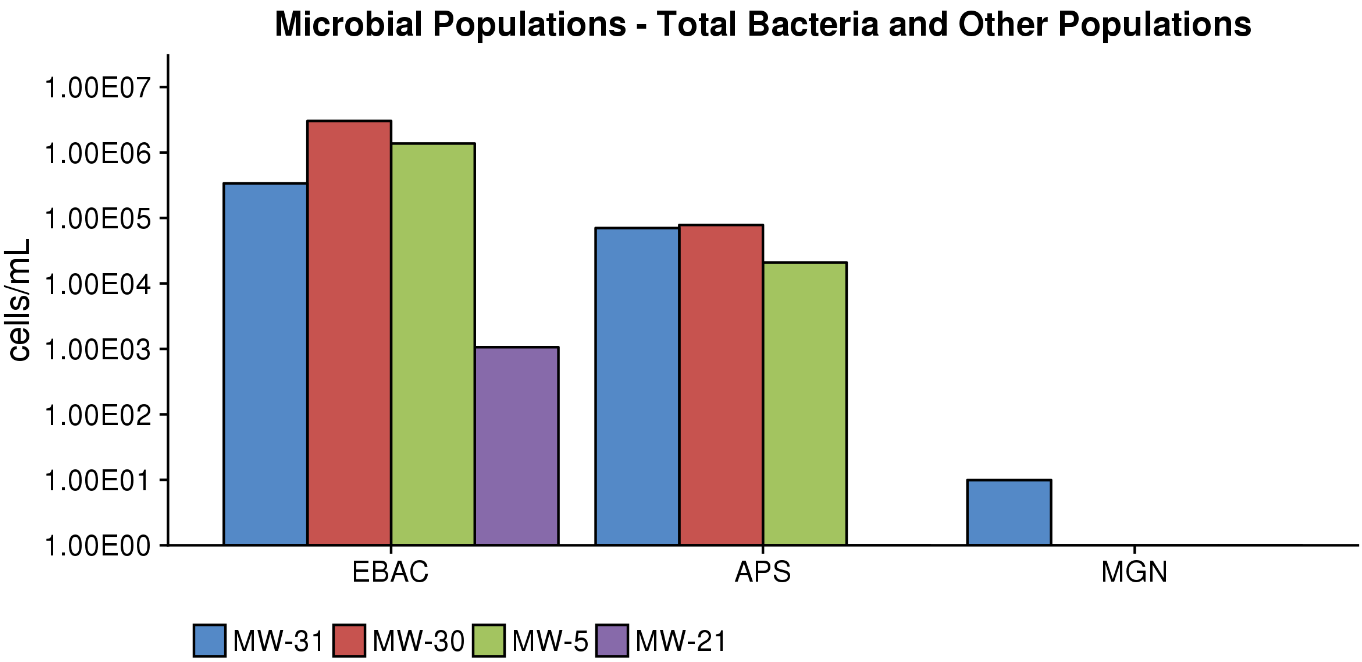

Figure 15: Comparison - microbial populations.

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Table 10: Summary of the QuantArray® results for total bacteria and other populations for samples MW-35, MW-12, MW-11, and MW-8.

Sample Name Sample Date	MW-35 02/13/2018	MW-12 02/14/2018	MW-11 02/14/2018	MW-8 02/14/2018
Other	cells/mL	cells/mL	cells/mL	cells/mL
Total Eubacteria (EBAC)	**1.53E+05**	**6.24E+05**	**1.21E+06**	**1.95E+05**
Sulfate Reducing Bacteria (APS)	**7.07E+03**	**1.39E+04**	**7.14E+04**	**1.02E+04**
Methanogens (MGN)	**3.54E+01**	**5.37E+01**	**1.32E+03**	<5.00E+00

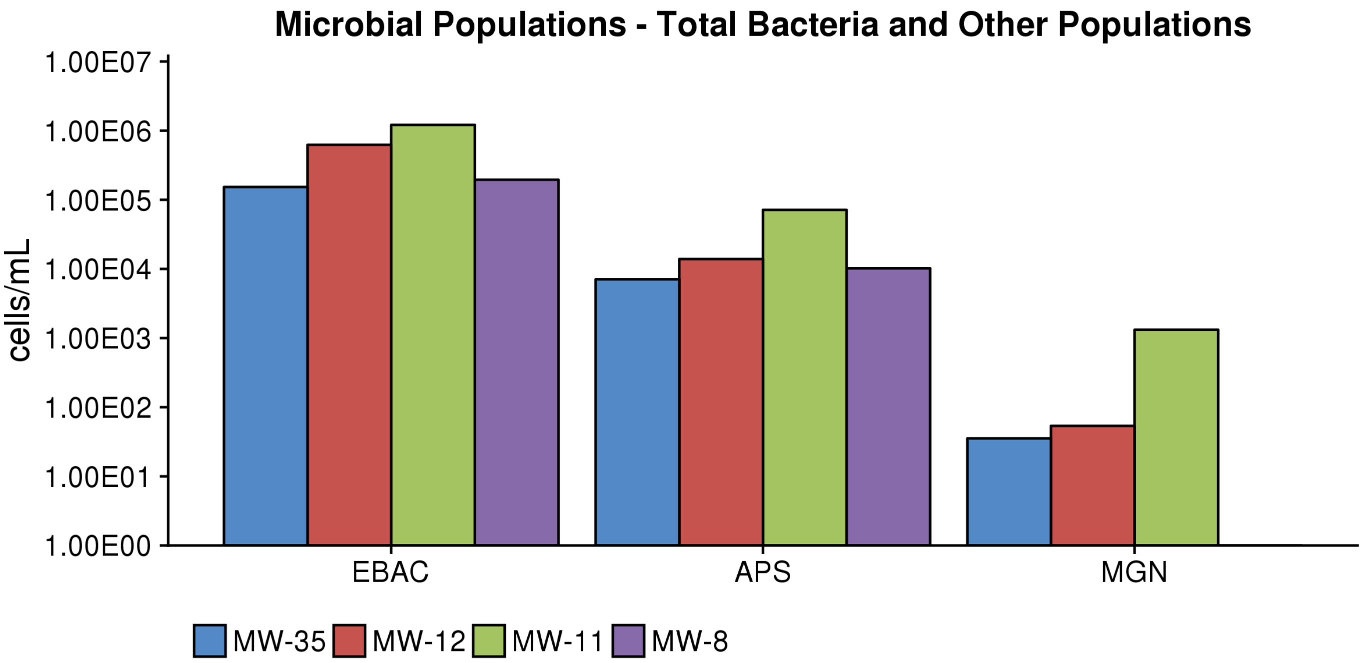

Figure 16: Comparison - microbial populations.

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Interpretation

The overall purpose of the QuantArray®-Chlor is to give site managers the ability to simultaneously yet economically evaluate the potential for biodegradation of a spectrum of common chlorinated contaminants through a multitude of anaerobic and aerobic (co)metabolic pathways in order to provide a clearer and more comprehensive view of contaminant biodegradation. The following discussion describes the interpretation of results in general terms and is meant to serve as a guide.

Reductive Dechlorination - Chlorinated Ethenes: While a number of bacterial cultures including *Dehalococcoides*, *Dehalobacter*, *Desulfitobacterium*, and *Desulfuromonas* spp. capable of utilizing PCE and TCE as growth-supporting electron acceptors have been isolated [1–5], *Dehalococcoides* may be the most important because they are the only bacterial group that has been isolated to date which is capable of complete reductive dechlorination of PCE to ethene [6]. In fact, the presence of *Dehalococcoides* has been associated with complete reductive dechlorination to ethene at sites across North America and Europe [7], and Lu et al. [8] have proposed using a *Dehalococcoides* concentration of 1 x 10^4 cells/mL as a screening criterion to identify sites where biological reductive dechlorination is predicted to proceed at "generally useful" rates.

At chlorinated ethene sites, any "stall" leading to the accumulation of daughter products, especially vinyl chloride, would be a substantial concern. While *Dehalococcoides* concentrations greater than 1 x 10^4 cells/mL correspond to ethene production and useful rates of dechlorination, the range of chlorinated ethenes degraded varies by strain within the *Dehalococcoides* genus [6, 9], and the presence of co-contaminants and competitors can have complex impacts on the halorespiring microbial community [10–15]. Therefore, QuantArray®-Chlor also provides quantification of a suite of reductive dehalogenase genes (PCE, TCE, BVC, VCR, CER, and TDR) to more definitively confirm the potential for reductive dechlorination of all chlorinated ethene compounds including vinyl chloride.

Perhaps most importantly, QuantArray®-Chlor quantifies TCE reductase (TCE) and both known vinyl chloride reductase genes (BVC, VCR) from *Dehalococcoides* to conclusively evaluate the potential for complete reductive dechlorination of chlorinated ethenes to nontoxic ethene [16–18]. In addition, the analysis also includes quantification of reductive dehalogenase genes from *Dehalogenimonas* spp. capable of reductive dechlorination of chlorinated ethenes. More specifically, these are the trans-1,2-DCE dehalogenase gene (TDR) from strain WBC-2 [19] and the vinyl chloride reductase gene (CER) from GP, the only known organisms other than *Dehalococcoides* capable of vinyl chloride reduction [20]. Finally, PCE reductase genes responsible for sequential reductive dechlorination of PCE to *cis*-DCE by *Sulfurospirillum* and *Geobacter* spp. are also quantified. In mixed cultures, evidence increasingly suggests that partial dechlorinators like *Sulfurospirillum* and *Geobacter* may be responsible for the majority of reductive dechlorination of PCE to TCE and *cis*-DCE while *Dehalococcoides* functions more as *cis*-DCE and vinyl chloride reducing specialists [10, 21].

Reductive Dechlorination - Chlorinated Ethanes: Under anaerobic conditions, chlorinated ethanes are susceptible to reductive dechlorination by several groups of halorespiring bacteria including *Dehalobacter*, *Dehalogenimonas*, and *Dehalococcoides*. While the reported range of chlorinated ethanes utilized varies by genus, species, and sometimes at the strain level, several general observations can be made regarding biodegradation pathways and daughter product formation. *Dehalobacter* spp. have been isolated that are capable of sequential reductive dechlorination of 1,1,1-TCA through 1,1-DCA to chloroethane [13]. Biodegradation of 1,1,2-TCA by several halorespiring bacteria including *Dehalobacter* and *Dehalogenimonas* spp. proceeds via dichloroelimination producing vinyl chloride [22–24]. Similarly, 1,2-DCA biodegradation by *Dehalobacter*, *Dehalogenimonas*, and *Dehalococcoides* occurs via dichloroelimination producing ethene. While not utilized by many *Desulfitobacterium* isolates, at least one strain, *Desulfitobacterium dichloroeliminans* strain DCA1, is also capable of dichloroelimination of 1,2-DCA [25]. The 1,2-dichloroethane reductive dehalogenase gene (DCAR) from members of *Desulfitobacterium* and *Dehalobacter* is known to dechlorinate 1,2-DCA to ethene, while the 1,1-dichloroethane reductive dehalogenase (DCA) targets the gene responsible for 1,1-DCA dechlorination in some strains of *Dehalobacter*. In addition to chloroform,chloroform reductase (CFR) has also been shown to be responsible for reductivedechlorination of 1,1,1-TCA [26].

Reductive Dechlorination - Chlorinated Methanes: Chloroform is a common co-contaminant at chlorinated solvent sites and can inhibit reductive dechlorination of chlorinated ethenes. Grostern et al. demonstrated that a *Dehalobacter* population was capable of reductive dechlorination of chloroform to produce dichloromethane [27]. The *cfrA* gene encodes the reductase which catalyzes this initial step in chloroform biodegradation [26]. Justicia-Leon et al. have since shown that dichloromethane can support growth of a distinct group of *Dehalobacter* strains via fermentation [28]. The *Dehalobacter* DCM assay targets the 16S rRNA gene of these strains.

Reductive Dechlorination - Chlorinated Benzenes: Chlorinated benzenes are an important class of industrial solvents and chemical intermediates in the production of drugs, dyes, herbicides, and insecticides. The physical-chemical properties of chlorinated benzenes as well as susceptibility to biodegradation are functions of their degree of chlorination and the positions of chlorine substituents. Under anaerobic conditions, reductive dechlorination of higher chlorinated benzenes including hexachlorobenzene (HCB),

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pentachlorobenzene (PeCB), tetrachlorobenzene (TeCB) isomers, and trichlorobenzene (TCB) isomers has been well documented [29], although biodegradation of individual compounds and isomers varies between isolates. For example, *Dehalococcoides* strain CBDB1 reductively dechlorinats HCB, PeCB, all three TeCB isomers, 1,2,3-TCB, and 1,2,4-TCB [9, 30]. *Dehalobium chlorocoercia* DF-1 has been shown to be capable of reductive dechlorination of HCB, PeCB, and 1,2,3,5-TeCB [31]. The dichlorobenzene (DCB) isomers and chlorobenzene (CB) were considered relatively recalcitrant under anaerobic conditions. However, new evidence has demonstrated reductive dechlorination of DCBs to CB and CB to benzene [32] with corresponding increases in concentrations of *Dehalobacter* spp. [33].

Reductive Dechlorination - Chlorinated Phenols: Pentachlorophenol (PCP) was one of the most widely used biocides in the U.S. and despite residential use restrictions, is still extensively used industrially as a wood preservative. Along with PCP, the tetrachlorophenol and trichlorophenol isomers were also used as fungicides in wood preserving formulations. 2,4-Dichlorophenol and 2,4,5-TCP were used as chemical intermediates in herbicide production (e.g. 2,4-D) and chlorophenols are known byproducts of chlorine bleaching in the pulp and paper industry. While the range of compounds utilized varies by strain, some *Dehalococcoides* isolates are capable of reductive dechlorination of PCP and other chlorinated phenols. For example, *Dehalococcoides* strain CBDB1 is capable of utilizing PCP, all three tetrachlorophenol (TeCP) congeners, all six trichlorophenol (TCP) congeners, and 2,3-dichlorophenol (2,3-DCP). PCP dechlorination by strain CBDB1 produces a mixture of 3,5-DCP, 3,4-DCP, 2,4-DCP, 3-CP, and 4-CP [34]. In the same study, however, *Dehalococcoides* strain 195 dechlorinated a more narrow spectrum of chlorophenols which included 2,3-DCP, 2,3,4-TCP, and 2,3,6-TCP, but no other TCPs or PCP. Similar to *Dehalococcoides*, some species and strains of *Desulfitobacterium* are capable of utilizing PCP and other chlorinated phenols. *Desulfitobacterium hafniense* PCP-1 is capable of reductive dechlorination of PCP to 3-CP [35]. However, the ability to biodegrade PCP is not universal among *Desulfitobacterium* isolates. *Desulfitobacterium* sp. strain PCE1 and *D. chlororespirans* strain Co23, for example, can utilize some TCP and DCP isomers, but not PCP for growth [2, 36].

Reductive Dechlorination - Chlorinated Propanes: *Dehalogenimonas* is a recently described bacterial genus of the phylum Chloroflexi which also includes the well-known chloroethene-respiring *Dehalococcoides* [23]. The *Dehalogenimonas* isolates characterized to date are also halorespiring bacteria, but utilize a rather unique range of chlorinated compounds as electron acceptors including chlorinated propanes (1,2,3-TCP and 1,2-DCP) and a variety of other vicinally chlorinated alkanes including 1,1,2,2-tetrachloroethane, 1,1,2-trichloroethane, and 1,2-dichloroethane [23].

Aerobic - Chlorinated Ethene Cometabolism: Under aerobic conditions, several different types of bacteria including methane-oxidizing bacteria (methanotrophs), and many benzene, toluene, ethylbenzene, xylene, and (BTEX)-utilizing bacteria can cometabolize or co-oxidize TCE, DCE, and vinyl chloride [37]. In general, cometabolism of chlorinated ethenes is mediated by monooxygenase enzymes with "relaxed' specificity that oxidize a primary (growth supporting) substrate (*e.g.* methane) and co-oxidize the chlorinated compound (*e.g.*TCE). QuantArray®-Chlor provides quantification of a suite of genes encoding oxygenase enzymes capable of co-oxidation of chlorinated ethenes including soluble methane monooxygenase (sMMO). Soluble methane monooxygenases co-oxidize a broad range of chlorinated compounds [38–41] including TCE, *cis*-DCE, and vinyl chloride. Furthermore, soluble methane monooxygenases are generally believed to support greater rates of aerobic cometabolism [40]. QuantArray®-Chlor also quantifies aromatic oxygenase genes encoding ring hydroxylating toluene monooxygenase genes (RMO, RDEG), toluene dioxygenase (TOD) and phenol hydroxylases (PHE) capable of TCE co-oxidation [42–46]. TCE or a degradation product has been shown to induce expression of toluene monooxygenases in some laboratory studies [43, 47] raising the possibility of TCE cometabolism with an alternative (non-aromatic) growth substrate. Moreover, while a number of additional factors must be considered, recent research under ESTCP Project 201584 has shown positive correlations between concentrations of monooxygenase genes (soluble methane monooxygenase, ring hydroxylating monooxygenases, and phenol hydroxylase) and the rate of TCE degradation [48].

Aerobic - Chlorinated Ethane Cometabolism: While less widely studied than cometabolism of chlorinated ethenes, some chlorinated ethanes are also susceptible to co-oxidation. As mentioned previously, soluble methane monooxygenases (sMMO) exhibit very relaxed specificity. In laboratory studies, sMMO has been shown to co-oxidize a number of chlorinated ethanes including 1,1,1-TCA and 1,2-DCA [38, 40].

Aerobic - Vinyl Chloride Cometabolism: Beginning in the early 1990s, numerous microcosm studies demonstrated aerobic oxidation of vinyl chloride under MNA conditions without the addition of exogenous primary substrates. Since then, strains of

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Mycobacterium, *Nocardioides*, *Pseudomonas*, *Ochrobactrum*, and *Ralstonia* species have been isolated which are capable of aerobic growth on both ethene and vinyl chloride (see Mattes et al. [49] for a review). The initial steps in the pathway are the monooxygenase (*etn*ABCD) catalyzed conversion of ethene and vinyl chloride to their respective epoxyalkanes (epoxyethane and chlorooxirane), followed by epoxyalkane:CoM transferase (*etn*E) mediated conjugation and breaking of the epoxide [50].

Aerobic - Chlorinated Benzenes: In general, chlorobenzenes with four or less chlorine groups are susceptible to aerobic biodegradation and can serve as growth-supporting substrates. Toluene dioxygenase (TOD) has a relatively relaxed substrate specificity and mediates the incorporation of both atoms of oxygen into the aromatic ring of benzene and substituted benzenes (toluene and chlorobenzene). Comparison of TOD levels in background and source zone samples from a CB-impacted site suggested that CBs promoted growth of TOD-containing bacteria [51]. In addition, aerobic biodegradation of some trichlorobenzene and even tetrachlorobenzene isomers is initiated by a group of related trichlorobenzene dioxygenase genes (TCBO). Finally, phenol hydroxylases catalyze the continued oxidation and in some cases, the initial oxidation of a variety of monoaromatic compounds. In an independent study, significant increases in numbers of bacteria containing PHE genes corresponded to increases in biodegradation of DCB isomers [51].

Aerobic - Chlorinated Methanes: Many aerobic methylotrophic bacteria, belonging to diverse genera (*Hyphomicrobium*, *Methylobacterium*, *Methylophilus*, *Pseudomonas*, *Paracoccus*, and *Alibacter*) have been isolated which are capable of utilizing dichloromethane (DCM) as a growth substrate. The DCM metabolic pathway in methylotrophic bacteria is initiated by a dichloromethane dehalogenase (DCMA) gene. DCMA is responsible for aerobic biodegradation of dichloromethane by methylotrophs by first producing formaldehyde which is then further oxidized [52]. As discussed in previous sections, soluble methane monooxygenase (sMMO) exhibits relaxed specificity and co-oxidizes a broad spectrum of chlorinated hydrocarbons. In addition to chlorinated ethenes, sMMO has been shown to co-oxidize chloroform in laboratory studies [38, 41].

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BSCSS ERDR - Attachment B

microbialinsights

10515 Research Dr
Knoxville, TN 37932
865-573-8188

www.microbe.com

REPORT TO:

Name: John Kane
Company: Kane Environmental Inc
Address: 3815 Woodland Park Ave N, Suite 102 Seattle WA 98103
email: jkane@kane-environmental.com
Phone: 206 715 2779
Fax: -

INVOICE TO: (For Invoices paid by a third party it is imperative that all information be provided)

Name:
Company: Kane Environmental Inc
Address: PO Box 31936, Seattle, WA 98103
email: dp@kane-environmental.com
Phone: 206 691 0476
Fax: -

Project Manager: John Kane
Project Name: BSCSS
Project No.: 82302- Task 9.2

Purchase Order No.:
Subcontract No.:
MI Quote No.:

Please Check One:
☒ More samples to follow
☐ No Additional Samples

Report Type: ☑ Standard (default) ☐ Microbial Insights Level III raw data (15% surcharge) ☐ Microbial Insights Level IV (25% surcharge) ☐ Comprehensive Interpretive (15%) ☐ Historical Interpretive (35%)

EDD type: ☐ Microbial Insights Standard (default) ☐ All other available EDDs (5% surcharge) Specify EDD Type: ______

Please contact us with any questions about the analyses or filling out the COC at (865) 573-8188 (9:00 am to 5:00 pm EST, M-F). After hours email: customerservice@microbe.com

Sample Information						Analyses				CENSUS: Please select the target organism/gene																									
MI ID (Laboratory Use Only)	Sample Name	Date Sampled	Time Sampled	Matrix	Total Number of Containers	PLFA	NGS	QuantArray Chlor	QuantArray Petro	DHC (Dehalococcoides)	DHC Functional genes (bvc, tce, vcr)	DHBt (Dehalobacter)	DHG (Dehalogenimonas)	DSM (Desulfuromonas)	DSB (Desulfitobacterium)	EBAC (Total)	SRB (Sulfate Reducing Bacteria-APS)	MGN (Methanogens)	MOB (Methanotrophs)	SMMO	DNF (Dentrifiers-nirS and nirK)	AMO (ammonia oxidizing bacteria)	PM1 (MTBE aerobic)	RMO (Toluene Monooxygenase)	RDEG (Toluene Monooxygenase)	PHE (Phenol Hydroxylase)	NAH (Napthalene-aerobic)	BSSA (Toluene/Xylene-Anaerobic)	add. qPCR:	RNA (Expression Option)*	Other:	Other:	Other:		
027PB1	MW-31	2-12-18	11:30	GW	1			X																											
2	MW-30	2-12-18	13:00	GW	1			X																											

Relinquished by: John Kane Date: 2-12-18

Received by: [signature] Date: 2/13/18

It is vital that chain of custody is filled out correctly & that all relative information is provided.
Failure to provide sufficient and/or correct information regarding reporting, invoicing & analyses requested information may result in delays for which MI will not be liable.

* additional cost and sample preservation are associated with RNA samples.

**Saturday delivery: See sampling protocol for alternate shipping address.

REPORT TO:
Name: John Kane
Company: Kane Environmental Inc
Address: 3815 Woodland Park Av N, Suite 102, Seattle WA 98103
email: jkane@kane-environmental.com
Phone: 206 715 2779
Fax: –

INVOICE TO: (For Invoices paid by a third party it is imperative that all information be provided)
Name:
Company: Kane Environmental Inc
Address: PO Box 31936, Seattle WA 98103
email: ap@kane-environmental.com
Phone: 206 691 0476
Fax: –

microbialinsights
10515 Research Dr
Knoxville, TN 37932
865-573-8188
www.microbe.com

Project Manager: John Kane
Project Name: BSCSS Task 9.2
Project No.: 82302 Task 9.2

Purchase Order No.:
Subcontract No.:
MI Quote No.:

Please Check One:
☑ More samples to follow
☐ No Additional Samples

Report Type: ☑ Standard (default) ☐ Microbial Insights Level III raw data(15% surcharge) ☐ Microbial Insights Level IV (25% surcharge) ☐ Comprehensive Interpretive(15%) ☐ Historical Interpretive (35%)

EDD type: ☐ Microbial Insights Standard (default) ☐ All other available EDDs (5% surcharge) Specify EDD Type:

Please contact us with any questions about the analyses or filling out the COC at (865) 573-8188 (9:00 am to 5:00 pm EST, M-F). After hours email: customerservice@microbe.com

Sample Information						Analyses				CENSUS: Please select the target organism/gene																							
MI ID (Laboratory Use Only)	Sample Name	Date Sampled	Time Sampled	Matrix	Total Number of Containers	PLFA	NGS	QuantArray Chlor	QuantArray Petro	DHC (Dehalococcoides)	DHC Functional genes (bvc, tce, vcr)	DHBt (Dehalobacter)	DHG (Dehalogenimonas)	DSM (Desulfuromonas)	DSB (Desulfitobacterium)	EBAC (Total)	SRB (Sulfate Reducing Bacteria-APS)	MGN (Methanogens)	MOB (Methanotrophs)	SMMO	DNF (Dentrifiers-nirS and nirK)	AMO (ammonia oxidizing bacteria)	PM1 (MTBE aerobic)	RMO (Toluene Monooxygenase)	RDEG (Toluene Monooxygenase)	PHE (Phenol Hydroxylase)	NAH (Napthalene-aerobic)	BSSA (Toluene/Xylene-Anaerobic)	add. qPCR:	RNA (Expression Option)*	Other:	Other:	Other:
027PB3	MW-5	2/13/18	1405					X																									
4	MW-21	↓	1505					X																									
5	MW-35	↓	1610					X																									
6	MW-12	2/14/18	0945					X																									
7	MW-11	↓	1115					X																									
8	MW-8	↓	1220					X																									

Relinquished by: John Kane Date: 2-14-18 Received by: [signature] Date: 2/15/18 900

It is vital that chain of custody is filled out correctly & that all relative information is provided.
Failure to provide sufficient and/or correct information regarding reporting, invoicing & analyses requested information may result in delays for which MI will not be liable.

* additional cost and sample preservation are associated with RNA samples.

**Saturday delivery: See sampling protocol for alternate shipping address.

How to Use Estimated Percentile Ranks from the Microbial Insights Database

The MI Database and Client Portal

The Microbial Insights Database is the largest collection of field concentrations of key microorganisms and functional genes currently containing qPCR and QuantArray results for more than 32,000 unique groundwater, soil, and sediment samples from all 50 states and 33 countries worldwide. Driven by field samples, the database reflects the impacts of common contaminants, geochemical conditions, and site management practices on critical microbial populations.

With your report, you received a passcode enabling you to retrieve estimates of the percentile ranks of your results based on those compiled in the MI database at no additional charge. When accessing the database, you will be asked to provide background information about the sample (e.g. contaminant concentrations) to aid in understanding the links between environmental conditions and microbial populations. As with all client information provided to MI, site specific data will be treated as confidential.

Is that low, medium or high?

In practice, biodegradation depends not just on the presence but the actual concentrations of the contaminant degrading microorganisms. Simply put, qPCR and QuantArray results demonstrating high concentrations of target microorganisms or functional genes suggest in situ selection, enrichment and growth of those specific contaminant degraders and therefore a greater probability that monitored natural attenuation (MNA) or bioremediation will be successful.

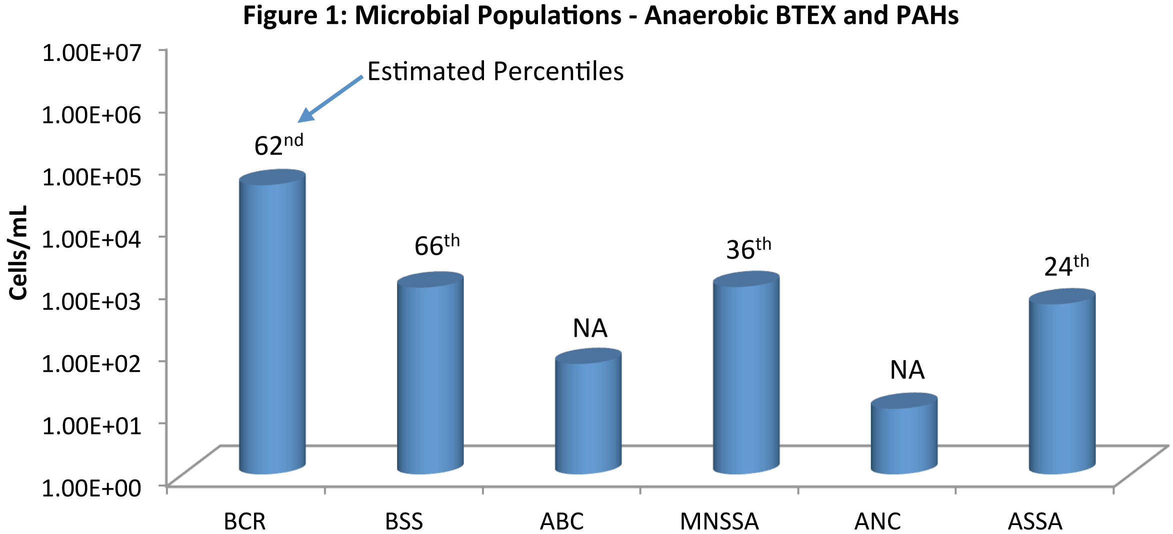
Is that a low, medium, or high concentration? The estimated percentile ranks retrieved from the MI Database answer that question by comparing your qPCR and QuantArray results to those of the literally thousands of other environmental samples submitted to MI for analysis over the last 20+ years.

Using the Estimated Percentile - Interpretation Examples

MNA Assessment – Petroleum Hydrocarbon Site:

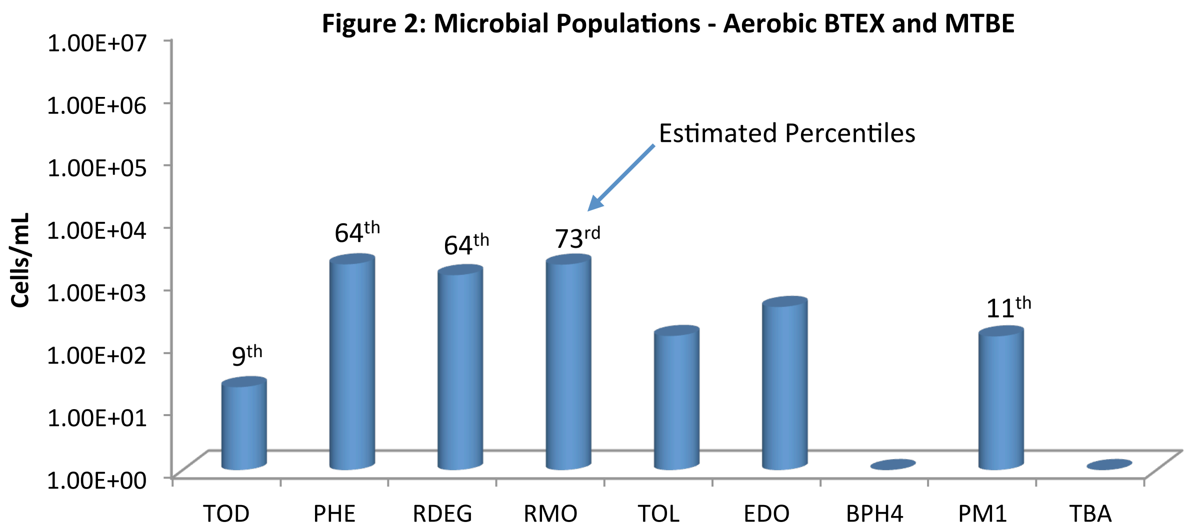
Whenever possible, interpretation of qPCR and QuantArray results should include comparisons between samples obtained from background and impacted wells. The estimated percentile ranks however provide an additional avenue for comparison and evaluation of treatment options as shown below.

Figure 1: Microbial Populations - Anaerobic BTEX and PAHs



Anaerobic BTEX and PAH Biodegradation (Figure 1):

- With moderate concentrations of functional genes involved in anaerobic BTEX metabolism detected, the QuantArray-Petro® results were encouraging in terms of evaluating biodegradation potential under existing site conditions.
- More specifically, benzylsuccinate synthase (BSS) was detected on the order of nearly 10^3 cells/mL indicating the presence of a substantial population (66th percentile) capable of anaerobic biodegradation of toluene and other alkyl substituted benzenes.
- Naphthyl-2-methylsuccinate synthase (MNSSA) and alkylsuccinate synthase (ASSA) genes were also detected indicating the potential for anaerobic biodegradation of 2-methylnaphthalene and normal alkanes.
- The concentration of MNSSA genes would be considered modest with an estimated percentile of 36th.
- While the percentile rank for MNSSA would be "below average", a number of additional factors should be considered.
    - First, anaerobic hydrocarbon degraders are less prevalent than aerobic BTEX degraders and overall detection frequencies for many genes involved in anaerobic hydrocarbon biodegradation are less than 50%.
    - Therefore, the detection of genes like BSS, MNSSA, ASSA, anaerobic benzene carboxylase (ABC), and anaerobic naphthalene carboxylase (ANC) even at low concentrations is certainly noteworthy and inherently "better than average".
    - The estimated percentiles for all assays are based only on samples where the concentration of the target gene was greater than the practical quantitation limit (PQL).
    - For less commonly detected targets like many of the genes involved in anaerobic hydrocarbon biodegradation this is an especially important consideration.
    - Excluding samples where a gene target is below the PQL ensured that the median concentrations of less commonly detected targets would not be unduly biased low by the fact that the gene is not detected in most samples.
- Anaerobic benzene carboxylase (ABC) and naphthalene carboxylase (ANC) genes were also detected indicating the presence of bacterial populations capable of anaerobic biodegradation of benzene and naphthalene.
- For newly identified genes like ABC and ANC, estimated percentile ranks are not yet available due to the limited number of field samples that have been analyzed to date.
- However, like MNSSA and other genes involved in anaerobic hydrocarbon biodegradation, ABC and ANC detection frequencies are relatively low so the detection of these genes even at low concentrations should be considered when evaluating biodegradation potential under existing site conditions.

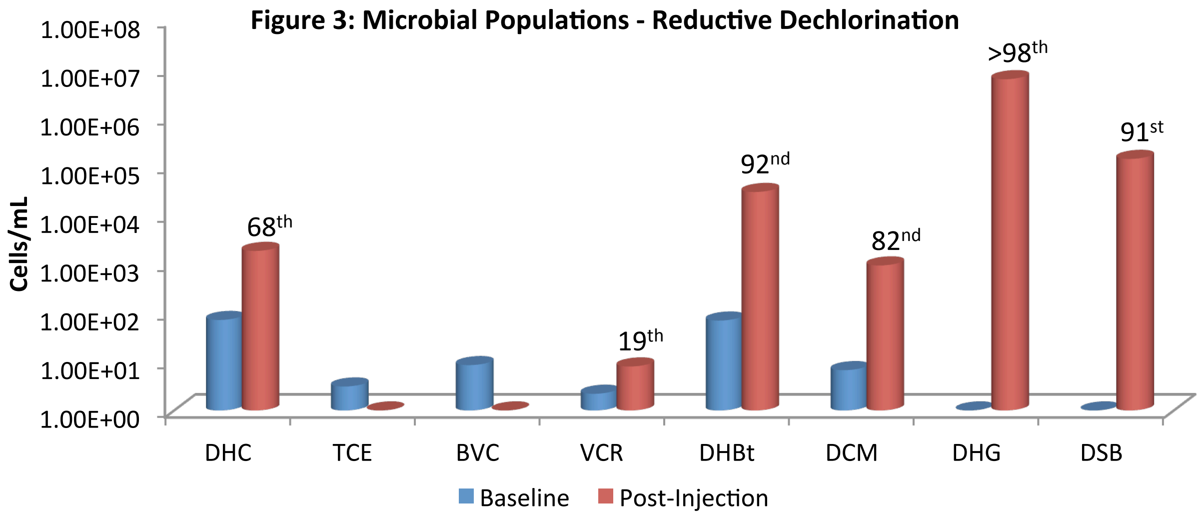


Aerobic BTEX and MTBE Biodegradation (Figure 2):

- With growing evidence that aromatic oxygenases function at low dissolved oxygen concentrations, aerobic BTEX biodegradation pathways should also be evaluated when considering MNA.
- Again, the QuantArray-Petro results were encouraging – genes encoding the first step in multiple pathways for aerobic BTEX biodegradation were detected indicating the presence of a diverse population of aerobic BTEX degraders.
- However, aerobic BTEX degraders are often considered ubiquitous. Therefore answering the question "Is that low, medium or high?" becomes especially important when evaluating aerobic BTEX biodegradation at petroleum hydrocarbon sites.
- In this case, the estimated percentile ranks of the concentrations of toluene/benzene monooxygenase (RMO and RDEG) and phenol hydroxylase (PHE) genes ranged from the 64th to 73rd percentile.
- In other words, the concentrations of RMO, RDEG, and PHE detected in this groundwater sample were greater than the concentrations detected in 64% to 73% of all other groundwater samples where these genes were analyzed and detected above the PQL.
- Aerobic BTEX degraders are common in the environment, but in this sample concentrations of toluene/benzene monooxygenase genes could be viewed as "better than average" when compared to the MI Database.

Biostimulation – Chlorinated Solvent Site:

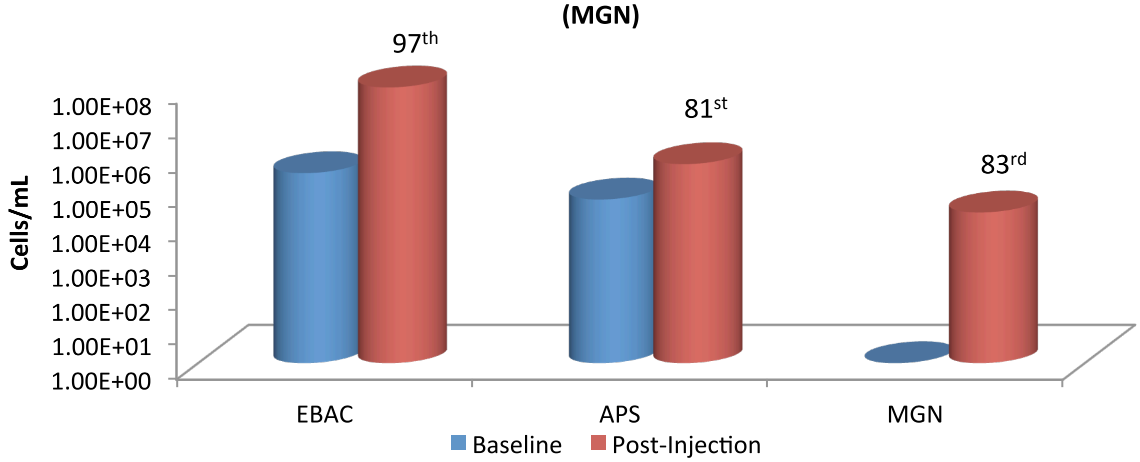
Whenever possible, interpretation of qPCR and QuantArray results should include comparisons between baseline and post-injection monitoring events as shown below (Figure 3). The estimated percentile ranks however provide an additional avenue for comparison and evaluation of remedy performance.



- During the baseline groundwater sampling event, *Dehalococcoides* and vinyl chloride reductase genes were detected indicating the potential for complete reductive dechlorination of PCE and TCE to ethene.
- However, the *Dehalococcoides* concentration was well below the 10^4 cells/mL recommended by Lu et al. (2006) for generally effective rates of reductive dechlorination.
- Based on qPCR results as well as traditional groundwater monitoring, biostimulation with electron donor addition was selected as the site management plan.
- By the first monitoring event after injection, populations of halorespiring bacteria had increased substantially in response to electron donor addition.
    - *Dehalobacter* populations increased by more than two orders of magnitude to post-injection concentrations greater than 10^4 cells/mL (92^{nd} percentile).
    - *Dehalogenimonas* (10^6 cells/mL) and *Desulfitobacterium* (10^5 cells/mL) which had not been detected prior electron donor addition were present at concentrations greater than observed in over 90% of other groundwater samples where these halorespiring bacteria were detected.
- After injection, *Dehalococcoides* populations increased by more than an order of magnitude to a concentration of over 10^3 cells/mL (68^{th} percentile) demonstrating growth of this key group of halorespiring bacteria.
- Despite a substantial increase and a "better than average" concentration, the *Dehalococcoides* population was still below the 10^4 cells/mL threshold and vinyl chloride reductase gene copies were low (19^{th} percentile).
    - In terms of electron donors and acceptors, the metabolic capabilities of *Dehalococcoides* are rather specialized (hydrogen utilizing obligate halorespiring bacteria) so the median concentration is low. With a low median concentration across the database, a "better than average" *Dehalococcoides* concentration in a given sample may not exceed the 10^4 cells/mL threshold established for effective reductive dechlorination (Lu et al. 2006) and ethene production (Microbial Insights, unpublished data).

- In this case, the initial growth of *Dehalococcoides* was substantial but may have been somewhat hindered by competition with sulfate reducing bacteria (Figure 4 below).
  - The baseline population of sulfate reducing bacteria was moderate (10^4 cells/mL; 63rd percentile). Consistent with an observed decreased in dissolved sulfate concentrations, populations of sulfate reducing bacteria increased and were detected at a relatively high concentration (81st percentile) after electron donor addition.
  - After injection, methanogen populations also increased to a relatively high concentration (83rd percentile) suggesting generation of methanogenic conditions.
- With sulfate depletion and generation of highly anaerobic conditions more conducive to reductive dechlorination, *Dehalococcoides* populations may continue to increase and exceed the 10^4 *Dehalococcoides* cells/mL threshold in subsequent monitoring events.
- Overall, QuantArray analysis conclusively demonstrated that electron donor addition stimulated growth of halorespiring bacteria with the estimated percentiles retrieved from the MI Database providing the “low, medium or high” perspective to the observed changes in microbial populations.

Figure 4: Total Bacteria (EBAC), Sulfate Reducering Bacteria (APS) and Methanogens (MGN)



References

Lu, X., J.T. Wilson, and D.H. Kampbell. 2006. Relationship between *Dehalococcoides* DNA in ground water and rates of reductive dechlorination at field scale. *Water Research* 40 no. 16: 3131-3140.

How to Retrieve and Use Estimated Percentile Ranks from the Microbial Insights Database

The MI Database

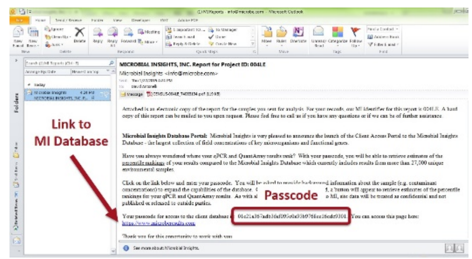
The Microbial Insights Database is the largest collection of field concentrations of key microorganisms and functional genes currently containing qPCR and QuantArray results for more than 40,000 unique groundwater, soil, and sediment samples from all 50 states and 33 countries worldwide.

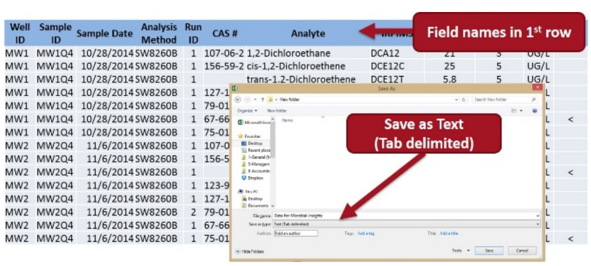
Is that low, medium or high?

In practice, biodegradation depends not just on the presence but the actual concentrations of the contaminant degrading microorganisms. The estimated percentile ranks retrieved from the MI Database answer the question "Is that low, medium or high?" by comparing your results to those of the literally thousands of other environmental samples submitted to MI for analysis over the last 20+ years.

Retrieving Estimated Percentile Ranks

With your report, you were emailed a passcode and link enabling you to login to the Client Portal. Just enter basic information about the sample (e.g. contaminant concentrations) to aid in understanding the links between environmental conditions and microbial populations and you can retrieve estimates of the percentile ranks of your results based on those compiled in the MI database at no additional charge.





All site specific data will be treated as confidential and uploading is easy.

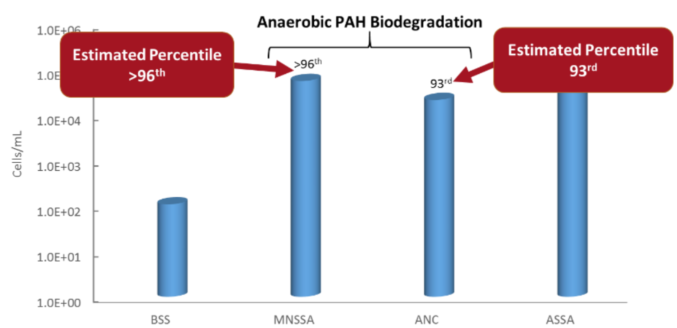
You can even upload chemical and geochemical data from EDDs. Just save as a Tab Delimited text file.

Example - Using Estimated Percentile for MNA Assessment at an MGP Site

CENSUS® qPCR was performed to quantify anaerobic naphthalene carboxylase (ANC) and naphthyl-2-methylsuccinate synthase (MNSSA) to assess anaerobic biodegradation of naphthalene and methyl-naphthalene under existing site conditions.

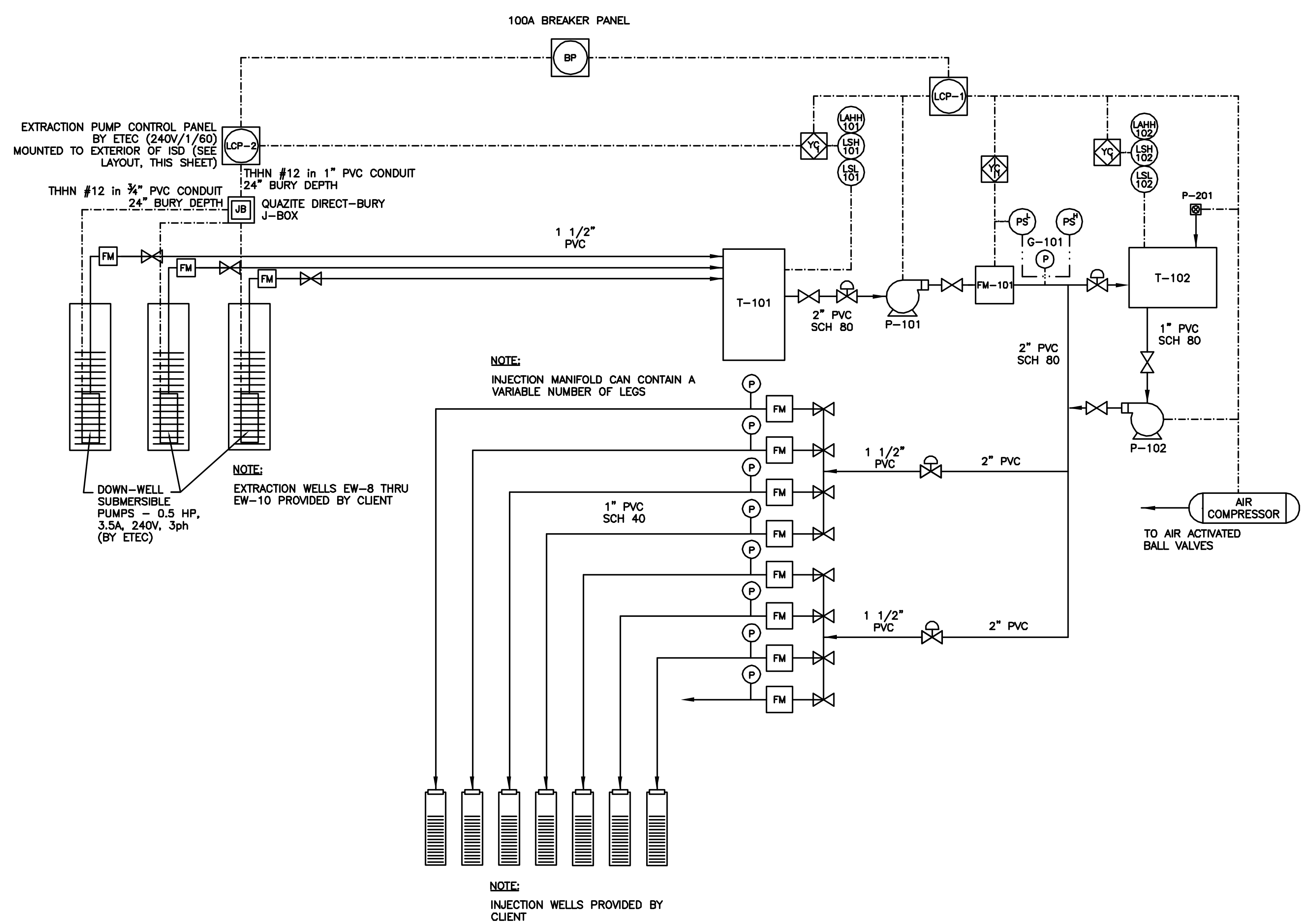
- Not only were ANC and MNSSA genes detected, but these functional genes responsible for anaerobic biodegradation of PAHs were present at concentrations "far better than average" based on the estimated percentile ranks.

- Demonstrating high concentrations of ANC and MNSSA gave an additional line of evidence indicating growth substantial populations of anaerobic PAH degraders and suggested a greater probability that monitored natural attenuation (MNA) will be successful.

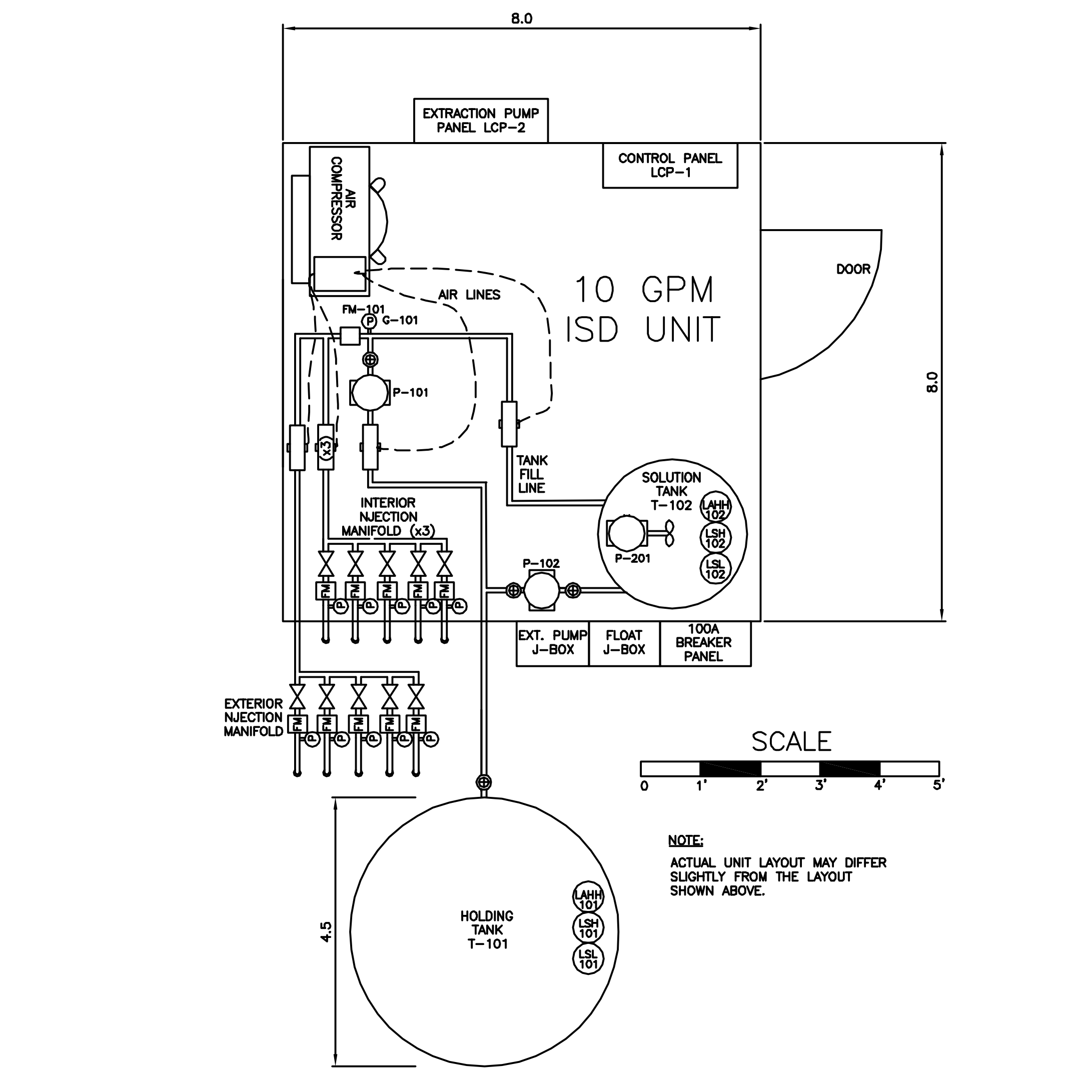


Attachment C

Layout of the Bioremediation and Groundwater Recirculation System



P & ID DIAGRAM



ISD SYSTEM LAYOUT WITH EXTRACTION PUMP PANEL (LCP-2) LOCATION

H:/ACAD/ISD.dwg

EQUIPMENT REFERENCE TABLE

DESCRIPTION	P&ID REF.
HOLDING TANK	T-101
SUBSTRATE SOLUTION TANK	T-102
MAIN INJECTION PUMP	P-101
SUBSTRATE METERING PUMP	P-102
SUBSTRATE MIXER PUMP	P-201
MAIN INJECTION TOTALIZER FLOWMETER	FM-101
PRESSURE GAGE AND SWITCHES FOR MAIN INJECTION PUMP	G-101
TANK T-101 FLOAT CONTROLS	LSL/LSH/LAHH 101
TANK T-102 FLOAT CONTROLS	LSL/LSH/LAHH 102
ISD CONTROL PANEL & PLC	LCP-1
EXTRACTION PUMP CONTROL PANEL	LCP-2

P & ID SYMBOL LEGEND

DESCRIPTION	SYMBOL
BALL VALVE	
AIR-ACTUATED BALL VALVE	
FLOW METER	FM
PRESSURE GAGE	P
LOW PRESSURE SWITCH	PS
HIGH PRESSURE SWITCH	PS
PUMP	
LEVEL SWITCH - HIGH	LSH
LEVEL SWITCH - LOW	LSL
LEVEL ALARM - HIGH/HIGH	LAHH
LOGIC INPUT DECISION	YC

REVISION	DESCRIPTION	DATE	APPROVED

tec LLC

10-GPM ISD RECIRCULATION SYSTEM

PROCESS AND INSTRUMENTATION DIAGRAM

DRAWN BY	DKL	DATE JUNE 2013
DESIGNED BY	GJL	DRAWING NO. 1
CHECKED BY	BT	
APPROVED BY	BT	REVISION 0

Attachment D

Completed Permits

BSCSS ERDR Attachment D

King County

Wastewater Treatment Division
Industrial Waste Program
Department of Natural Resources and Parks
201 South Jackson Street, Suite 513
Seattle, WA 98104-3855
206-477-5300 Fax 206-263-3001
TTY Relay: 711

April 24, 2018

CERTIFIED MAIL
RETURN RECEIPT REQUESTED

Nduta Mbuthia
City of Bothell
18415 101st Ave. NE
Bothell, WA 98117

Issuance of Wastewater Discharge Authorization No. 1084-01 to City of Bothell - 98th Avenue NE and Main Street Groundwater Remediation Project

Dear Ms. Nduta Mbuthia:

The King County Industrial Waste Program (KCIW) has reviewed your application to discharge industrial wastewater to the sewer system from the City of Bothell Groundwater Remediation Project located at 98th Avenue NE And Main Street, Bothell, Washington, and has issued the enclosed Minor Discharge Authorization..

This authorization permits you to discharge limited amounts of industrial wastewater into King County's sewer system in accordance with the effluent limitations and other requirements and conditions set forth in the document and the regulations outlined in King County Code 28.84.060 (enclosed). As long as you maintain compliance with regulations and do not change the nature and volume of your discharge, KCIW will not require you to apply for an industrial wastewater discharge permit, a type of approval that would result in additional requirements and increased fees.

If you propose to increase the volume of your discharge or change the type or quantities of substances discharged, you must contact KCIW at least 60 days before making these changes.

King County Code 28.84 authorizes a fee for each Minor Discharge Authorization issued by the King County Department of Natural Resources and Parks. The current fee for issuance of a Minor Discharge Authorization is $1,750. King County will send you an invoice for this amount.

If you have any questions about this discharge authorization or your wastewater discharge, please call me at 206-477-5462 or email me at peggy.rice@kingcounty.gov. You may also wish to visit our program's Internet pages at: www.kingcounty.gov/industrialwaste.

Thank you for helping support our mission to protect public health and enhance the environment.

Sincerely,

Peggy Rice
Compliance Investigator

Enclosures

cc: Don Fiene, City of Bothell
Carl Sandberg, Cascade Technical Services
Nduta Mbuthia, City of Bothell

King County

MINOR DISCHARGE AUTHORIZATION

King County Industrial Waste Program
201 S. Jackson Street, Suite 513
Seattle, WA 98104-3855

NUMBER 1084-01

City of Bothell - 98th Avenue NE and Main Street Groundwater Remediation Project

GWR Project address: 98th Avenue NE and Main Street
Bothell, WA 98011

Mailing address: 18415 101st Ave. NE
Bothell, WA 98117

Phone: 425-806-6829

Emergency phone: 406-806-6829

Industry type: Groundwater Remediation - Organics

Discharge to: Brightwater Treatment Plant

*Note: This authorization is valid only for the specific discharges shown below:

Discharge process: Wastewater generated by Groundwater Remediation
Electronic Resistance Heating, GAC

Effective date: April 24, 2018 **Expiration date:** April 23, 2020

DESCRIPTION OF SAMPLE SITES AND DISCHARGE VOLUMES

Sample Site	Description	Maximum Volume (gallons per day)
IW1404A	Sampling Spigot after GAC	3,240

Permission is hereby granted to discharge industrial wastewater from the above-identified facility into the King County sewer system in accordance with the effluent limitations and monitoring requirements set forth in this authorization.

If the industrial user wishes to continue to discharge after the expiration date, an application must be filed for re-issuance of this discharge authorization at least 90 days prior to the expiration date. For information concerning this King County Discharge Authorization, please call Industrial Waste Compliance Investigator Peggy Rice at 206-477-5462.

24-HOUR EMERGENCY NOTIFICATION
Brightwater Treatment Plant: 206-263-9500
Washington State Department of Ecology: 425-649-7000

GENERAL DISCHARGE LIMITATIONS

Operating criteria

There shall be no odor of solvent, gasoline, or hydrogen sulfide (rotten egg odor), oil sheen, unusual color, or visible turbidity. The discharge must remain translucent. If any of the discharge limits are exceeded, you must stop discharging and notify KCIW at 206-477-5300.

Corrosive substances

Limits

Maximum:	pH 12.0 (s.u.)
Instantaneous minimum:	pH 5.0 (s.u.)
Daily minimum:	pH 5.5 (s.u.)

The instantaneous minimum pH limit is violated whenever any single grab sample or any instantaneous recording is less than pH 5.0. The daily minimum pH limit is violated whenever any continuous recording of 15 minutes or longer remains below pH 5.5 or when each pH value of four consecutive grab samples collected at 15-minute intervals or longer within a 24-hour period remains below pH 5.5.

Discharges of more than 50 gallons per day of caustic solutions equivalent to more than 5 percent NaOH by weight or greater than pH 12.0 are prohibited unless authorized by KCIW and subject to special conditions to protect worker safety, the collection system, and treatment works.

Fats, oils, and grease

Discharge of FOG shall not result in significant accumulations that either alone or in combination with other wastes are capable of obstructing flow or interfere with the operation or performance of sewer works or treatment facilities.

Dischargers of polar FOG (oil and grease from animal and/or vegetable origin) shall minimize free-floating polar FOG. Dischargers may not add emulsifying agents exclusively for the purpose of emulsifying free-floating FOG.

Nonpolar FOG limit: 100 mg/L

The limit for nonpolar FOG is violated when the arithmetic mean of the concentration of three grab samples, taken no more frequently than at five minute intervals, or when the results of a composite sample exceed the limitation.

Flammable or explosive materials

No person shall discharge any pollutant, as defined in 40 CFR 403.5, that creates a fire or explosion hazard in any sewer or treatment works, including, but not limited to, waste streams with a closed cup flashpoint of less than 140° Fahrenheit or 60° Centigrade using the test methods specified in 40 CFR 261.21.

At no time shall two successive readings on an explosion hazard meter, at the point of discharge into the system (or at any point in the system), be more than 5 percent nor any single reading be more than 10 percent of the lower explosive limit (LEL) of the meter.

Pollutants subject to this prohibition include, but are not limited to, gasoline, kerosene, naphtha, benzene, toluene, xylene, ethers, alcohols, ketones, aldehydes, peroxides, chlorates, perchlorates, bromates, carbides, hydrides, and sulfides, and any other substances that King County, the fire department, Washington State, or the U.S. Environmental Protection Agency has notified the user are a fire hazard or a hazard to the system.

Petroleum Compounds	Maximum Concentration ppm (mg/L)
Benzene	0.07
Ethylbenzene	1.7
Toluene	1.4
Total xylenes	2.2

Heavy metals/cyanide

The industrial user shall not discharge wastes, which exceed the following limitations:

Heavy Metals & Cyanide	Daily Maximum ppm (mg/L)[1]
Arsenic	4.0
Cadmium	0.6
Chromium	5.0
Copper	8.0
Lead	4.0
Mercury	0.2
Nickel	5.0
Silver	3.0
Zinc	10.0
Cyanide	3.0

[1] The daily maximum is violated whenever any sample exceeds the limitation.

High temperature

The industrial user shall not discharge material with a temperature in excess of 65° C (150° F).

Hydrogen sulfide

Atmospheric hydrogen sulfide: 10.0 ppm
(As measured at a monitoring manhole designated by KCIW)

Soluble sulfide limits may be established on a case-by-case basis depending upon volume of discharge and conditions in the receiving sewer, including oxygen content and existing sulfide concentrations.

Organic compounds

No person shall discharge any organic pollutants that result in the presence of toxic gases, vapors, or fumes within a public or private sewer or treatment works in a quantity that may cause worker health and safety problems.

Organic pollutants subject to this restriction include, but are not limited to: Any organic pollutants compound listed in 40 CFR Section 433.11 (e) (total toxic organics [TTO] definition), acetone, 2-butanone (MEK), 4-methyl-2-pentanone (MIBK), and xylenes.

Screening Levels for Selected Organic Compounds

Discharges that exceed the following screening levels have the potential to cause health hazards in the sewage collection system or indicate that treatment has not been sufficient enough to remove hazardous waste characteristics.

Compound	CAS Number	Wastewater Screening Level (mg/L)
Vinyl Chloride	75-01-4	0.012
Trichloroethene (TCE)	79-01-6	0.50
Tetrachloroethene (PCE)	127-18-4	0.24
Cis-1,2 Dichloroethene	540-59-0	2.0

Settleable solids

Settleable solids concentrations: 7.0 ml/L

GENERAL CONDITIONS

A. All requirements of King County Code pertaining to the discharge of wastes into the municipal sewer system are hereby made a condition of this discharge authorization.

B. The industrial discharger shall implement measures to prevent accidental spills or discharges of prohibited substances to the municipal sewer system. Such measures include, but are not limited to, secondary containment of chemicals and wastes, elimination of connections to the municipal sewer system, and spill response equipment.

C. Any facility changes, which will result in a change in the character or volume of the pollutants discharged to the municipal sewer system, must be reported to your KCIW representative. Any facility changes that will cause the violation of the effluent limitations specified herein will not be allowed.

D. In the event the permittee is unable to comply with any of the conditions of this discharge authorization because of breakdown of equipment or facilities, an accident caused by human error, negligence, or any other cause, such as an act of nature the company shall:

1. Take immediate action to stop, contain, and clean up the unauthorized discharges and correct the problem.
2. Immediately notify KCIW and, if after 5 p.m. weekdays and on weekends, call the emergency King County treatment plant phone number on Page 1 so steps can be taken to prevent damage to the sewer system.
3. Submit a written report within 14 days of the event (*14-Day Report*) describing the breakdown, the actual quantity and quality of resulting waste discharged, corrective action taken, and the steps taken to prevent recurrence.

E. Compliance with these requirements does not relieve the permittee from responsibility to maintain continuous compliance with the conditions of this discharge authorization or the resulting liability for failure to comply.

F. The permittee shall, at all reasonable times, allow authorized representatives of KCIW to enter that portion of the premises where an effluent source or disposal system is located or in which any records are required to be kept under the terms and conditions of this authorization.

G. Nothing in this discharge authorization shall be construed as excusing the permittee from compliance with any applicable federal, state, or local statutes, ordinances, or regulations including discharge into waters of the state. Any such discharge is subject to regulation and enforcement action by the Washington State Department of Ecology.

H. This discharge authorization does not authorize discharge after its expiration date. If the permittee wishes to continue to discharge after the expiration date, an application must be filed for reissuance of this discharge authorization at least 90 days prior to the expiration date. If the permittee submits its reapplication in the time specified herein, the permittee shall be deemed to have an effective wastewater discharge authorization until KCIW issues or denies the new wastewater discharge authorization. If the permittee fails to file its reapplication in the time period specified herein, the permittee will be deemed to be discharging without authorization.

Compliance Investigator: Peggy Rice (signature) Date: April 24, 2018
Peggy Rice

BSCSS ERDR - Attachment D

City of Bothell™

Utility

Permit Number: UTL2018-19017
Type: Utility
Work Class: Type I
Issue Date: 05/11/2018

Permit Information

Job Address:

Parcel: 2374200065

Sub Area: Downtown

Expiration Date: 05/10/2020

Inspector:

Description: Public Works, Downtown Contaminated Soil & Groundwater Cleanup, connect to existing potable water valve box to supply water for the operation of an electrical resistance heating system(ERH) to remediate site soil and ground water. Side sewer connection for an ERH system water discharge. The system is necessary to remediate contaminated soil and ground water.

Contacts

Type	Contact Name	Address	Phone
Contractor	CASCADE TECHNICAL SERVICES	1081 COLUMBIA BLVD. LONGVIEW, WA 98632	
Owner	CITY OF BOTHELL	18415 101ST AVE NE BOTHELL, WA 98011	

Fees Paid

Fee	Amount
Side Sewer Conn - Detached MF	$240.00

Agreement

The City approved plans, permit and inspection record must remain on the job site for use by City inspection personnel

If applicable to your project: Prior to commencing any work, a pre-construction conference is required. Call 425-806-6400 to schedule.

Work performed under this permit must be inspected. See reverse side of this form for instructions.

This permit, the inspection record and the plans approved by the City must remain together in a visible and easily accessible location on the job site for use by City inspectors. Failure to comply with this requirement can result in delayed inspections and imposition of re-inspection fees.

I certify that the information furnished by me is true and correct to the best of my knowledge and the applicable City of Bothell requirements will be met.

☐ Owner or ☒ Agent
(Check one)

Greg Sandberg
(Print Name)

5/11/18
DATE:

[signature]
(Signature)

The listed inspections below are required for your project. If you are unclear as to what a particular inspection is for, please contact the applicable discipline, as shown.

You may request inspections online at www.MyBuildingPermit.com, or call 425-806-6107, and provide the following information, in order:

1. Complete permit number;
2. Jobsite address;
3. Inspection type;
4. Desired inspection date;
5. Preferred time (a.m. or p.m.);
6. Residential or commercial; and
7. Contact name and telephone number.

If you want your inspection the next business day, call prior to 4 p.m. Requests received after 4 p.m. will be scheduled for the second business day.

For occupied residential units, you must be present at the inspection: failure to attend can result in delayed inspection and imposition of re-inspection fees. The inspector will evaluate the work performed for compliance with the City approved plans: Please make sure you follow those plans precisely.

Required Inspections

1. Final - CI
2. Miscellaneous Engineering Inspection
3. Site Precon
4. Side Sewer
5. Meter Assembly

Finally, for Building Permits other than Single Family, please note the Form 55, attached to your plan set. This is the form the inspectors from all the applicable disciplines sign once they have completed their final inspections, to indicate your project has been completed and may be occupied or otherwise put into use. This form must remain with the permit and the approved plans.

JOBSITE COPY
ELECTRICAL CONTRACTOR
ELECTRICAL WORK PERMIT #3006558E

Contractor Name
ADVANCED ELECTRICAL TECHNLGIES

License Number
ADVANET895R9

Installation Description:
temporary 1200 amp service installiation

Services to inspect:

Description	Quantity	Amount
Temporary Service for constr or stage concert - OV	1	$143.30

Inspection Fee: $143.30

The department will perform 1 inspection for permits where total fee paid on permit is less than $93.59. For more than 1 inspection, additional fees are required.

Additional Fees May Be Assessed Upon Field Inspection

Purchaser's mailing address
1121 COLUMBIA BLVD
LONGVIEW WA 98632

Telephone number
3604232245

Premises owner's name
GRS

Address of inspection
18107 Bothell Way NE
BOTHELL

Power company
Puget Sound Energy

This permit expires one (1) year after the date of purchase.

Applied:4/12/2018 Expiration:4/12/2019

	Date	Approved By		Date	Approved By
WALLS					
Insulation Only			**SERVICE**		
Cover			**FEEDER**		
CEILING					
Insulation Only			**THERMOSTAT**		
Cover			**DITCH**		

Inspection Date	Area, Building or Equipment Inspected	Action Taken	Electrical Inspector
4/30/18	TEMP SERVICE 1200 AMP	OKD	[signature]

Property Owner: Retain Permit Number for your records

Attention Applicant! The Department will not conduct this inspection if there are unrestrained animals on the premises. Failure to comply with this requirement may result in additional inspection service fees and delay in service.

~~BSCSS~~ ERDR - Attachment D

City of Bothell™

Hydrant

Permit Number: HYD2018-19151
Type: Hydrant
Work Class: Hydrant
Issue Date:

Permit Information

Job Address:	18107 96TH AVE NE	**Sub Area:**	Downtown
Parcel:	3173600010	**Expiration Date:**	12/31/2018
Description:	Hydrant Make-up #8 SnAB1047342		

Contacts

Type	Contact Name	Address	Phone
Contractor	CASCADE THERMAL (GLOBAL REMEDIATION SOLUTIONS)	1081 COLUMBIA BLVD LONGVIEW, WA 98632	406-250-9404

Fees Paid

Fee	Amount
Hydrant Permit (per year)	$121.00
Meter Make-up Deposit	$1,500.00
Hydrant Deposit	$1,000.00

Agreement

The City approved plans, permit and inspection record must remain on the job site for use by City inspection personnel.

If applicable to your project: Prior to commencing any work, a pre-construction conference is required. Call 425-806-6400 to schedule.

Work performed under this permit must be inspected. See reverse side of this form for instructions.

This permit, the inspection record and the plans approved by the City must remain together in a visible and easily accessible location on the job site for use by City inspectors. Failure to comply with this requirement can result in delayed inspections and imposition of re-inspection fees.

I certify that the information furnished by me is true and correct to the best of my knowledge and the applicable City of Bothell requirements will be met.

☐ Owner or ☒ Agent
(Check one)

LUKE KNEPPER
(Print Name)

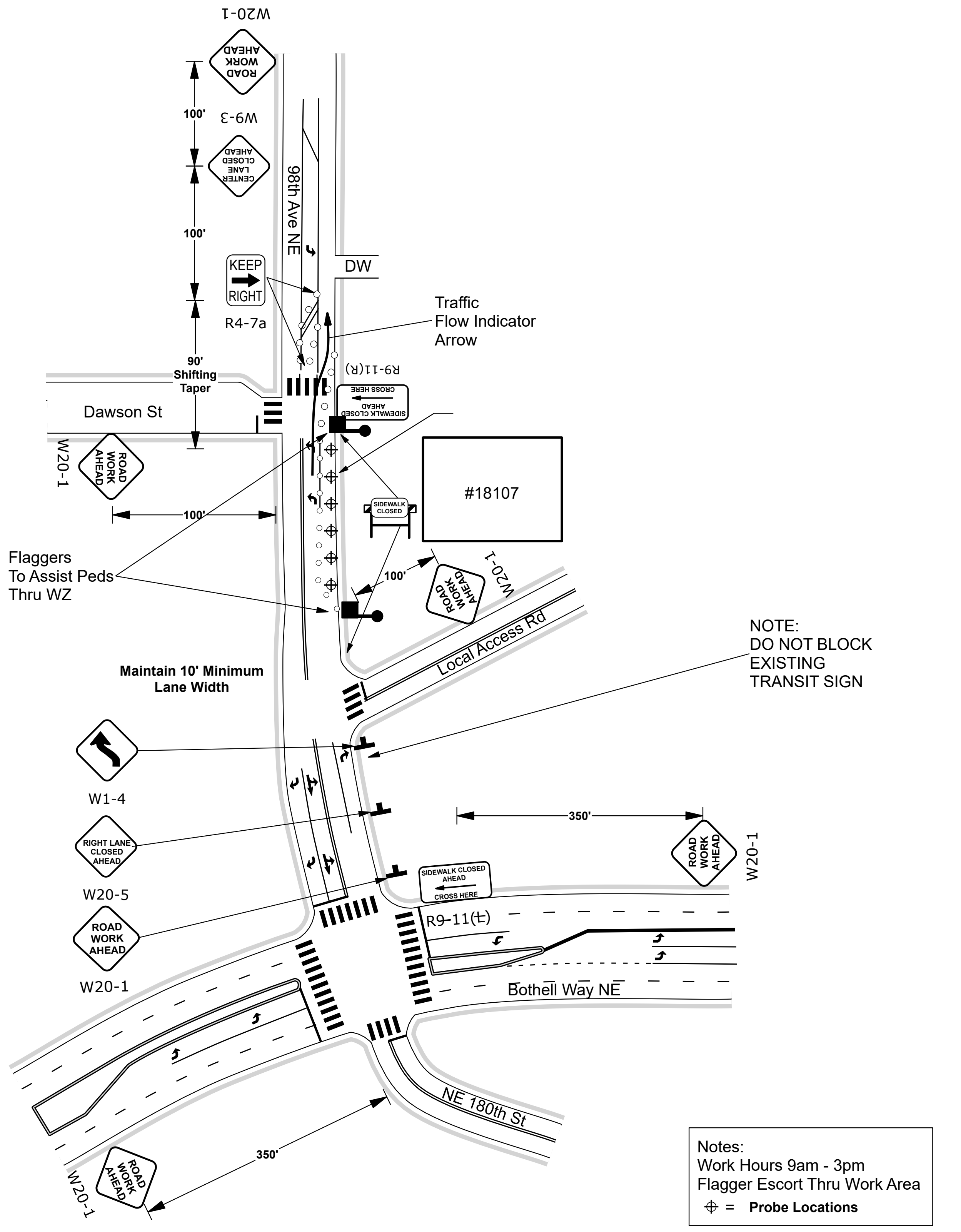
[signature]
(Signature)

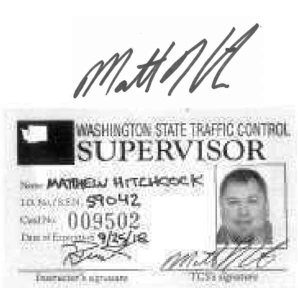
4/23/18
DATE:

www.invarion.com

BSCSS ERDR - Attachment D

REQUESTED DATES: ____________ WORK HOURS: 9am - 3pm	ADDRESS: 18107 Bothell Way NE Bothell, WA 98011	PERMIT:





TCP REVISED TO REFLECT
CITY OF BOTHELL ROW COMMENTS
TO PREVIOUS VERSION OF TCP

Taper Length In Feet

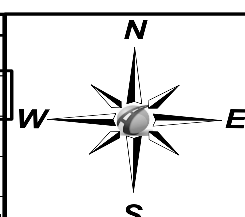
Speed (MPH)	LANE WIDTH 10FT	LANE WIDTH 11FT	LANE WIDTH 12FT	LONG. BUFFER
25 or less	105'	115'	125'	
30	150'	165'	180'	90'
35	205'	225'	245'	120'
40	270'	295'	320'	155'
45	450'	495'	540'	195'
50	500'	550'	600'	240'
55	550'	605'	660'	295'
60	600'	660'	720'	350'
65	650'	725'	780'	410'
70	700'	770'	840'	475'
75	750'	825'	900'	540'
80	800'	880'	960'	

CHANNELIZATION DEVICE SPACING

MPH	TAPER	TANGENT
65	40	130
60	40	120
55	40	110
50	40	100
45	40	90
40	40	80
35	35	70
30	30	60
25	25	50

SIGN SPACING

ROAD TYPE	A	B	C
Urban Low Speed	100'	100'	100'
Urban High Speed	350'	350'	350'
Rural	500'	500'	500'
Expressway/ Freeway	1000'	1500'	2640'



Summary of Devices

- 6 - 48" Road Work Ahead
- 1 - 48" Right Lane Closed Ahead
- 1 - Reverse Curve
- 1 - 48" Center Lane Closed Ahead
- 2 - Keep Right
- 2 - Type II Sidewalk Closed
- 2 - Sidewalk Closed Cross Here (<--,-->)
- 20 - Cones
- 2 - Flagger/Spotter To Assist Peds

ALTUS TRAFFIC
(720) 343-2335

Across America, Altus Traffic is the trusted name for:

- *Traffic management*
- *Flagging*
- *Traffic control, and*
- *Traffic management plans.*

Location:	**18107 Bothell Way NE, Bothell, WA 98011**
For:	**Kane Envirenmental, Inc**
Name:	**Jeff Jensen 206-673-5731**
Date:	**March 30, 2018**
Drawn By:	**Matt Hitchcock**
ATTSA Cert#:	**59042**
Job#:	**18107 Bothell**

MHT#1

NOT DRAWN TO SCALE

REVIEWED:

LEGEND

	Type 3 Barricade		Channelizing Devices
	Heavy Work Vehicle		Truck Mounted Attenuator
	Trailer Mounted Flashing Arrow Board		Portable Changeable Message Sign (PCMS)
	Sign		Traffic Flow
R8-3	No Parking Sign		Uniformed Traffic Officer
	Flagger		Advance Warning Signs

Lane Shift

NOTES:

NO PARKING SIGNS TO BE SET 24 HOURS PRIOR TO WORK

ALL DEVICES TO CONFORM TO CURRENT MUTCD

From: Nduta Mbuthia <Nduta.Mbuthia@bothellwa.gov>
Sent: Friday, May 18, 2018 10:09 AM
To: John Kane
Subject: RE: [EXTERNAL] Permits for BSCSS

John,

We did not need a grading permit for this project. thanks

Nduta

From: John Kane
Sent: Monday, April 9, 2018 2:44 PM
To: Madeline Camp
Subject: Re: NOC application 11544

Thank you!

John

John Kane, CEO/President
Kane Environmental, Inc.
Environmental Issues. Business Solutions.
Headquarters 3815 Woodland Park Avenue N, Suite 102, Seattle, WA 98103
Tel 206-691-0476   Cell 206-715-2779
Toll Free 1-844-529-KANE
jkane@kane-environmental.com
www.kane-environmental.com

Seattle, WA | Tacoma, WA | San Francisco, CA | Phoenix, AZ | Nationwide Services

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From: Madeline Camp <MadelineC@pscleanair.org>
Sent: Monday, April 9, 2018 2:40:03 PM
To: John Kane
Subject: RE: NOC application 11544

Hi John,

As we discussed, your project will not need a permit. The recent OA for a similar project can be used as an example of relevant requirements for the substantive requirements of the NOC process for your use during design and operation of your project.
Please let me know if you have any additional questions moving forward.

Thanks,

Madeline Camp
Engineer
MadelineC@pscleanair.org
206.689.4063

Puget Sound Clean Air Agency
1904 3rd Ave – Suite 105
Seattle, WA 98101

"Working together for clean air"

From: Madeline Camp <MadelineC@pscleanair.org>
Sent: Tuesday, April 3, 2018 2:37:42 PM
To: John Kane
Subject: RE: NOC application 11544

Hi John,

I'm Madeline Camp and I will be your main contact for your permit application moving forward. Thank you for your patience with our review.

I see from your DNS that your source is a MTCA site. As a reminder, MTCA sites are exempted from the procedural requirements for notice of construction applications and do not need to go through the notice of construction process. Typically, we provide template orders of approval or orders of approval from similar projects so that you can determine the estimated applicable and relevant requirements, had a permit been required.

Below please find the applicable sections of the rule that exempt you from our NOC process for information purposes. Importantly, you are exempt from the "procedural requirements" of our NOC process but not the substantial parts of the program (e.g. BACT).

Attached please a final approval for a similar project (carbon adsorption for PCE/TCE/DCE/VC) so you can determine the estimated applicable and relevant requirements, had a permit been required.

Please let me know if you have any questions.

Thanks,
Madeline

RCW 70.105D.090

Remedial actions—Exemption from procedural requirements.

(1) A person conducting a remedial action at a facility under a consent decree, order, or agreed order, and the department when it conducts a remedial action, are exempt from the procedural requirements of chapters 70.94, 70.95, 70.105, 77.55, 90.48, and 90.58 RCW, and the procedural requirements of any laws requiring or authorizing local government permits or approvals for the remedial action. The department shall ensure compliance with the substantive provisions of chapters 70.94, 70.95, 70.105, 77.55, 90.48, and 90.58 RCW, and the substantive provisions of any laws requiring or authorizing local government permits of approvals. The department shall establish procedures for ensuring that such remedial actions comply with the substantive requirements adopted pursuant to such laws, and shall consult with the state agencies and local governments charged with implementing these laws. The procedures shall provide an opportunity for comment by the public and by the state agencies and local governments that would otherwise implement the laws referenced in this section. Nothing in this section is intended to prohibit implementing agencies from charging a fee to the person conducting the remedial action to defray the costs of services rendered relating to the substantive requirements for the remedial action.

(2) An exemption in this section or in RCW 70.94.335, 70.95.270, 70.105.116, * 77.55.030, 90.48.039, and 90.58.355 shall not apply if the department determines that the exemption would result in loss of approval from a federal agency necessary for the state to administer any federal law, including the federal resource conservation and recovery act, the federal clean water act, the federal clean air act, and the federal coastal zone management act. Such a determination by the department shall not affect the applicability of the exemptions to other statutes specified in this section.
[2003 c 39 § 30; 1994 c 257 § 14.]

Model Toxic Control Act (MTCA) (outlined here http://app.leg.wa.gov/RCW/default.aspx?cite=70.105D)

Madeline Camp
Engineer
MadelineC@pscleanair.org
206.689.4063Puget Sound Clean Air Agency
1904 3rd Ave – Suite 105
Seattle, WA 98101

"Working together for clean air"

STATE OF WASHINGTON
DEPARTMENT OF ECOLOGY
PO Box 47600 • Olympia, WA 98504-7600 • 360-407-6000
711 for Washington Relay Service • Persons with a speech disability can call 877-833-6341

June 27, 2018

Nduta Mbuthia
City of Bothell
18415 101st Ave NE
Bothell, WA 98011

RE: Registration with the Underground Injection Control (UIC) Program, Bothell Service Center/Simon & Sons, 18107 Bothell Way NE, Bothell, WA

Dear Nduta Mbuthia:

This letter is to acknowledge receipt of your registration form received June 18, 2018 to register the above-mentioned site with the UIC program. The UIC wells are rule authorized and do not need a State Waste Discharge Permit to operate. The UIC site number is 34034.

The City of Bothell is working with Ecology's Toxic Cleanup Program under the Model Toxic Control Act (MTCA) Consent Decree 33215922 to remediate the contamination at the site. Remediation projects under a MTCA legal agreement have to meet the substantive requirements of other laws which ground water protection is one. Meeting the substantive requirements will fulfill the groundwater protection requirement of the UIC Program.

Please refer to the UIC site number in all correspondence concerning this site. Also contact us if the property owner changes or the use of the well.

Please call me at (360) 407-6143 if you have any questions. Additional information can also be found at our website http://www.ecy.wa.gov/programs/wq/grndwtr/uic/index.html.

Sincerely,

Mary SHansen

Mary Shaleen-Hansen
UIC Coordinator
Water Quality Program

Cc: John Kane, Kane Environmental Inc.

Attachment E

ERH Installation HASP and Spill Prevention and Containment Plan

KANE ENVIRONMENTAL INC

Site Health and Safety Plan

ERH Installation
Bothell Service Center Simon & Son
18107 Bothell Way NE
Bothell, Washington

Date of Preparation:

February 19, 2018

KANE ENVIRONMENTAL INC

EMERGENCY CONTACTS AND EMERGENCY INFORMATION

POLICE:.. **911**
FIRE:... **911**
FIRST AID:.. **911**

In the event of an emergency, be prepared to give the following information:

- Location of Emergency

  Site Location: .... **18107 Bothell Way NE**
  Bothell, WA

  Nearest Cross Street: .... **98th Ave NE**

- Phone Number That You Are Calling From: .... **field personnel cell**

- What Happened?
  * Type of Accident
  * Type(s) of Injuries
- How Many People Need Help?

Additional Emergency Information:

- Hospital Name: .... **OVERLAKE HOSPITAL**
  Address:.. 1035 116TH AVE NE
  City, State, Zip Code:.................................. BELLEVUE, WA 98004

  Phone Number: 425-688-5000

  The hospital route map is attached as Attachment 1.

- Site Health and Safety Officer................................ Jeffrey Jensen
  (425) 344-3707 Mobile phone

- Note: Contact a Principal at Kane Environmental, Inc. after Emergency Services have been called.

  Kane Environmental, Inc.. **(206) 691-0476**
  (206) 715-2779 Mobile phone

1.0 PLAN OBJECTIVES AND APPLICABILITY

This Health and Safety Plan has been written to comply with the standards prescribed by the Occupational Safety and Health Act (OSHA) and the Washington Industrial Safety and Health Act (WISHA).

The purpose of this health and safety plan is to establish protection standards and mandatory safe practices and procedures for all personnel involved with field activities at the site. This plan assigns responsibilities, establishes standard operating procedures, and provides for contingencies that may occur during field activities. The plan consists of site and facility descriptions, a summary of work activities, an identification and evaluation of chemical and physical hazards, monitoring procedures, personnel responsibilities, a description of site zones, decontamination and disposal practices, emergency procedures, and administrative requirements.

Mr. Jensen, is the designated Site Health and Safety Officer. As Site Health and Safety Officer, the Site Health and Safety Officer has total responsibility for ensuring that the provisions outlined herein adequately protect worker health and safety and that the procedures outlined by this Health and Safety Plan are properly implemented. In this capacity, the Site Health and Safety Officer will conduct regular site inspections to ensure that this Health and Safety Plan remains current with potentially changing site conditions. The Site Health and Safety Officer has the authority to make health and safety decisions that may not be specifically outlined in this plan, should site conditions warrant such actions. In the event that the Site Health and Safety Officer leaves the site while work is in progress, an alternate Site Health and Safety Officer will be designated.

The provisions and procedures outlined by this Health and Safety Plan apply to all contractors, subcontractors, owner's representatives, oversight personnel, and any other persons involved with the field activities described herein. All such persons are required to read this Health and Safety Plan and indicate that they understand its contents by signing the Site Health and Safety Officer's copy of the Plan. Copies of this Health and Safety Plan have not been distributed to a designated representative of the following companies and /or organizations:

It should be noted that this Health and Safety Plan is based on information that was available as of the date indicated on the Title Page. It is possible that additional hazards that are not specifically addressed by this Health and Safety Plan may exist at the work-site, or may be created as a result of on-site activities. It is Kane Environmental's firm belief that active participation in health and safety procedures and acute awareness of on-site conditions by all site workers is crucial to the health and safety of everyone involved. If you identify a site condition that is not addressed by this Health and Safety Plan, or if you have any questions or concerns about site conditions or this Plan, immediately notify the Site Health and Safety Officer.

This Health and Safety Plan was prepared by:

Jeffrey Jensen, Project Geologist

2.0 BACKGROUND INFORMATION

The property contained a former dry cleaning operation from approximately 1990 to 1999. The property contains concentrations of volatile organic compounds (VOCs), including tetrachloroethylene (PCE), trichloroethylene (TCE), cis-1,2 dichloroethylene (cis-1,2 DCE), and vinyl chloride in soil and/or groundwater above state cleanup levels.

2.1 Scope of Work

Installation of electrical resistance heating (ERH) electrodes and temperature monitoring probes (TMP), throughout the site as well as in 98th Avenue NE.

3.0 HAZARD EVALUATION AND RISK ANALYSIS

In general, there are three broad hazard categories that may be encountered during site work; Chemical Exposure Hazards, Fire/Explosion Hazards, and Physical Hazards. Subsections 3.1 through 3.3 deal with specific hazards falling within each of these broad categories.

3.1 Chemical Exposure Hazards

Petroleum Hydrocarbons

Not expected to be encountered during this scope of work

Volatile Organic Compounds (VOCs)

VOCs including PCE and TCE, may encounter cis-1,2 DCE and vinyl chloride.

3.2 Fire and Explosion Hazards

It is highly unlikely that gasoline vapors will be present at levels sufficient to create an explosion and/or fire hazard. It should be noted, however, that the 1996 Emergency Response Guidebook, published by the United States Department of Transportation, identifies the following explosion and/or fire hazards associated with gasoline vapors.

- Flammable/combustible material
- May be ignited by heat, sparks or flames
- Vapors may travel to a source of ignition and flash back
- Containers may explode in heat or fire
- Vapor explosion hazards indoors, outdoors or in sewers
- Run-off to sewers may cause a fire or explosion hazard

3.3 Physical Hazards

Following is a summary of a variety of physical hazards that may be encountered on the job-site. For convenience, these hazards have been categorized into several general groupings and suggested preventative measures are also included.

Category	Cause	Prevention
Head Hazards	Falling and/or sharp objects, bumping hazards.	Hard hats will be worn by all personnel at all times.
Foot/Ankle Hazards	Sharp objects, dropped objects, uneven and/or slippery surfaces, chemical exposure	Chemical resistant, steel-toed boots must be worn at all times on-site.
Eye Hazards	Sharp objects, poor lighting, bright lights (welding equipment), exposure due to splashes	Safety glasses/face shields will be worn when appropriate. Shaded welding protection will be worn when appropriate.
Electrical Hazards	Underground utilities, overhead utilities	Locator service mark-outs, visual inspection of work area prior to starting work. Verification of location of all overhead power lines, maintain 10-foot clearance to all parts of equipment and personnel. If 10-foot clearance is not possible, de-energize the lines.
Gas Utility	Underground utility (fire/explosion/toxic gas hazard)	Locator service mark-outs, visual inspection of work area prior to starting work, minimum 4-foot separation from marked location, excavation adjacent to utility protected by trench box
Sewer Utility	Underground utility	Locator service mark-outs, visual inspection of work area prior to starting work, minimum 4-foot separation from marked location,

		excavation adjacent to utility protected by trench box
Mechanical Hazards	Heavy equipment such as drill rigs, service trucks, excavation equipment, saws, drills, etc.	Competent operators, backup alarms, regular maintenance, daily mechanical checks, proper guards, designated haul routes, traffic control personnel, barricades/street use permits to prevent public access.
Noise Hazards	Machinery creating >85 decibels TWA, >115 decibels continuous noise, or peak at >140 decibels	Wear earplugs or protective ear muffs.
Fall Hazards	Elevated and/or slippery or uneven surfaces. Trips caused by poor "housekeeping" practices	Care should be used to avoid such accidents and to maintain good "housekeeping". Fall protection devices must be used when work proceeds on elevated surfaces.
Lifting Hazards	Injury due to improper lifting techniques, overreaching/overextending, heavy objects	Use proper lifting techniques, mechanical devices where appropriate.
Lighting Accidents	Accidents due to improper illumination	Work will proceed during daylight hours only, or under sufficient artificial illumination.
Traffic Hazards	Accidents involving traffic associated with the operational gas station and convenience store, or the adjacent streets	Delineate work areas with cones and caution tape and be aware of nearby vehicular traffic.

3.4 Personal Protective Equipment

Minimum personal protective equipment (Level D) shall include:

1. Hardhat
2. Safety glasses/goggles
3. Chemical resistant boots
4. Hearing protection (muffs or ear plugs)
5. Nitrile gloves
6. High-visibility vest

PPE will be cleaned daily and stored in clean bags/containers outside the contamination reduction zone, away from light/heat, etc. Disposable PPE, where used, will be disposed of as solid waste.

4.0 AIR/SITE MONITORING

The following section describes monitoring techniques and equipment that are to be used during site work. The Site Health and Safety Officer, or a designated alternate, is responsible for performing all monitoring activities. Air and site monitoring will be used to determine the level of protection that is required for work to proceed safely.

4.1 Air Monitoring

No outdoor ambient air monitoring will be conducted during completion of the tasks outlined in Section 2.1. A photoionization detector (PID) will be used for screening soils during ERH electrode installation.

4.2 Site Monitoring

The Site Health and Safety Officer will visually inspect the work-site at least daily to identify whether any new potential hazards have arisen. If and whenever possible, immediate measures will be taken to eliminate, or reduce the risks associated with these hazards.

5.0 EMERGENCY RESPONSE AND CONTINGENCY PLAN

The purpose of this section is to define procedures and specific responsibilities that are to be followed in the event that a chemical spill or release, a fire or explosion, or an accident involving injuries occurs. The Site Health and Safety Officer, or a designated alternate, will determine when emergency and/or regulatory agencies should be contacted and which agencies are appropriate to contact. It should be noted that if injuries have occurred, all site workers have the responsibility to secure medical help for the affected worker(s). Medical emergency help can be contacted at the appropriate phone numbers listed on the summary page at the beginning of this Plan.

In all emergency situations, the rule is SAFETY FIRST! Do not, under any circumstances, endanger yourself or others to rescue a fallen co-worker. It is far better to rescue one person after proper safety measures for the rescue have been carefully considered, then to have to rescue additional people whose haste to help out got them in trouble.

The principal hazards addressed by the Emergency Response Plan include the following: fire or explosion, medical emergencies, uncontrolled contaminant release, and situations such as the presence of chemicals above exposure guidelines or inadequate protective equipment for the hazards present. However, in order to help anticipate potential emergency situations, field personnel shall always exercise caution and look for signs of potentially hazardous situations, including the following as examples:

- visible or odorous chemical contaminants;
- drums or other containers;
- general physical hazards (traffic, moving equipment, sharp or hot surfaces, slippery or uneven surfaces, etc.);
- possible sources of radiation;
- live electrical wires or equipment
- underground pipelines or cables; and
- poisonous plants or dangerous animals

These and other problems should be anticipated and steps taken to avert problems before they occur.

The Emergency Response Plan shall be reviewed and rehearsed, as necessary, during the on-site health and safety briefing. This ensures that all personnel will know what their duties shall be if an actual emergency occurs.

5.1 Plan Implementation

The Field H&S Manager shall act as the lead individual in the event of an emergency situation and evaluate the situation. He/she will determine the need to implement the emergency procedures, in concert with other resource personnel including client representatives, the Project Manager, and the Corporate H&S Manager. Other on-site field personnel will assist the Manager as required during the emergency.

In the event that the Emergency Response Plan is implemented, the Field H&S Manager or designee is responsible for alerting all personnel at the affected area by use of a signal device (such as a hand-held air horn) or visual or shouted instructions, as appropriate.

Emergency evacuation routes and safe assembly areas shall be identified and discussed in the on-site health and safety briefing, as appropriate. The buddy-system will be employed during evacuation to ensure safe escape, and the Field H&S Manager shall be responsible for roll-call to account for all personnel.

5.2 Emergency Response Contacts

Site personnel must know whom to notify in the event of Emergency Response Plan implementation. The following information will be readily available at the site in a location known to all workers:

Emergency Telephone Numbers -- see list at the beginning of this plan;

Route to Nearest Hospital -- see list at the beginning of this plan and route map at the end of this plan;

Site Descriptions -- see the description at the beginning of this plan; and

If significant environmental release of contaminants occurs, the federal, state, and local agencies noted in this plan must be immediately notified.

In the event of an emergency situation requiring implementation of the Emergency Response Plan (fire or explosion, serious injury, tank leak or other material spill, presence of chemicals above exposure guidelines, inadequate personnel protection equipment for hazards present, etc.), cease all work immediately. Offer whatever assistance is required, but do not enter work areas without proper protection equipment. Workers not needed for immediate assistance will decontaminate per normal procedures (if possible) and leave work area, pending approval by the Field Safety Manager for re-start of work. The following general emergency response safety procedures should be followed.

5.3 Fires

Site personnel will attempt to control only very small fires if the person is comfortable doing so and only after 911 has been called. If an explosion appears likely, evacuate the area immediately. If a fire occurs which cannot be controlled, then immediate intervention by the local fire department or other appropriate agency is imperative. Use these steps:

- Evacuate the area to a previously agreed upon, upwind location
- Contact fire agency identified in the site specific plan; and
- Inform Project Manager or Field H&S Manager of the situation.

5.4 Medical Emergencies

Contact the agency listed in the site-specific plan if the medical emergency occurs. If a worker leaves the site to seek medical attention, another worker should accompany the patient. When in doubt about the severity of an accident or exposure, always seek medical attention as a conservative approach. Notify the Project Manager of the outcome or the medical evaluation as soon as possible. For minor cuts and bruises, an on-site first aid kit will be available.

If a worker is seriously injured or becomes ill or unconscious, immediately request assistance from the emergency contact sources noted in the site-specific plan. Do not attempt to assist an unconscious worker in a confined space without applying confined space entry procedures. Do not attempt to assist an unconscious worker in an untested or known dangerous atmosphere area without using proper respiratory protection.

In the event that a seriously injured person is also heavily contaminated, use clean plastic sheeting to prevent contamination of the inside of the emergency vehicle. Less severely injured individuals may also have their protective clothing carefully removed or cut off before transport to the hospital.

5.5 Uncontrolled Contaminant Release

In the event of a tank rupture or other material spill, attempt to stop and contain the flow of material using absorbents, booms, dirt, or other appropriate material, if it is safe to do so. Prevent migration of liquids into catchbasins, streams or other bodies of water by building trenches, dikes, etc. Drum the material for proper disposal or contact a spill removal firm for material cleanup and disposal, as required. Observe all fire and explosion precautions while dealing with spills.

6.0 ADMINISTRATIVE

6.1 Medical Surveillance

Personnel involved with field activities must be covered under their employer's medical surveillance program that includes annual physical examinations and certification to wear respiratory protective equipment. These medical monitoring programs must be in compliance with all applicable worker health and safety regulations.

6.2 Record Keeping

The Site Health and Safety Officer, or a designated alternate, will be responsible for keeping daily logs of workers and visitors present at the work site, attendance lists of personnel present at site health and safety meetings, accident reports, air monitoring results, and signatures of all personnel who have read this Health and Safety Plan.

SIGNATURE PAGE

I have read this Health and Safety Plan and understand its contents. I agree to abide by its provisions and will immediately notify the Site Health and Safety Officer if site conditions or hazards not specifically designated herein are encountered.

Name (Print)	Signature	Date	Company/Affiliation

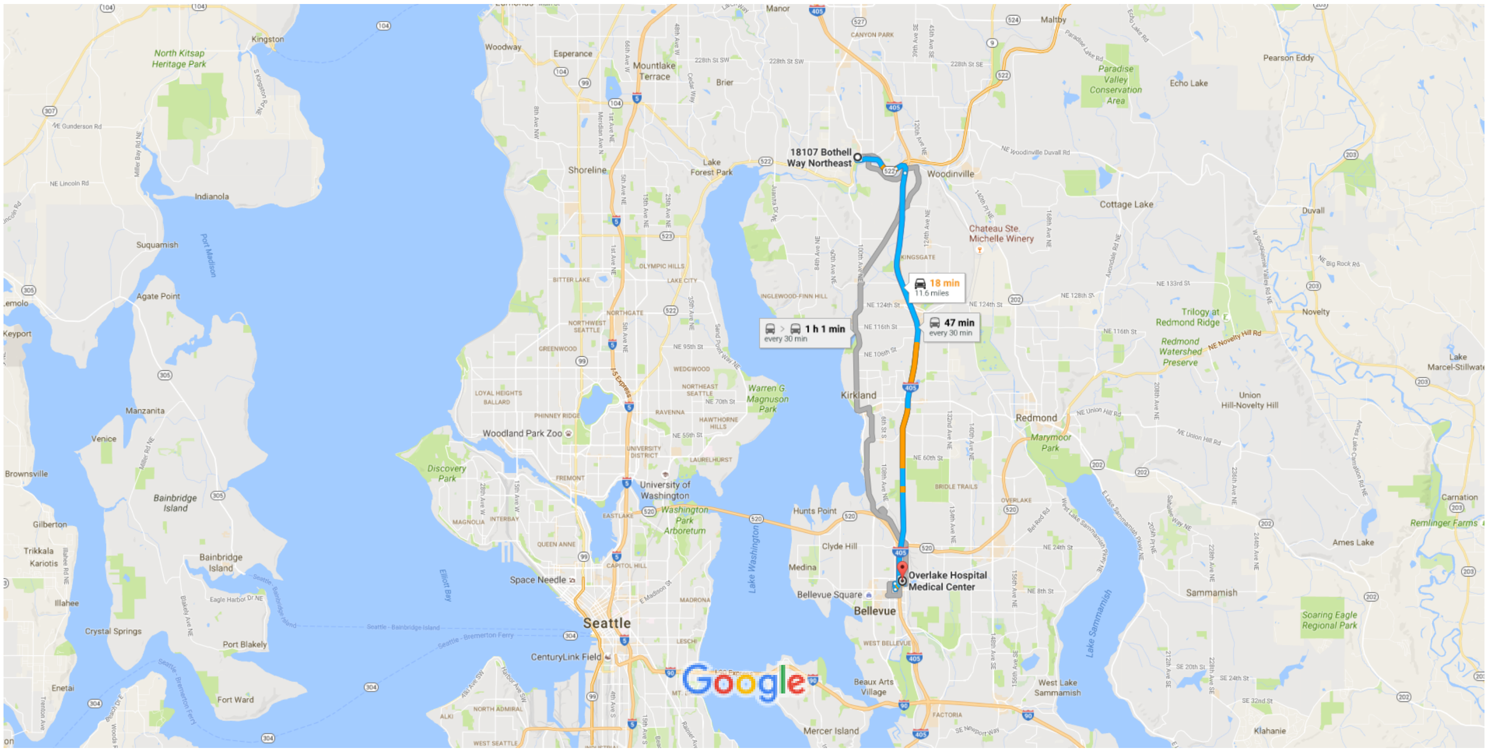
Attachment 1
Map from Site to Hospital

BSCSS ERDR - Attachment E

Google Maps

18107 Bothell Way NE, Bothell, WA to overlake hospital

Drive 11.6 miles, 18 min



Map data ©2016 Google 1 mi

BSCSS ERDR - Attachment E

18107 Bothell Way Northeast

Bothell, WA 98011

Take I-405 S to 112th Ave NE in Bellevue. Take exit 13B from I-405 S

14 min (11.2 mi)

1. Head southwest toward 98th Ave NE/Glenwood Ave

75 ft

2. Turn left onto 98th Ave NE/Glenwood Ave

371 ft

3. Turn left onto Bothell Way NE

0.1 mi

4. Continue onto WA-522 E/Woodinville Dr

   Continue to follow WA-522 E

0.9 mi

5. Use the right 2 lanes to take the Interstate 405 S exit toward Bellevue

0.4 mi

6. Merge onto I-405 S

9.3 mi

7. Use the right 2 lanes to take exit 13B for NE 8th St W

0.3 mi

Continue on 112th Ave NE to your destination

2 min (0.4 mi)

8. Sharp right onto 112th Ave NE

0.1 mi

9. Turn right onto NE 10th St

0.2 mi

10. Turn left onto Felix Terry Swistak Dr NE

223 ft

11. Turn left

    Destination will be on the right

125 ft

Overlake Hospital Medical Center

1035 116th Avenue Northeast, Bellevue, WA 98004

These directions are for planning purposes only. You may find that construction projects, traffic, weather, or other events may cause conditions to differ from the map results, and you should plan your route accordingly. You must obey all signs or notices regarding your route.

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Drilling • Investigation
Advanced Site Characterization
Remediation Solutions

SPILL PREVENTION AND CONTAINMENT PLAN (SPCP)

Bothell Service Center ERH Project

18107 Bothell Way NE

Bothell, Washington

FSID # 33215922

VCP # NW2946

March 23rd, 2018

Disclaimer: This Spill Prevention and Containment plan (SPCP), and each of its provisions, is applicable only to, and for use only by, Cascade Technical Services (Cascade), its affiliates, and its subcontractors. Any use of this Plan by other parties, including, without limitation, third party contractors on projects where Cascade is providing engineering, remediation or similar services, without the express written permission of Cascade, will be at that party's sole risk, and Cascade shall have no responsibility therefore. The existence and use of this Plan by Cascade shall not be deemed an admission or evidence of the acceptance of any safety responsibility by Cascade for other parties unless such responsibility is expressly assumed in writing by Cascade in a specific contract.

THIS SPILL PREVENTION AND CONTAINMENT PLAN (SPCP) IS TO BE USED FOR THE SPECIFIC PROJECT DESCRIBED HEREIN. IT IS NOT TO BE USED FOR ANY OTHER PROJECT. THIS PLAN IS TO BE REVISED AS APPROPRIATE TO ADDRESS CHANGING SITE CONDITIONS OR MODIFICATIONS IN SCOPE OF WORK.

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TABLES

FIGURES

ACRONYMS AND ABBREVIATIONS

°C	Degree Celsius
Kane	Kane Environmental
Baker	Baker Tanks
Bg	Below Grade
Cascade	Cascade Technical Services
CCTV	Closed Circuit Television
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
COC	Contaminants of Concerns
CPVC	Chlorinated Polyvinyl Chloride
CVOCs	Chlorinated Volatile
cy	Cubic Yard
ERH	Electrical Resistance Heating
ISTR	*In Situ* Thermal Remediation
Hg	mercury
KO	Knock Out
kWh	Kilowatt per hour
LPGAC	Liquid Phase Granular Activated Carbon
LWMS	Liquid Waste Management System
MCL	Maximum Concentration Levels
OSHA	Occupational Safety and Health Administration
PCE	Tetrachloroethylene
PDS	Power Delivery System
RSL	Regional Screening Level
scfm	Standard Cubic Feet Per Minute
sf	square feet
SOP	Standard Operation Procedure
SSO	Site Safety Officer
STS	Safety Trained Supervisor
SVE	Soil Vapor Extraction
TCE	Trichloroethylene
VOC	Volatile Organic Compounds

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1 INTRODUCTION

This Spill Prevention and Containment plan (SPCP) has been prepared for operations associated with Cascade's In Situ Thermal Remediation (ISTR) of the Former Bothell Service Center property in Bothell, WA (Site). The selected treatment technology will be a combination of Electrical Resistance Heating (ERH) for the ISTR technology and heat enhanced Bioremediation/Recirculation System. This Plan focuses solely on the ERH portion of the combined remedy system and will be implemented concurrently with additional plans prepared to complete the ERH project.

The SPCP outlines and addresses relevant work activities and health and safety procedures that will be conducted during the construction, remediation and site restoration activities to minimize potential impacts to the Site environment. This plan, applies to persons conducting remediation and associated activities within the specified work areas for the ERH treatment of the Site (**Figure 1)**.

Figure 1. Aerial Overview of Site location

Environmental protection is the prevention and control of environmental pollution and the reduction of habitat disruption that may occur to soil, groundwater, biological, and air resources during the remedial activities. Site personnel to the extent possible will management or reduce the impact to visual aesthetics, noise, solid, chemical, gaseous, and liquid wastes.

The SPCP will be referenced to determine procedures and methods for minimizing environmental pollution and damages that may occur as the result of construction and remediation operations. The environmental resources within the project boundaries and those resources that may potentially be affected at the perimeter of the work area will be identified and protected to the extent possible during the entire phase of the field activities associated with this contract.

1.1 Site Background

The property containing the source of contamination was previously owned by Bothell Service Center Associates (BSCA) and managed by NLO Property Management (BSCA property). The City of Bothell is the current owner of the BSCA property and the City owns roadways and other parcels adjacent to the BSCA property, which are also part of the Site. The City is in the process of obtaining a Consent Decree to implement a Cleanup Action Plan for the Site with Ecology and the Attorney General's Office. The BSCA property address is 18107 Bothell Way NE, Bothell, WA 98011, located at 47.760 degrees north and -122.209 degrees west in Section 7 of Township 26 north, Range 5 east. The King County Assessor's Office lists the parcel number as 237420-0065, which is 0.62 acres in size. The BSCA property previously included a one-story, masonry, commercial building approximately 8,410 square feet in area, containing five tenant suites. The former building on the BSCA property and associated aboveground features were demolished in August 2016. The BSCA property currently contains the concrete at-grade floor of the former building, and the asphalt paving is also still present. Stormwater drains and piping are still functional on the BSCA property while the sanitary sewer and water lines were disconnected in August 2016. This BSCA property is located on the northeast comer of the intersection of 98th Avenue Northeast and the former State Route 522. The Site also includes a portion of the vacated State Route 522, and a portion of a parcel south of that. Vacant properties located to the east, south, and southeast of the BSCA property are owned by the City, and are in the process of being redeveloped. Private residential properties are located to the west and north of the Site. General location of the Site is shown on **Figure 1**.

1.2 Project Description

ERH wells will be installed in the area of the former dry cleaning operation, and will extend to the west along the east side of 98th Avenue NE, south beyond the former BSC building footprint, and east to approximately half the distance of the former BSC building footprint. Energy will be input to the subsurface at 36 co-located electrode/VR wells. Spaced at 16-feet on center, these electrodes cover the two Treatment Zones as shown on **Figure 2**. Subsurface temperatures will be monitored at three Temperature Monitoring Points (TMPs) located across the Treatment Area. Each TMP contains a thermocouple string with sensors set at 5-foot depth intervals.

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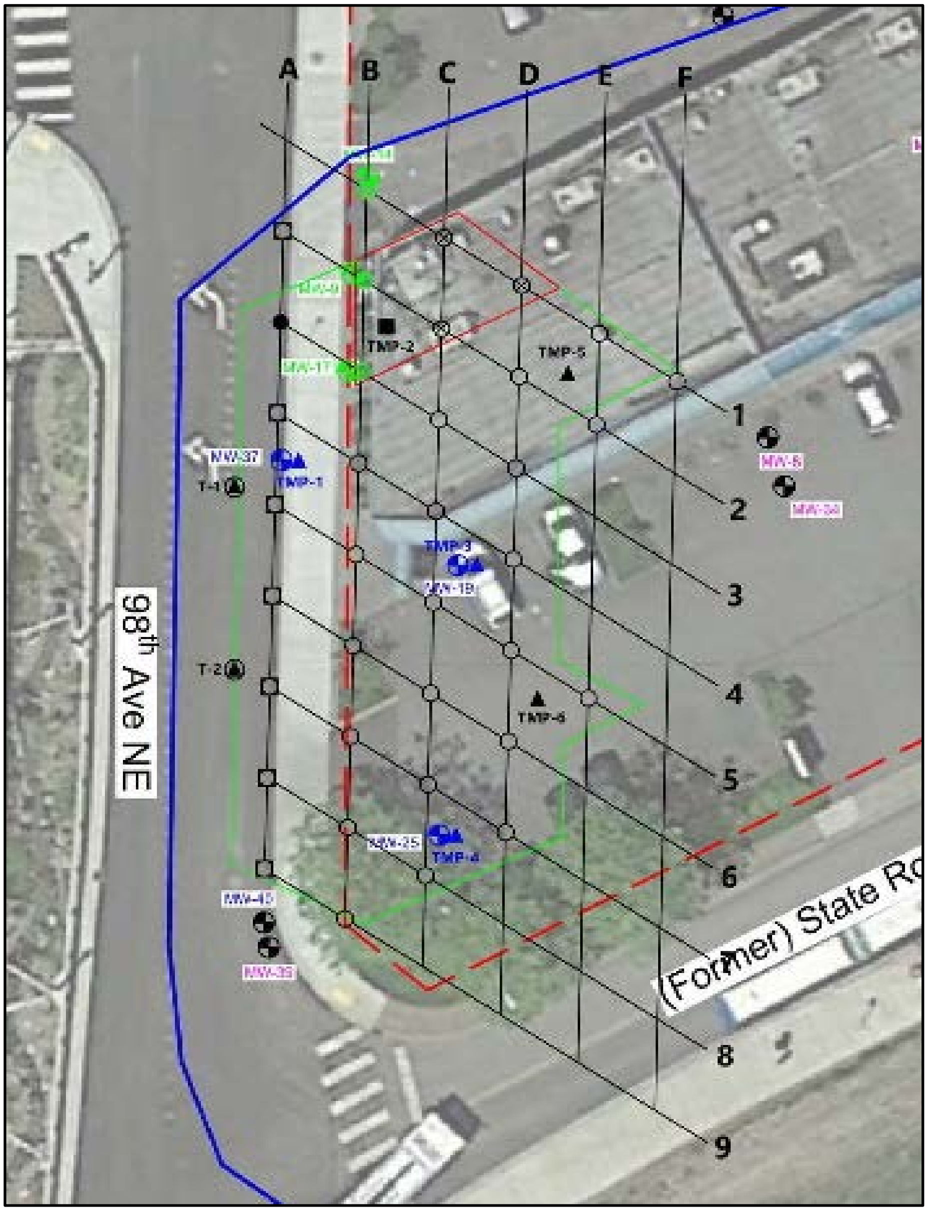

Figure 2. Electrode Field Layout and Treatment Area

Assuming a starting groundwater temperature of 15°C, it will take approximately 85 days to reach boiling conditions across the two Treatment Zones. Once achieved, boiling temperatures will be maintained for approximately 73-days, producing a total treatment time of 158-days.

Calculation of the heat-up interval assumes a 1°C increase in subsurface temperature per day of power application. This heating rate represents the average rate Cascade has achieved on ERH sites across North America and our Past Sites Database indicates it is very consistent from site to site. Typically, heating is a bit faster at the start of the ERH process and slows as the boiling point of the contaminant/water mix present at the site is approached.

Required days at boiling calculations are based upon contaminant type and cleanup goal. The more recalcitrant the contaminant and stringent the cleanup goal, the greater the energy density (expressed as kWh/cy of treatment volume) required to clean the site. For example, PCE boils at a higher temperature than TCE and it requires additional energy to clean a PCE site than a TCE site. Additionally, it requires additional energy input to reach increasingly stringent contaminant reduction percentages. Our estimated heating time at the Bothell site is based upon actual accomplishments at previous ERH sites with similar contaminant and subsurface profiles and equal clean-up requirements

1.2.1 Treatment Zone

Treatment Area is comprised two Treatment Zones. Zone 1 is the source area where heating will extend from 5 to 55-ft bg. Zone 2 is the remainder of the Treatment Area where heating will extend from 5 to 25-ft bg. The conceptual ERH system design parameters for Version 9 are summarized in **Table 1**.

Table 1. Summary of Design Parameters

Zone	Area (sf)	Start Heating	End Heating	Heating Interval	Volume
1	510	5-ft bg	55-ft bg	50-feet	944
2	5,150	5-ft bg	25-ft bg	20-feet	3,815
Total	5,660	NA	NA	NA	4,759

1.3 Contaminants of Concern and Treatment Goals

As identified in the RI/FS, chemicals of concern (COCs) in Site soil and groundwater are halogenated volatile organic compounds (HVOCs), primarily:

- Tetrachloroethene (PCE)
- Trichloroethene (TCE)
- Cis-1,2 Dichloroethene (cis-1,2 DCE), and
- Vinyl Chloride (VC)

Treatment goals are summarized in **Table 2** below.

Table 2. Summary of Clean-Up Objectives in Site Media

Media	Maximum Starting PCE Concentrations	Clean-up goal (from avg.)	% Clean-up
Soil	35,000 mg/kg	0.05 mg/kg	99.99%
Groundwater	86,000 µg/l	5 µg/l	99.99

1.3.1 Soil Clean-up Goals

HVOCs in concentrations exceeding MTCA Method A and B cleanup levels occur in soil beneath, and to the west, southwest, south, east, and southeast of the former structure on the BSCA property. HVOC concentrations generally decrease with depth and distance from the source. **Figures 3 & 4** show the 3-D

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EVS modelling output results of the contaminant plume (10-mg/kg isocontour) targeted by thermal remediation at this Site. The volume of soil to be treated is estimated to be 4,944 cubic yards.

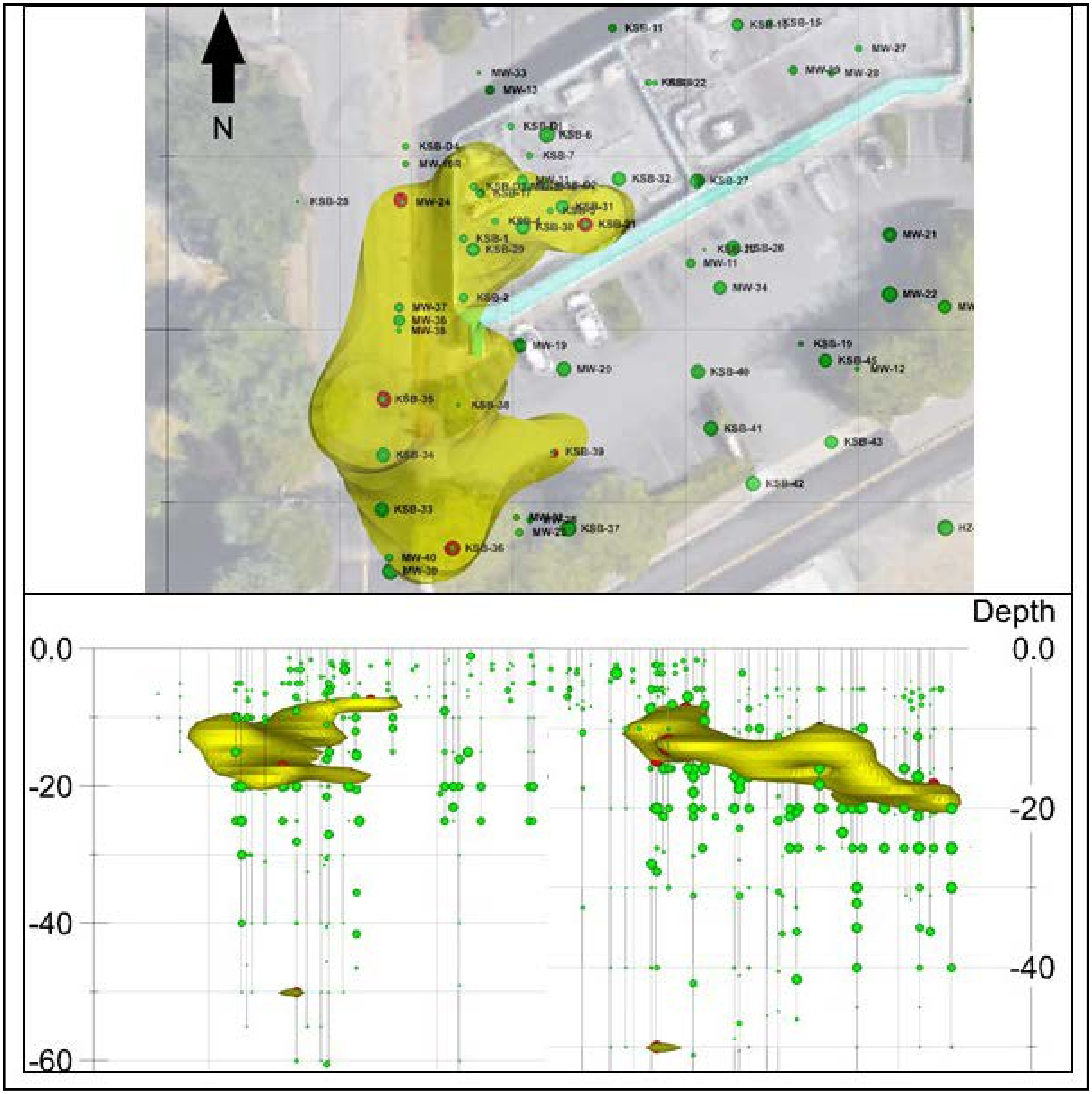

Figure 3. Plan View (top) and Side views looking North (right) and East (left)

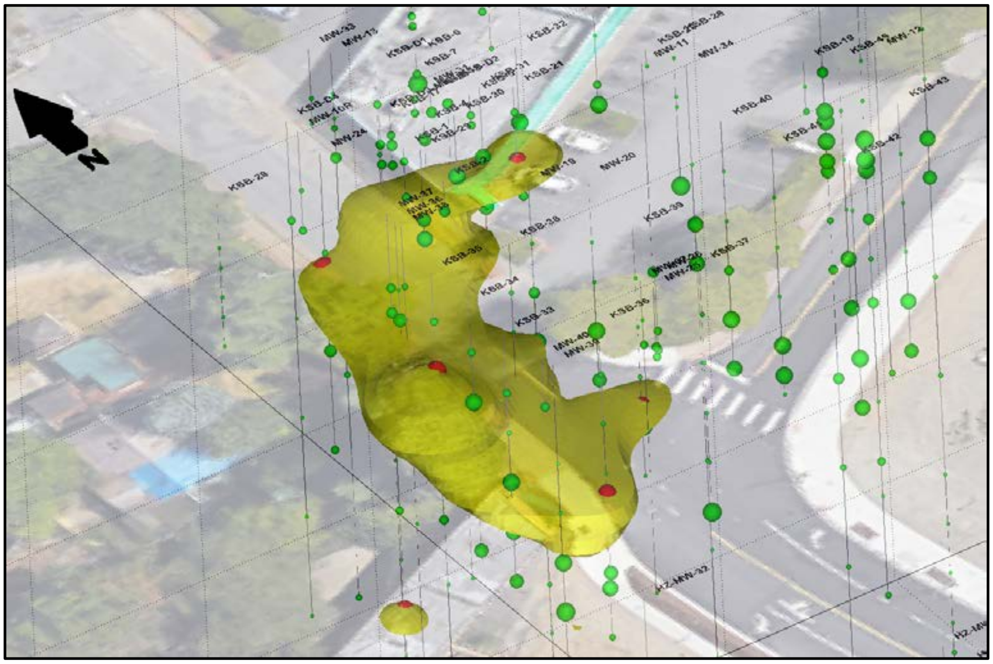

Figure 4. 3-D EVS model output 10-mg/kg PCE plume – Angled view looking Northeast

1.3.2 Groundwater Clean-up Goals

HVOCs in concentrations exceeding MTCA Method A and B clean-up levels exist across the entire diffuse dissolved phase plume present at the Site. **Figure 5** shows the estimated extent of the dissolved phase HVOC plume in groundwater.

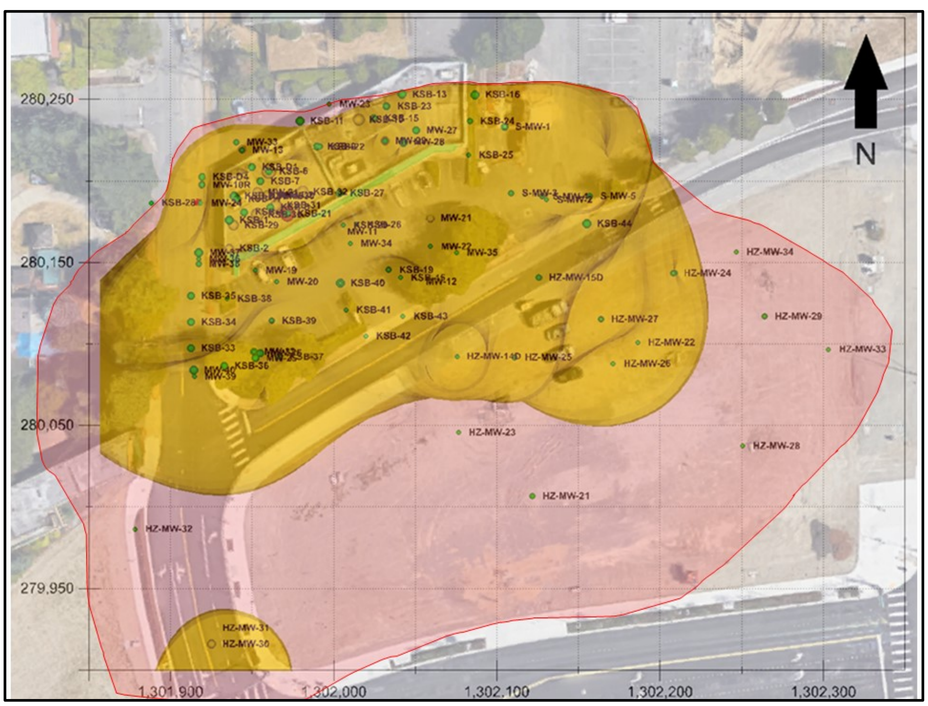

Figure 5. Extent of Dissolved Phase Plume above ERH Project Clean-up goal (5-µg/L)

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1.3.3 Mass of COCs to be treated

Based off of historic Site characterization data concerning contaminant concentrations in Site soil, Cascade has generated a preliminary mass estimate model to quantify the total mass of all COCs that may be removed from the subsurface during heating. Our model was developed using the arithmetic mean averages of all four COCs, and the following assumptions:

- A homogenous 4,759 cy subsurface
- An effective porosity of 0.30
- An assumed bulk density of 1,180-kg/cy (1.54-g/cm^3)

The results of Cascades' mass estimate model are summarized in **Table 3** below.

Table 3. Summary of Mass Estimate Model

	PCE	TCE	Cis-1,2-DCE	VC
Mean Concentrations (µg/kg)	456,394.0	369.0	34.0	ND
Mass of Contaminant in Soil (lbs)	5,869.96	4.75	0.44	ND
Percent of Total COC mass (%)	99.91%	0.08%	0.01%	0%
Total Estimated CVOC Mass (lbs)	5,875.14			

It should be noted that, due to the nature of environmental sampling and COC mass estimate models, inherent limitations in mathematical and analytical methods, characteristics of analytes, errors associated with sampling and analysis procedures, data set outliers, and imposed interpolation between data points, the results of environmental analysis and related mass estimate models contain elements of uncertainty, and may, in some cases, be significantly biased. However, a sample set with high enough data resolution effectively mitigates a large number of the variables that add to the inherent limitations of a mass estimate model. The Former BSC site mass estimates were based off of an extensive sample set of historic analytical soil samples, minimizing the inherent error in these calculations. However, these estimates are still subject to the amount of interpolation as the data set required.

2 SCOPE

The scope of this plan is to instill awareness and briefly address work activities and procedures to prevent environmental pollution and damages as the result of remedial operations of the ERH project at the Site. For the purpose of this plan, environmental pollution and damage is defined as chemical, physical, or biological elements or agents which adversely affect human health or welfare; unfavorably alter local ecological balance; affect other species; or degrade the aesthetic, cultural, and/or historical elements of the environment.

The control of the environmental pollution associated with the treatment system and the consideration of potential damages to air, water, and land are addressed in this plan. The procedures and activities prescribed in this plan also include site aesthetics, noise, and the management of solid waste, as well as pollutants.

The Cascade site manager or his designee will be responsible for ensuring that the elements of the SPCP are followed and that all site activities have a minimal impact to environmental resources on or immediately adjacent to the project site.

3 PROTECTION OF ENVIRONMENTAL RESOURCES

Site equipment, the remediation system and its components proposed to be operated for this contract will be operated to the extent possible to have a minimal impact on the environmental resources within the project boundaries. Cascade will confine work activities to the project and treatment areas as defined by contract specifications. The specific treatment areas and associated work areas will be clearly marked by Cascade. Project tasks will not require disturbance of areas outside the Site boundaries.

The project site is fenced along the access road and is well defined and distinguishable from the surrounding environmental resources such as natural vegetation areas. During site activities, Cascade will comply with federal and state laws when handling, storing, or transporting hazardous and non-hazardous wastes.

3.1 Training

All site personnel involved with operating, constructing or sampling the treatment system will be 40-hour Hazardous Waste Operations Response trained in compliance with Occupational Safety & Health Administration (OSHA) 29 Code of Federal Regulations (CFR) 1910.120, and possess a valid annual certificate to perform on-site activities. A copy of these certificates for project personnel will be maintained on-site.

Site personnel will also be trained in all phases of environmental protection and pollution control. The Cascade Site Manager and Cascade Project Manager will conduct a review meeting and awareness debriefing discussing the SPCP and site pollution control with the field crew prior to initiating site work for system installation activities, and again prior to initiating system operations. This meeting will be documented on the daily quality control (QC) report with a list of attendees provided.

A copy of this plan will be posted in a conspicuous location on-site for personnel review and reference. Prior to performing site activities, personnel will be briefed regarding site conditions, and the contents and objectives of this Environmental Protection Plan.

Additionally, project personnel will have adequate awareness training in the location and use of environmental protection and pollution control equipment. Additional meetings will be conducted for new personnel and when site conditions change.

3.2 Perimeter Monitoring

Monitoring for fugitive air emissions will be performed at selected sites along the site boundary and at the effluent location of the air/vapor treatment system (VPGAC). Monitoring will be conducted to assess the concentrations being released, determine the potential for measurable COCs to reach the project perimeter, and ensure that the air emissions are meeting the project air discharge permit requirements in accordance with the terms of the substantive requirements of the Puget Sound Clean Air Agency (PSCAA). The ambient source impact levels (ASILs) are presented below.

Table 4. Ambient Source Impact Levels

Chemical Name	ASIL (µg/m^3)*	Averaging Time
TCE	0.59	Annual Mean
DCE	2,600	24-hour Mean
PCE	1.1	Annual Mean
TCA	6,400	24-hour Mean
VC	0.012	Annual Mean

* - micrograms per cubic meter

3.3 Land Resources

It is not anticipated that treatment areas will require the clearing of trees or the filling or modification of significant land resources. If at all, a minimal amount of grasses, shrubs, and topsoil, will be removed or cut to accommodate treatment system construction.

A well-defined work area will be established to protect land and vegetation resources not required for clearance during construction activities.

3.4 Water Resources

Cascade will implement best work practices to prevent additional COCs or other pollutants from further impacting site ground water.

There is no surface water present on or in the immediate vicinity of the Site. The application of pesticides, insecticides, toxic or hazardous chemicals to soil or vegetation is not approved and will not be conducted during this project.

3.5 Spill Response and Control Plan

3.5.1 General

When spills or releases of hazardous materials or material that is suspected to be hazardous occurs, the following procedures will be implemented immediately:

- Work will be suspended in the area
- The spill or leak source will be identified and controlled with the appropriate protective gear
- Containment actions such as earthen beams, use of sorbet booms and/or pads, or excavating a shallow ditch to capture the release
- Additional measures will be taken to minimize further movement and effect of the spill or leak on the surrounding area.

3.5.2 Above Grade Treatment System

A generalized Process Flow Diagram (PFD) for the above grade treatment system is shown on **Figure 6** below.

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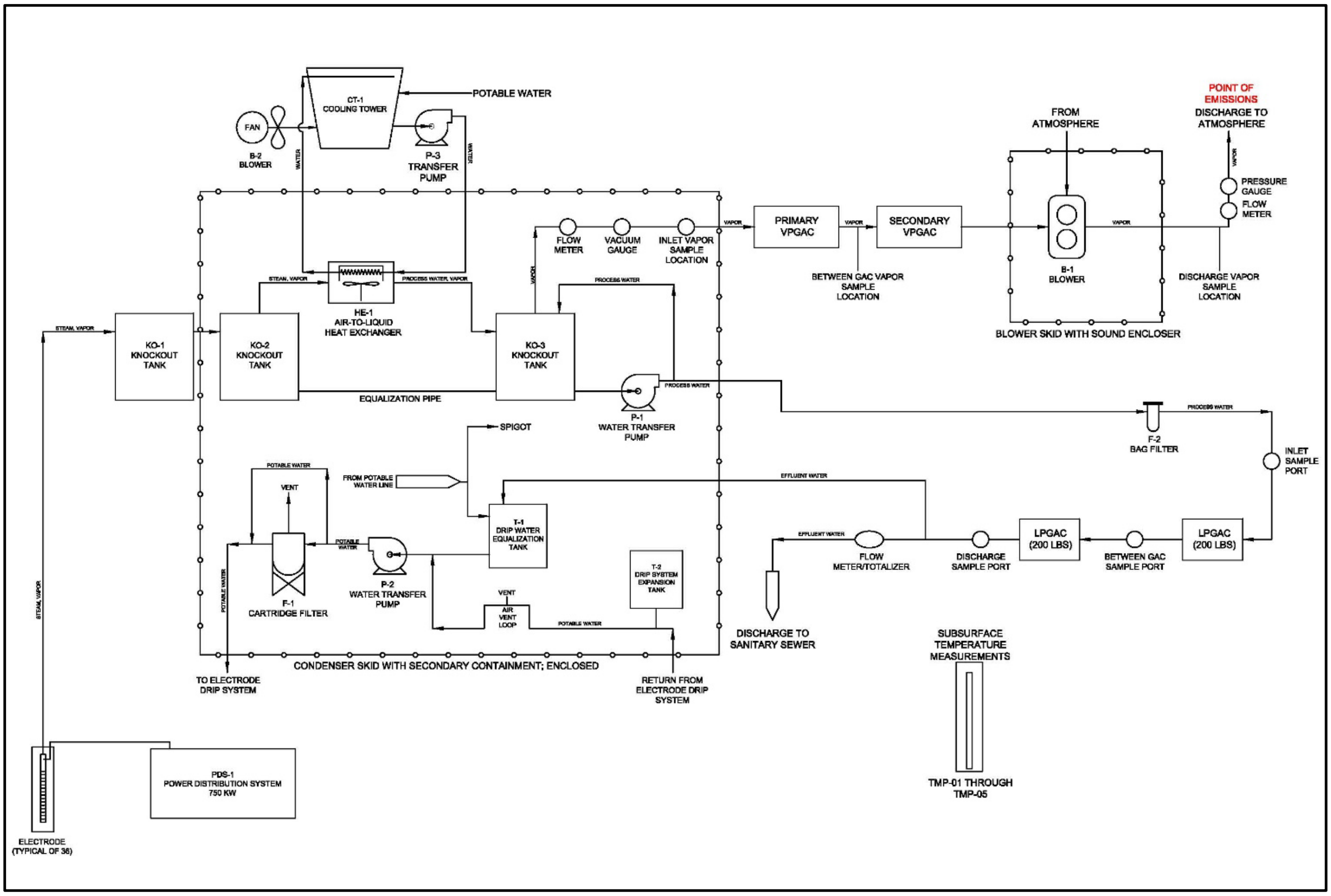

Figure 6. Process Flow Diagram

3.5.2.1 Phase Separator (KO-1)

After exiting the wellfield, the process stream will be drawn to a phase separator tank (KO-1) to remove condensate and entrained solids in the vapor stream.

3.5.2.2 Knockout Tanks (KO-2 & KO-3)

Following the phase separator tank (KO-1), the vapor stream will be drawn through a knockout tank to remove any generated condensate. Water collected in the knockout tank will be pumped to the liquid treatment system.

The moisture separator is equipped with a pair of parallel discharge pumps connected to the liquid effluent port. The moisture separator has nozzles, for vapor inlet/outlet connections and side- mounted level sensors and a sight glass for level monitoring. Manways are located on top of the moisture separators for inspection and cleaning of the vessel.

Level sensors installed through the ports on the moisture separator provide discrete input signals to the local skid-mounted control panel for operation of the two moisture separator condensate transfer pumps and provide a high-high level interlock alarm.

Knockout tanks KO-2 (prior to heat exchanger) and KO-3 (after heat exchanger) are contained within the enclosed condenser skid equipped with robust secondary containment liquid spill management systems surrounding all equipment.

3.5.2.3 Vapor (Air-to-Liquid) Heat Exchanger

After the phase separator the vapors are processed in a plate and frame style heat exchanger to cool and condense the incoming steam and reduce the moisture content of the vapor stream for the remaining steps in the process. The vapors entering the heat exchanger are cooled using a recirculating loop of water supplied by a cooling tower. The heat exchanger and cooling tower system are designed to sufficiently reduce the temperature of the vapor stream to the point where the bulk of the moisture is removed from the wellfield vapors. Both the vapor stream and cooling fluid side of the heat exchangers are instrumented with temperature indicators to allow adjustment of the recirculation loop flow to maintain proper moisture removal.

The heat exchanger selected is designed to operate with cooling water supply at the worst case summer cooling water temperatures. Spare capacity is included in the heat exchanger design.

The Vapor Heat Exchanger is contained within the enclosed condenser skid equipped with robust secondary containment liquid spill management systems surrounding all equipment.

3.5.2.4 Air Water Separator (KO-3)

Vapor from the knockout tanks is then combined with vented vapors from the cap vent line. The combined stream is then processed through KO-3 to remove any remaining entrained liquid from the vapor stream prior to treatment through vapor phase granular activated carbon (VPGAC).

KO-3 is contained within the enclosed condenser skid equipped with robust secondary containment liquid spill management systems surrounding all equipment.

3.5.3 Vapor Phase Granular Activated Carbon Vessels

The vapor phase carbon vessels (VPGAC Primary and Secondary) are used to adsorb the contaminants of concern from the vapor stream prior to discharge. The vessels will each contain 2,000 lbs of activated carbon and will be plumbed in series. Each vessel will be equipped with sample ports so that the adsorption efficiency can be evaluated during operation. Two spare vessels will be filled with carbon and available onsite for change-outs as necessary.

3.5.4 Cooling Tower

A cooling tower will be used to provide non-contact cooling water for vapor heat exchanger. The cooling tower will be supplied with makeup water via the city water line. The selected unit will have sufficient cooling capacity to cool and condense the vapor stream to the desired temperature under worst-case ambient temperature conditions. The cooling tower pumps will recirculate water through the heat exchanger and back to the cooling tower.

The Cooling Tower (CT-1) features a robust secondary containment liquid spill management system surrounding the tower.

3.5.5 *Bag Filters*

Dual bag filters will be used to remove any entrained particulate from the liquid stream before it is processed through liquid phase carbon. This will prevent the liquid carbon vessels from becoming clogged with particulate matter and causing high pressure drops across the vessels.

3.5.6 *Liquid Phase Carbon Vessel (LGAC-01)*

Condensate collected in the storage tank will be pumped through the bag filters, followed by a pair of liquid phase granular activated carbon vessels operated in series to remove any dissolved organic contaminants prior to discharge. The selected vessel will be sized for 500 lbs of carbon each for appropriate adsorption efficiency and change-out frequencies. Treated water will be discharged to the sanitary sewer following treatment through carbon.

3.6 Air Resources

Equipment operation, activities, or process performed at the Site will be in accordance with Federal and state air emissions and within applicable standards.

Remediation activities will be performed in a manner that minimizes the quantity of dust and gaseous vapors that may be released. Dust emissions and particulate will be controlled to the extent possible by implementing dust control measures, spraying water to minimize dust, and limiting the movement of vehicles and other dust suppression techniques, if necessary. Loads on trucks that could emit dust or falling debris will be covered.

3.6.1 Particulates

Cascade will maintain haul roads, permanent and temporary access roads, and other work areas within or outside the project boundaries free from particulates which would cause the Federal, state, and local air pollution standards to be exceeded or which would cause a hazard or a nuisance. Sprinkling the roadway with water or other methods will be used to control particulates in the work area. Minimizing vehicle speeds and traffic, wetting dry soils, maintaining freeboard in truck beds, covering all loads, and other similar measures, will control particulates along site roads. Particulate control will be performed as the work proceeds and whenever a particulate nuisance or hazard is identified.

It is anticipated that the only fuel-burning equipment on-site will be vehicles. All vehicles used on-site will meet the federal emissions standard for each type of vehicle.

3.6.2 Odors

The specific remediation treatment areas will be covered with an asphalt cap and any vapors are captured and removed through the extraction wells and treated. Air monitoring equipment will be used at the effluent exhaust of the air/vapor treatment system (VPGAC). Appropriate actions will be taken if excess vapors or odor concentrations are discovered. Little or no vapors and odors are expected to move off site during construction or during the remedial phase. In the event system vapors are reported or noticed off-site, action similar to the spill notification procedures will apply.

3.6.3 VOCs

VPGAC exhaust effluent will be sampled, analyzed and recorded weekly by PID with interim calibration events conducted by GC/MS at an analytical facility to verify compliance with the emission limit. Running total annual CVOC emissions will be calculated and recorded weekly based on the weekly monitoring results, the exhaust flow rate, and the weekly hours of operation..

3.7 Chemical Materials Management and Waste Disposal

3.7.1 Solid Waste Handling and Disposal

Non-hazardous solid waste will be placed in dumpsters or other appropriate containers with lids. Dumpsters will be emptied on a regular basis. Cardboard, paper, and plastics will be segregated from other debris and disposed at the base recycling facility. Construction debris and other non-hazardous debris generated during site operations will be disposed accordingly and recycled to the extent possible. All waste will be handled as stated in this section. Handling and disposal of site debris and waste will be conducted to prevent further or additional contamination of the soil and groundwater at the site.

Additional segregation and handling procedures will be implemented so that hazardous or toxic waste will not be co-mingled with non-hazardous wastes. The containers of hazardous wastes will be labeled and stored in a designated location for transport to an appropriate disposal/recycling facility.

Non-hazardous solid waste hauling and disposal will be performed in accordance with applicable Washington State regulations. Disposal of any undefined or questionable waste stream will not be conducted until the appropriate analysis and characterization are completed.

3.7.2 Chemicals and Hazardous Chemical Wastes

Hazardous or toxic waste will be handled in accordance with applicable Federal, state, and local regulations. Cascade will segregate hazardous waste from other materials, protect it from weather, and take precautionary measures against accidental spillage. Hazardous materials and wastes handling and disposal will be conducted in a manner that prevents contamination of the soil or groundwater.

Cascade will take sufficient measures to prevent spillage of hazardous and toxic materials during dispensing. Chemicals will be dispensed with caution and appropriate equipment to minimize spillage or exposure to site personnel. Periodic inspections of chemical storage areas will be performed and documented to critique procedures, housekeeping, and identify those items that may require corrective action.

Chemicals are not anticipated to be necessary for operation of the LWMS. In the event that chemicals such as acid and alkali are needed to break emulsions, these chemicals will be stored in accordance with applicable rules and requirements.

Chemical waste are not anticipated to be generated, however if produced during project operations, they will be collected in corrosion resistant, Federal Department of Transportation (DOT)-approved, compatible containers. The volumes or amounts in the collection drums will be monitored to ensure the drums may be safely moved to a staging or storage area. No additional material will be added to a drum when the contents are approximately 6-inches from the top of the drum.

Wastes will be classified, managed, stored, and disposed of in accordance with federal, state, and local laws and regulations.

3.7.3 Wastewater Management

The remedial treatment system will generate a substantial quantity of water during the treatment process. Approximately half of this water will be treated by the LWMS and re-injected into groundwater via the infiltration gallery or injection wells. The LWMS includes surge equalization, and air sparging to remove dissolved VOCs prior to re-injection. The LWMS is designed to meet the MCLs for VOCs and is driven by the MCL for PCE alongside of Site COCs including all documented CVOC contaminant species. Re-injected groundwater must meet the MCL for the COCs and meet the substantive requirements for state and federal underground injection control programs as summarized in **Table 5** .

Table 5. Maximum Concentration Limits for Groundwater Re-injection

Chemical Name	MCL (µg/L)*
TCE	5
DCE	70
PCE	5
TCA	200
VC	2

* - micrograms per liter

Leaks, spills, or discharges of wastewater from the system will be contained, managed, and appropriate corrective action taken as addressed in the WMP. Refer to the WMP for the procedures addressing spill and leaks.

Sanitary wastewater will not be generated at the site during field activities. An adequate number of self-contained, portable toilets with hand-washing stations will be available and serviced on a timely basis.

3.8 Waste Minimization

Cascade will minimize the generation of non-hazardous solid waste and hazardous waste to the maximum extent practicable.

Some examples of waste minimization strategies that may be implemented at the Site are:

- Cascade will take necessary precautions to avoid mixing clean and contaminated wastes.
- Cascade will ensure all waste storage, bins, drums, and other waste containers are covered in order to eliminate rainwater and addition of other liquids.
- Containers for recyclable materials will be made available to separate those materials from other waste streams.

4 POST REMEDIATION CLEANUP

Cascade will ensure that the project area is free of debris, materials, and hardware associated with the remedial activities. Cascade will remove all temporary structures and facilities once the remedial activities are completed.

4.1 Asphalt Surfaces at the Treatment Areas

Cascade will leave the asphalt surfaces in-place at the treatment areas within the project boundary and within the portion of the system being installed within active roadways. Any disturbed asphalt in the roadways during installation will be repaired to the extent necessary to ensure un-impacted traffic may resume as normal.

4.2 Removal of Treatment Hardware and Facilities

Cascade, unless necessitated by further remedial actions at the Site (ie. Recirculating warm water bioremediation system) will remove all remediation facilities including process equipment, above-grade piping and appurtenances, valves, instruments, electrical control panels, site trailers, support structures, storage areas, and stockpiles prior to final acceptance of work.