Self-sustaining Treatment for Active Remediation (STAR) Pre-Design Evaluation (PDE) Report

Quendall Terminals, Renton, Washington

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BTEX	benzene, toluene, ethylbenzene and xylene
CEMS	continuous emission monitoring system
CO	carbon monoxide
CO_2	carbon dioxide
DPT	direct push technology
EA	evaluation area
ft bgs	feet below ground surface
ft	feet
GAC	granular activated carbon
gal	gallons
gpm	gallons per minute
in	inches
IP	ignition point
LFL	lower flammability limit
mg/kg	milligrams per kilogram
NAPL	non-aqueous phase liquid
O_2	oxygen
PAH	polycyclic aromatic hydrocarbon
PDE	pre-design evaluation
PID	photoionization detector
ppm	parts per million
ROI	radius of influence
scfm	standard cubic feet per minute
STAR	Self-sustaining Treatment for Active Remediation
SVE	soil vapor extraction
TarGOST®	Tar-specific Green Optical Screening Tool
TC	thermocouple
TP	test pit
TPH	total petroleum hydrocarbon
VEP	vapor extraction point
VOC	volatile organic compound

1. INTRODUCTION

This report has been prepared by Savron, a wholly owned division of Geosyntec Consultants, Inc., on behalf of CH2M/Jacobs to present the results of the Pre-Design Evaluation (PDE) of the Self-Sustaining Treatment for Active Remediation (STAR) technology to treat historic releases of creosote and coal tar at the Quendall Terminals Superfund Site located in Renton, Washington (the "Site"). The activities presented herein are part of the comprehensive STAR PDE conducted for the Site that began with laboratory treatability testing of Site soils (Savron, 2018a). The bench-scale testing confirmed that the impacted soils could undergo smoldering combustion in a self-sustaining manner given sufficient petroleum hydrocarbon concentrations and demonstrated the feasibility of applying this technology at the Site. This STAR PDE report describes the field activities, test results, and recommendations.

2. BACKGROUND

Quendall Terminals is a former industrial site located along the southeast shore of Lake Washington. Creosote manufacturing was conducted on Site from 1916 to 1969, where coal and oil-gas tar residues were distilled into fractions for a variety of uses. During this period, environmental releases of coal tar and distillate products occurred, particularly in areas where material handling, production, storage and disposal were performed. Previous investigations by others have identified dense nonaqueous phase liquid (DNAPL) impacts to a maximum observed depth of 34 feet below ground surface (ft bgs).

2.1 Site Location

The Site is located at 4503 Lake Washington Boulevard North in Renton, Washington (Figure 1). The property is bordered by Lake Washington to the west, the Virginia Mason Athletic Center to the north and residential housing to the south. Interstate 405 is located approximately 500 feet to the east of the Site.

2.2 Local Geology

The Site is located in the Puget Sound Lowland, with geologic features dominated by repeated advances and recessions of glacial ice. The Site geology consists of an upper fill layer ranging from ground surface to between 1 and 10 feet below ground surface (ft bgs), with an underlying shallow alluvium (May Creek delta deposit) extending to between 30 and 50 ft bgs. This alluvium layer consists of discontinuous gently dipping beds of peat and organic silts with loose, silty, fine to medium sand (CH2M, 2018).

Based on soil borings collected for pre- and post-STAR characterization, the subsurface geology in the vicinity of the evaluation area (EA) consists of top soil, quarry spalls and compact silty sand from ground surface to a depth of approximately 5 ft bgs, silt, sand, and pebbles from 5 to 6.5 ft bgs, silty clay from 6.5 to 8 ft bgs, silty fine sand from 8 to 10 ft bgs, followed by alternating layers of medium to fine sand and silty clay extending from 10 ft bgs to 18 ft bgs. The depth of the groundwater table in the EA during the time of system installation was approximately 8 ft bgs.

2.3 NAPL Distribution

Based on previous investigations performed by others, the majority of the hydrocarbon contamination at the Site was found to be present in the shallow alluvium in thin, discontinuous layers separated by low permeability soils. This contamination extends to a maximum observed depth of 34 ft bgs, with most of the contamination concentrated in the upper 20 ft bgs. Soil borings collected at QP-6 and QP-7 (Aspect Consulting, 2009) in the vicinity of the EA indicate that hydrocarbon impacts are generally present between 8 and 17 ft bgs, with the highest concentrations expected between 12 and 15 ft bgs.

3. STAR TECHNOLOGY, DEVELOPMENT AND PDE OBJECTIVES

3.1 STAR Technology

STAR is an innovative in situ thermal technology based on the principles of smoldering combustion, where organic contaminants are the source of fuel. The smoldering process is sustained by the addition of air through a well to the target treatment zone and is initiated through a short duration, low energy "ignition event." Once the process is initiated (ignited), the energy of the reacting contaminants is used to pre-heat and initiate combustion of contaminants in adjacent areas, propagating a combustion front through the contaminated zone in a self-sustaining manner (i.e., no external energy or added fuel input following ignition) provided a sufficient flux of air is supplied. Active control of the combustion front is maintained by the air supply. This efficient recycling of energy is made possible by the presence of the porous matrix (i.e., contaminated aquifer) that is being remediated.

The above-ground equipment used to implement the technology is similar to that used in Air Sparge (AS) / Soil Vapor Extraction (SVE) systems and includes compressors for sub-surface air delivery, blowers for vapor collection, and, as needed, vapor-phase activated carbon for vapor treatment. The specialized equipment associated with the STAR process includes the use of 2-inch diameter, carbon steel ignition wells with a stainless-steel screen, temporary in-well heaters to initiate the process, and subsurface multi-level thermocouple bundles to track the combustion process. A specially designed STAR Ignition Trailer contains data logging and real-time monitoring equipment, all control systems necessary for manipulating air flow rates and heater temperatures, as well as analyzers for monitoring extracted process vapors for carbon monoxide (CO) and carbon dioxide (CO_2) concentrations, in addition to lower flammability limit (LFL).

3.2 Treatability Study

A laboratory treatability study was conducted on two soil samples collected from test pits (TPs) in March 2018, representing impacted zones from the Former May Creek area (“TP-1” soils) and the Quendall Pond/Still House (“TP-2” soils). While the received TP-2 soil sample contained insufficient total petroleum hydrocarbon (TPH) concentrations (i.e., <3,000 – 5,000 milligrams per kilogram [mg/kg]) to support a smoldering combustion reaction, the TP-1 soil sample demonstrated self-sustaining smoldering combustion. Sub-samples of the soil before and after treatment were collected to assess treatment efficacy. A greater than 99.8% soil concentration decrease of TPH and polycyclic aromatic hydrocarbons (PAHs) in the “after” sub-sample, confirmed through visual observation of the soils, showed treatment of TP-1 site soils. In addition, samples of the emissions stream were collected to aid in the design of the pilot test vapor capture and treatment system described herein.

As described in the treatability study report (Savron, 2018a), the remediation efficiency along with the concentration reductions observed through laboratory analysis and the calculated smoldering propagation velocity suggested that STAR could be successfully applied at the Site. Based on the results of the treatability study, a field pilot test was recommended to evaluate key design parameters for a full-scale STAR system and to evaluate the potential influence of Site-specific matrix heterogeneities on the process.

3.3 STAR PDE Objectives

The objectives of the PDE were to evaluate:

1. **Radius of influence (ROI)** – A multiple lines of evidence approach was used to determine combustion front ROI, including the measurement of subsurface temperatures with thermocouples installed in the target treatment zone, capture of combustion gases to assess duration of combustion, and confirmatory soil sampling. The ROI helps establish the spacing and number of ignition / air injection wells to treat a specified target volume of soil at the Site during full scale implementation.

2. **Mass destruction and combustion front propagation rates** – Thermocouple data and confirmatory soil sampling were used to estimate the combustion front propagation rate. An estimation of mass destroyed by the STAR process was also calculated using average pre- and post-STAR hydrocarbon concentrations in soil samples collected within the treatment zone. These data allow for an estimation of the time scales for full-scale implementation.

3. **Volatile mass loading** – Emissions were monitored to estimate the mass of volatile compounds in collected vapors. These data will be used to select and design an off-gas treatment system for collected vapors during full-scale implementation.

Evaluation of these three factors will allow costing and design for a full scale in situ STAR system to treat impacted materials at the Site.

4. PRE-DESIGN EVALUATION WORK PLAN

4.1 Summary of Pre-Design Evaluation Scope of Work

An operational work plan was prepared by Savron on behalf of CH2M/Jacobs to present the plans for the construction, operation, and sampling activities related to the PDE (Savron, 2018b). This work plan included the planned EA construction and instrumentation, the plan for the pre-characterization sampling locations, the procedures and methodologies for conducting the PDE, and the post-characterization and decommissioning activities.

The EA was located adjacent to historical borings QP-6/QP-7 (in the vicinity of TP-2), in an area containing elevated concentrations of petroleum hydrocarbons and non-aqueous phase liquid (NAPL) (Figure 2). While TP-2 soils contained insufficient concentrations of petroleum hydrocarbons to achieve self-sustaining smoldering during treatability testing, boring logs at QP-6 and QP-7 indicated that higher contaminant concentrations were likely to be present at depths below the water table. Due to the depth of this contamination, it could not be reached during test pit activities done to collect samples for the bench tests but was targeted for treatment during the STAR PDE. The PDE was designed to target the depth interval exhibiting the highest continuous concentration of petroleum hydrocarbons, which was estimated based on the inspection of boring logs to be a treatment zone with a base depth of approximately 15 ft bgs.

The EA shown in Figure 2 is approximately 50 ft by 50 ft. This area does not represent the extent of target treatment, but rather represents the areal extent of instrumentation for monitoring process conditions. Associated process equipment was located adjacent to the EA (Figure 3). Two ignition points, IP-1 and IP-2 (one primary and one backup), and four vapor extraction points (VEP-01 through VEP-04) were installed within the EA. Figure 4 shows the layout of the thermocouples that were installed around the ignition points. The locations shown on Figure 4 are approximate as the thermocouples were not surveyed after installation.

The air injection system consisted of one air compressor, a regenerative desiccant air dryer, and associated interconnecting piping, manifold, pressure regulating and relief valves, and pressure, flow and temperature indicators and transmitters. The vapor collection system consisted of a vapor mist accumulator, a continuous emissions monitoring system (CEMS), an LFL analyzer, a moisture / temperature knock-out tank, a condensate holding tank, an extraction blower, two vapor-phase vertical flow through granular activated carbon (GAC) units, a discharge stack, and associated interconnecting piping/ductwork, manifolds, pressure relief valves, gate/knife valves, sample ports, and flow, pressure and temperature indicators and transmitters. Figure 3 presents a schematic of the general equipment layout.

The air injection and SVE systems were designed so that they could be operated continuously for the duration of testing. Diesel-fueled electric generators were used to supply 120V/480V power to all equipment, as required.

4.2 Modifications to Work Plan

Based on site conditions encountered during drilling, some modifications were made to the evaluation area layouts and instrumentation which occurred after completion of the work plan. This section presents the changes made to the EA from the descriptions previously provided in the work plan.

1. The depths of ignition point screens and thermocouple bundles were estimated in the work plan but finalized during installation based on the contaminant distribution observed in the macrocores collected at IP-1 and IP-2. The ignition points IP-1 and IP-2 were installed with the screen from 16 to 17 ft bgs, and 16.5 to 17.5 ft bgs, respectively. The thermocouple bundles were then installed to position individual thermocouples at depths of 7, 12, 13.5, 15, 16 and 17 ft bgs.

2. The planned well screens for the vapor extraction points (VEP-01 to VEP-04) were 4 ft stainless steel continuous wire wrap screens (4 mm opening – 160 slot size) installed to a depth of 6 ft bgs. Due to the loose silty top soil present at surface, there were concerns about potential short circuiting of the vacuum influence to surface. Due to the inability to install the VEPs deeper because of the elevation of the water table, 1 ft was cut off the bottom of each screen, to provide a total VEP screen length of 3 ft. An installation depth of 6 ft bgs was maintained, permitting a better seal of the VEP screen to surface and therefore minimizing the potential for short circuiting from ground surface.

3. All four VEPs (VEP-01 to VEP-04) were installed using augers, instead of direct push technology (DPT) drilling techniques. Due to the shortened VEP screen length and a relatively compact geologic formation present between 3 and 6 ft bgs, augers were used to install the VEPs to minimize additional compaction of the soils around the VEP screens and improve overall extraction flow capacity.

4. TC-11 was shifted approximately 2 ft west of the originally proposed installation location due to near-surface refusal during collection of the pre-STAR soil boring. The updated installation location is reflected on the map of pre-STAR soil boring, ignition point and thermocouple locations (Figure 4).

5. STAR ignition and combustion front maintenance was conducted at both the primary and back-up ignition points (IP-2 and IP-1, respectively) to provide additional data regarding the performance of the technology within the target treatment zone.

5. RESULTS AND DISCUSSION

In the remainder of this report, the stages of smoldering combustion will be defined using the following terms: ignition, smoldering (or combustion), and self-sustaining smoldering (or self-sustaining combustion). Due to the presence of the contamination in a porous matrix (i.e., soil), smoldering is the only form of combustion that will occur, and therefore all uses of the term “smoldering” and “combustion” are synonymous. Ignition refers to the period during preheating (i.e., when the in-well heater is on), where indications of smoldering (or combustion) are first observed; that is, combustion gases are detected in the extracted vapors and/or a distinct inflection in subsurface temperatures is observed indicating that exothermic combustion reactions are occurring. The distinction between smoldering and self-sustaining smoldering refers to the source of the energy (or heat) used in the combustion reaction at a given location. Smoldering may still occur while an external heat source (i.e., in-well heater) is used to preheat the contaminants and initiate combustion. Self-sustaining smoldering refers specifically to the condition following ignition where the energy of the reacting contaminants themselves is used to preheat and initiate combustion of contaminants in adjacent areas (i.e., the reaction energy dominates over the external energy applied, or no external energy is applied at all).

5.1 Overview of Results

Two ignition points were installed for the pre-design evaluation: a primary and backup ignition point (IP-2 and IP-1, respectively). Operations were conducted between 20 July 2018 and 29 July 2018. Following a 12-hour startup period, IP-2 was operated for a period of 68 hours (2.8 days). At a time of 44 hours, the heating element installed at IP-2 failed. This equipment failure occurred before the standard heating duration was achieved (i.e., a minimum of 48-hours of heating during pilot testing where subsurface conditions and smoldering propagation characteristics are unknown). Since ignition did occur at IP-2 prior to the failure of the heating element, operations were continued for an additional 24 hours to assess subsurface temperatures and combustion gas concentrations. Operations were stopped at IP-2 and switched to the backup ignition point, IP-1.

STAR equipment was reconfigured for operations at IP-1, which was then operated for a period of 115 hours (4.8 days). Successful ignition and self-sustaining smoldering resulted in remediation of impacted soils within the target treatment zone. The objectives of the PDE were met based on the performance data collected during operations at IP-1 and IP-2. Detailed operational and performance evaluations for both IPs are summarized below in Sections 5.3 to 5.6, including a comparison of pre- and post-STAR soil conditions.

5.2 Pre-STAR Characterization

During construction of the EA, continuous soil borings were collected using macrocores and a DPT rig during the installation of the ignition points and some of the thermocouple bundles, and pre-STAR soil samples were collected from these cores (Figure 4). The locations selected for sampling were located at radial distances of 0, 5, and 10 ft from IP-1 and IP-2 in various directions to assess contaminant distribution throughout the EA. Most samples were collected from the target treatment zone, ranging from approximately 10 ft bgs to the base of the screened interval of the ignition points at 17 ft bgs (Figure 5). The soil samples were submitted by CH2M/Jacobs for analysis of petroleum hydrocarbons (gasoline range organics [GRO], diesel range organics

[DRO], and motor oil range organics [ORO]), polycyclic aromatic hydrocarbons (PAHs), and benzene, toluene, ethylbenzene, and xylene (BTEX). The estimated TPH concentration is calculated as the sum of the concentrations of GRO, DRO and ORO compounds.

Tables 1 and 2 present the results of the pre-STAR soil sample analyses, for samples collected at the IPs and TCs, respectively. Sampling depths are reported in the tables as observed in the macrocores and represent the approximate top and bottom of the sampling interval. The average estimated TPH concentration in the target treatment zone (not including additional samples above the target treatment zone collected at the ignition points and TC-12) is 12,200 mg/kg. There was, however, significant variability across the EA, with TPH concentrations ranging from 9 to 101,000 mg/kg. All PAHs analyzed (with the exception of 2-chloronaphthalene) were detected in pre-STAR soil samples, with total PAH concentrations ranging from 14 to 13,651 mg/kg. Total BTEX concentrations detected in the pre-STAR soil samples ranged from 0.2 to 497.8 mg/kg.

5.3 Operational Period

The combustion test (including operations at both IP-1 and IP-2) was conducted from 20 July to 29 July 2018. During this period, smoldering combustion reactions were initiated at both ignition points. During combustion, the air injection flow rate and pressure was systematically increased to propagate the combustion front radially outward from the point of ignition (IP-1 or IP-2). System operations were initiated but terminated at IP-2 due to an unanticipated failure of the ignition element. System operations at IP-1 were conducted for a total of five days, at which time the apparent ROI was reached. Operations at IP-1 were terminated following this five-day performance period as sufficient information had been collected to evaluate the ROI, propagation rate, and degree of treatment in this area.

5.4 Combustion at IP-2

<u>Assessment of the Ignition Event at IP-2</u>

The ignition event at IP-2 was achieved using a 9 kW in-well heater and the injection of air through the ignition point at flow rates starting at 20 scfm. Figure 6 presents the ignition curve for IP-2, showing both the development of increasing temperatures observed at the closest thermocouple probe in the monitoring network (TC-1, approximately 1 ft west of IP-2) and the evolution of CO measured in the extraction gas stream.

Combustion gases (CO and CO_2) are often used as an indicator of the onset and strength of combustion. In this case, however, the standard VEP design proposed for the PDE did not allow for complete capture of combustion gases. Due to the loose silty sand present in the upper 2-3 ft bgs, it was necessary to shorten the VEP screen length and install the screen in the more compact interval from 3 to 6 ft bgs to minimize the potential for short circuiting to surface. Due to a combination of poor capture and dilution air introduced into the system, CO_2 concentrations did not increase above background levels, and are therefore not shown on Figure 6. CO concentrations can be measured at a higher resolution by the continuous gas analyzer (i.e., CO is measured in parts per million [ppm], whereas CO_2 is measured in percent); therefore, CO concentrations are presented in Figure 6. Field screening data collected from soil vapor probes VP-01 through VP-05 (Figure 4) installed to 5 ft bgs in the four corners and center of the EA are also presented in Table A1 (Appendix A).

In addition to combustion gases, combustion can also be assessed through the evolution of temperatures over time and space and through post-STAR soil sampling results. Based on the treatability study results and the fact that peak combustion temperatures tend to be lower in-situ than in a laboratory environment, it is assumed that temperatures greater than 200°C are indicative of smoldering. The first thermocouple (TC) bundle in the monitoring network to detect subsurface temperatures indicative of combustion (200°C) was TC-1, located approximately 1 ft west of IP-2 (Figure 6). Combustion temperatures at TC-1 were first observed at 15 ft bgs, approximately 37 hours after the start of operations.

At a time of approximately 44 hours, a fuse blew indicating that one of the phases of the heating element installed in IP-2 had failed. A rigorous quality control program has been implemented with the heater manufacturer to minimize such failures, and an above ground heater testing protocol occurs on site prior to the installation of any heaters. However, despite the heater passing both tests, this rare type of failure can occur due to infrequent manufacturing defects which do not become apparent until a period of sustained use. Backup heaters were available on Site for the PDE to allow operations to restart at IP-1.

Combustion Front Propagation at IP-2

The combustion front at IP-2 continued to expand upwards, with the thermocouple at TC-1 located at a depth of 13.5 ft bgs reaching combustion temperatures approximately 19 hours after the 15 ft bgs thermocouple (or approximately 56 hours after the start of the test). The combustion front also proceeded to propagate radially outward from the ignition point as evidenced by combustion temperatures observed at TC-4 (approximately 2 ft north of IP-2). Figure 7 presents the temperature history (i.e., temperature versus time behavior) for TC-4. Combustion temperatures were observed at 13.5 ft bgs approximately 59 hours after the start of operations (or approximately 22 hours after TC-1).

Combustion gas (i.e., CO concentration) trends were also tracked during this time. As shown on Figure 6, combustion gas concentrations continued to trend downwards after the heating element failure that occurred at approximately 44 hours. At 68 hours into operations, combustion gas concentrations returned to baseline levels, indicating that combustion had been quenched and that a self-sustaining smoldering reaction had not been achieved prior to the heater failure. This was likely due, in part, to the lower total TPH concentrations present at the IP-2 screen (i.e., 3,270 mg/kg TPH from 16 to 17 ft bgs, and 3,500 mg/kg TPH from 14 to 15 ft bgs [Table 1]), resulting in a lower energy smoldering reaction. These lower energy reactions typically require additional heating time to achieve self-sustaining conditions. As a result, operations were terminated at IP-2 and initiated at the backup well (IP-1).

5.5 Combustion at IP-1

Assessment of the Ignition Event at IP-1

The ignition event at IP-1 was similarly achieved using a 9kW in-well heater and the injection of air through the ignition point at flow rates starting at 20 scfm. Figure 8 presents the ignition curve for IP-1, showing both the development of increasing temperatures observed at the closest thermocouple probe in the monitoring network (TC-14, located approximately 1 ft northeast of IP-1) and the evolution of CO measured in the extraction gas stream. As described for combustion at IP-2, limited vapor capture also occurred during operations of IP-1. CO concentrations in the collected vapors (as shown on Figure 8) are lower than typically observed during field applications. CO_2 concentrations again did not increase above background levels in the collected vapors, and therefore are not shown on Figure 8.

While combustion gas concentrations were low in the collected vapors, higher concentrations of CO and CO_2 were detected via field screening of gases from soil vapor probes installed to 5 ft bgs in the four corners and center of the EA. The field screening data for these vapor probes is presented in Appendix A. As shown in Table A2 for operations at IP-1, CO_2 concentrations increased significantly above initial screening levels at VP-03, VP-04, and VP-05 (Figure 4). CO concentrations were also detected at greater than 2000 ppm (the maximum range of the field meter) at four of the vapor probes. CO is not naturally occurring in the subsurface and therefore positive detection of CO provides proof of combustion.

The first thermocouple (TC) bundle in the monitoring network to detect subsurface temperatures indicative of combustion at IP-1 (200°C) was TC-14 (Figure 8). Combustion temperatures at TC-14 were first observed at 15 ft bgs, approximately 15 hours after the start of operations.

Combustion Front Propagation at IP-1

The combustion front continued to expand in thickness, with the TC-14 thermocouple bundle installed at a depth of 13.5 ft bgs reaching combustion temperatures approximately 46 hours after the start of the test. Higher peak temperatures and sustained elevated temperatures were observed at thermocouples surrounding IP-1, indicating higher concentrations and a more continuous distribution of fuel in the vicinity of the IP-1 in comparison to IP-2.

The combustion front also proceeded to propagate outward from the ignition point, with thermocouple TC-7, located 2 ft northwest of IP-1, reaching combustion temperatures at a time of approximately 26.5 hours (Figure 9). The shape of the temperature-time curves for thermocouples located 12 and 15 ft bgs shown in Figure 9 are indicative of sustained combustion with two key characteristics: 1) the distinct inflection point in the temperature curve (e.g., at a time of approximately 24 hours at the 15 ft bgs thermocouple) defining the transition from heat transfer from the in-well heater and combustion of adjacent contaminants during preheating to exothermic combustion at this location, and 2) the distinct definition of peak temperature (i.e., presence of peak temperatures within the same range as peak temperatures of thermocouples located closer to the ignition point [e.g., TC-14; Figure 8]). The fluctuating nature of the temperature curves shown in Figure 9 are representative of the layered distribution of contaminants. While limited temperature data is typical at sites of this nature due to the discrete installation depths of the thermocouples and the heterogeneous contaminant distribution, evidence of self-sustaining smoldering can be observed through the presence of combustion gases and gradual increases in thermocouple temperatures (indicating smoldering in the vicinity of the thermocouples).

Figure 10 presents the maximum temperature achieved (at any depth in the thermocouple bundle) in plan view, as well as the maximum temperatures at each thermocouple in the bundles along northeast-southwest and northwest-southeast cross section views during operations at IP-1. Temperatures in excess of 200°C, displayed as orange and red symbols in the figures, are considered indicative of combustion at the thermocouple location. Temperatures between 100°C and 200°C, displayed as yellow symbols, are considered to be in the vicinity of (i.e., six to twelve inches) the combustion front. Temperatures between 40°C and 100°C, displayed as light blue and light green symbols, indicate a minor influence of heat generated by the combustion front in that area, and temperatures below 40°C, displayed as dark blue, are considered to be unaffected by the combustion front. As shown in Figure 10, combustion temperatures and locations influenced by the combustion front were observed at depths between 12 and 16 ft bgs in the target treatment zone.

While combustion temperatures (>200°C) were not detected by thermocouples installed beyond a radial distance of 2 ft (i.e., TC-7) from IP-1, combustion gas concentrations remained elevated throughout the test indicating continued propagation of the smoldering front beyond TC-7. The lack of clear peak temperatures beyond TC-7 may be due to subsurface heterogeneities (i.e., thermocouples installed within a clay lens or above or below the zone of impacted soils) or insufficient physical connection of the thermocouple with surrounding subsurface soil. This can occur in heterogeneous depositional environments with interbedded fine and coarse-grained soil where contaminated zones can be thin, and thermocouples can be isolated in low permeability lenses that are not exposed to the elevated temperatures associated with smoldering combustion.

Evidence of combustion beyond 2 ft from IP-1 was obtained from both the combustion gas data (i.e., elevated concentrations of CO detected and maintained following propagation of the combustion front beyond the 2-foot thermocouple) as well as post-STAR soil visual and analytical data (discussed in detail in Section 5.6). Operations were terminated at IP-1 on 29 July 2018 when the combustion gas concentrations returned to background levels (after 110 hours of operations), indicating that the ROI had been reached in the EA.

5.6 Post-STAR Characterization

Post-STAR characterization activities commenced immediately following shutdown of operations at IP-1. Characterization work included drilling and collection of macrocores at ten (10) locations between 1 August 2018 and 2 August 2018. A DPT rig was used to collect the macrocores to a depth of 17 ft bgs at each of the ten post-STAR locations. At each location, two post-treatment samples were collected from within the target treatment depth interval (between approximately 10 and 17 ft bgs), at comparable depths to the pre-STAR samples. Figure 11 shows the locations of all pre- and post-STAR characterization macrocores.

The post-STAR sampling locations shown in Figure 11 were selected based on three criteria: proximity to pre-STAR sampling locations, radial distance from IP-1, and pre-STAR concentrations. The post-STAR sampling plan was designed to incrementally step out from IP-1 to confirm the ROI achieved. As discussed earlier, pre-STAR samples were collected at 0, 5, and 10 ft distances from IP-1 and IP-2. Most post-STAR samples were collected within 1 ft of the pre-

STAR sampling locations; however, in some cases post-STAR samples were slightly farther away and were collected to assess treatment at intervals closer than 5 ft. Fewer samples were collected to the west of IP-1 due to lower pre-STAR concentrations (i.e., <1,100 mg/kg TPH at TC-12).

Analytical Assessment of Post-STAR Soil Quality

A total of 20 soil samples were collected at distances ranging from 1 to 9 feet from IP-1 and submitted for laboratory analysis by CH2M/Jacobs to assess post-STAR soil quality. Table 4 presents analytical results for pre- and post-STAR soil samples collected at radial distances between 0 and 5 ft from IP-1 (i.e., from within the estimated ROI); percent reductions in concentration for each analyte measured are also indicated. Table 5 presents analytical results for pre- and post-STAR samples at radial distances of 7 ft from IP-1 (i.e., at the estimated ROI), and at 9 ft from IP-1 (i.e., from outside of the estimated ROI). A 7-ft ROI was estimated based on visual and analytical observations of treatment up to and including 7 ft from IP-1, but not beyond 7 ft from IP-1. A clear difference in visual characteristics of soil in the target treatment zone was observed between 5 and 9 ft from IP-1. At radial distances up to and including 5 ft from IP-1, soils in the treatment zone were characteristically dry and loose, with a notable color change to light brown with occasional reddish banding (as compared to dark grey-brown soils observed in pre-STAR borings).

Field screening of soils indicated significantly reduced PID readings in shallower intervals (i.e., 9 to 12 ft bgs) at post-STAR sampling locations up to 5 ft from IP-1. Partial treatment was observed at 7 ft from IP-1, with similar observations of dry, loose and light brown soils at deeper intervals of the target treatment zone, but with more variable PID screening readings in shallower intervals. At 9 ft from IP-1, soils in the target treatment zone were moist and more compact, with less distinct color changes from pre-STAR observations. These visual observations are supported by analytical data as presented in Tables 4 to 6 below, which show significant reductions in hydrocarbon concentrations at radial distances up to and including 5 ft from IP-1. Slightly reduced concentration reductions were observed as the ROI was approached at 7 ft from IP-1, and limited treatment was observed beyond the ROI at 9 ft from IP-1. Based on visual observations and post-STAR soil analytical data, treatment occurred at depth intervals ranging from 10 to 17 ft bgs.

In total, 12 pairs of samples (co-located pre- and post-STAR samples) were collected within the 7-ft ROI (Table 4), with an additional 3 pairs of samples collected at or beyond the 7-ft ROI (Table 5). Four post-STAR samples were also collected from sample locations and/or depth intervals where no pre-STAR comparison sample was collected (Table 6). Within the treatment horizon (i.e., within the 7 ft ROI), significant reductions in total TPH concentrations (from 73% to greater than 99% reductions) were observed at all sampling locations. Similarly, and with two exceptions, from 77% to greater than 99% reductions in total PAHs was achieved in the treatment zone. Two sampling locations displayed slightly lower reductions at 51% (PT-04-14) and 64% (PT-03-15). At PT-04-14, while some of the heavier PAHs with lower pre-STAR concentrations did not show significant reductions, naphthalene reductions at this location were greater than 99%. Similar to the heavier PAHs at PT-04-14, the pre-STAR concentrations were lower for all PAHs at PT-03-15 (282 mg/kg total PAHs). The lower reduction at this location is, therefore, due primarily to the lower initial concentrations. Greater than 95% reduction in total BTEX concentrations were also observed for all sampling locations where initial BTEX concentrations were greater than 4 mg/kg. No concentration reductions were observed for paired samples with initial concentrations less than 4 mg/kg due to sample variability and laboratory reported estimated concentrations for some analytes.

At the 7-ft ROI (Table 5), reductions of total TPH, total PAHs and total BTEX ranged between 56% and greater than 99%. The slightly reduced concentration reductions for TPH and BTEX (e.g., 61% and 56% reductions, respectively, at PT-10-14.5) suggest that the samples were collected at or near the ROI of the combustion reaction. At 9 ft from IP-1 (beyond the ROI), total TPH and total PAH concentrations of post-STAR samples remained relatively consistent with pre-STAR levels, confirming that treatment efficiency was significantly reduced beyond 7 ft.

Figures 12a, 12b, and 12c present summary plots of the pre- and post-STAR total TPH, total PAH, and total BTEX concentrations, respectively, for all pre- and post-STAR sampling locations. In general, for samples collected from within the treatment zone (i.e., within 7 ft from IP-1 and between approximately 10 and 17 ft bgs), there is a significant reduction in TPH, PAH, and BTEX concentrations.

A direct comparison of pre- and post-treatment soils (both analytical and visual observations) is the most reliable metric for assessing treatment ROI. Thermocouple and combustion gas data are used primarily to guide operations; however, these data may be used as an additional line of evidence in determining ROI if direct connection of the thermocouples to the contaminated interval and complete gas capture is achieved.

Visual Assessment of Post-STAR Soil Quality

Figures 13 through 22 present photographic comparisons of soils collected from within the EA both 'before' and 'after' the combustion test initiated at IP-1 for sampling locations shown in Tables 4, 5 and 6. Analytical sampling results of total TPH for pre- and post-STAR soils, as well as PID screening values recording during logging of soil borings are also shown on each comparison figure. In all cases, pre-STAR photos show wet, dark grey soils, often with the presence of sheen or visible product in the macrocores collected from 10 to 17 ft bgs. The visible contamination extends to 17 ft bgs at the location of the IPs (IP-1 and IP-2), however, the lower bounding silty clay layer begins at approximately 15.5 to 16 ft bgs in the majority of the EA. The post-STAR photos at comparable locations and depth intervals, show much less visible contamination within the treatment zone, with areas of dry soils observed at some locations and depth intervals. Note that no recovery is common for treated soils due to challenges with retaining dry, loose sandy soil in direct push macrocore liners. The intervals of no recovery on Figures 13 to 22 are not logged as treated due to lack of visual or analytical confirmation but likely represent treated zones.

Combustion Front Propagation Rate

Operations at IP-1 were conducted for a total of 4.8 days. Based on a combination of the temperature data shown in Figure 10 and the post-STAR soil analytical data, the treatment zone extends approximately 7 ft radially away from IP-1. Based on a treatment radius of 7 ft, this results in an average combustion front propagation rate of approximately 1.4 ft/day. These data allow for an estimation of the time scales for full-scale implementation.

5.7 Quantitative Assessment of STAR Performance at IP-1

An estimation of mass destroyed by the STAR process was calculated based on the assumed thickness and radius of the treatment zone (i.e., volume of soil treated) and the average pre- and post-STAR hydrocarbon concentrations in the soil samples collected within that zone. A simplified geologic cross section of the EA is presented in Figure 5. Focusing on the medium to fine sand units in the depth interval where contamination was observed (10 to 17 ft bgs), the combined thickness of the treatment zone is 3.5 ft (i.e., from 10 to 11 ft bgs, and 13.5 to 16 ft bgs). Assuming a treatment radius of 7 ft, the volume of treated soils is therefore approximately 540 ft^3 (15.3 m^3). Based on the average pre-treatment TPH concentration of 12,200 mg/kg, the average post-treatment concentration of 1,120 mg/kg and assumed densities of the soil and NAPL of 1,600 kg/m^3 and 1,100 kg/m^3, respectively, an estimated 270 kg of petroleum hydrocarbons was removed from the treatment zone during the 5-day combustion test at IP-1. This total includes both mass destroyed and mass volatilized and collected by the vapor extraction system.

The mass of contaminant destroyed can also be estimated using a carbon mass balance approach and the concentrations of CO and CO_2 in the collected vapor stream as follows:

$$M_{Creosote\ (or\ Coal\ Tar)} = \frac{\left[M_{CO_2} \bullet \frac{MW_C}{MW_{CO_2}} + M_{CO} \bullet \frac{MW_C}{MW_{CO}}\right]}{R^C_{Creosote\ (or\ Coal\ Tar)}}$$

where:

$M_{Creosote\ (or\ Coal\ Tar)}$ is the mass of creosote or coal tar destroyed;

M_{CO_2} is the mass of carbon dioxide measured in the vapor stream (calculated as the product of the carbon dioxide concentration and the vapor phase flow rate);

M_{CO} is the mass of carbon monoxide measured in the vapor stream (calculated as the product of the carbon monoxide concentration and the vapor phase flow rate);

MW_C is the molecular weight of carbon;

MW_{CO_2} is the molecular weight of carbon dioxide;

MW_{CO} is the molecular weight of carbon monoxide; and

$R^C_{creosote\ (or\ Coal\ Tar)}$ is the mass ratio of carbon to the molecular weight of creosote or coal tar.

Due to a combination of poor capture and dilution of combustion gases, the mass destroyed using this method could not be estimated for the PDE. Vapor capture at this Site could be improved for future applications of the STAR technology through the use of a surface vapor collection system. This would permit screening of the vapor extraction wells in the near-surface, loose silty soil while minimizing the risk of short circuiting to surface. The use of combustion gases for making operational decisions (e.g., when to cease operations) and for estimating mass destroyed could, therefore, be used during full-scale implementation of STAR at the site. The carbon mass balance method for estimating mass destroyed eliminates the assumptions for treatment volume and soil/NAPL densities required for the soil concentration method. The carbon mass balance method is considered to be a conservative estimate due to the potential for mass to be collected in the vapor collection system via volatilization (which is not accounted for in the mass balance), as well as the potential for the dissolution of CO_2 in groundwater prior to reaching the vadose zone.

An estimation of the mass of volatile compounds captured by the vapor collection system is based on vapor samples collected during the operations period. Table 3 presents sulfur compounds, fixed gases, and VOCs in vapors collected during the test initiated at IP-2 (collected on 22 July 2018) and during the test initiated at IP-1 (collected on 26 July 2018 and 29 July 2018). Vapor samples were collected from sampling port SP-101 (Drawing D03 of STAR PDE Operation Work Plan) via bottle vacs and sent for laboratory analysis by CH2M/Jacobs. Similar to previous field trials conducted at other sites, certain high volatility constituents of the NAPL were observed in the collected vapors. Compounds detected during this test are shaded in grey in Table 3. Using the average measured VOC concentrations in the collected vapor samples during IP-1 operations, an average daily SVE system extraction rate (305 scfm), and extrapolating these results over the 5-day operations period, the estimated total mass of volatile compounds emitted as vapors and captured by the SVE system during IP-1 operations was 0.15 kg. The mass volatilized represents a small fraction of the total mass removed from the treatment zone (i.e., >99% mass destroyed via combustion during the PDE).

6. ADDITIONAL DRILLING

Due to the complex geology and significant variability of contaminant concentration distribution through the PDE area, two additional areas of the Site were selected for further subsurface investigation. The purpose of this investigation was to characterize geologic features and baseline contaminant concentrations in soil in these areas. A comparison with baseline conditions observed in the PDE area would allow for an assessment of anticipated STAR effectiveness in other areas of the site and allow for better definition of full-scale implementation assumptions.

The two areas selected for further investigation are shown on the Site layout (Figure 2): the May Creek area of the Site (in the vicinity of boring MC-1), and the Quendall Pond area (in the vicinity of boring QP-1). In each of these areas, soil borings were collected to the anticipated total depth of contamination (i.e., up to a maximum depth of 25 ft bgs in the vicinity of QP-1 and up to 35 ft bgs in the MC-1 area). Discrete soil samples, selected based on visual evidence of NAPL and/or elevated PID readings, were collected and sent for laboratory analysis of GRO, DRO, ORO, PAHs, and BTEX by CH2M/Jacobs. Sampling locations were spaced at linear distances of 5 ft (to assess small-scale spatial variability) and 15 ft (representing the intersection of the ROI of two hypothetical IPs installed in the area).

6.1 Investigation Results near QP-1

Ten (10) soil borings were collected to a depth of between 20 and 25 ft bgs in the vicinity of QP-1, as shown on Figure 23. A simplified cross section for the QP-1 area is shown in Figure 24. The geologic conditions are similar to those found in the PDE EA (i.e., fine to medium sand layers separated by lenses of silty clay); however, the thicker layers of fine to medium sand and thinner lenses of clay in the QP-1 area provides more ideal geologic conditions for STAR implementation compared with the PDE area. During STAR implementation the achievable thickness of the treatment zone in alluvial deposits is often limited by horizontally-oriented lower permeability layers which can restrict vertical air flow. In the presence of thinner and less frequent low permeability clay layers, as was observed in the vicinity of QP-1, it is anticipated that there will be fewer air flow limitations and improved treatment in impacted areas. Boring logs detailing lithologic descriptions, visual observations of relative contamination levels, and PID screening values are detailed in Appendix D.

A summary of the TPH, PAH, and BTEX concentrations in soil samples collected in the QP-1 area investigation is presented in Table 7. Similar to the PDE area, significant variability in contaminant concentrations is present throughout the QP-1 area. Total TPH concentrations throughout the area range from non-detect to 17,200 mg/kg, with an average concentration of 3,260 mg/kg. Of the ten locations sampled, only four locations (QP-1-01, QP-1-02, QP-1-03, and QP-1-08) had TPH concentrations detected in excess of 3,000 mg/kg, with QP-1-03 containing concentrations closer to 3,000 mg/kg TPH. The minimum threshold required for self-sustaining smoldering combustion is in the range of 3,000 to 5,000 mg/kg TPH. The higher contaminant concentration samples are focused in the fine to medium sand layers from 15 to 20 ft bgs, and 20 to 22 ft bgs at these locations. Lower concentrations (i.e., <2,000 mg/kg TPH) are present in the upper fine to medium sand layer from 8 to 11 ft bgs.

6.2 Investigation Results near MC-1

Eight (8) soil borings were collected to a depth of between 20 and 35 ft bgs in the vicinity of MC-1, as shown on Figure 25. A simplified cross section for the MC-1 area is presented in Figure 26. The geologic conditions are similar to both the QP-1 and the PDE EA (i.e., with fine to medium sand layers separated by lenses of silty clay); however, the alternating layering of these two predominant units is more significant in the MC-1 area. Boring logs detailing lithologic descriptions, visual observations of relative contamination levels, and PID screening readings are detailed in Appendix E. With visual observations of contamination and elevated PID readings spanning the depth of approximately 10 to 30 ft bgs at some boring locations, there is the potential requirement for multiple STAR ignition point depths in this area to target distinct impacted layers.

A summary of the TPH, PAH, and BTEX concentrations in soil samples collected in the MC-1 area investigation is presented in Table 8. Similar to the QP-1 and PDE EA, significant variability in contaminant concentrations is present throughout the MC-1 area. Total TPH concentrations throughout the area range from non-detect to 118,000 mg/kg, with an average concentration of 31,850 mg/kg. Six of the eight locations sampled (all boring locations, except MC-1-07 and MC-1-08) contained total TPH concentrations in excess of the 3,000 to 5,000 mg/kg STAR self-sustainability threshold. The MC-1-07 and MC-1-08 boring locations are located near the eastern boundary of the estimated extent of upland DNAPL in the May Creek Area (Figure 25), so the lower concentrations present at these locations may be representative of the approximate edge of the DNAPL body. Overall, TPH concentrations in the MC-1 area are higher. The higher concentration samples are focused in the sand layers from approximately 10 ft bgs to 28 ft bgs at these locations.

7. SUMMARY AND CONCLUSIONS

As summarized in this report, the objectives of the PDE were met through the STAR combustion tests at IP-1 and IP-2. The PDE successfully evaluated the ROI, smoldering front propagation rate, and volatile emissions levels that can be anticipated during full-scale implementation of STAR at the Site. The results of the combustion test are summarized below.

	STAR Treatment
Observed Radius of Influence (ROI)	7 ft
Treatment Zone Thickness	~ 7 ft
Smoldering Front Propagation Rate	1.4 ft/day
Estimated Mass Removed via Volatilization (kg)	0.15
Estimated Mass Destroyed via Combustion (kg)	270 [1]

[1] Mass destroyed via combustion calculated based on ROI, treatment zone thickness, pre- and post-STAR TPH concentrations in the treatment zone, and emissions data

Within the PDE area, successful treatment, as well as propagation of a self-sustaining smoldering front, were achieved. Treatment was achieved in multiple sand layers separated by layers of silty clay, indicating that air and heat are capable of transferring through thinner silty clay layers to continue STAR propagation. In the presence of thicker clay layers or in areas with extensive layering, it is possible that multiple STAR ignition wells would be required for treatment. Significant contaminant reductions were observed throughout the treatment area; therefore, the end result of STAR treatment in this area should be understood as the bulk removal of coal tar and creosote, which in turn will dramatically lower the corresponding dissolved-phase mass flux and overall dissolved-phase groundwater concentrations. The ROI and propagation rate achieved during the PDE are consistent with STAR PDE results observed at other sites and are amenable to a cost-effective full-scale implementation of STAR at the Site.

The additional drilling investigation in the vicinity of QP-1 indicated that significant variability in contaminant concentrations can be expected across the Quendall Pond area. Geologic observations in the QP-1 area indicated more favorable conditions for STAR (i.e., presence of fewer low permeability layers within the target treatment zone resulting in improved air flow distribution) relative to the PDE EA. In the QP-1 area, however, only 40% of locations sampled contained sufficient total TPH concentrations for the combustion reaction to propagate in a self-sustaining manner. It is therefore expected that additional characterization (via soil boring logging and/or TarGOST® survey) will be required prior to (or during) the installation of IPs for full-scale implementation. Only areas with initial total TPH concentrations exceeding 3,000 – 5,000 mg/kg would be targeted for IP installation. While the 3,000 – 5,000 mg/kg initial TPH criteria would be the threshold for installing an IP, both higher and lower concentration areas around the IP are expected to undergo combustion and be treated to low-level concentrations (i.e., non detect to 100s of mg/kg) as observed in post-treatment soils during the PDE. A self-sustaining smoldering front can treat areas with small zones of low concentrations; however, given a sufficiently large area with low initial TPH concentrations, the smoldering reaction would no longer be self-sustaining.

Additional drilling in the MC-1 (May Creek) area indicated that higher initial TPH concentrations are likely to be present relative to the QP-1 area. These higher initial TPH concentrations allow for a more robust self-sustaining smoldering reaction and are favorable for STAR implementation. Geologic observations from the additional investigation, however, suggest that more significant layering of low permeability (i.e., silty clay) lenses is expected in this area. It was demonstrated in the PDE that STAR is capable of treating multiple sand layers separated by thin silty clay layers (i.e., approximately 1.5 to 2.5 ft thick layer of silty clay in the EA); however, with the more extensive layering and thicker impacted zone in the May Creek area, it is anticipated that multiple ignition points may be required to treat the entire impacted depth interval in this area of the Site. Similar to the QP-1 area, similar treatment to what was observed during the PDE is expected at locations with sufficient initial TPH concentrations.

Additional details and recommendations for full-scale implementation at the Site are provided in Section 8.

8. RECOMMENDATIONS FOR FULL-SCALE IMPLEMENTATION OF STAR

This section presents a conceptual approach to a full-scale implementation of STAR at the Site. This approach is based on an assumed treatment area and may be modified as necessary based on the treatment area ultimately selected.

8.1 Basis of Design

8.1.1 Treatment Zone Definition

For generating this conceptual approach, it was assumed that the target treatment area is the entire region defined as the “estimated extent of upland DNAPL” (Figure 2). This area is approximately 420,865 ft^2 and has been further subdivided into ten (10) zones for the assessment of other remediation alternatives (Figure 27). Analytical results from the additional drilling investigation indicate that contaminant distribution varies significantly across the Site; however, in the absence of detailed characterization across the entire DNAPL boundary, it has been further assumed that the entire 420,865 ft^2 would be amenable to STAR treatment. The strategy for implementing STAR in areas with variable initial TPH concentrations is discussed further in Section 8.1.3 below.

The maximum target treatment depth in each of the ten zones is indicated on Figure 27. It was assumed that the entire thickness of impacts can be treated from an IP installed at a single depth. The strategy for managing areas where multiple ignition point depths may be required is also discussed in Section 8.1.3.

8.1.2 STAR Full-Scale Treatment Approach

The two key variables that affect the STAR design are the: (1) combustion front propagation velocity; and (2) ignition well ROI – the two key parameters evaluated during the PDE. Based on the results of the PDE discussed above, the full-scale conceptual approach presented herein will be based on a propagation rate of 1.4 ft/day and an ROI of 7 ft.

To treat the total area of 420,865 ft^2, approximately 2,740 ignition points will be required. Groups of up to 8 ignition points will be organized into “cells”, and all 8 ignition points within a single cell will be ignited and combusted simultaneously. Multiple cells are further arranged into treatment nodes consisting of all cells within a 225-ft radius of a STAR treatment trailer (Figure 27). Full-scale STAR implementation benefits from this grouping of ignition points into cells via treatment of a contaminated area from multiple directions. For example, if a given location cannot be reached from a combustion front initiated at one ignition point, it may be reached from combustion initiated at an adjacent ignition point.

The ignition wells will be installed by direct push to the base of the target treatment area. Up to 12 multi-level thermocouple probes will be installed per treatment cell to facilitate real-time monitoring of the STAR combustion front. Thermocouples will be installed using DPT and will be used to confirm ignition and track the progression of the combustion front between ignition points. Well materials and thermocouple probes will be recycled from cell to cell to reduce infrastructure costs.

Removable electric heaters will be inserted into each ignition well within the operating cell and used to raise the temperature of the impacted soils near the ignition screen. An inventory of spare heaters will be part of the built-in system redundancy on Site. Once the combustion reaction is initiated, the supply of compressed air into the ignition wells will sustain the reaction. The air flow rate into each well will vary between 10 scfm and 200 scfm depending on the stage of the combustion process, the distance of the combustion front from the point of ignition, the permeability of the soil, and as determined by the system operator to optimize the mass destruction rate and the performance of the system.

Vapors generated by the STAR process will consist of combustion gases (CO and CO_2), moisture, and volatilized Site contaminants. Combustion gases, moisture, and Site contaminants will be collected through vapor extraction points (Site-specific design to be developed to improve vapor capture from that observed during the PDE), manifolded and routed to an SVE and treatment system operating at a flow rate of approximately 3,000 scfm. A CEMS will sample the SVE system to measure the presence of combustion gases within the emissions. Prior to discharge, emissions treatment will be by propane-supplemented thermal oxidation. Placement of the thermal oxidizer will be selected to optimize the area that can be accessed, and therefore minimize the number of required relocations of the oxidizer.

System operation generally proceeds from cell to cell in a continuous manner, with drilling and installation activities occurring in parallel to maximize operational efficiency.

Using three (3) treatment systems (where each "system" consists of its own treatment cells, air injection equipment, vapor extraction and emissions treatment equipment, other ancillaries, and operations staff), the period of active operation is approximately 2.5 years to address the entire 420,865 ft^2 treatment area. The full-scale remedy would include:

- Full-scale remedy design, contracting, subcontracting, and reporting;
- System installation, shakedown, operation, demobilization; and
- Project management.

8.1.3 Implementation Strategy for Managing Site Uncertainty

As discussed in Section 8.1.1, there are two key uncertainties that will affect the total number of ignition points required for treatment at the Site: variability in the distribution of contaminant concentrations sufficient for self-sustaining smoldering (i.e., greater than 3,000 to 5,000 mg/kg for IP installation), and presence of multiple layers of contamination requiring more than one ignition point installation depth at a given location. As such, the proposed strategy is to design the STAR treatment systems and deployment strategy for treatment of the "base case" (i.e., treatment of the entire 420,865 ft^2 assuming that the entire thickness of impact can be treated from an IP installed at a single depth) and adjust during operations to account for Site uncertainty. Site uncertainty will be addressed in "real time" by pre-characterizing the planned IP installation locations via TarGOST® and/or field screening of direct push soil borings. Based on this pre-characterization, if contaminant concentrations are sufficient for self-sustaining smoldering, IPs and remaining cell infrastructure will be installed and operated (on a per cell cost basis); however, if insufficient contaminant concentrations are present, the pre-characterization borings will be abandoned, and no additional installation or operations costs will apply (i.e., fewer IPs required than base case resulting in reduced costs). The pre-characterization will also identify multiple IP depths at a given location in areas where distinct layers of impacts are present (i.e., additional IPs required resulting in increased costs). The overall number of IPs (and therefore costs) required for treatment may increase or decrease from the base case depending on the balance of these two uncertainties across the Site.

8.1.4 Utility Requirements

Electrical power is required for the air injection compressor, the SVE blower, the vapor treatment system, and the ignition well heaters. The project will require a source of 3-phase 480-volt AC power. This power may be supplied via utility drops installed in the vicinity of the target treatment areas, or mobile diesel generators and diesel air compressors could be used. The type of power supply selected will impact overall project costs. Propane and associated infrastructure will also be required to act as a supplemental fuel for the thermal oxidation treatment plant(s).

8.1.5 Waste Quantities and Material Consumption

Consumables primarily consist of diesel (if generators are used) and propane.

Waste generated by the STAR process is limited to liquid condensate collection in the vapor collection and treatment system. This waste stream is primarily water with VOCs. The production rate of condensate is related to several factors, including the proximity of groundwater to the surface (or to the VEPs), which will vary across the Site and will vary throughout a calendar year. The condensate production rate will also be influenced by precipitation. Due to these factors, the average production rate of condensate cannot be predicted.

8.2 Implementation

8.2.1 Responsibility Matrix

Savron would be responsible for the design, setup, and operational activities related to the STAR system, including:

- Project management;
- Design calculations and drawings;
- Work plan preparation;
- STAR Site Health & Safety Plan (HASP) preparation;
- Drafting and issuing of procurement packages for drilling and contractor activities;
- Procurement bid evaluation;
- Staffing of STAR operation with 24/7 supervision;
- Demobilization and decontamination of supplied equipment.

Additional negotiated/shared project execution tasks include (but are not limited to):

- Coordination of site access;
- Permitting;
- Utility clearance;
- Subsurface obstruction removal;
- Site security;
- Pre- and post-characterization of soils;
- Waste removal;
- Complete restoration of the Site.

8.2.2 Predicted Remediation Achievements

STAR is typically used as a source treatment technology where the goal is “free product” destruction to the extent practicable. Mass treatment rates on the order of hundreds of kilograms per day per ignition point are typical, with propagation rates on the order of feet per day. Thus, relative to most in situ technologies, STAR is rapid and capable of significant mass reductions.

STAR results in the near complete removal of organic compounds wherever combustion occurs. Due to the geologic heterogeneity and presence of low permeability layers affecting air flow distribution at this Site, total TPH concentration reductions between 75% and greater than 99% are expected in treated areas. Some areas located near a treatment zone may experience increased temperatures although no direct combustion and, therefore, would experience partial treatment via preferential removal of the higher volatile fraction, which is often the most water soluble.

Untreated fringe areas may not contain a large enough proportion of soluble compounds to contribute to groundwater impacts. Therefore, the end result of the STAR process should be understood as the bulk removal of free product from the Site, which can significantly lower the corresponding dissolved-phase mass flux from the Site and overall dissolved-phase groundwater concentrations. However, STAR alone may not result in site closure for unrestricted use. Low-intensity groundwater remedy such as MNA may still be considered as part of the overall site remediation strategy.

In summary, the successful implementation of STAR will result in:

- Free product destruction / removal in treated areas;
- Limited residual contaminant mass;
- Reduced groundwater contaminant mass flux which can be addressed through MNA; and,
- An enhanced site exit strategy, reduced lifecycle costs, and reduced risk as a result of the above STAR-related benefits.

9. REFERENCES

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Savron. (2018b). STAR Operation Work Plan: Self-sustaining Treatment for Active Remediation (STAR) Pre-design Evaluation (PDE) – Port Quendall Terminals, Renton, WA. Included as Appendix A of the Work Plan for the Self-Sustaining Treatment for Active Remediation Pre-Design Evaluation, Quendall Terminals Superfund Site, Operable Unit 1, prepared by CH2M for U.S. EPA Region 10, June 21, 2018.

TABLES

Table 1
Pre-STAR Soil Analytical Results (IPs)
Quendall Terminals
Renton, Washington

Boring ID	**IP-01**				**IP-02**						
Sample ID	2018QT-SB-IP01-6.5-06282018	2018QT-SB-IP01-11-06282018	2018QT-SB-IP01-14-06282018	2018QT-SB-IP01-16-06282018	2018QT-SB-IP02-07-06282018	2018QT-SB-IP02-10-06282018	2018QT-SB-IP02-12-06282018	2018QT-SB-IP02-13.5-06282018	2018QT-SB-IP02-15-06282018	2018QT-SB-IP02-16-06282018	2018QT-SB-IP02-16FD-06282018
Depth (ft bgs)	6.5 - 7.5	11 - 12	14 - 15	16 - 17	7 - 8	10 - 11	12 - 13	13.5 - 15	15 - 16	16 - 17.5	16 - 17.5 (Duplicate)
Date	6/28/2018	6/28/2018	6/28/2018	6/28/2018	6/28/2018	6/28/2018	6/28/2018	6/28/2018	6/28/2018	6/28/2018	6/28/2018
Petroleum Hydrocarbons											
Gasoline Range Organics	5,300	390	1,800	570	120	1,000	210	130	450	930	1,100
Diesel Range Organics	10,000	2,800	1,700	2,700	11,000	3,200	310	3,700	1,600	3,000	2,600
Motor Oil Range Organics	<120	<140	<120	<170	<120	<120	<150	<110	<120	<130	<120
TOTAL TPH	**15,300**	**3,190**	**3,500**	**3,270**	**11,120**	**4,200**	**520**	**3,830**	**2,050**	**3,930**	**3,700**
Polycyclic Aromatic Hydrocarbons (PAHs)											
2-Chloronaphthalene	<0.61	<0.29	<0.54	<0.86	<0.6	<0.23	<0.078	<0.58	<0.49	<0.58	<0.61
2-Methylnaphthalene	380	80	60	65	260	92	44	120	24	110	94
Acenaphthene	550	120	18	61	400	95	5.8	69	14	28	29
Acenaphthylene	3.8	0.97	1	1.7	4.1	1.2	0.15	2.6	0.87	1.2	1.2
Anthracene	230	61	5.1	38	110	42	0.82	18	4.5	6.4	6.6
Benzo(a)anthracene	63	13	22	23	45	9	0.32	30	17	24	25
Benzo(a)pyrene	17	4.5	40	27	20	2.9	0.16	44	31	42	43
Benzo(g,h,i)perylene	5.9	1.8	23	16	8	0.95	<0.078	25	18	24	25
Benzo[b]Fluoranthene	26	6.4	53	36	38	4.4	0.22	63	43	62	61
Benzo[k]floranthene	12	3.4	19	12	41	1.6	0.081	18	11	16	16
Chrysene	49	12	24	27	39	8.2	0.24	36	20	32	25
Dibenzo[a,h]anthracene	1.9	0.61	5.7	4	2.6	0.38	<0.078	6.5	4.6	6.2	6.5
Fluoranthene	380	87	18	66	280	66	1.6	61	14	22	23
Fluorene	410	88	11	47	280	78	2.9	42	9.3	14	14
Indeno(1,2,3-cd)pyrene	5.7	1.7	16	12	7.9	1	0.078	18	13	17	18
Naphthalene	2,100	580	51	230	1,400	320	49	170	16	230	190
Phenanthrene	1,100	220	25	140	770	190	4.8	130	20	32	33
Pyrene	280	64	29	58	200	49	1.3	66	22	32	33
TOTAL PAHs	**5,614**	**1,344**	**421**	**864**	**3,906**	**962**	**111**	**919**	**282**	**699**	**643**
BTEX											
Benzene	0.57	0.16	1.7	4.3	0.06	0.18	0.45	0.21	0.26	0.28	0.58
Ethylbenzene	5	1	13	16	0.29	1.4	1.1	0.94	2.1	4.1	5.3
m+p-Xylene	5.7	0.53	14	1.6	0.28	1.3	0.07	0.92	1.9	4	4.4
o-Xylene	2.8	0.54	5.3	0.76	0.14	0.7	0.53	0.41	0.92	1.8	1.9
Toluene	2.2	0.08	0.37	<0.94	0.12	0.35	<0.22	0.032	0.05	0.08	0.05
TOTAL BTEX	**16.3**	**2.3**	**34.4**	**22.7**	**0.9**	**3.9**	**2.2**	**2.5**	**5.2**	**10.3**	**12.2**

Notes:
1. All units are measured in milligrams per kilogram (mg/kg), unless otherwise indicated
2. < denotes less than the method detection limit (MDL)
3. Sample ID describes sample location, upper depth of the sampling interval, and date collected
(e.g., 2018QT-SB-IP01-6.5-06282018 represents a soil sample collected at IP-01 at a depth from approximately 6.5 to 7.5 ft bgs on 06/28/2018)
Indicates analyte measured above the MDL
Indicates J-flag (analyte measured above the MDL, but concentration is estimated)

Table 2
Pre-STAR Soil Analytical Results (TCs)
Quendall Terminals
Renton, Washington

Boring ID	**TC-05**			**TC-06**		**TC-09**		**TC-10**		**TC-11**		
Sample ID	2018QT-SB-TC05-15-06292018	2018QT-SB-TC05-15FD-06292018	2018QT-SB-TC05-16-06292018	2018QT-SB-TC06-13.5-06292018	2018QT-SB-TC06-15.5-06292018	2018QT-SB-TC09-14-06292018	2018QT-SB-TC09-15-06292018	2018QT-SB-TC10-14-06292018	2018QT-SB-TC10-15-06292018	2018QT-SB-TC11-11-07022018	2018QT-SB-TC11-13.5-07022018	2018QT-SB-TC11-13.5FD-07022018
Depth (ft bgs)	15 - 16	15 - 16 (Duplicate)	16 - 17	13.5 - 15	15.5 - 17	14 - 15	15 - 16	14 - 15	15 - 16	11 - 12	13.5 - 15	13.5 - 15 (Duplicate)
Date	6/29/2018	6/29/2018	6/29/2018	6/29/2018	6/29/2018	6/29/2018	6/29/2018	6/29/2018	6/29/2018	7/2/2018	7/2/2018	7/2/2018
Petroleum Hydrocarbons												
Gasoline Range Organics	90	65	44,000	570	1,000	130	460	450	120	65,000	20	2,000
Diesel Range Organics	7,900	7,100	38,000	5,800	6,500	77	1,000	1,400	4,000	36,000	6,100	6,500
Motor Oil Range Organics	<120	<120	<860	<110	<140	<140	<130	<120	<120	<130	<110	<110
TOTAL TPH	**7,990**	**7,165**	**82,000**	**6,370**	**7,500**	**207**	**1,460**	**1,850**	**4,120**	**101,000**	**6,120**	**8,500**
Polycyclic Aromatic Hydrocarbons (PAHs)												
2-Chloronaphthalene	<0.55	<0.6	<1.8	<1	<0.71	<0.069	<0.07	<0.26	<0.58	<1.3	<0.58	<0.56
2-Methylnaphthalene	320	260	1,800	140	290	4	36	55	140	900	200	210
Acenaphthene	190	150	1,100	120	80	1.2	46	20	34	1300	69	72
Acenaphthylene	7.1	6	41	2.3	3.4	<0.069	1	0.65	1.8	14	2.4	2.6
Anthracene	64	44	360	20	21	0.21	14	5	9.9	250	13	15
Benzo(a)anthracene	57	40	280	33	52	0.15	6.5	12	30	150	58	60
Benzo(a)pyrene	53	38	200	42	84	0.082	2	25	46	43	93	97
Benzo(g,h,i)perylene	24	21	87	23	43	<0.069	0.68	12	27	13	55	57
Benzo[b]Fluoranthene	67	46	250	50	110	0.09	2.6	29	70	61	120	120
Benzo[k]floranthene	23	17	78	19	30	<0.069	1.3	10	24	24	39	31
Chrysene	52	37	250	32	71	0.094	5.1	14	33	130	57	59
Dibenzo[a,h]anthracene	6	5.2	24	6.2	13	<0.069	0.21	3.1	7.4	4.2	12	13
Fluoranthene	170	130	920	94	52	0.64	37	15	29	880	46	56
Fluorene	140	110	780	72	36	0.61	35	12	17	860	28	30
Indeno(1,2,3-cd)pyrene	18	16	71	17	33	<0.069	0.63	8.8	20	13	33	37
Naphthalene	710	540	4,300	350	950	28	100	0,110	500	3,800	660	780
Phenanthrene	370	300	2,300	220	100	1.6	95	37	45	2,300	74	77
Pyrene	150	120	810	79	70	0.51	29	19	38	640	79	82
TOTAL PAHs	**2,421**	**1,880**	**13,651**	**1,320**	**2,038**	**37**	**412**	**388**	**1,072**	**11,382**	**1,638**	**1,799**
BTEX												
Benzene	0.65	0.04	24	0.58	3.6	0.31	0.26	0.56	0.56	3.2	0.02	0.47
Ethylbenzene	3.9	0.21	190	4.2	9.7	3.4	2.5	2.5	5.6	36	0.07	12
m+p-Xylene	3.8	0.19	190	4.5	11	2.1	0.95	2.1	6.5	36	0.05	14
o-Xylene	1.8	0.1	89	1.8	4.5	0.69	0.48	1.1	2.6	17	0.04	5.8
Toluene	0.11	<0.13	4.8	0.13	0.17	<0.33	0.21	0.23	0.12	17	<0.13	0.7
TOTAL BTEX	**10.3**	**0.5**	**497.8**	**11.2**	**29.0**	**6.5**	**4.4**	**6.5**	**15.4**	**109.2**	**0.2**	**33.0**

Notes:
1. All units are measured in milligrams per kilogram (mg/kg), unless otherwise indicated
2. < denotes less than the method detection limit (MDL)
3. Sample ID describes sample location, upper depth of the sampling interval, and date collected
(e.g., 2018QT-SB-TC05-15-06292018 represents a soil sample collected at TC-05 at a depth from approximately 15 to 16 ft bgs on 06/29/2018)
Indicates analyte measured above the MDL
Indicates J-flag (analyte measured above the MDL, but concentration is estimated)

Table 2
Pre-STAR Soil Analytical Results (TCs)
Quendall Terminals
Renton, Washington

Boring ID	TC-12		TC-16		TC-18		TC-20	
Sample ID	2018QT-SB-TC12-09-07022018	2018QT-SB-TC12-14-07022018	2018QT-SB-TC16-14-07022018	2018QT-SB-TC16-15-07022018	2018QT-SB-TC18-11-07022018	2018QT-SB-TC18-14-07022018	2018QT-SB-TC20-11-07022018	2018QT-SB-TC20-15-07022018
Depth (ft bgs)	9 - 10	14 - 15	14 - 15	15 -16	11 - 12	14 - 15	11 - 12	15 - 16
Date	7/2/2018	7/2/2018	7/2/2018	7/2/2018	7/2/2018	7/2/2018	7/2/2018	7/2/2018
Petroleum Hydrocarbons								
Gasoline Range Organics	32	57	4,800	16,000	140	9.1	1,700	5,300
Diesel Range Organics	130	1,900	4,600	8,800	3,700	<46	18,000	14,000
Motor Oil Range Organics	<120	<110	<120	<150	<130	<110	<130	<160
TOTAL TPH	**162**	**1,957**	**9,400**	**24,800**	**3,840**	**9**	**19,700**	**19,300**
Polycyclic Aromatic Hydrocarbons (PAHs)								
2-Chloronaphthalene	<0.063	<0.11	<0.49	<0.75	<0.26	<0.059	<0.66	<0.83
2-Methylnaphthalene	3.6	62	190	400	130	2.4	640	600
Acenaphthene	2.2	46	71	160	100	0.62	790	400
Acenaphthylene	0.075	0.94	2.1	5.3	5.7	<0.059	7.9	14
Anthracene	0.56	7.8	13	40	31	0.13	220	130
Benzo(a)anthracene	0.57	24	37	95	18	0.067	100	100
Benzo(a)pyrene	0.19	42	71	140	10	<0.059	28	61
Benzo(g,h,i)perylene	<0.063	24	34	80	4.2	<0.059	9.3	30
Benzo[b]Fluoranthene	0.26	52	89	180	12	<0.059	38	87
Benzo[k]floranthene	0.12	17	26	45	4.5	<0.059	18	32
Chrysene	0.49	30	48	83	15	<0.059	91	89
Dibenzo[a,h]anthracene	<0.063	5.1	8.9	18	1.3	<0.059	2.9	8
Fluoranthene	2.7	25	46	130	75	0.16	560	350
Fluorene	1.5	27	39	100	73	0.36	560	300
Indeno(1,2,3-cd)pyrene	0.074	18	25	51	3.8	<0.059	9	25
Naphthalene	19	110	280	980	290	9.6	2,600	1,400
Phenanthrene	4.2	54	89	260	180	0.46	1,600	860
Pyrene	2	34	64	160	67	0.14	430	300
TOTAL PAHs	**38**	**579**	**1,133**	**2,927**	**1,021**	**14**	**7,704**	**4,786**
BTEX								
Benzene	<0.14	<0.13	1.8	13	0.05	0.07	0.31	4.2
Ethylbenzene	0.12	0.13	33	130	0.75	0.11	3	28
m+p-Xylene	0.09	0.1	32	120	0.62	<0.27	2.8	30
o-Xylene	0.06	0.07	13	57	0.38	<0.14	1.5	13
Toluene	<0.14	<0.13	0.4	<10	0.03	<0.14	1	<4.4
TOTAL BTEX	**0.3**	**0.3**	**80.2**	**320.0**	**1.8**	**0.2**	**8.6**	**75.2**

Notes:
1. All units are measured in milligrams per kilogram (mg/kg), unless otherwise indicated
2. < denotes less than the method detection limit (MDL)
3. Sample ID describes sample location, upper depth of the sampling interval, and date collected
(e.g., 2018QT-SB-TC05-15-06292018 represents a soil sample collected at TC-05 at a depth from approximately 15 to 16 ft bgs on 06/29/2018)
Indicates analyte measured above the MDL
Indicates J-flag (analyte measured above the MDL, but concentration is estimated)

Table 3
Summary of Vapour Sampling Results
Quendall Terminals
Renton, Washington

Sample Location	SP-101 (Raw Influent)		
Sample ID	2018QT-VP-SP101-0825-07222018	2018QT-VP-SP101-0805-07262018	2018QT-VP-SP101-1000-07292018
Sample Date	7/22/2018	7/26/2018	7/29/2018
Sample Time	8:25	8:05	10:00
Sulfur Compounds (ppbv)			
2,5-Dimethylthiophene	<8	<8.7	<10
2-Ethylthiophene	<8	<8.7	<10
3-Methylthiophene	<8	<8.7	<10
Carbon Disulfide	<4	<4.4	<5
Carbonyl Sulfide	8.3	<8.7	<10
Diethyl Disulfide	<4	<4.4	<5
Diethyl Sulfide	<8	<8.7	<10
Dimethyl Sulfide	<8	<8.7	<10
Dimethyldisulfide	<4	<4.4	<5
Ethyl Mercaptan	<8	<8.7	<10
Ethyl Methyl Sulfide	<8	<8.7	<10
Hydrogen Sulfide	<8	<8.7	<10
Isobutyl Mercaptan	<8	<8.7	<10
Isopropyl Mercaptan	<8	<8.7	<10
Methyl Mercaptan	<8	<8.7	<10
n-Butyl Mercaptan	<8	<8.7	<10
n-Propyl Mercaptan	<8	<8.7	<10
Tert-Butyl mercaptan	<8	<8.7	<10
Tetrahydrothiophene	<8	<8.7	<10
Thiophene	<8	<8.7	<10
Permanent Gases (%)			
Carbon Monoxide	0.201	0.206	<0.2
Carbon Dioxide	<0.16	<0.17	<0.2
Hydrogen	<0.16	<0.17	<0.2
Methane	<0.16	<0.17	<0.2
Nitrogen	77.8	77.8	77.7
Oxygen	22	22	22.2
Volatile Organic Compounds			
1,1,1-Trichloroethane	<2.2	<2.3	<2.7
1,1,2,2-Tetrachloroethane	<2.1	<2.3	<2.6
1,1,2-Trichloroethane	<2.1	<2.3	<2.6
1,1-Dichloroethane	1.2	1.5	1.3
1,1-Dichloroethene	<2.1	<2.3	<2.6
1,2,4-Trichlorobenzene	<2.2	<2.4	<2.7
1,2,4-Trimethylbenzene	150	160	480
1,2-Dibromo-3-chloropropane	<2.1	<2.3	<2.6
1,2-Dibromoethane	<2.1	<2.3	<2.6
1,2-Dichloro-1,1,2,2-tetrafluoroethane	<2	<2.2	<2.5
1,2-Dichlorobenzene	0.83	0.68	2.7
1,2-Dichloroethane	<2.1	<2.3	<2.6
1,2-Dichloropropane	<2.1	<2.3	<2.6
1,3,5-Trimethylbenzene	84	94	300
1,3-Butadiene	4.9	6.2	<2.6
1,3-Dichlorobenzene	<2.2	<2.3	<2.7
1,4-Dichlorobenzene	<2.1	<2.3	<2.6
1,4-Dioxane	<2.1	<2.3	<2.6
2-Butanone	2.6	4.2	10
2-Hexanone	<2.1	<2.3	<2.6
4-Ethyltoluene	85	100	290
4-Methyl-2-Pentanone	1.1	1.3	1.7
Acetone	21	28	81
Acetonitrile	<2.1	0.87	18
Acrolein	<4.4	<4.8	1.1
Acrylonitrile	<2.1	<2.3	1
Allyl chloride	<2.1	<2.3	<2.6
alpha-Pinene	12	9.9	14
Benzyl chloride	<4.4	<4.8	<5.5
Bromodichloromethane	<2.1	<2.3	<2.6
Bromoform	<2.1	<2.3	<2.6
Bromomethane	0.75	0.69	<2.5
Carbon Disulfide	11	20	15
Carbon tetrachloride	0.38	0.38	0.37
Chlorobenzene	<2.1	<2.3	<2.6
Chlorodibromomethane	<2.1	<2.3	<2.6
Chloroethane	<2	<2.2	<2.5
Chloroform	<2.1	<2.3	<2.6

Table 3
Summary of Vapour Sampling Results
Quendall Terminals
Renton, Washington

Sample Location	SP-101 (Raw Influent)		
Sample ID	2018QT-VP-SP101-0825-07222018	2018QT-VP-SP101-0805-07262018	2018QT-VP-SP101-1000-07292018
Sample Date	7/22/2018	7/26/2018	7/29/2018
Sample Time	8:25	8:05	10:00
Chloromethane	9.5	9.5	1.3
cis-1,2-Dichloroethene	<2.1	<2.3	<2.6
cis-1,3-Dichloropropene	<2.2	<2.4	<2.8
Cyclohexane	15	14	9.6
Dichlorodifluoromethane	2.3	2.2	2.1
Dichloromethane	<2.1	0.76	0.91
D-Limonene	<2	<2.2	<2.5
Ethanol	8.1	23	16
Ethyl acetate	1.8	11	<5.5
Ethylbenzene	--	390	--
Freon 113	0.42	0.4	<2.6
Hexachlorobutadiene	<2.1	<2.3	<2.6
Isopropyl Alcohol (Isopropanol)	<8.4	<9.1	3.3
Isopropylbenzene	58	50	160
m+p-Xylenes	540	520	--
Methyl methacrylate	<4.4	<4.8	<5.5
Methyl tert-butyl ether (MTBE)	<2.2	<2.3	<2.7
Naphthalene	230	310	--
N-Butyl Acetate	<2.1	<2.3	<2.6
N-HEPTANE	57	61	39
n-Hexane	32	23	10
Nonane	110	99	210
n-Propylbenzene	16	14	46
Octane	74	85	110
Propene	120	170	8.6
Styrene	13	12	38
Tetrachloroethene	0.62	0.6	1.6
Tetrahydrofuran	1.2	0.31	0.56
Toluene	390	450	--
trans-1,2-Dichloroethene	<2.2	<2.3	<2.7
trans-1,3-Dichloropropene	<2.1	<2.3	<2.6
Trichloroethylene	<2.1	0.33	0.61
Trichlorofluoromethane	1.1	1.2	1.1
Vinyl Acetate	<21	<23	<26
Vinyl Chloride	<2.1	<2.3	<2.6
Xylene, o	240	230	--

Notes:
1. All units are measured in micrograms per cubic meter for air (ug/m^3 air) unless otherwise indicated
2. < denotes less than the method detection limit (MDL)
3. Sample location SP-101 shown on drawing D03 of the STAR PDE Operation Work Plan

Shaded result denotes exceedance of reporting limit
Indicates J-flag (analyte measured above the MDL, but concentration is estimated)

Table 4
Summary of Soil Concentration Reductions (Inside Treatment Zone)
Quendall Terminals
Renton, Washington

Pre-STAR Location	IP-01														
Sample ID	2018QT-SB-IP01-11-06282018	PT-02-11	% Reduction	PT-07-9	% Reduction	2018QT-SB-IP01-14-06282018	PT-01-14	% Reduction	PT-02-14.5	% Reduction	PT-07-13.5	% Reduction	2018QT-SB-IP01-16-06282018	PT-01-15	% Reduction
Distance from IP-1 (ft)	--	2		2		--	1		2		2		--	1	
Depth (ft bgs)	11 - 12	11 - 12		9 - 11.5		14 - 15	14 - 15		14.5 - 15.5		13.5 - 14.5		16 - 17	15 - 16	
Date	6/28/2018	8/1/2018		8/1/2018		6/28/2018	8/1/2018		8/1/2018		8/1/2018		6/28/2018	8/1/2018	
Total Petroleum Hydrocarbons															
Gasoline Range Organics	390	510	-30.77%	580	-48.72%	1,800	12	99.33%	<6.1	98.92%	<6.2	99.83%	570	30	94.74%
Diesel Range Organics	2,800	260	90.71%	280	90.00%	1,700	460	97.09%	<39	97.12%	210	97.24%	2,700	810	70.00%
Motor Oil Range Organics	<140	<150	--	<140	--	<120	<99	--	<98	--	<94	--	<170	<100	--
TOTAL TPH	**3,190**	**770**	**75.86%**	**860**	**73.04%**	**3,500**	**472**	**86.51%**	**ND**	**99.44%**	**210**	**94.00%**	**3,270**	**840**	**74.31%**
Polycyclic Aromatic Hydrocarbons															
2-Chloronaphthalene	<0.29	<0.071	--	<0.068	--	<0.54	<0.05	--	<0.048	--	<0.049	--	<0.86	<0.1	--
2-Methylnaphthalene	80	10	87.50%	14	82.50%	60	2.9	95.17%	0.054	99.91%	1.1	98.17%	65	4.5	93.08%
Acenaphthene	120	1.5	98.75%	8.4	93.00%	18	2.2	87.78%	<0.048	99.87%	0.76	95.78%	61	3.2	94.75%
Acenaphthylene	0.97	<0.071	96.34%	0.11	88.66%	1	0.23	77.00%	<0.048	97.60%	0.097	90.30%	1.7	0.13	92.35%
Anthracene	61	0.16	99.74%	2.3	96.23%	5.1	0.94	81.57%	<0.048	99.53%	1.7	66.67%	38	2.6	93.16%
Benzo(a)anthracene	13	0.11	99.15%	0.76	94.15%	22	5.2	76.36%	<0.048	99.89%	0.82	96.27%	23	2.1	90.87%
Benzo(a)pyrene	4.5	<0.071	99.21%	0.25	94.44%	40	6.3	84.25%	<0.048	99.94%	0.87	97.83%	27	1.1	95.93%
Benzo(g,h,i)perylene	1.8	<0.071	98.03%	0.1	94.44%	23	8.4	63.48%	0.12	99.48%	5.1	77.83%	16	5.4	66.25%
Benzo[b]Fluoranthene	6.4	<0.071	99.45%	0.33	94.84%	53	18	66.04%	0.27	99.49%	14	73.58%	36	7.9	78.06%
Benzo[k]floranthene	3.4	<0.071	98.96%	0.14	95.88%	19	4	78.95%	0.058	99.69%	2.2	88.42%	12	1.9	84.17%
Chrysene	12	<0.071	99.70%	0.66	94.50%	24	9	62.50%	0.07	99.71%	3.5	85.42%	27	3.9	85.56%
Dibenzo[a,h]anthracene	0.61	<0.071	94.18%	<0.068	88.85%	5.7	2.5	56.14%	<0.048	99.58%	1.7	70.18%	4	1.4	65.00%
Fluoranthene	87	0.38	99.56%	4.3	95.06%	18	6.3	65.00%	0.065	99.64%	2	88.89%	66	5.6	91.52%
Fluorene	88	0.47	99.47%	4.9	94.43%	11	2.2	80.00%	<0.048	99.78%	0.77	93.00%	47	2.3	95.11%
Indeno(1,2,3-cd)pyrene	1.7	<0.071	97.91%	0.1	94.12%	16	5.7	64.38%	0.093	99.42%	3.8	76.25%	12	3.4	71.67%
Naphthalene	580	110	81.03%	96	83.45%	51	4.8	90.59%	0.19	99.63%	4.2	91.76%	230	22	90.43%
Phenanthrene	220	1.2	99.45%	13	94.09%	25	8.7	65.20%	0.064	99.74%	3	88.00%	140	8.1	94.21%
Pyrene	64	0.34	99.47%	3.4	94.69%	29	6	79.31%	<0.048	99.92%	0.93	96.79%	58	3.2	94.48%
TOTAL PAHs	**1,344**	**124**	**90.76%**	**149**	**88.94%**	**421**	**93**	**77.81%**	**1**	**99.77%**	**47**	**88.94%**	**864**	**79**	**90.88%**
BTEX															
Benzene	0.16	0.076	52.50%	0.17	-6.25%	1.7	<0.0015	99.96%	<0.0014	99.96%	0.023	98.65%	4.3	0.0019	99.96%
Ethylbenzene	1	1.5	-50.00%	1.4	-40.00%	13	0.0093	99.93%	<0.0014	99.99%	<0.0015	99.99%	16	0.031	99.81%
m+p-Xylene	0.53	0.68	-28.30%	0.59	-11.32%	14	<0.003	99.99%	<0.0029	99.99%	<0.0029	99.99%	1.6	0.015	99.06%
o-Xylene	0.54	0.75	-38.89%	0.8	-48.15%	5.3	0.0017	99.97%	<0.0014	99.99%	<0.0015	99.99%	0.76	0.0075	99.01%
Toluene	0.08	<0.0014	99.13%	0.02	75.00%	0.37	<0.0015	99.80%	<0.0014	99.81%	0.0027	99.27%	<0.94	<0.0017	--
TOTAL BTEX	**2.3**	**3.0**	**-30.13%**	**3.0**	**-29.00%**	**34.4**	**0.01**	**99.97%**	**ND**	**99.81%**	**0.03**	**99.93%**	**22.7**	**0.06**	**99.76%**

Notes:
1. All units are measured in milligrams per kilogram (mg/kg), unless otherwise indicated
2. < denotes less than the method detection limit (MDL)
3. Sample ID describes sample location, upper depth of sampling interval, and date collected
(e.g., 2018QT-SB-IP01-6.5-06282018 represents a soil sample collected at IP-01 at a depth from approximately 6.5 to 7.5 ft bgs on 06/28/2018)
4. For the calculation of % reduction for compounds less than the detection limit, the concentration was taken as 50%*detection limit
-- Not measured, or % reduction not calculated (if both pre- and post-STAR concentrations are below the detection limit)

Indicates analyte measured above the MDL
Indicates J-flag (analyte measured above the MDL, but concentration is estimated)
Greater than 70% reduction achieved
Greater than 90% reduction achieved

Table 4
Summary of Soil Concentration Reductions (Inside Treatment Zone)
Quendall Terminals
Renton, Washington

Pre-STAR Location	**TC-16**						**IP-02**					
Sample ID	2018QT-SB-TC16-14-07022018	PT-04-14	% Reduction	2018QT-SB-TC16-15-07022018	PT-04-15	% Reduction	2018QT-SB-IP02-10-06282018	PT-03-10	% Reduction	2018QT-SB-IP02-15-06282018	PT-03-15	% Reduction
Distance from IP-1 (ft)	5	4		5	4		5.5	4		5.5	4	
Depth (ft bgs)	14 - 15	14 - 15		15 - 16	15 - 16		10 - 11	10 - 11		15 - 16	15 - 16	
Date	7/2/2018	8/1/2018		7/2/2018	8/1/2018		6/28/2018	8/1/2018		6/28/2018	8/1/2018	
Total Petroleum Hydrocarbons												
Gasoline Range Organics	4,800	<7.7	99.92%	16,000	1000	93.75%	1,000	240	76.00%	450	<10	98.89%
Diesel Range Organics	4,600	1400	69.57%	8,800	760	91.36%	3,200	590	81.56%	1,600	360	77.50%
Motor Oil Range Organics	<120	<100	--	<150	<120	--	<120	<150	--	<120	<100	--
TOTAL TPH	**9,400**	**1,400**	**85.11%**	**24,800**	**1,760**	**92.90%**	**4,200**	**830**	**80.24%**	**2,050**	**360**	**82.44%**
Polycyclic Aromatic Hydrocarbons												
2-Chloronaphthalene	<0.49	<0.2	--	<0.75	<0.12	--	<0.23	<0.073	--	<0.49	<0.051	--
2-Methylnaphthalene	190	2.1	98.89%	400	15	96.25%	92	56	39.13%	24	4	83.33%
Acenaphthene	71	4.1	94.23%	160	6.9	95.69%	95	22	76.84%	14	5.3	62.14%
Acenaphthylene	2.1	1	52.38%	5.3	0.42	92.08%	1.2	0.46	61.67%	0.87	0.31	64.37%
Anthracene	13	9.2	29.23%	40	2.3	94.25%	42	4.8	88.57%	4.5	8.1	-80.00%
Benzo(a)anthracene	37	36	2.70%	95	11	88.42%	9	2.2	75.56%	17	4.4	74.12%
Benzo(a)pyrene	71	44	38.03%	140	18	87.14%	2.9	0.67	76.90%	31	5.7	81.61%
Benzo(g,h,i)perylene	34	47	-38.24%	80	13	83.75%	0.95	0.2	78.95%	18	6.2	65.56%
Benzo[b]Fluoranthene	89	90	-1.12%	180	6.8	96.22%	4.4	1	77.27%	43	13	69.77%
Benzo[k]floranthene	26	34	-30.77%	45	7.7	82.89%	1.6	0.37	76.88%	11	2.9	73.64%
Chrysene	48	62	-29.17%	83	13	84.34%	8.2	1.9	76.83%	20	6.1	69.50%
Dibenzo[a,h]anthracene	8.9	10	-12.36%	18	3.6	80.00%	0.38	0.086	77.37%	4.6	2	56.52%
Fluoranthene	46	46	0.00%	130	23	82.31%	66	12	81.82%	14	7.5	46.43%
Fluorene	39	7.7	80.26%	100	4.5	95.50%	78	14	82.05%	9.3	3.6	61.29%
Indeno(1,2,3-cd)pyrene	25	32	-28.00%	51	9.8	80.78%	1	0.23	77.00%	13	4.8	63.08%
Naphthalene	280	2	99.29%	980	63	93.57%	320	65	79.69%	16	5.2	67.50%
Phenanthrene	89	85	4.49%	260	19	92.69%	190	31	83.68%	20	15	25.00%
Pyrene	64	38	40.63%	160	28	82.50%	49	8.8	82.04%	22	6.3	71.36%
TOTAL PAHs	**1,133**	**550**	**51.45%**	**2,927**	**245**	**91.63%**	**962**	**221**	**77.05%**	**282**	**100**	**64.43%**
BTEX												
Benzene	1.8	0.0021	99.88%	13	0.0024	99.98%	0.18	0.58	-222.22%	0.26	<0.0013	99.75%
Ethylbenzene	33	0.0027	99.99%	130	0.004	100.00%	1.4	2	-42.86%	2.1	0.021	99.00%
m+p-Xylene	32	<0.0031	100.00%	120	<0.0027	100.00%	1.3	0.26	80.00%	1.9	0.024	98.74%
o-Xylene	13	<0.0016	99.99%	57	<0.0013	100.00%	0.7	0.89	-27.14%	0.92	0.012	98.70%
Toluene	0.4	0.004	99.00%	<10	<0.0013	--	0.35	0.013	96.29%	0.05	0.0038	92.40%
TOTAL BTEX	**80.2**	**0.01**	**99.99%**	**320.0**	**0.01**	**100.00%**	**3.9**	**3.74**	**4.76%**	**5.2**	**0.06**	**98.84%**

Notes:

1. All units are measured in milligrams per kilogram (mg/kg), unless otherwise indicated
2. < denotes less than the method detection limit (MDL)
3. Sample ID describes sample location, upper depth of sampling interval, and date collected
(e.g., 2018QT-SB-IP01-6.5-06282018 represents a soil sample collected at IP-01 at a depth from approximately 6.5 to 7.5 ft bgs on 06/28/2018)
4. For the calculation of % reduction for compounds less than the detection limit, the concentration was taken as 50%*detection limit

-- Not measured, or % reduction not calculated (if both pre- and post-STAR concentrations are below the detection limit)

Indicates analyte measured above the MDL
Indicates J-flag (analyte measured above the MDL, but concentration is estimated)
Greater than 70% reduction achieved
Greater than 90% reduction achieved

Table 4
Summary of Soil Concentration Reductions (Inside Treatment Zone)
Quendall Terminals
Renton, Washington

Pre-STAR Location	**TC-20**					
Sample ID	2018QT-SB-TC20-11-07022018	PT-08-9	% Reduction	2018QT-SB-TC20-15-07022018	PT-08-14.5	% Reduction
Distance from IP-1 (ft)	6	5		6	5	
Depth (ft bgs)	11 - 12	9 - 10.5		15 - 16	14.5 - 15.25	
Date	7/2/2018	8/2/2018		7/2/2018	8/2/2018	
Total Petroleum Hydrocarbons						
Gasoline Range Organics	1,700	56	96.71%	5,300	<6	99.94%
Diesel Range Organics	18,000	59	99.67%	14,000	130	99.07%
Motor Oil Range Organics	<130	<120	--	<160	<100	--
TOTAL TPH	**19,700**	**115**	**99.42%**	**19,300**	**130**	**99.33%**
Polycyclic Aromatic Hydrocarbons						
2-Chloronaphthalene	<0.66	<0.063	--	<0.83	<0.05	--
2-Methylnaphthalene	640	2.4	99.63%	600	2	99.67%
Acenaphthene	790	0.77	99.90%	400	12	97.00%
Acenaphthylene	7.9	<0.063	99.60%	14	0.21	98.50%
Anthracene	220	<0.063	99.99%	130	0.61	99.53%
Benzo(a)anthracene	100	<0.063	99.97%	100	0.29	99.71%
Benzo(a)pyrene	28	<0.063	99.89%	61	0.21	99.66%
Benzo(g,h,i)perylene	9.3	<0.063	99.66%	30	0.097	99.68%
Benzo[b]Fluoranthene	38	<0.063	99.92%	87	0.27	99.69%
Benzo[k]floranthene	18	<0.063	99.83%	32	0.1	99.69%
Chrysene	91	<0.063	99.97%	89	0.23	99.74%
Dibenzo[a,h]anthracene	2.9	<0.063	98.91%	8	<0.05	99.69%
Fluoranthene	560	0.081	99.99%	350	0.51	99.85%
Fluorene	560	0.19	99.97%	300	3.6	98.80%
Indeno(1,2,3-cd)pyrene	9	<0.063	99.65%	25	0.08	99.68%
Naphthalene	2,600	17	99.35%	1,400	0.79	99.94%
Phenanthrene	1,600	0.17	99.99%	860	2.8	99.67%
Pyrene	430	<0.063	99.99%	300	0.64	99.79%
TOTAL PAHs	**7,704**	**21**	**99.73%**	**4,786**	**24**	**99.49%**
BTEX						
Benzene	0.31	0.08	74.19%	4.2	<0.0011	99.99%
Ethylbenzene	3	0.19	93.67%	28	<0.0011	100.00%
m+p-Xylene	2.8	0.013	99.54%	30	<0.0023	100.00%
o-Xylene	1.5	0.11	92.67%	13	<0.0011	100.00%
Toluene	1	0.0023	99.77%	<4.4	<0.0011	--
TOTAL BTEX	**8.6**	**0.40**	**95.41%**	**75.2**	**ND**	**100.00%**

Notes:
1. All units are measured in milligrams per kilogram (mg/kg), unless otherwise indicated
2. < denotes less than the method detection limit (MDL)
3. Sample ID describes sample location, upper depth of sampling interval, and date collected
(e.g., 2018QT-SB-IP01-6.5-06282018 represents a soil sample collected at IP-01 at a depth from approximately 6.5 to 7.5 ft bgs on 06/28/2018)
4. For the calculation of % reduction for compounds less than the detection limit, the concentration was taken as 50%*detection limit
-- Not measured, or % reduction not calculated (if both pre- and post-STAR concentrations are below the detection limit)

Indicates analyte measured above the MDL
Indicates J-flag (analyte measured above the MDL, but concentration is estimated)
Greater than 70% reduction achieved
Greater than 90% reduction achieved

Table 5
Summary of Soil Concentration Reductions (At ROI and Outside Treatment Zone)
Quendall Terminals
Renton, Washington

Pre-STAR Location	**TC-11 (At ROI)**					**TC-06 (At ROI)**			**TC-05 (Outside Treatment Zone)**		
Sample ID	2018QT-SB-TC11-13.5FD-07022018	PT-10-14.5	% Reduction	PT-10-15.25	% Reduction	2018QT-SB-TC06-15.5-06292018	PT-06-14.8	% Reduction	2018QT-SB-TC05-15-06292018	PT-09-14.1	% Reduction
Distance from IP-1 (ft)	10.5	7		7		8.5	7		10	9	
Depth (ft bgs)	13.5 - 15	14.5 - 15.25		15.25 - 16		15.5 - 17	14.8 - 15.6		15 - 16	14.1 - 15	
Date	7/2/2018	8/2/2018		8/2/2018		6/29/2018	8/1/2018		6/29/2018	8/2/2018	
Total Petroleum Hydrocarbons											
Gasoline Range Organics	2,000	20	99.00%	<5.6	99.86%	1,000	<5.9	99.71%	90	19	78.89%
Diesel Range Organics	6,500	3300	49.23%	680	89.54%	6,500	2000	69.23%	7,900	6100	61.39%
Motor Oil Range Organics	<110	<100	--	<95	--	<140	<96	--	<120	<100	--
TOTAL TPH	**8,500**	**3,320**	**60.94%**	**680**	**92.00%**	**7,500**	**2,000**	**73.33%**	**7,990**	**6,119**	**23.42%**
Polycyclic Aromatic Hydrocarbons											
2-Chloronaphthalene	<0.56	<0.23	--	<0.1	--	<0.71	<0.19	--	<0.55	<0.26	--
2-Methylnaphthalene	210	13	93.81%	1.5	99.29%	290	14	95.17%	320	270	15.63%
Acenaphthene	72	56	22.22%	1.1	98.47%	80	3.5	95.63%	190	180	5.26%
Acenaphthylene	2.6	2	23.08%	0.44	83.08%	3.4	0.95	72.06%	7.1	6	15.49%
Anthracene	15	14	6.67%	1.5	90.00%	21	4.4	79.05%	64	62	3.13%
Benzo(a)anthracene	60	51	15.00%	16	73.33%	52	45	13.46%	57	56	1.75%
Benzo(a)pyrene	97	72	25.77%	21	78.35%	84	48	42.86%	53	70	-32.08%
Benzo(g,h,i)perylene	57	47	17.54%	18	68.42%	43	45	-4.65%	24	44	-83.33%
Benzo[b]Fluoranthene	120	94	21.67%	41	65.83%	110	100	9.09%	67	86	-28.36%
Benzo[k]floranthene	31	37	-19.35%	15	51.61%	30	42	-40.00%	23	32	-39.13%
Chrysene	59	61	-3.39%	21	64.41%	71	66	7.04%	52	64	-23.08%
Dibenzo[a,h]anthracene	13	11	15.38%	4.4	66.15%	13	12	7.69%	6	11	-83.33%
Fluoranthene	56	59	-5.36%	16	71.43%	52	47	9.62%	170	130	23.53%
Fluorene	30	36	-20.00%	2.5	91.67%	36	11	69.44%	140	130	7.14%
Indeno(1,2,3-cd)pyrene	37	35	5.41%	14	62.16%	33	36	-9.09%	18	32	-77.78%
Naphthalene	780	11	98.59%	3.6	99.54%	950	17	98.21%	710	120	83.10%
Phenanthrene	77	96	-24.68%	18	76.62%	100	74	26.00%	370	350	5.41%
Pyrene	82	89	-8.54%	16	80.49%	70	38	45.71%	150	130	13.33%
TOTAL PAHs	**1,799**	**784**	**56.41%**	**211**	**88.27%**	**2,038**	**604**	**70.38%**	**2,421**	**1,773**	**26.77%**
BTEX											
Benzene	0.47	<0.0011	99.88%	0.0044	99.06%	3.6	<0.0012	99.98%	0.65	<0.0012	99.91%
Ethylbenzene	12	<0.0011	100.00%	0.011	99.91%	9.7	<0.0012	99.99%	3.9	<0.0012	99.98%
m+p-Xylene	14	<0.0023	99.99%	0.014	99.90%	11	<0.0024	99.99%	3.8	<0.0024	99.97%
o-Xylene	5.8	<0.0011	99.99%	0.0045	99.92%	4.5	<0.0012	99.99%	1.8	<0.0012	99.97%
Toluene	0.7	<0.0011	99.92%	0.0029	99.59%	0.17	<0.0012	99.65%	0.11	<0.0012	99.45%
TOTAL BTEX	**33.0**	**ND**	**100.00%**	**0.04**	**99.89%**	**29.0**	**ND**	**100.00%**	**10.3**	**ND**	**99.99%**

Notes:
1. All units are measured in milligrams per kilogram (mg/kg), unless otherwise indicated
2. < denotes less than the method detection limit (MDL)
3. Sample ID describes sample location, upper depth of sampling interval, and date collected
(e.g., 2018QT-SB-IP01-6.5-06282018 represents a soil sample collected at IP-01 at a depth from approximately 6.5 to 7.5 ft bgs on 06/28/2018)
4. For the calculation of % reduction for compounds less than the detection limit, the concentration was taken as 50%*detection limit
-- Not measured, or % reduction not calculated (if both pre- and post-STAR concentrations are below the detection limit)

Indicates analyte measured above the MDL
Indicates J-flag (analyte measured above the MDL, but concentration is estimated)
Greater than 70% reduction achieved
Greater than 90% reduction achieved

Table 6
Post-STAR Soil Analytical Results with No Pre-STAR Comparison
Quendall Terminals
Renton, Washington

Boring ID	**PT-05**		**PT-06**	**PT-09**
Sample ID	PT-05-11.2	PT-05-14.8	PT-06-11	PT-09-11
Distance from IP-1 (ft)	4	4	7	9
Depth (ft bgs)	11.2 - 12	14.8 - 15.8	11 - 12	11 - 12
Date	8/1/2018	8/1/2018	8/1/2018	8/2/2018
Petroleum Hydrocarbons				
Gasoline Range Organics	<5.3	<6.9	210	<5.6
Diesel Range Organics	3600	620	2000	<41
Motor Oil Range Organics	<99	<98	<110	<100
TOTAL TPH	**3,600**	**620**	**2,210**	**ND**
Polycyclic Aromatic Hydrocarbons (PAHs)				
2-Chloronaphthalene	<0.22	<0.095	<0.24	<0.052
2-Methylnaphthalene	4.6	0.74	2.8	0.68
Acenaphthene	56	1.8	25	1.7
Acenaphthylene	1.3	0.3	1	0.063
Anthracene	22	4.1	9	0.25
Benzo(a)anthracene	53	12	39	0.13
Benzo(a)pyrene	59	6	63	<0.052
Benzo(g,h,i)perylene	55	6.6	41	<0.052
Benzo[b]Fluoranthene	100	20	77	<0.052
Benzo[k]floranthene	40	4.5	28	<0.052
Chrysene	75	21	41	0.052
Dibenzo[a,h]anthracene	12	2	9.8	<0.052
Fluoranthene	180	32	47	0.28
Fluorene	67	11	26	0.85
Indeno(1,2,3-cd)pyrene	42	5.1	31	<0.052
Naphthalene	2.6	2	2.7	0.69
Phenanthrene	250	71	61	1
Pyrene	120	25	55	0.52
TOTAL PAHs	**1,140**	**225**	**559**	**6**
BTEX				
Benzene	<0.0012	<0.0015	0.059	<0.0011
Ethylbenzene	0.0027	0.011	0.59	<0.0011
MP-Xylene	<0.0024	0.012	0.21	<0.0023
o-Xylene	<0.0012	0.0044	0.26	<0.0011
Toluene	<0.0012	0.0052	<0.0012	<0.0011
TOTAL BTEX	**0.003**	**0.033**	**1.1**	**ND**

Notes:
1. All units are measured in milligrams per kilogram (mg/kg), unless otherwise indicated
2. < denotes less than the method detection limit (MDL)
3. Sample ID describes sample location and upper depth of the sampling interval
(e.g., PT-05-11.2 represents a soil sample collected at PT-05 at a depth from approximately 11.2 to 12 ft bgs)

Indicates analyte measured above the MDL
Indicates J-flag (analyte measured above the MDL, but concentration is estimated)

Table 7
Additional Drilling Investigation Soil Analytical Results (QP-1 Area)
Quendall Terminals
Renton, Washington

Boring ID	**QP-1-01**			**QP-1-02**		**QP-1-03**		**QP-1-04**		**QP-1-05**	
Sample ID	2018QT-SB-QP101-17-08222018	2018QT-SB-QP101-17FD-08222018	2018QT-SB-QP101-20.9-08222018	2018QT-SB-QP102-20-08222018	2018QT-SB-QP102-21.1-08222018	2018QT-SB-QP103-19-08222018	2018QT-SB-QP103-21.1-08222018	2018QT-SB-QP104-14-08232018	2018QT-SB-QP104-16.6-08232018	2018QT-SB-QP105-14-08232018	2018QT-SB-QP105-16.8-08232018
Depth (ft bgs)	17 - 19	17 - 19 (Duplicate)	20.9 - 21.9	20 - 21.1	21.1 - 22.2	19 - 20	21.1 - 22.1	14 - 15	16.6 - 17.6	14 - 15	16.8 - 17.8
Date	8/22/2018	8/22/2018	8/22/2018	8/22/2018	8/22/2018	8/22/2018	8/22/2018	8/23/2018	8/23/2018	8/23/2018	8/23/2018
Petroleum Hydrocarbons											
Gasoline Range Organics	900	2,000	2,200	5,000	610	420	28	15	600	<6.4	7.1
Diesel Range Organics	8,400	8,800	15,000	1,300	6,500	2,800	<48	<50	180	<49	<49
Motor Oil Range Organics	<120	<120	<120	<120	<120	<130	<120	<120	<150	<120	<120
TOTAL TPH	**9,300**	**10,800**	**17,200**	**6,300**	**7,110**	**3,220**	**28**	**15**	**780**	**ND**	**7**
Polycyclic Aromatic Hydrocarbons (PAHs)											
2-Methylnaphthalene	330	250	180	40	180	16	8.8	0.8	4.3	0.25	0.2
Acenaphthene	50	37	34	8.1	29	4.4	3.6	0.26	<7	0.06	0.098
Acenaphthylene	41	31	13	5.7	21	<7.5	0.21	<0.2	<7	<0.21	<0.22
Anthracene	30	23	15	4.3	17	2.4	1.6	0.073	<7	<0.21	<0.22
Benzo(a)anthracene	32	24	25	5.8	18	2.6	2.1	0.1	<7	<0.21	<0.22
Benzo(a)pyrene	56	43	45	9.7	32	4.3	3.5	0.19	<7	<0.21	<0.22
Benzo[b]Fluoranthene	67	51	54	11	36	4.8	4.4	0.22	<7	<0.21	<0.22
Benzo(g,h,i)perylene	31	26	26	6.4	20	2.8	2	0.097	<7	<0.21	<0.22
Benzo[k]floranthene	18	13	14	3.2	11	<7.5	1.3	0.069	<7	<0.21	<0.22
Chrysene	45	35	39	7.9	26	12	2.9	0.14	<7	<0.21	<0.22
Dibenzo[a,h]anthracene	8	6.6	7.2	<5.9	5	<7.5	0.55	<0.2	<7	<0.21	<0.22
Fluoranthene	65	48	37	10	36	4.2	3.3	0.16	<7	<0.21	<0.22
Fluorene	47	35	18	6.9	26	3.3	2.3	0.13	<7	<0.21	<0.22
Indeno(1,2,3-cd)pyrene	22	18	19	4.4	14	<7.5	1.4	0.07	<7	<0.21	<0.22
Naphthalene	1,200	940	540	130	560	40	13	3	40	2.6	1.2
Phenanthrene	160	120	57	18	69	9.1	6.3	0.32	<7	<0.21	0.064
Pyrene	57	44	37	9.9	33	4.5	3.2	0.16	<7	<0.21	<0.22
TOTAL PAHs	**2,259**	**1,745**	**1,160**	**281**	**1,133**	**110**	**60**	**6**	**44**	**3**	**2**
BTEX											
Benzene	35	8.4	110	0.74	5.9	0.77	0.75	0.2	0.56	0.19	0.32
Ethylbenzene	190	38	500	2	35	2.3	0.55	0.015	0.16	0.025	0.16
m+p-Xylene	220	47	610	1.9	39	0.65	0.058	<0.0051	0.0042	<0.0058	0.0073
o-Xylene	83	19	230	0.9	15	0.42	0.12	0.0021	0.026	0.0038	0.018
Toluene	62	15	210	0.32	8.2	<0.48	<0.29	<0.0051	<0.0066	<0.0058	<0.0058
TOTAL BTEX	**590**	**127**	**1,660**	**5.9**	**103**	**4.1**	**1.5**	**0.2**	**0.8**	**0.2**	**0.5**

Notes:
1. All units are measured in milligrams per kilogram (mg/kg), unless otherwise indicated
2. < denotes less than the method detection limit (MDL)
3. Sample ID describes sample location, upper depth of the sampling interval, and date collected
(e.g., 2018QT-SB-QP101-17-08222018 represents a soil sample collected at QP1-01 at a depth from approximately 17 to 19 ft bgs on 08/22/2018)
Indicates analyte measured above the MDL
Indicates J-flag (analyte measured above the MDL, but concentration is estimated)
-- No result reported
ND - non detect

Table 7
Additional Drilling Investigation Soil Analytical Results (QP-1 Area)
Quendall Terminals
Renton, Washington

Boring ID	**QP-1-06**		**QP-1-07**		**QP-1-08**		**QP-1-09**		**QP-1-10**			
Sample ID	2018QT-SB-QP106-10.9-08232018	2018QT-SB-QP106-15-08232018	2018QT-SB-QP107-10.7-08222018	2018QT-SB-QP107-15.7-08222018	2018QT-SB-QP108-19-08222018	2018QT-SB-QP108-21.1-08222018	2018QT-SB-QP109-10.7-08222018	2018QT-SB-QP109-18.5-08222018	2018QT-SB-QP110-10.5-08222018	2018QT-SB-QP110-17.5-08222018	2018QT-SB-QP-17.5FD-08222018	2018QT-SB-QP110-20.9-08222018
Depth (ft bgs)	10.9 - 11.9	15 - 15.8	10.7 - 11.7	15.7 - 16.7	19 - 20	21.1 - 22.3	10.7 - 11.5	18.5 - 19.3	10.5 - 11.5	17.5 - 19.5	17.5 - 19.5 (Duplicate)	20.9 - 21.8
Date	8/23/2018	8/23/2018	8/22/2018	8/22/2018	8/22/2018	8/22/2018	8/22/2018	8/22/2018	8/22/2018	8/22/2018	8/22/2018	8/22/2018
Petroleum Hydrocarbons												
Gasoline Range Organics	22	<6.3	14	9.4	11	210	<10	110	27	6.5	23	280
Diesel Range Organics	<55	<49	<55	<59	10,000	4,100	1,400	<48	1,800	720	550	940
Motor Oil Range Organics	<140	<120	<140	<150	<120	<120	<120	<120	<120	<120	<120	<120
TOTAL TPH	**22**	**ND**	**14**	**9**	**10,011**	**4,310**	**1,400**	**110**	**1,827**	**727**	**573**	**1,220**
Polycyclic Aromatic Hydrocarbons (PAHs)												
2-Methylnaphthalene	0.47	0.14	0.11	0.14	190	71	30	3.5	12	11	11	23
Acenaphthene	2.7	0.6	1.2	2.4	59	22	160	8.7	34	5.5	5.7	11
Acenaphthylene	<0.22	0.13	<0.21	<0.26	2.3	<5.5	0.58	<0.2	0.17	0.33	0.36	0.56
Anthracene	0.094	0.4	<0.21	<0.26	23	8.4	63	3	11	2.6	3	4.1
Benzo(a)anthracene	<0.22	0.25	<0.21	<0.26	28	11	36	1.8	4.4	4.7	4.6	6.7
Benzo(a)pyrene	<0.22	0.29	<0.21	<0.26	52	21	<81	0.55	1.5	8.5	8.3	13
Benzo[b]Fluoranthene	<0.22	0.35	<0.21	<0.26	62	23	<81	0.81	2.1	9.9	9.7	14
Benzo(g,h,i)perylene	<0.22	0.15	<0.21	<0.26	32	13	3.1	0.096	0.25	4.7	4.6	8.7
Benzo[k]floranthene	<0.22	0.1	<0.21	<0.26	16	7.6	<81	0.31	0.77	3	2.9	4.2
Chrysene	<0.22	0.34	<0.21	<0.26	32	13	33	1.6	4.3	4.8	4.3	7.4
Dibenzo[a,h]anthracene	<0.22	<0.21	<0.21	<0.26	8.2	3.2	1.2	<0.2	0.098	1.2	1.3	1.8
Fluoranthene	0.19	0.69	<0.21	<0.26	51	19	220	13	31	7.5	7.4	10
Fluorene	1.1	0.43	0.54	1.1	37	14	190	9.2	29	3.6	3.8	6.1
Indeno(1,2,3-cd)pyrene	<0.22	0.12	<0.21	<0.26	22	8.9	<81	0.11	0.28	3.1	3.3	5.8
Naphthalene	0.12	0.081	0.063	1.5	400	190	<81	7.9	10	27	27	61
Phenanthrene	2.1	1.2	0.29	0.5	110	36	650	33	88	11	12	19
Pyrene	0.11	0.67	<0.21	<0.26	52	18	180	9.4	23	7.4	7.4	11
TOTAL PAHs	**7**	**6**	**2**	**6**	**1,177**	**479**	**1,567**	**93**	**252**	**116**	**117**	**207**
BTEX												
Benzene	0.0014	<0.0049	<0.0054	<0.0069	3.2	1.5	<0.33	0.12	<0.3	0.4	0.65	1.9
Ethylbenzene	0.00091	0.00018	<0.0054	0.0008	21	3.7	0.052	0.067	<0.3	0.53	0.85	4.8
m+p-Xylene	<0.0053	<0.0049	<0.0054	<0.0069	3.2	0.56	0.037	0.0095	<0.3	0.04	0.063	0.073
o-Xylene	0.00085	0.00019	0.00022	0.00034	3.5	0.61	0.037	0.019	<0.3	0.11	0.16	0.4
Toluene	<0.0053	<0.0049	<0.0054	<0.0069	<1.1	<0.29	<0.33	<0.0064	<0.3	<0.31	<0.31	<0.33
TOTAL BTEX	**0.003**	**0.0004**	**0.0002**	**0.001**	**30.9**	**6.4**	**0.1**	**0.2**	**ND**	**1.1**	**1.7**	**7.2**

Notes:
1. All units are measured in milligrams per kilogram (mg/kg), unless otherwise indicated
2. < denotes less than the method detection limit (MDL)
3. Sample ID describes sample location, upper depth of the sampling interval, and date collected
(e.g., 2018QT-SB-QP101-17-08222018 represents a soil sample collected at QP1-01 at a depth from approximately 17 to 19 ft bgs on 08/22/2018)

Indicates analyte measured above the MDL
Indicates J-flag (analyte measured above the MDL, but concentration is estimated)
-- No result reported
ND - non detect

Table 8
Additional Drilling Investigation Soil Analytical Results (MC-1 Area)
Quendall Terminals
Renton, Washington

Boring ID	MC-1-01				MC-1-02		MC-1-03		MC-1-04		
Sample ID	2018QT-SB-MC101-12.5-082318	2018QT-SB-MC101-17.5-08232018	2018QT-SB-MC101-20-08232018	2018QT-SB-MC101-20FD-08232018	2018QT-SB-MC102-18.3-08232018	2018QT-SB-MC102-30-08232018	2018QT-SB-MC103-20.5-08242018	2018QT-SB-MC103-25-08242018	2018QT-SB-MC104-10.2-08242018	2018QT-SB-MC104-17.5-08242018	2018QT-SB-MC104-17.5FD-08242018
Depth (ft bgs)	12.5 - 13	17.5 - 18.5	20 - 21.6	20 - 21.6 (Duplicate)	18.3 - 19.3	30 - 30.9	20.5 - 21.5	25 - 25.5	10.2 - 11.1	17.5 - 19.5	17.5 - 19.5 (Duplicate)
Date	8/23/2018	8/23/2018	8/23/2018	8/23/2018	8/23/2018	8/23/2018	8/24/2018	8/24/2018	8/24/2018	8/24/2018	8/24/2018
Petroleum Hydrocarbons											
Gasoline Range Organics	8,000	15,000	430	800	4,400	1,600	1,600	--	5,200	830	33,000
Diesel Range Organics	110,000	37,000	9,400	8,600	32,000	27,000	13,000	100,000	6,600	59,000	59,000
Motor Oil Range Organics	<610	<110	<110	<110	<110	<130	<130	<620	<140	<120	<620
TOTAL TPH	**118,000**	**52,000**	**9,830**	**9,400**	**36,400**	**28,600**	**14,600**	**100,000**	**11,800**	**59,830**	**92,000**
Polycyclic Aromatic Hydrocarbons (PAHs)											
2-Methylnaphthalene	1,600	640	150	240	980	830	270	1,300	110	890	790
Acenaphthene	1,000	470	110	180	600	510	180	800	70	640	570
Acenaphthylene	21	7.8	2.2	3	9.9	7.4	2.5	16	<6.4	<61	<57
Anthracene	800	740	410	620	2200	1,700	77	340	38	240	220
Benzo(a)anthracene	540	210	54	75	280	230	69	270	19	220	210
Benzo(a)pyrene	440	160	40	57	220	180	57	220	15	180	170
Benzo[b]Fluoranthene	530	200	52	69	250	210	68	260	18	220	210
Benzo(g,h,i)perylene	180	75	13	23	91	75	29	110	7.6	99	91
Benzo[k]floranthene	160	82	15	21	110	75	23	81	4.5	67	65
Chrysene	650	680	320	520	2,000	1,500	45	210	21	150	140
Dibenzo[a,h]anthracene	54	23	4.5	7.7	40	25	6.9	28	1.7	23	22
Fluoranthene	1,500	670	140	230	820	690	240	1,100	88	900	850
Fluorene	850	380	94	150	470	400	130	560	47	420	380
Indeno(1,2,3-cd)pyrene	140	61	11	19	73	60	21	84	5.4	72	67
Naphthalene	2,700	580	73	110	860	560	400	2,400	87	2,000	1,800
Phenanthrene	3,000	1,400	330	540	1,800	1,500	540	2,500	200	1,900	1,800
Pyrene	1,300	590	130	210	780	630	230	1,100	86	810	760
TOTAL PAHs	**15,465**	**6,969**	**1,949**	**3,075**	**11,584**	**9,182**	**2,388**	**11,379**	**818**	**8,831**	**8,145**
BTEX											
Benzene	5.4	<0.56	<1.3	<0.32	<2.8	<3.6	<1.9	--	<0.4	<42	<0.34
Ethylbenzene	77	0.061	0.78	0.29	3.9	0.97	<1.9	--	0.85	130	<0.34
m+p-Xylene	110	0.043	0.48	0.2	3.1	1.1	<1.9	--	<0.4	130	<0.34
o-Xylene	50	0.039	0.44	0.18	2.4	0.66	<1.9	--	0.41	63	<0.34
Toluene	39	<0.56	<1.3	0.014	<2.8	<3.6	<1.9	--	<0.4	<42	<0.34
TOTAL BTEX	**281.4**	**0.1**	**1.7**	**0.7**	**9.4**	**2.7**	**ND**	**--**	**1.3**	**323.0**	**ND**

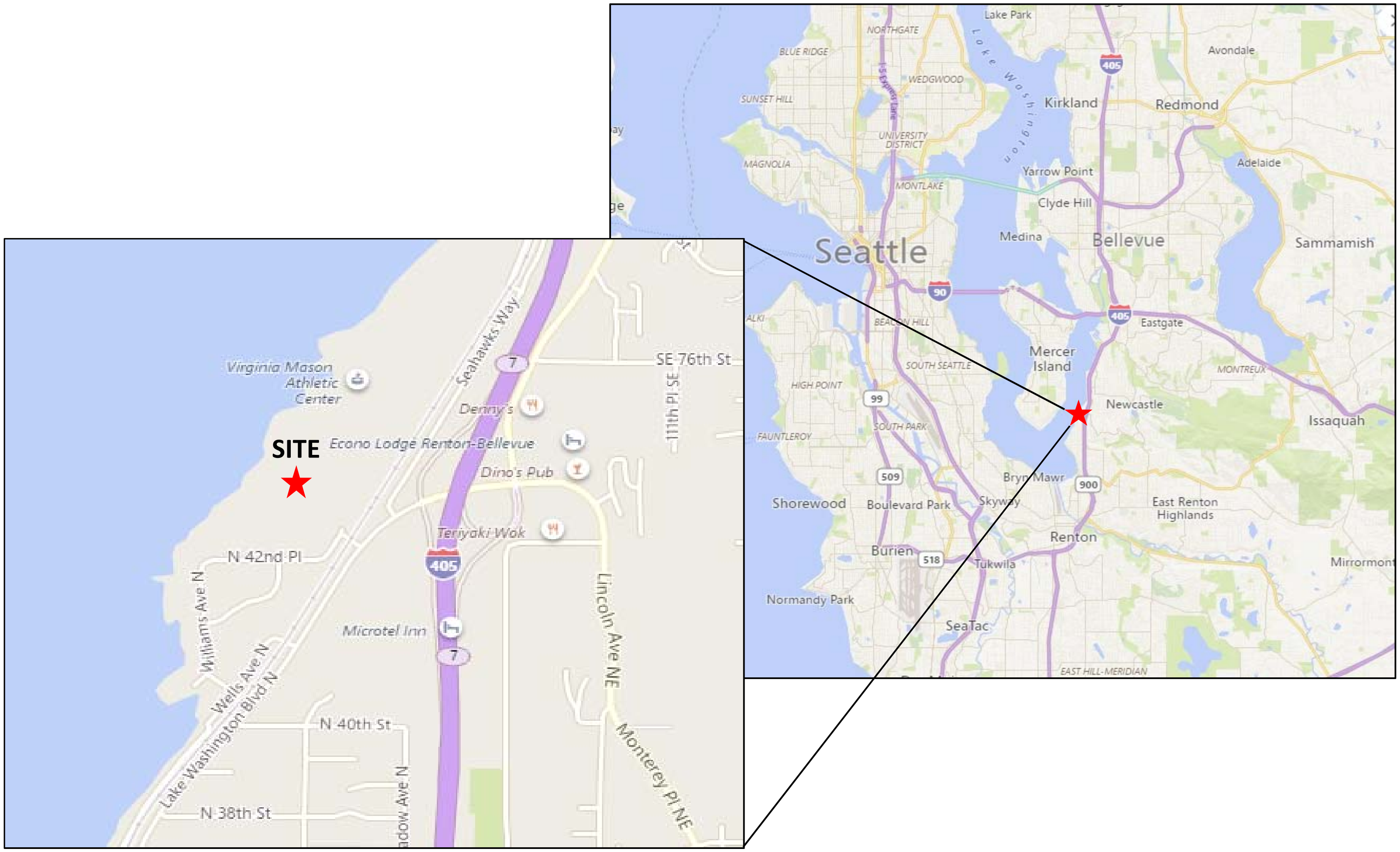
Notes:
1. All units are measured in milligrams per kilogram (mg/kg), unless otherwise indicated
2. < denotes less than the method detection limit (MDL)
3. Sample ID describes sample location, upper depth of the sampling interval, and date collected
(e.g., 2018QT-SB-MC101-12.5-08232018 represents a soil sample collected at MC1-01 at a depth from approximately 12.5 to 13 ft bgs on 08/23/2018)
Indicates analyte measured above the MDL
Indicates J-flag (analyte measured above the MDL, but concentration is estimated)
-- No result reported
ND - non detect

Table 8
Additional Drilling Investigation Soil Analytical Results (MC-1 Area)
Quendall Terminals
Renton, Washington

Boring ID	MC-1-05		MC-1-07	MC-1-08			MC-1-09	
Sample ID	2018QT-SB-MC105-10-08242018	2018QT-SB-MC105-17-08242018	2018QT-SB-MC107-9.5-08242018	2018QT-SB-MC108-10-08242018	2018QT-SB-MC108-15-08242018	2018QT-SB-MC108-17.9-08242018	2018QT-SB-MC109-10-08242018	2018QT-SB-MC109-17-08242018
Depth (ft bgs)	10 - 11	17 - 18	9.5 - 10.5	10 - 11	15 - 15.5	17.9 - 18.9	10 - 10.7	17 - 17.5
Date	8/24/2018	8/24/2018	8/24/2018	8/24/2018	8/24/2018	8/24/2018	8/24/2018	8/24/2018
Petroleum Hydrocarbons								
Gasoline Range Organics	48	300	<7.8	2,900	2,200	1,600	350	<7.2
Diesel Range Organics	1,900	8,000	420	37,000	9,300	7,600	1,000	<50
Motor Oil Range Organics	<120	<130	<140	<110	<130	<120	<140	<120
TOTAL TPH	**1,948**	**8,300**	**420**	**39,900**	**11,500**	**9,200**	**1,350**	**ND**
Polycyclic Aromatic Hydrocarbons (PAHs)								
2-Methylnaphthalene	6.8	160	13	550	180	180	6.3	15
Acenaphthene	8.9	140	12	360	120	78	12	10
Acenaphthylene	<6	<6.3	0.13	4.3	<6	<6	<7.7	<6.1
Anthracene	38	54	4.1	910	110	36	9.5	10
Benzo(a)anthracene	8.7	54	3.5	170	45	23	7.6	4.1
Benzo(a)pyrene	6.4	46	2.7	120	36	17	3.8	3.2
Benzo[b]Fluoranthene	7.2	57	3.2	140	43	22	5.1	3.7
Benzo(g,h,i)perylene	3.4	22	1.4	57	16	8	<7.7	<6.1
Benzo[k]floranthene	2.1	14	1.1	51	12	5.2	1.5	1.2
Chrysene	11	32	2.4	760	46	17	5.4	4.9
Dibenzo[a,h]anthracene	<6	5.6	0.33	19	4.7	2.1	<7.7	<6.1
Fluoranthene	47	210	15	510	160	92	27	14
Fluorene	8.9	94	8.5	280	82	54	13	7.7
Indeno(1,2,3-cd)pyrene	2.4	17	1	45	13	6	<7.7	<6.1
Naphthalene	3.4	260	9.9	980	310	320	<7.7	26
Phenanthrene	69	430	34	1,100	340	270	59	29
Pyrene	44	190	14	470	140	85	24	13
TOTAL PAHs	**267**	**1,786**	**126**	**6,526**	**1,658**	**1,215**	**174**	**142**
BTEX								
Benzene	<0.85	<0.41	0.011	<0.25	<0.35	<0.35	<0.46	<0.0056
Ethylbenzene	<0.85	1.2	0.016	3.6	6.2	4.7	<0.46	<0.0056
m+p-Xylene	<0.85	<0.41	0.0012	3.8	5.4	4.9	<0.46	<0.0056
o-Xylene	<0.85	<0.41	0.0044	2.2	3.4	3.2	<0.46	<0.0056
Toluene	<0.85	<0.41	<0.0066	0.11	<0.35	<0.35	<0.46	<0.0056
TOTAL BTEX	**ND**	**1.2**	**0.03**	**9.7**	**15.0**	**12.8**	**ND**	**ND**

Notes:
1. All units are measured in milligrams per kilogram (mg/kg), unless otherwise indicated
2. < denotes less than the method detection limit (MDL)
3. Sample ID describes sample location, upper depth of the sampling interval, and date collected
(e.g., 2018QT-SB-MC101-12.5-08232018 represents a soil sample collected at MC1-01 at a depth from approximately 12.5 to 13 ft bgs on 08/23/2018)
Indicates analyte measured above the MDL
Indicates J-flag (analyte measured above the MDL, but concentration is estimated)
-- No result reported
ND - non detect

FIGURES



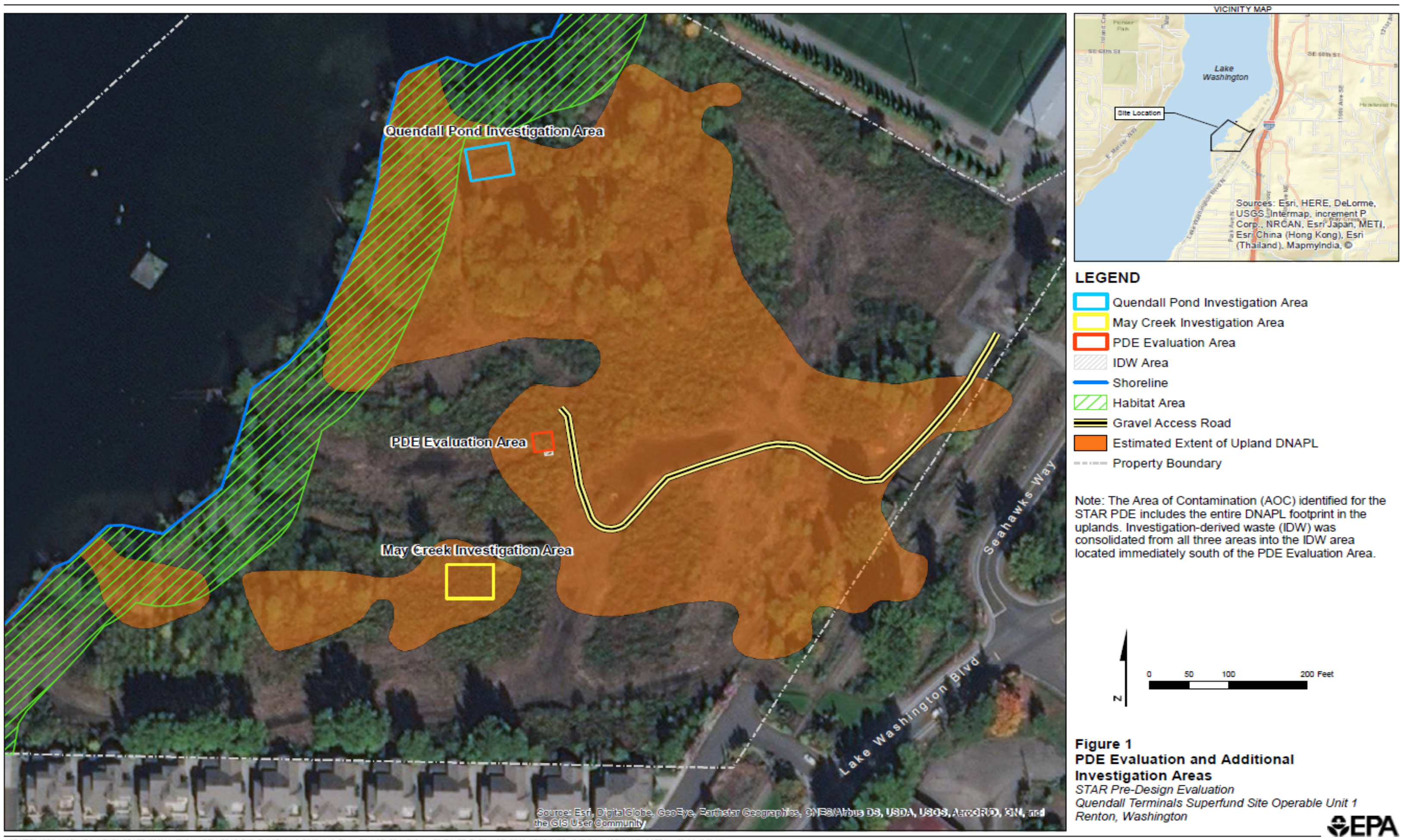
Site Location

Quendall Terminals, Renton, WA

STAR PDE

October 2018

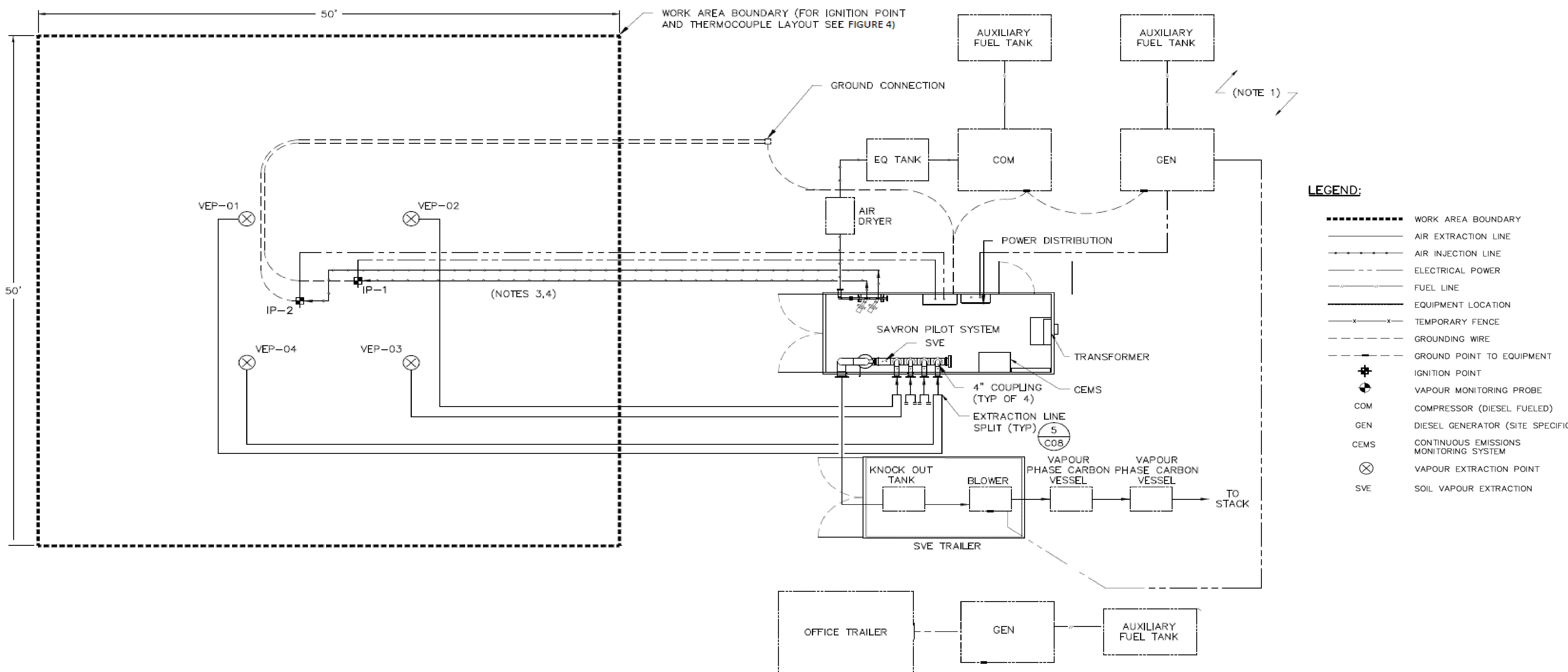
Figure 1



Notes:

Figure obtained from CH2M/Jacobs (September, 2018).

Site Layout Quendall Terminals, Renton, WA STAR PDE	
savron	**October 2018**
	Figure 2



Notes:

Equipment layout approximate and not to scale.

Pre-Design Evaluation Area Schematic

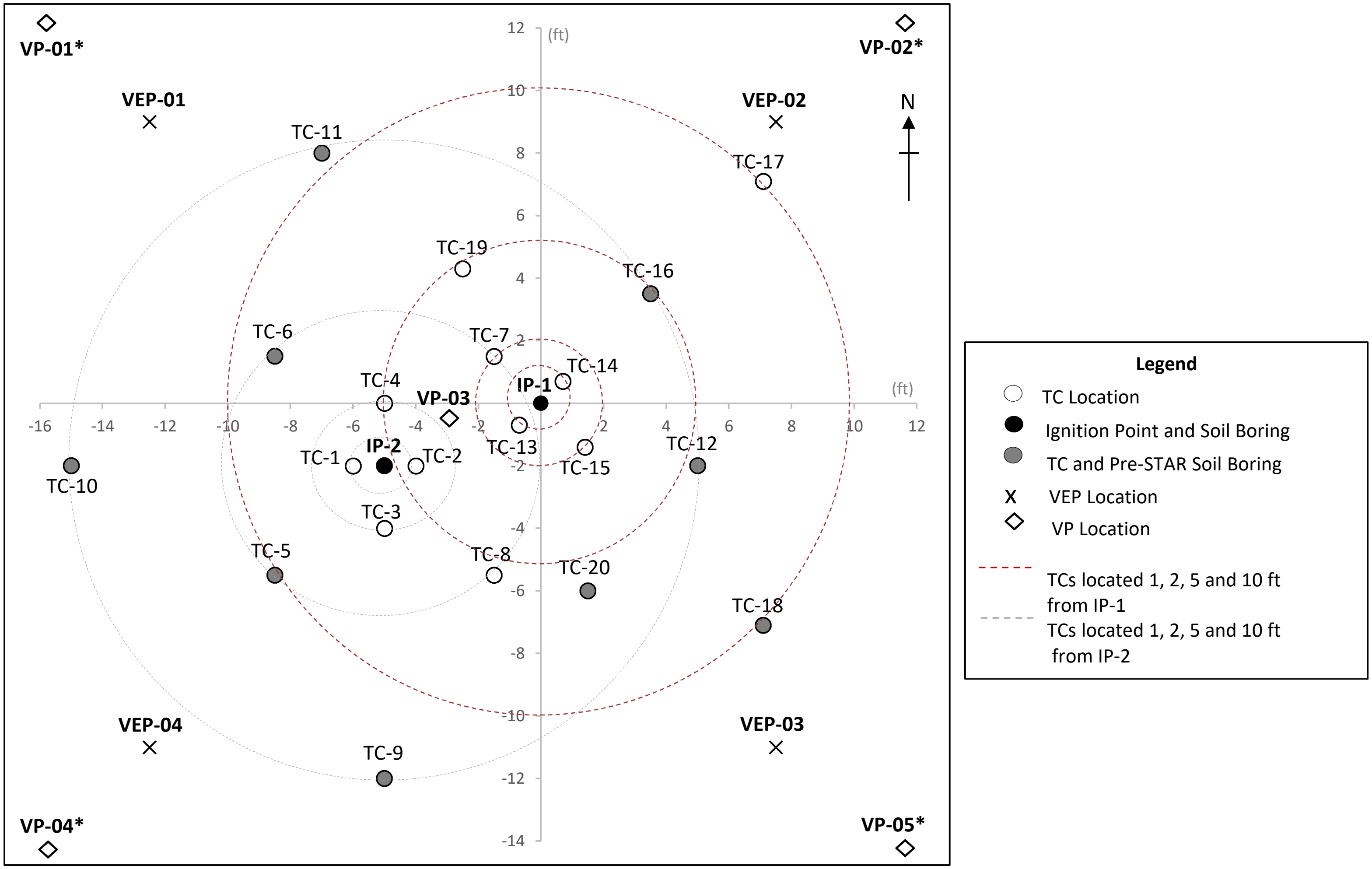
Quendall Terminals, Renton, WA

STAR PDE

savron

October 2018

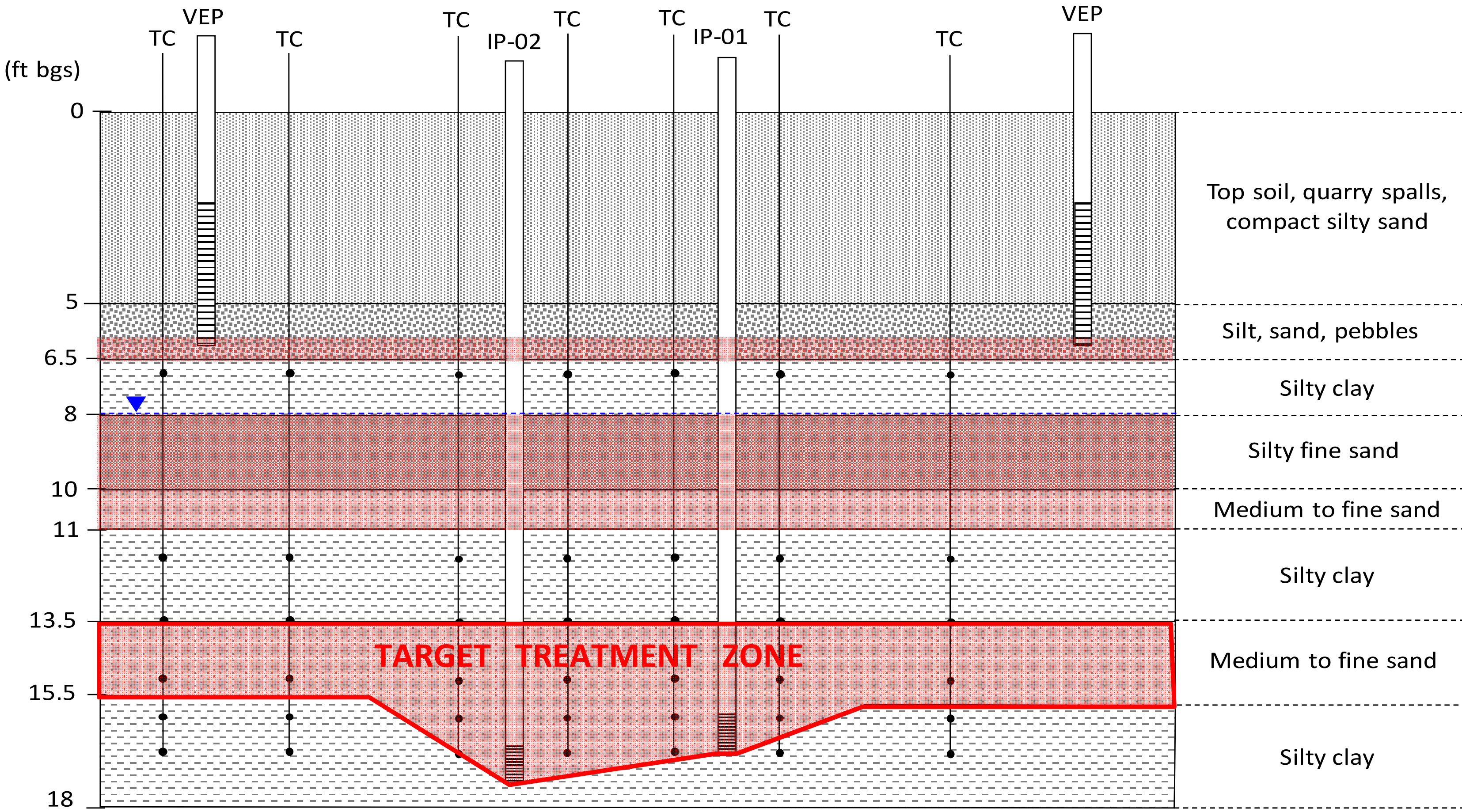
Figure 3



Notes:

TC: Thermocouple
IP: Ignition Point
VEP: Vapor Extraction Point
VP: Vapor Probe
Locations are approximate.
*Vapor probes (VP-01, VP-02, VP-04, VP-05) located at four corners of a 50 ft square centred around VP-03.

Pre-STAR Soil Boring, Ignition Point and Thermocouple Location Map Quendall Terminals, Renton, WA STAR PDE	
savron	**October 2018**
	Figure 4



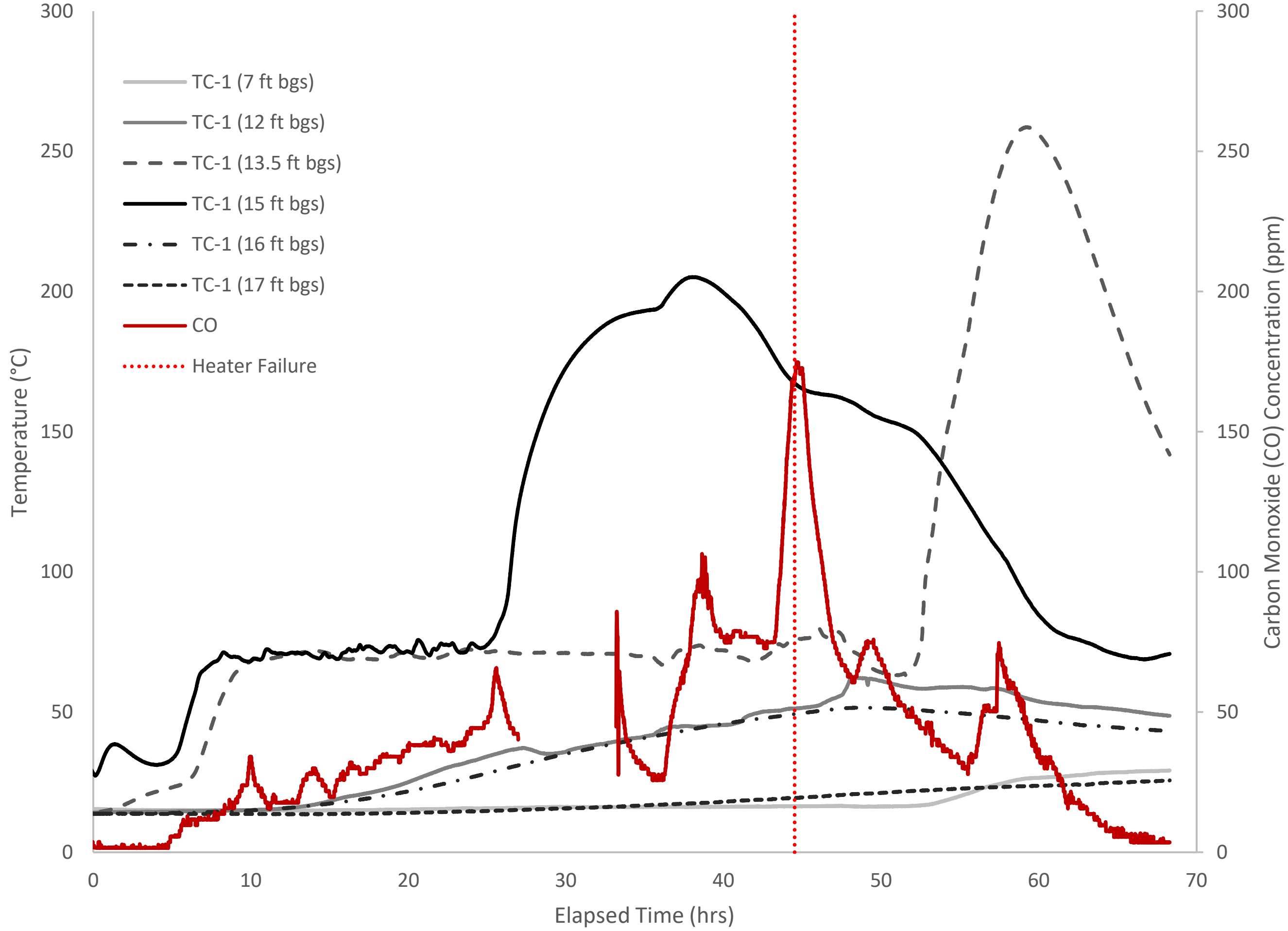
Notes:

Schematic not to scale.

Water elevation
TC Thermocouple
VEP Vapor Extraction Point
IP Ignition Point
Well screen

Visual/analytical evidence of impacts pre-STAR
Target treatment zone for PDE

Simplified Geologic Cross-Section in PDE Area Quendall Terminals, Renton, WA STAR PDE	
savron	**October 2018**
	Figure 5



Notes

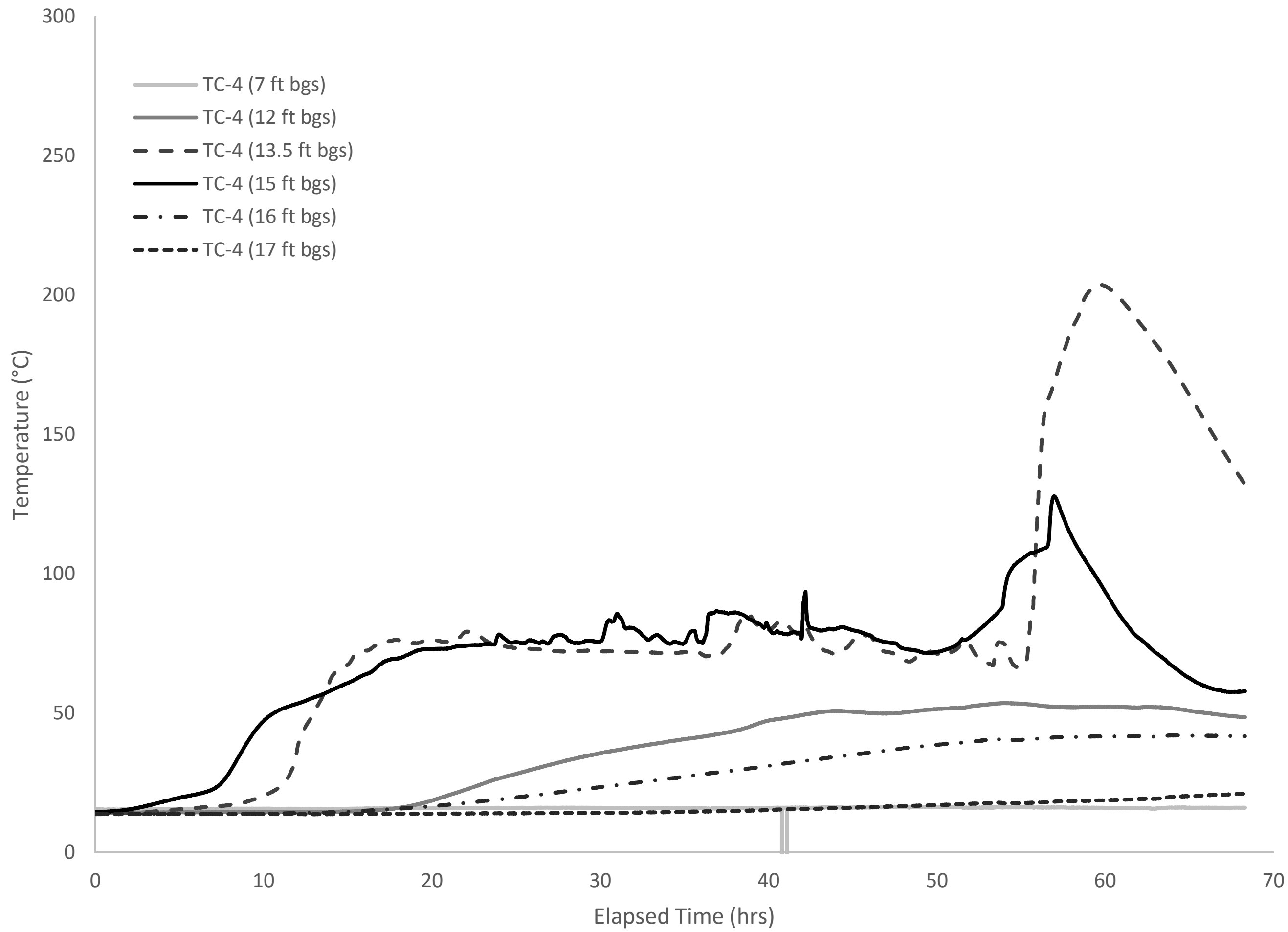
TC-1 located 1 ft from IP-2

IP-2 screen installed at 16.5 to 17.5 ft bgs

Missing CO data from approximately 26 to 33 hours

Heater failure occurred at a time of 44 hours

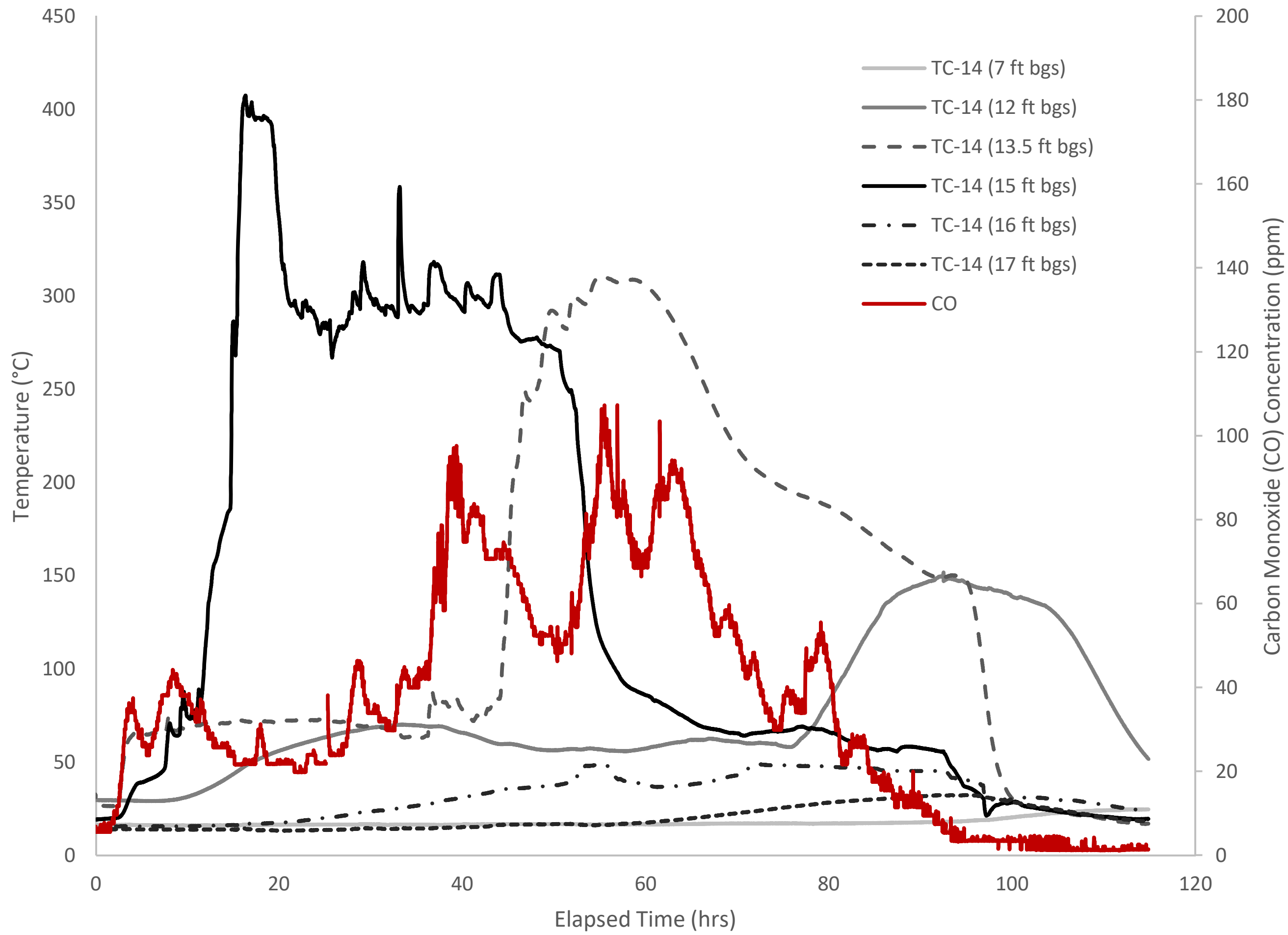
IP-2 Ignition Curve Quendall Terminals, Renton, WA STAR PDE	
savron	**October 2018**
	Figure 6



Notes:

TC-4 located 2 ft from IP-2

IP-2 Combustion Front Propagation (2 ft) Quendall Terminals, Renton, WA STAR PDE	
savron	October 2018
	Figure 7

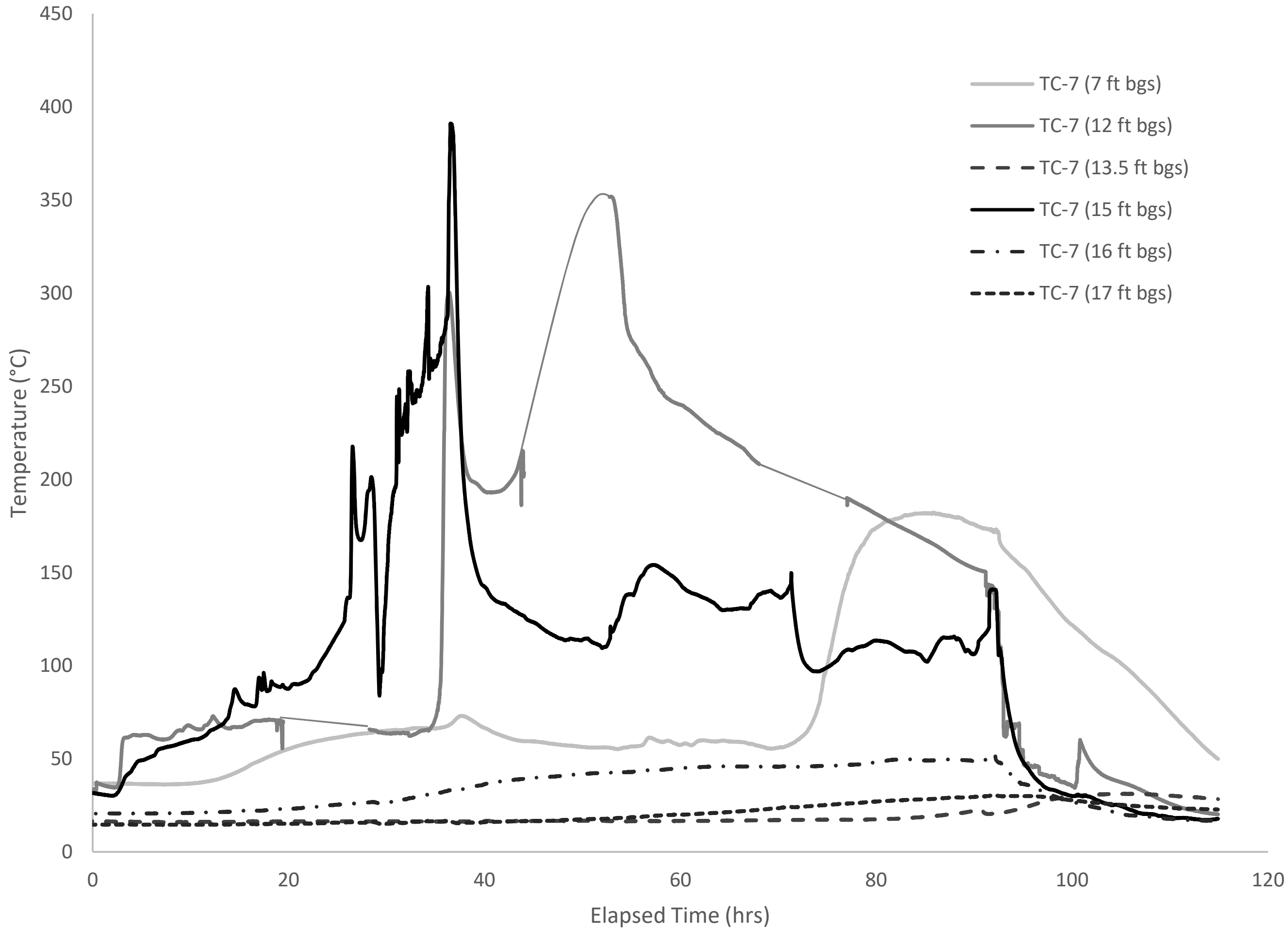


Notes:

TC-14 located 1 ft from IP-1

IP-1 screen installed at 16 to 17 ft bgs

IP-1 Ignition Curve Quendall Terminals, Renton, WA STAR PDE	
savron	**October 2018**
	Figure 8

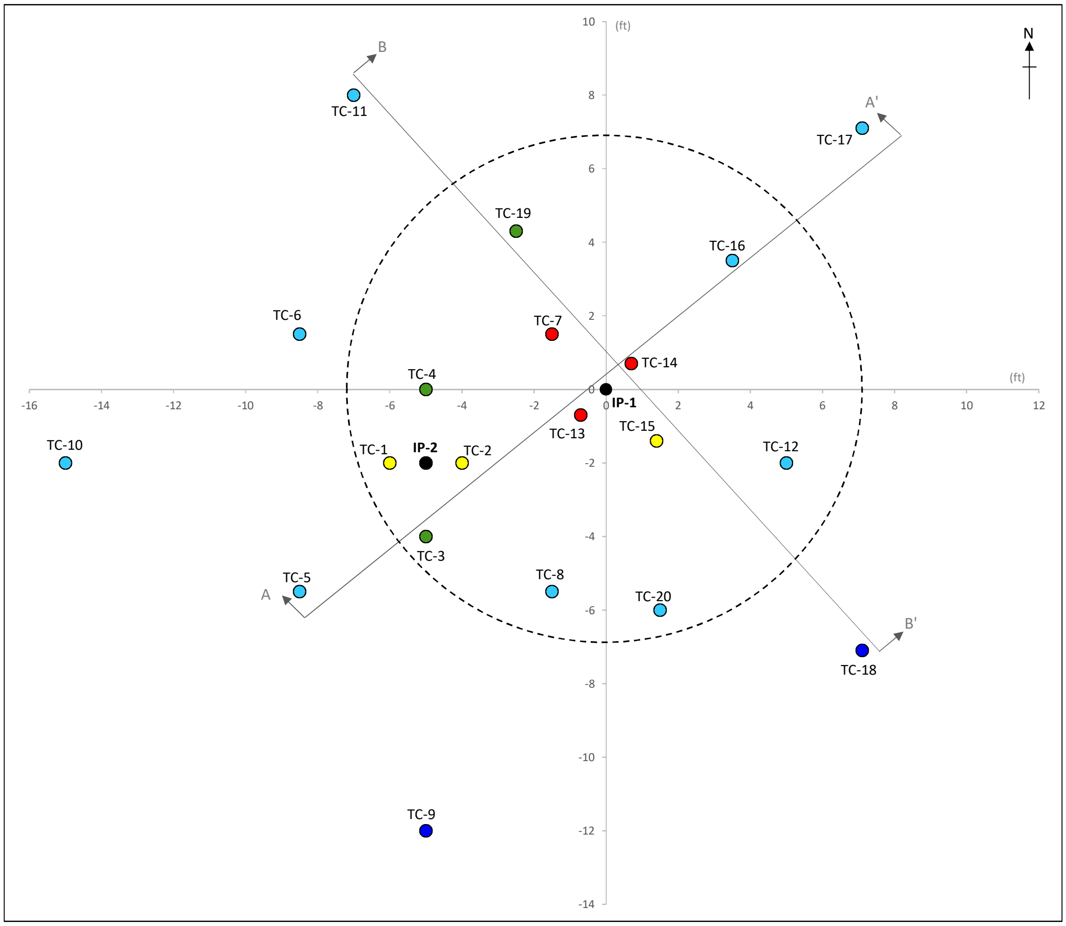


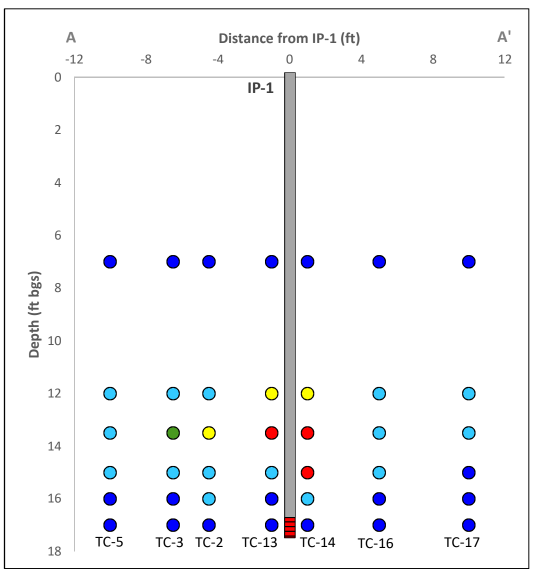
Notes:

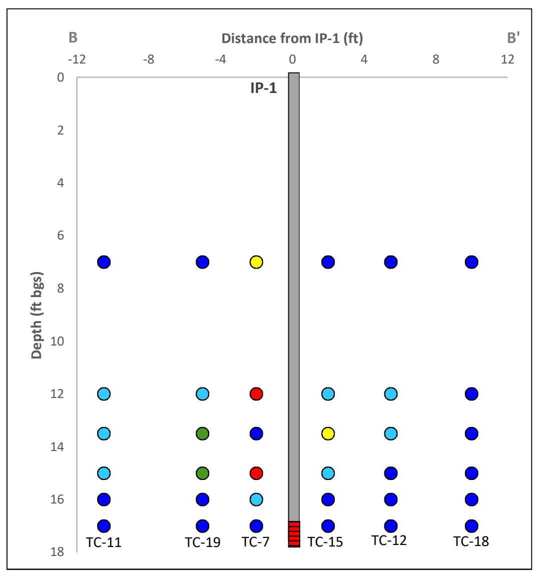
TC-7 located 2 ft from IP-1

Sporadic missing data at TC-7 (12 ft bgs) due to poor connection at thermocouple leads. Missing data indicated by thin lines in graph.

IP-1 Combustion Front Propagation (2 ft) Quendall Terminals, Renton, WA STAR PDE	
savron	**October 2018**
	Figure 9







Legend

Maximum Temperature (°C)

- ≤ 40
- > 40 – 75
- > 75 – 100
- > 100 – 200
- > 200 – 300
- > 300

- Ignition point
- Radius of influence

IP-1 Peak Temperature Observations (Plan View and Cross Sections)

Quendall Terminals, Renton, WA

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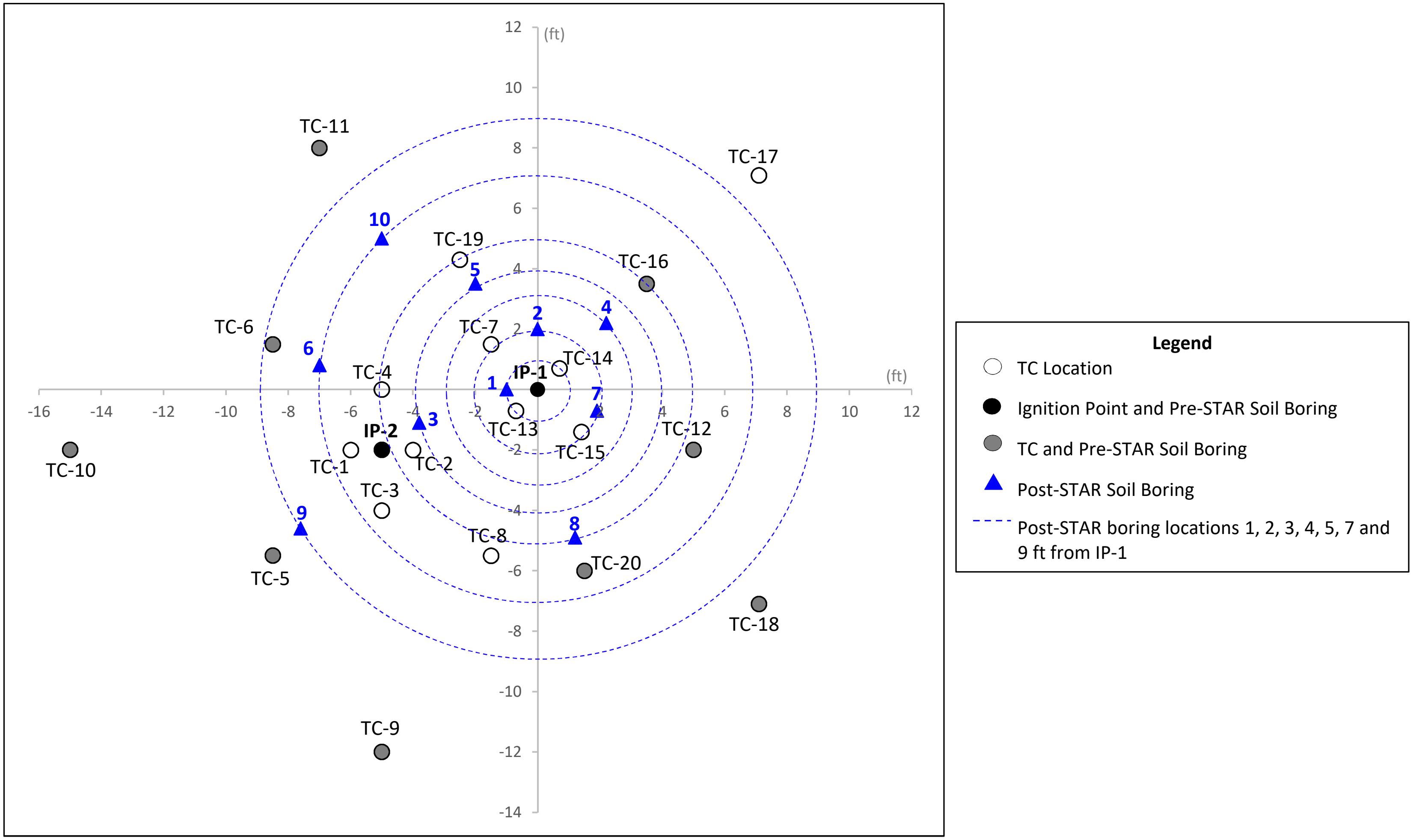
Figure 10



Notes:

TC: Thermocouple
IP: Ignition Point

Pre- and Post-STAR Soil Boring Locations
Quendall Terminals, Renton, WA
STAR PDE

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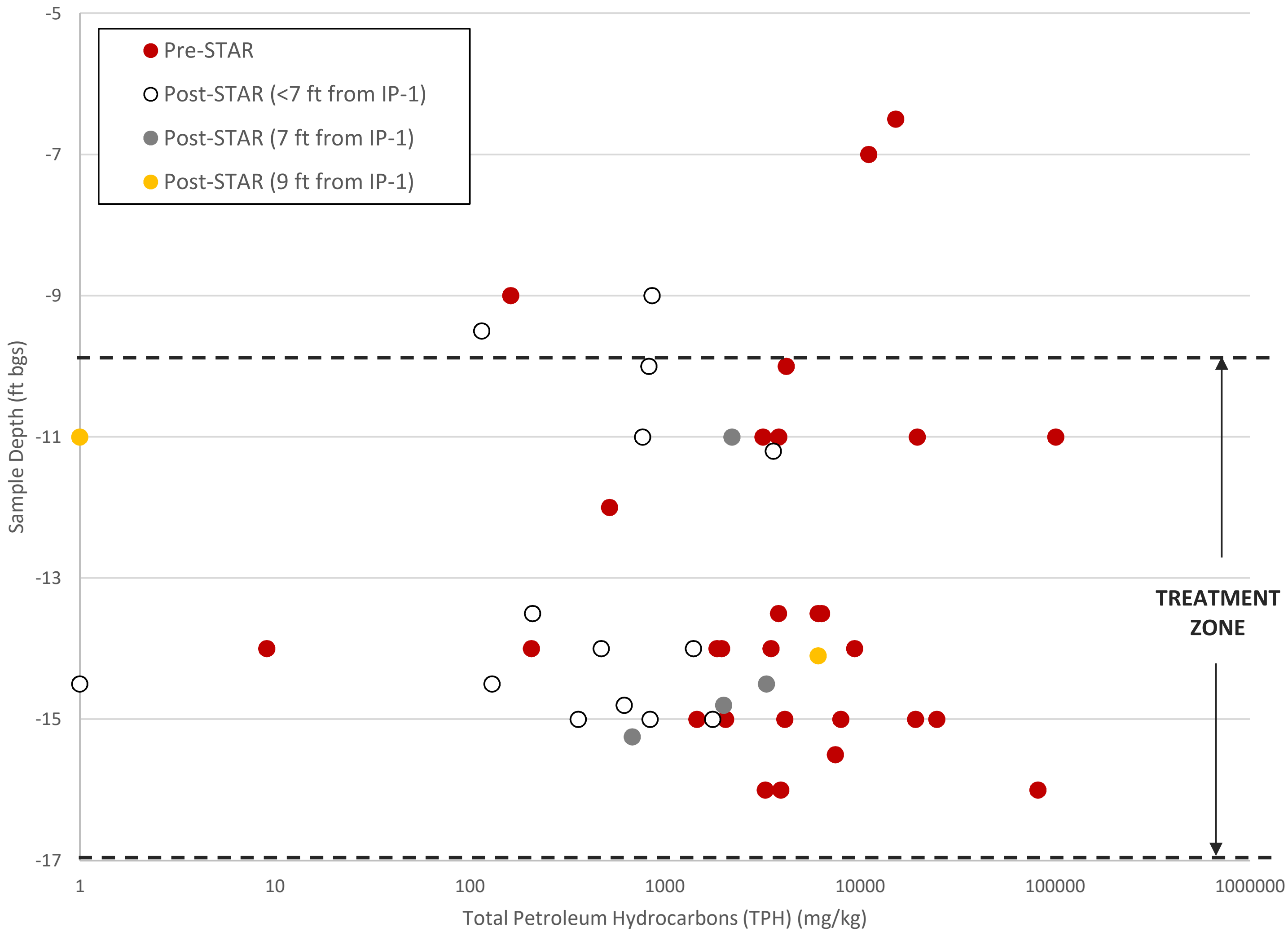
Figure 11



Notes:
Soil samples collected at locations 0 to 9 ft from IP-1

TPH = Total Petroleum Hydrocarbons
ft bgs = feet below ground surface
mg/kg = milligrams per killogram of soil

Pre- and Post-STAR TPH Concentrations
Quendall Terminals, Renton, WA
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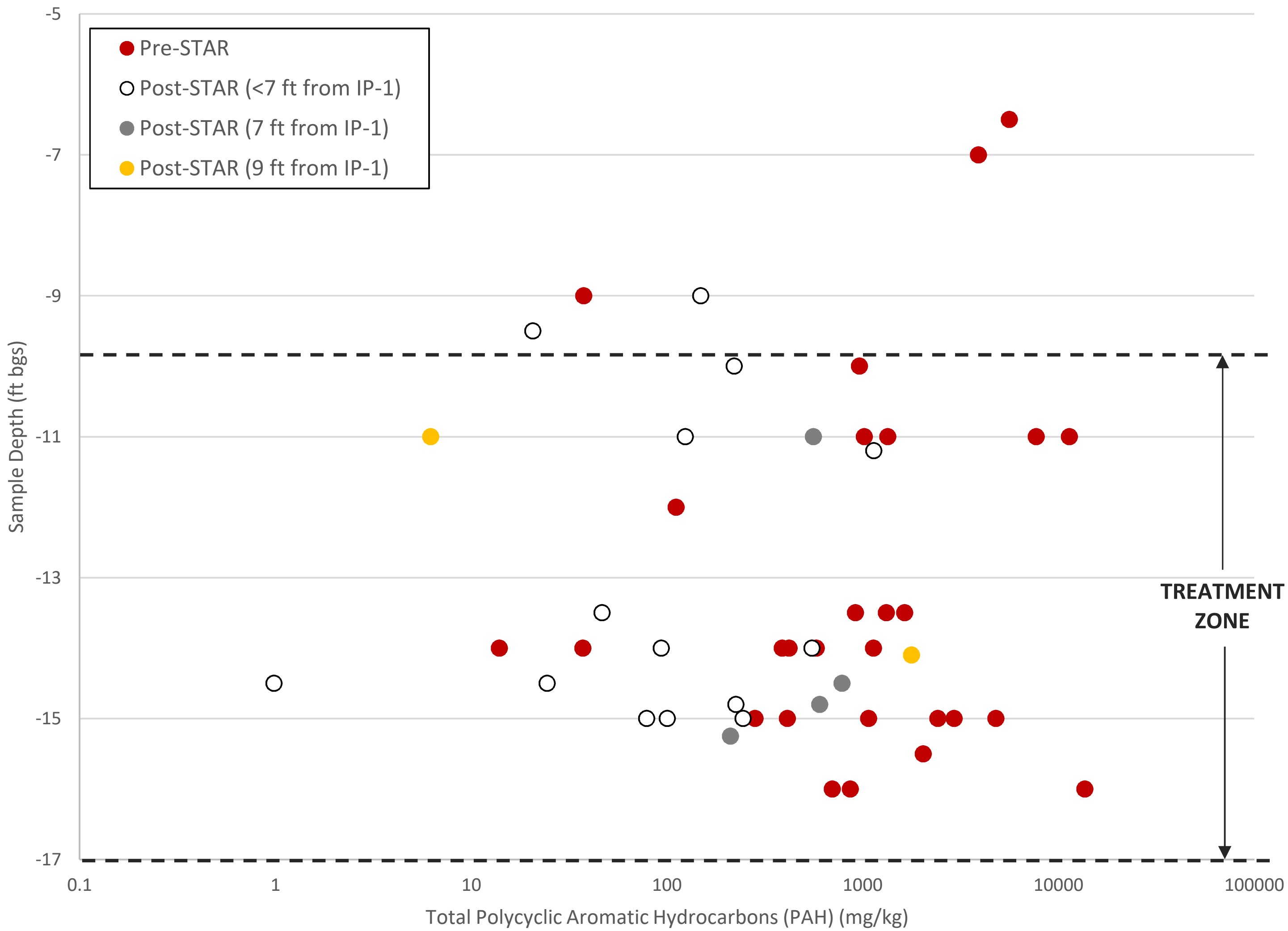
Figure 12a



Notes:

Soil samples collected at locations 0 to 9 ft from IP-1

PAH = Polycyclic Aromatic Hydrocarbon
ft bgs = feet below ground surface
mg/kg = milligrams per kilogram of soil

Total PAHs calculated as the sum of all measured PAHs.

Pre- and Post-STAR PAH Concentrations

Quendall Terminals, Renton, WA

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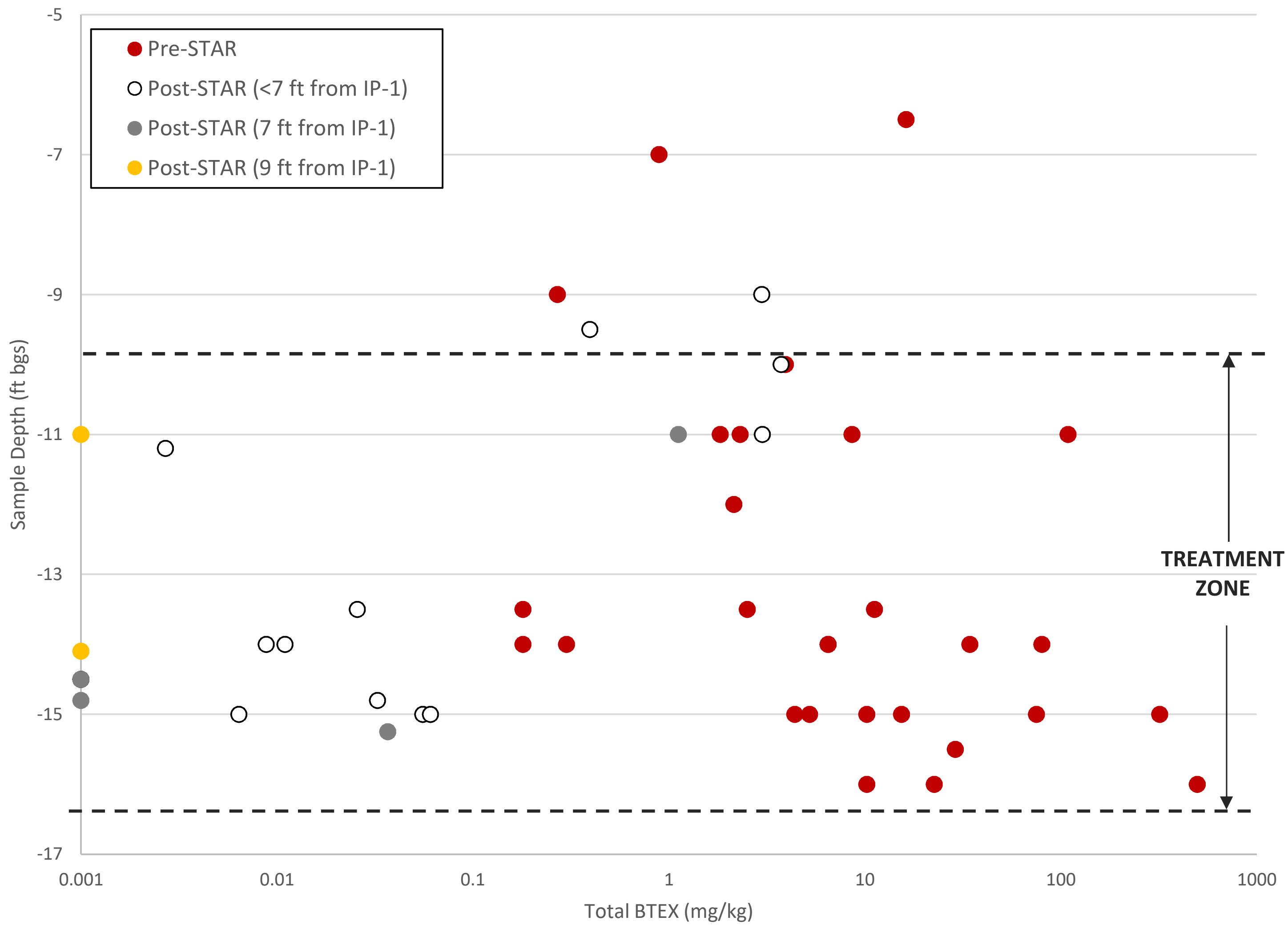
Figure 12b

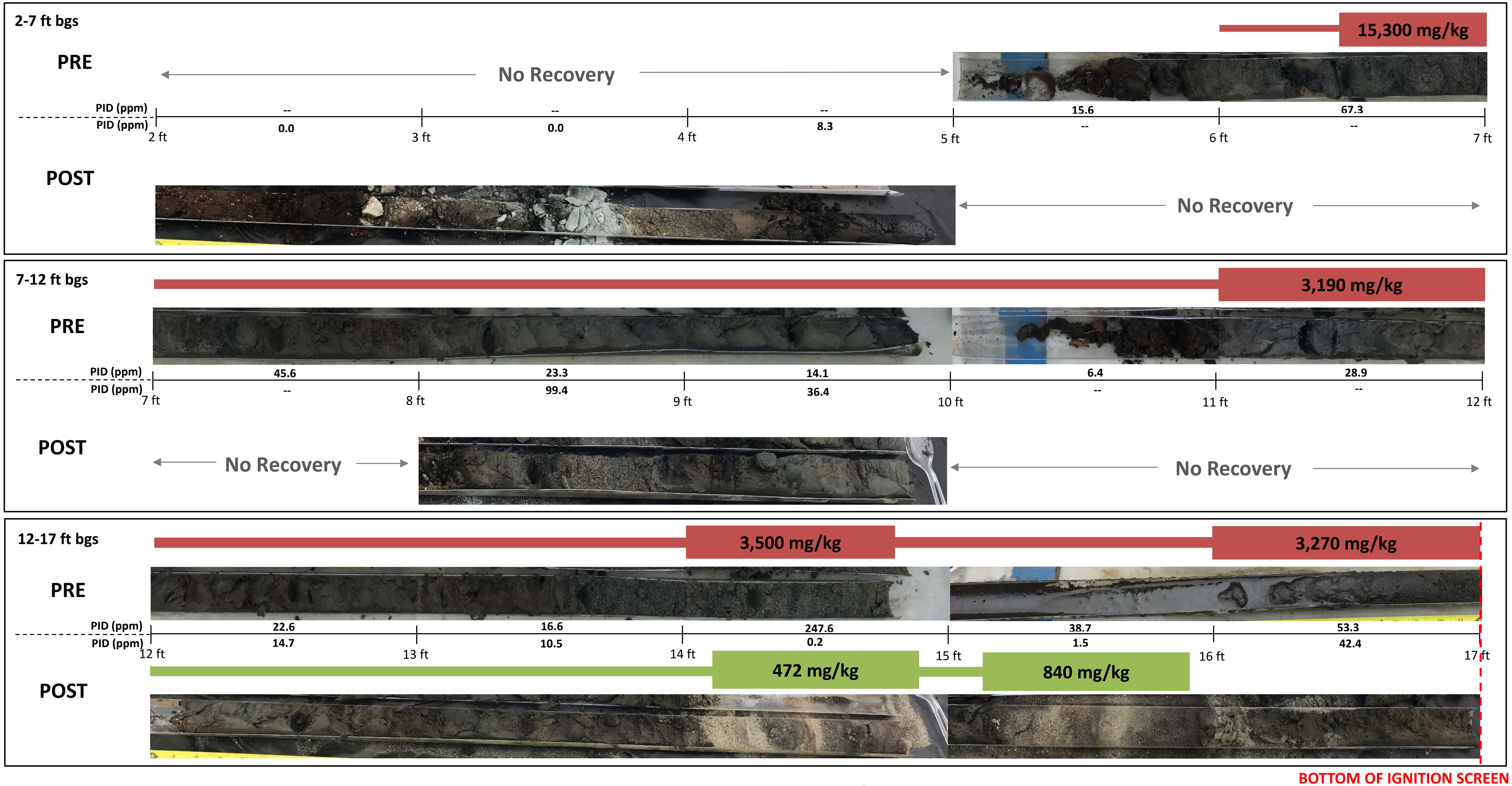


Notes:
Soil samples collected at locations 0 to 9 ft from IP-1

ft bgs = feet below ground surface
mg/kg = milligrams per killogram of soil

Total BTEX calculated as the sum of benzene, ethylbenzene, m+p-xylene, o-xylene, and toluene concentrations.

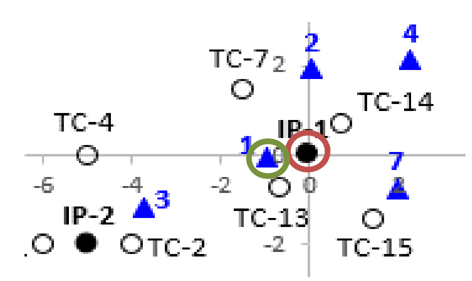
Pre- and Post-STAR BTEX Concentrations Quendall Terminals, Renton, WA STAR PDE	
savron	**October 2018**
	Figure 12c



Notes:

- Impacted Soil (pre-STAR)
- Visual/Analytical Evidence of Treatment (post-STAR)

Pre-STAR Core: IP-1
Post-STAR Core: PT-01



Pre- and Post-STAR Soil Boring Visual Comparison - 1 ft W of IP-1

Quendall Terminals, Renton, WA

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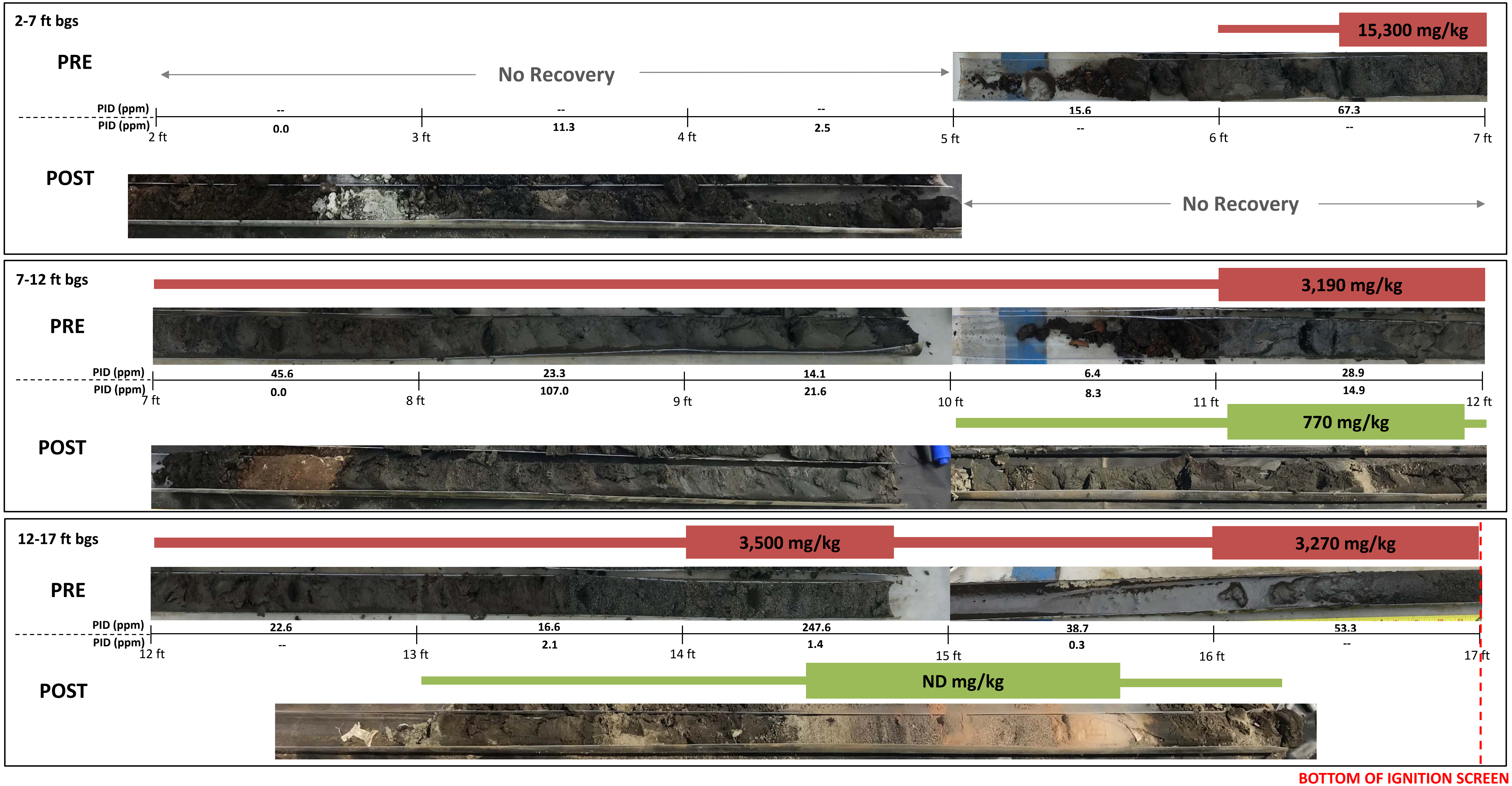
Figure 13



Notes:

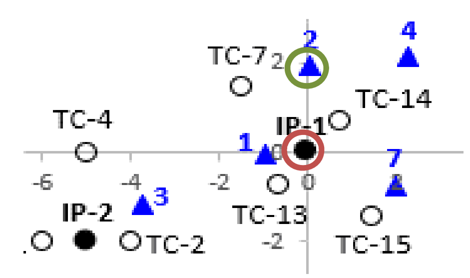
Impacted Soil (pre-STAR)

Visual/Analytical Evidence of Treatment (post-STAR)

ND = non detect

Pre-STAR Core: IP-1

Post-STAR Core: PT-02



Pre- and Post-STAR Soil Boring Visual Comparison - 2 ft N of IP-1

Quendall Terminals, Renton, WA

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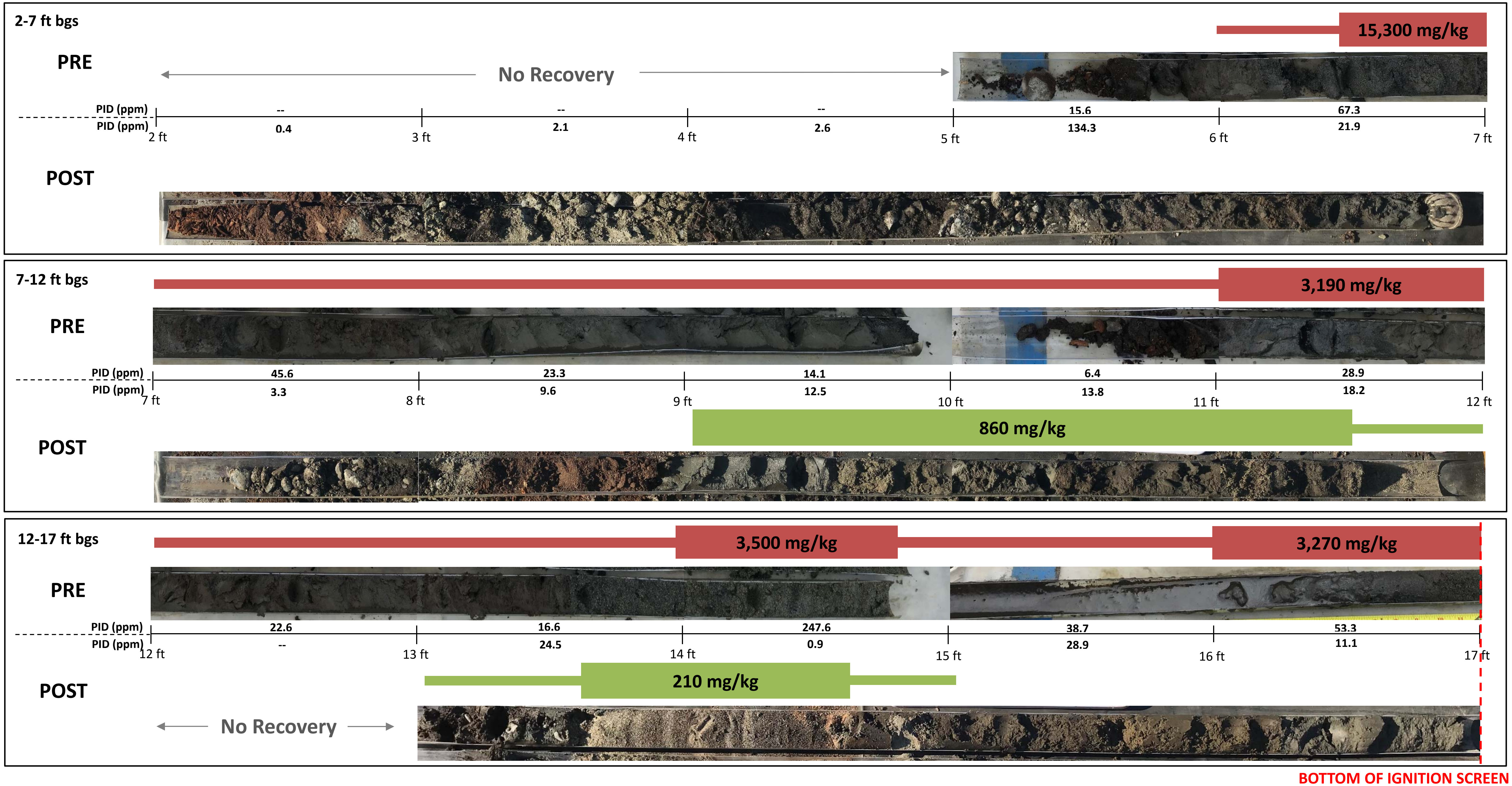
Figure 14



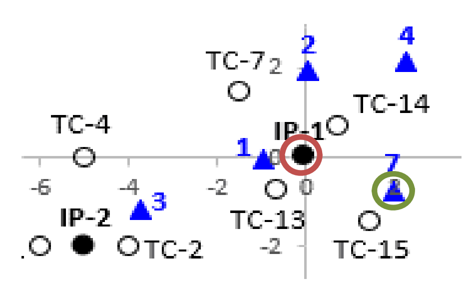
Notes:

Impacted Soil (pre-STAR)

Visual/Analytical Evidence of Treatment (post-STAR)

Pre-STAR Core: IP-1

Post-STAR Core: PT-07



Pre- and Post-STAR Soil Boring Visual Comparison - 2 ft SE of IP-1

Quendall Terminals, Renton, WA

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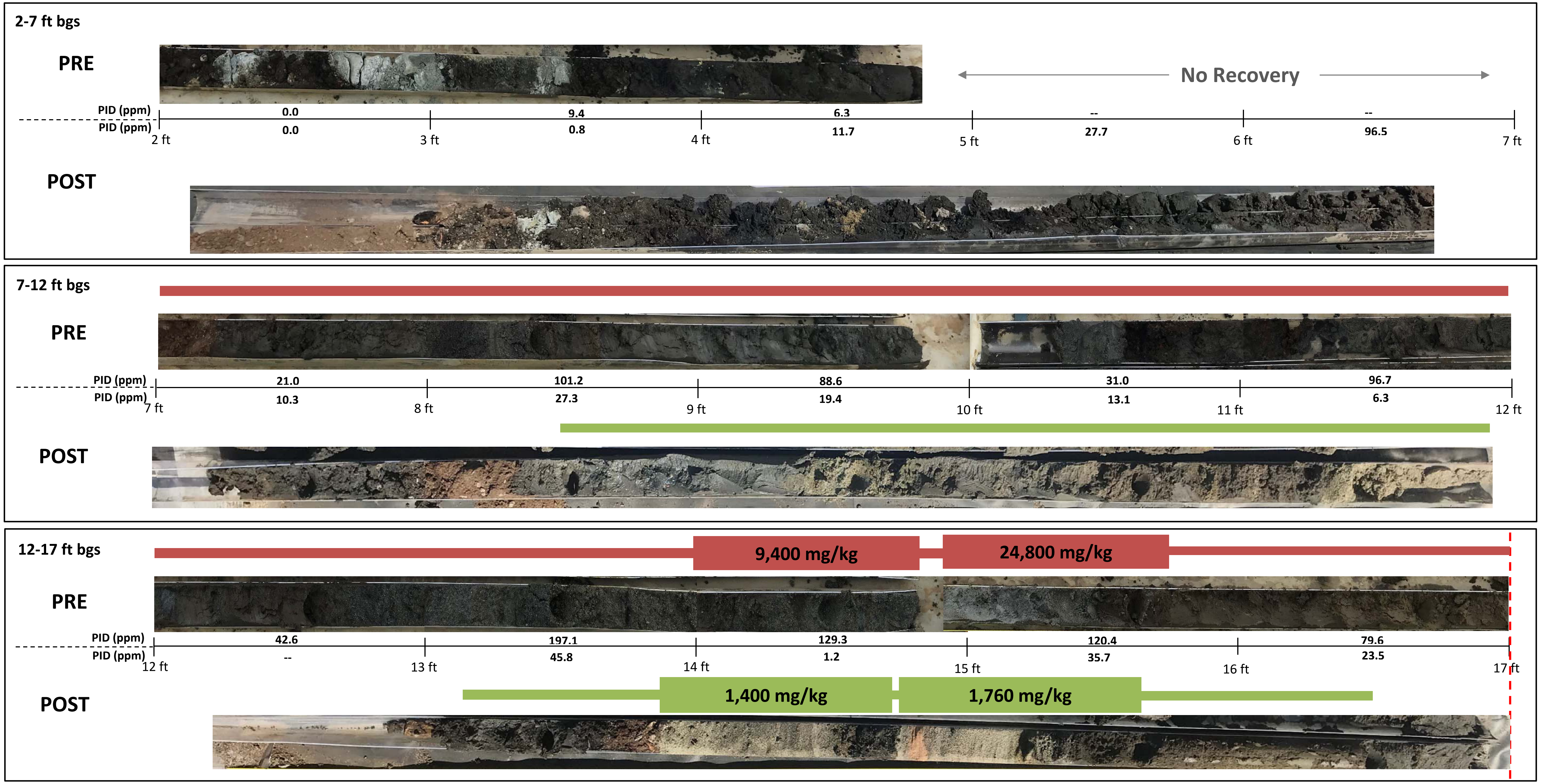
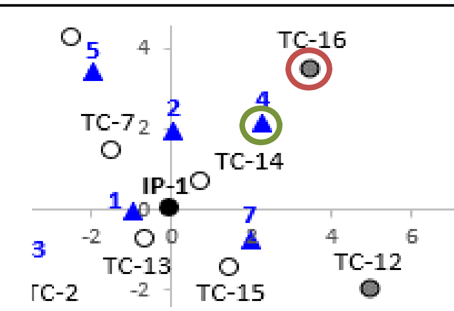
Figure 15



Notes:

- Impacted Soil (pre-STAR)
- Visual/Analytical Evidence of Treatment (post-STAR)

Pre-STAR Core: TC-16
Post-STAR Core: PT-04



Pre- and Post-STAR Soil Boring Visual Comparison - 3 ft NE of IP-1

Quendall Terminals, Renton, WA

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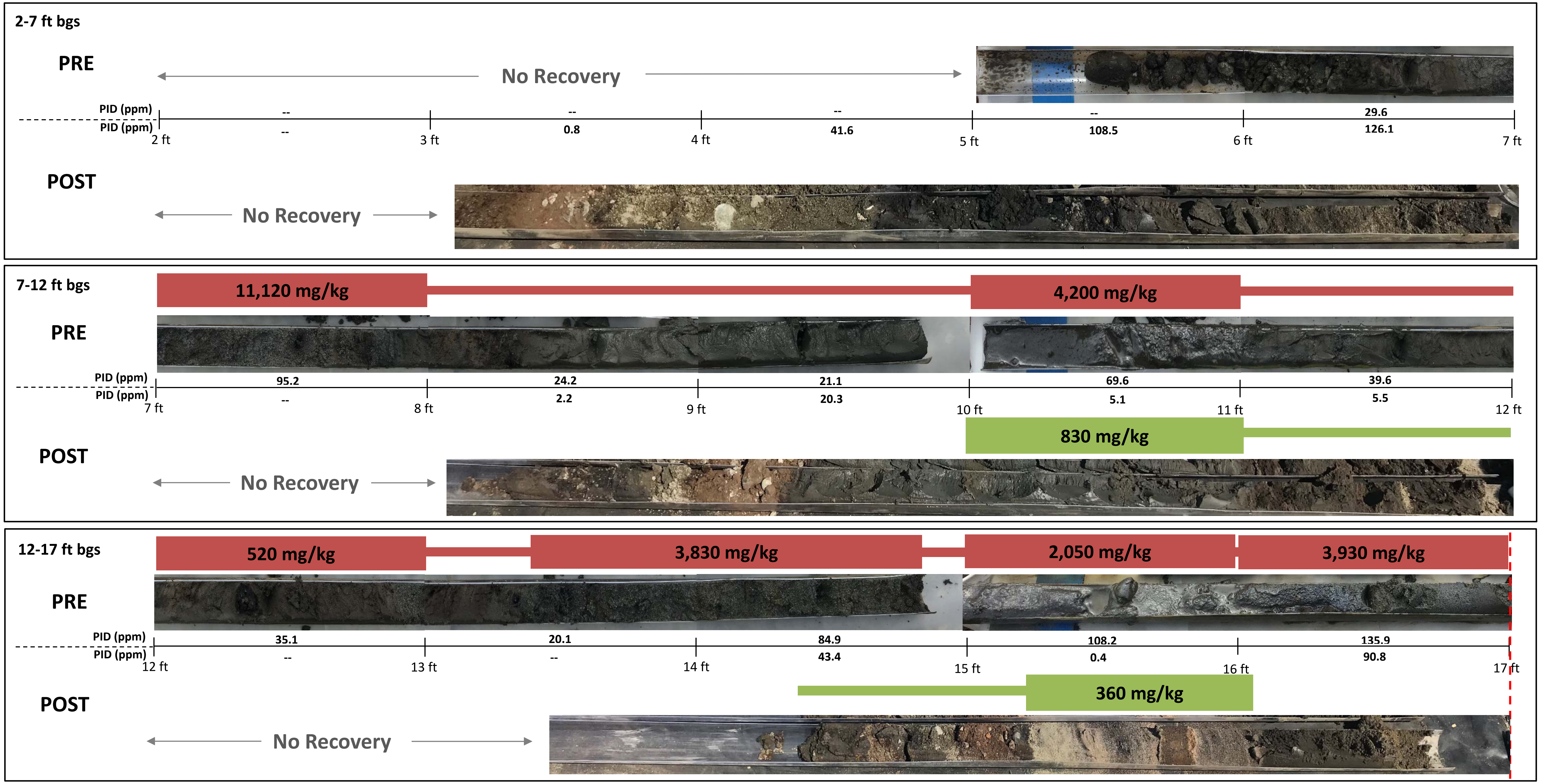
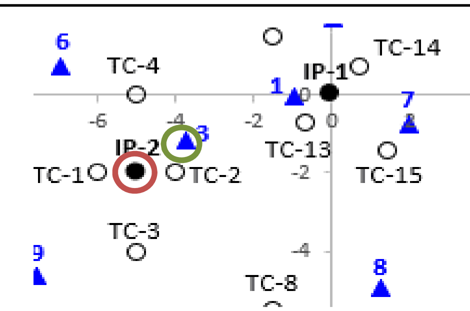
Figure 16



Notes:

- Impacted Soil (pre-STAR)
- Visual/Analytical Evidence of Treatment (post-STAR)

Pre-STAR Core: IP-02
Post-STAR Core: PT-03



Pre- and Post-STAR Soil Boring Visual Comparison - 4 ft SW of IP-1 Quendall Terminals, Renton, WA STAR PDE	
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	Figure 17

2-7 ft bgs

PRE — No Pre Boring

PID (ppm)	--	--	--	--	--
PID (ppm)	0.2	0.2	0.4	29.2	44.4

2 ft · 3 ft · 4 ft · 5 ft · 6 ft · 7 ft

POST

7-12 ft bgs

PRE — No Pre Boring

PID (ppm)	--	--	--	--	--
PID (ppm)	8.2	20.7	16.3	7.9	0.0

7 ft · 8 ft · 9 ft · 10 ft · 11 ft · 12 ft

3,600 mg/kg

POST

12-17 ft bgs

PRE — No Pre Boring

PID (ppm)	--	--	--	--	--
PID (ppm)	--	--	27.7	0.2	69.8

12 ft · 13 ft · 14 ft · 15 ft · 16 ft · 17 ft

620 mg/kg

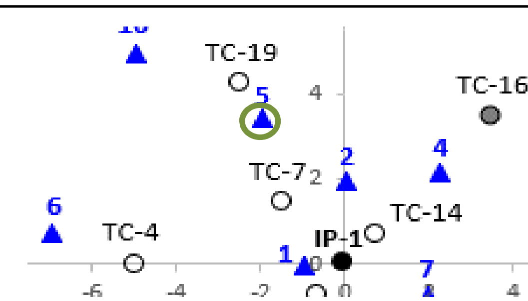
POST — No Recovery

BOTTOM OF IGNITION SCREEN

Notes:

- Impacted Soil (pre-STAR)
- Visual/Analytical Evidence of Treatment (post-STAR)

Pre-STAR Core: n/a
Post-STAR Core: PT-05



Pre- and Post-STAR Soil Boring Visual Comparison - 4 ft NW of IP-1

Quendall Terminals, Renton, WA

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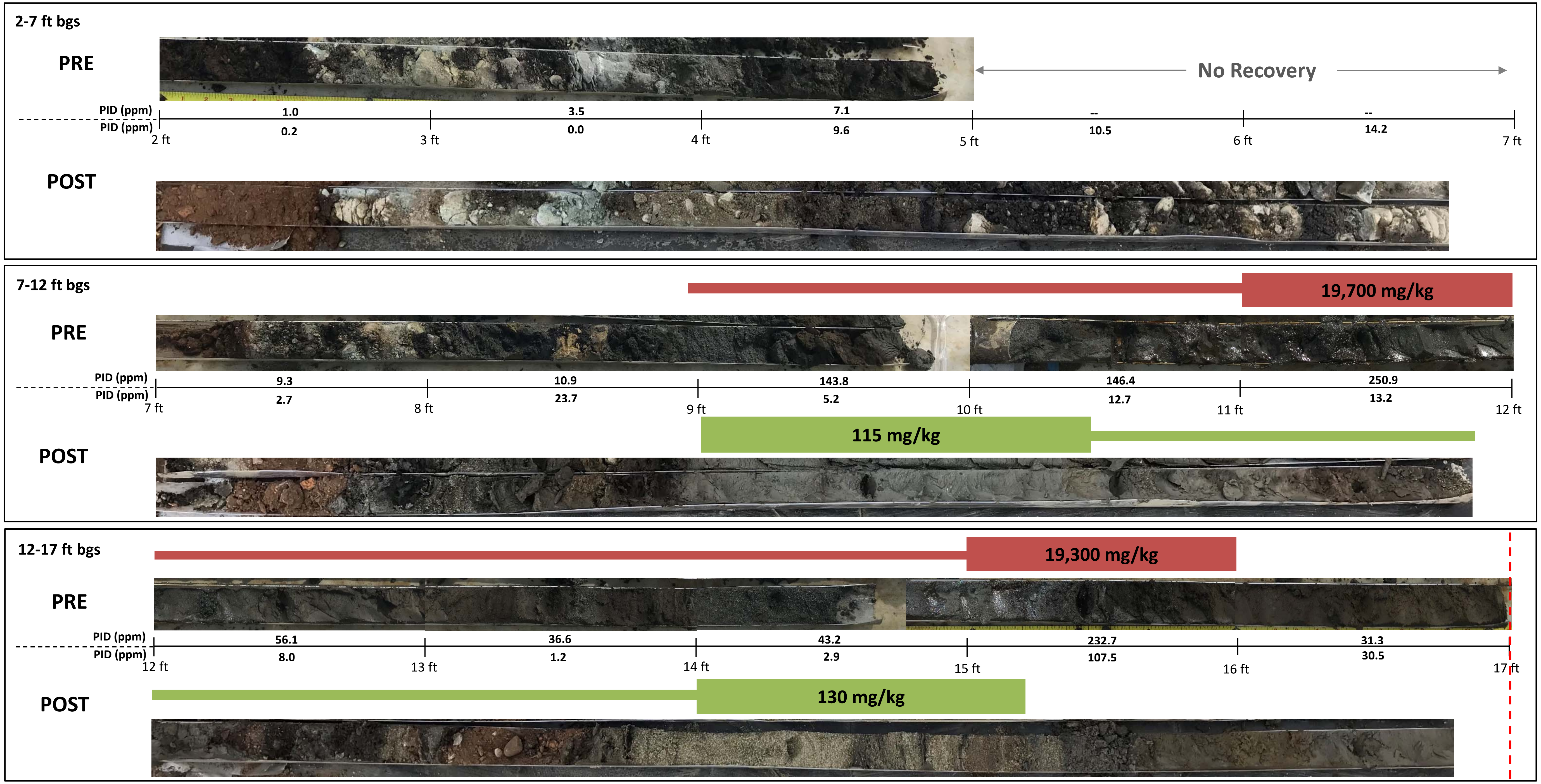
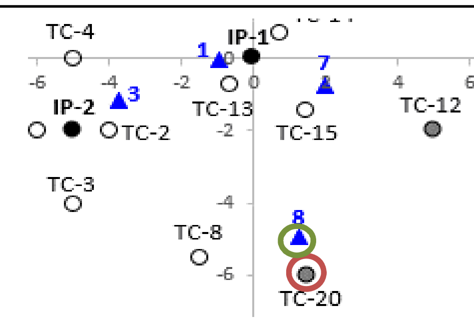
Figure 18



Notes:

- Impacted Soil (pre-STAR)
- Visual/Analytical Evidence of Treatment (post-STAR)

Pre-STAR Core: TC-20
Post-STAR Core: PT-08



Pre- and Post-STAR Soil Boring Visual Comparison - 5 ft SE of IP-1

Quendall Terminals, Renton, WA

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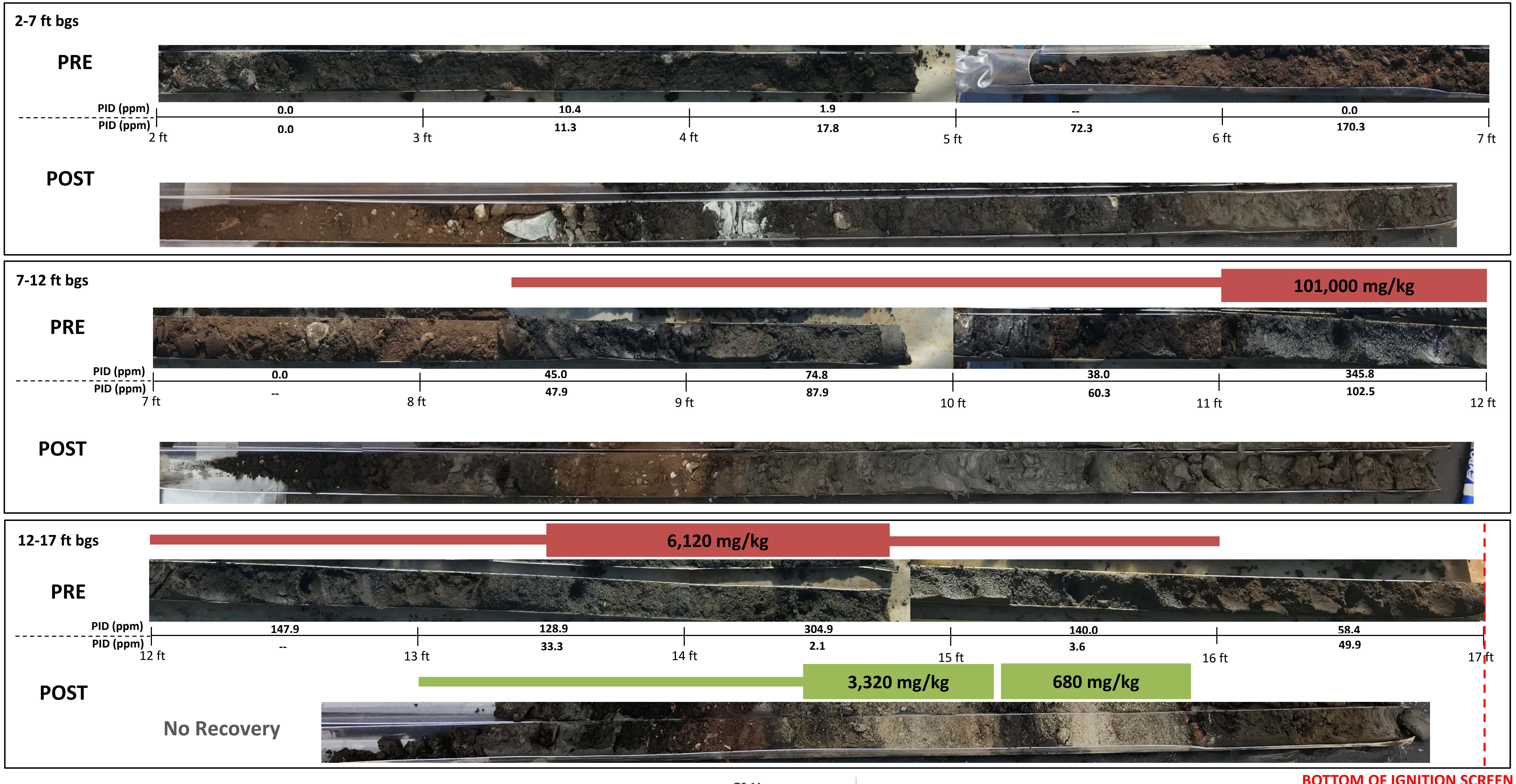
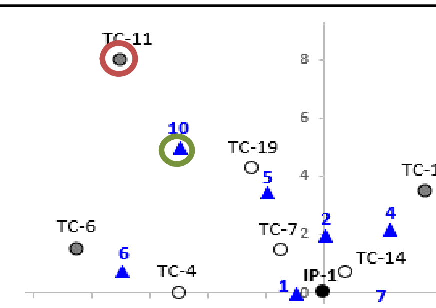
Figure 19



Notes:

- Impacted Soil (pre-STAR)
- Visual/Analytical Evidence of Treatment (post-STAR)

Pre-STAR Core: TC-11
Post-STAR Core: PT-10



Pre- and Post-STAR Soil Boring Visual Comparison - 7 ft NW of IP-1

Quendall Terminals, Renton, WA

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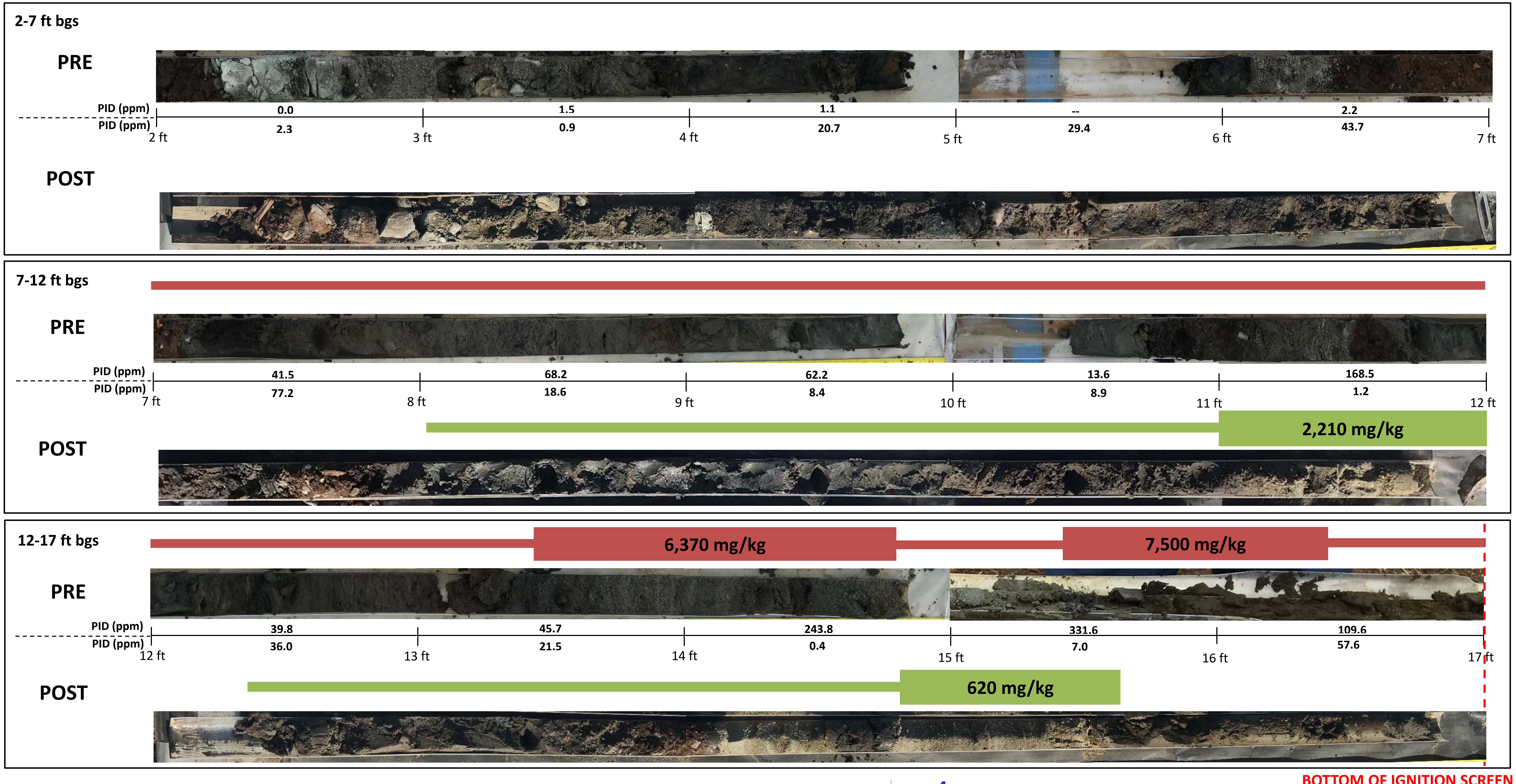
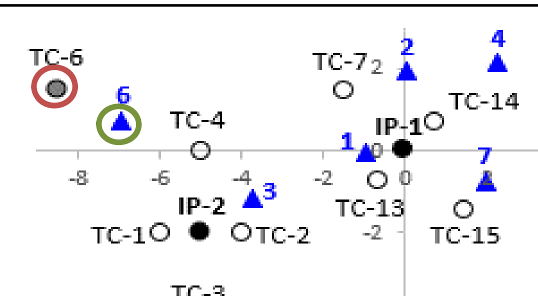
Figure 20



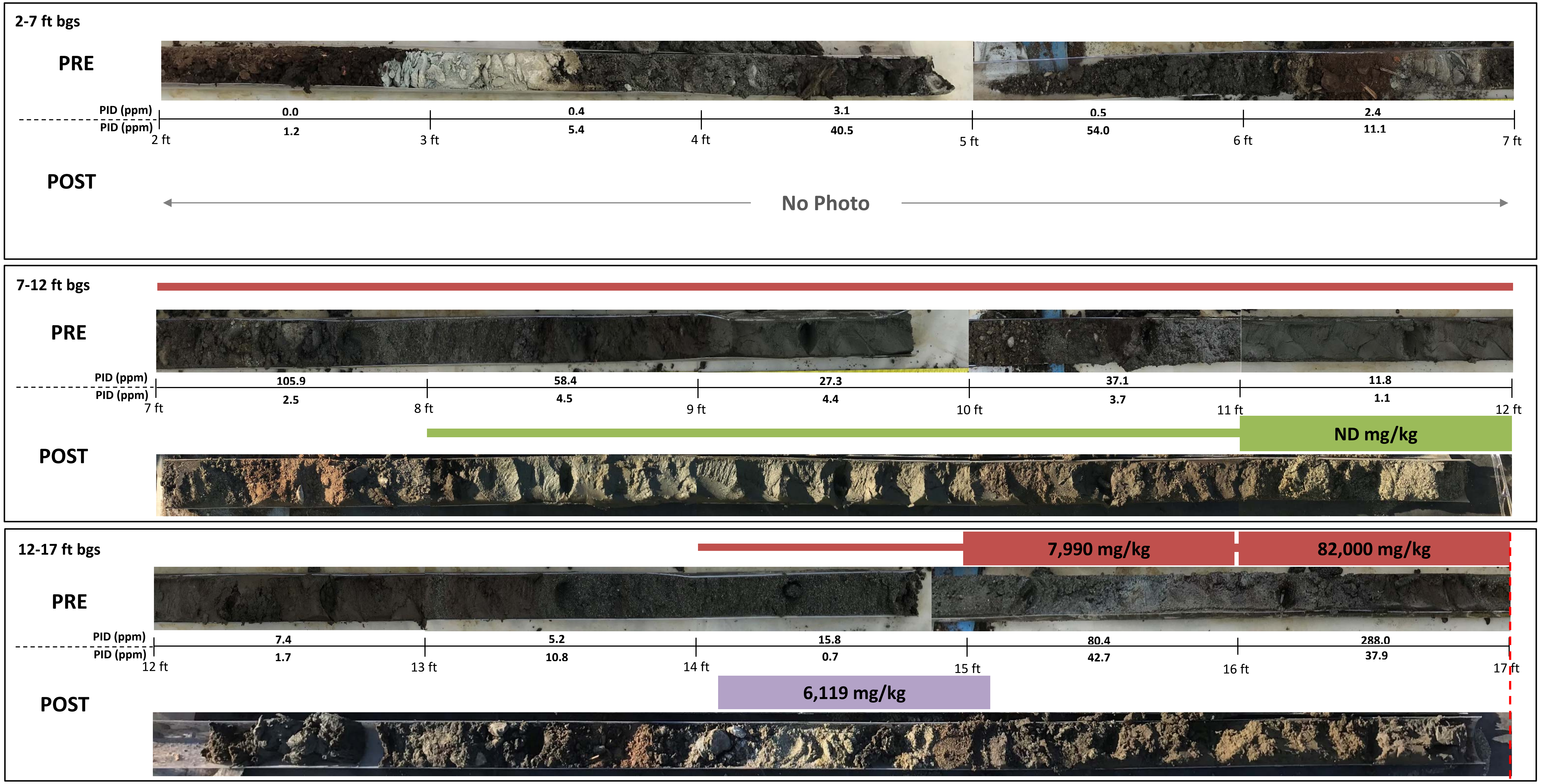
Notes:

- Impacted Soil (pre-STAR)
- Visual/Analytical Evidence of Treatment (post-STAR)

Pre-STAR Core: TC-6
Post-STAR Core: PT-06



Pre- and Post-STAR Soil Boring Visual Comparison - 7 ft W of IP-1 Quendall Terminals, Renton, WA STAR PDE	
savron	**October 2018**
	Figure 21

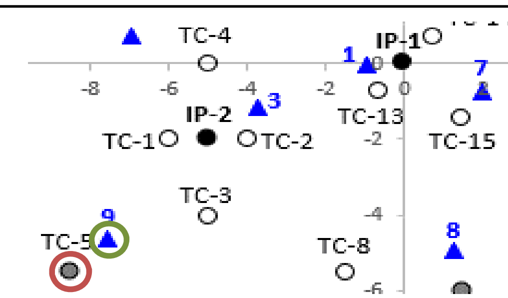


Notes:

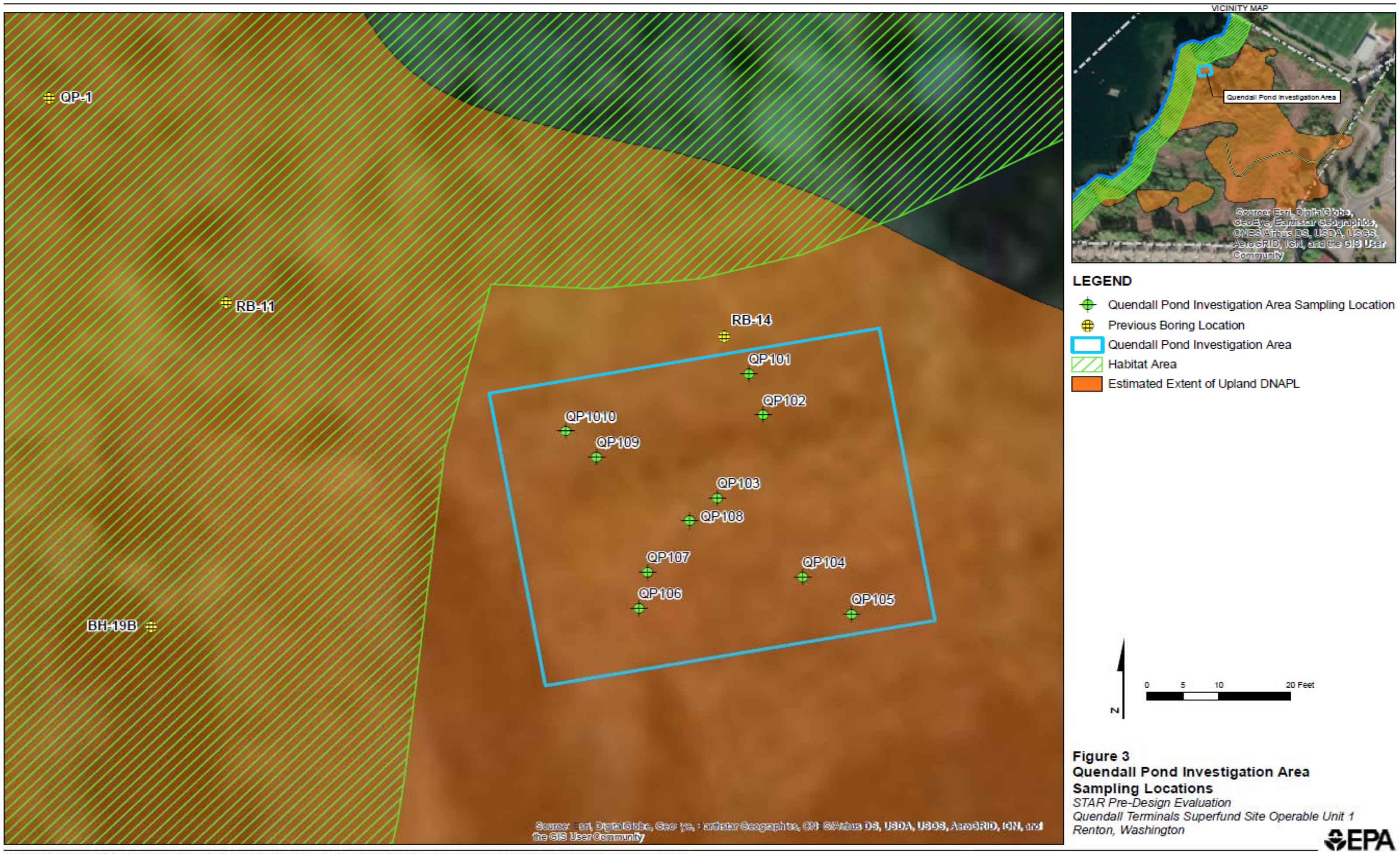
- Impacted Soil (pre-STAR)
- Visual/Analytical Evidence of Treatment (post-STAR)
- Partial or no treatment (post-STAR)

ND = non detect

Pre-STAR Core: TC-5
Post-STAR Core: PT-09



Pre- and Post-STAR Soil Boring Visual Comparison - 9 ft SW of IP-1 Quendall Terminals, Renton, WA STAR PDE	
savron	**October 2018** **Figure 22**



Notes:

Figure obtained from CH2M/Jacobs (September, 2018).

QP-1 Area Sampling Locations

Quendall Terminals, Renton, WA

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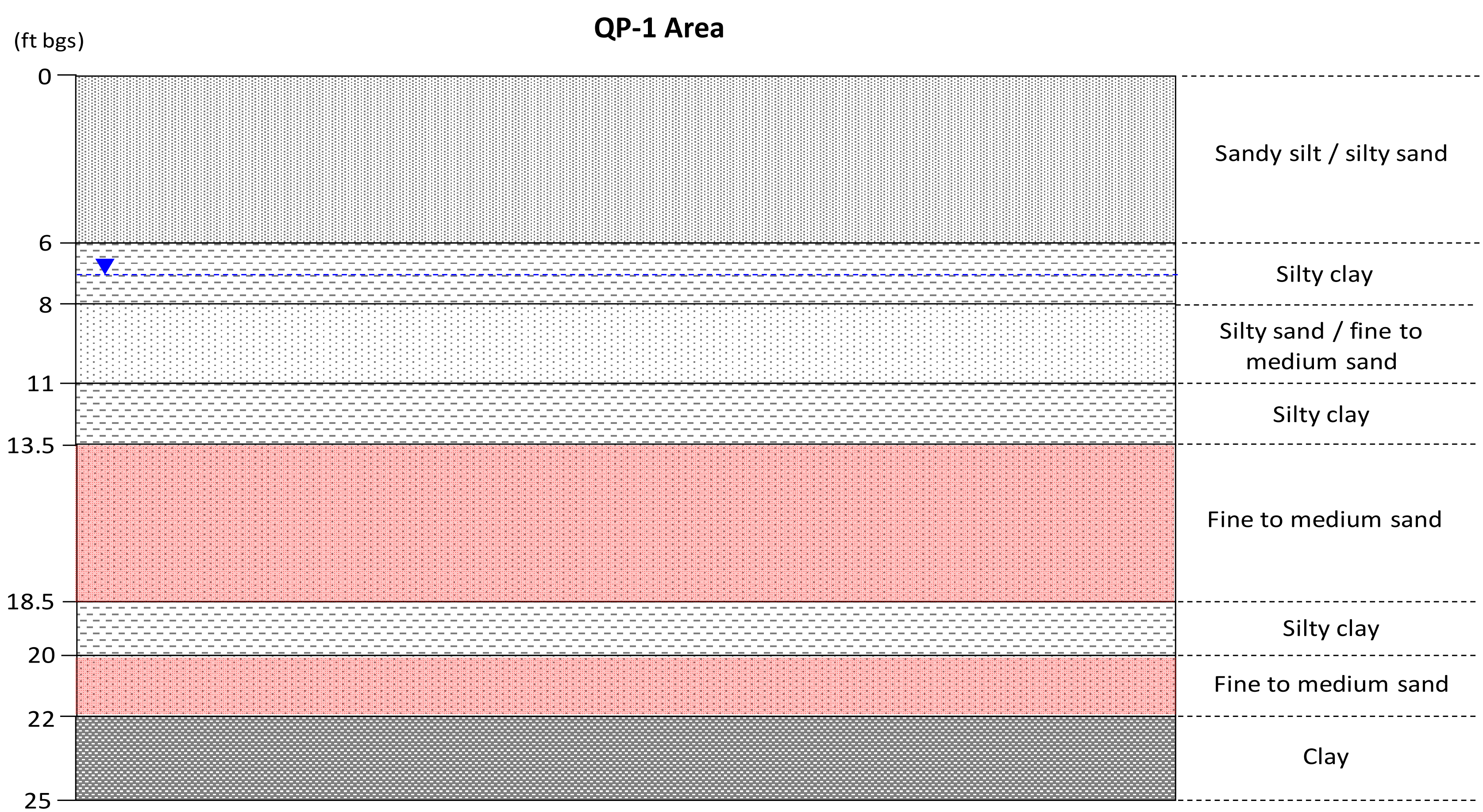
Figure 23



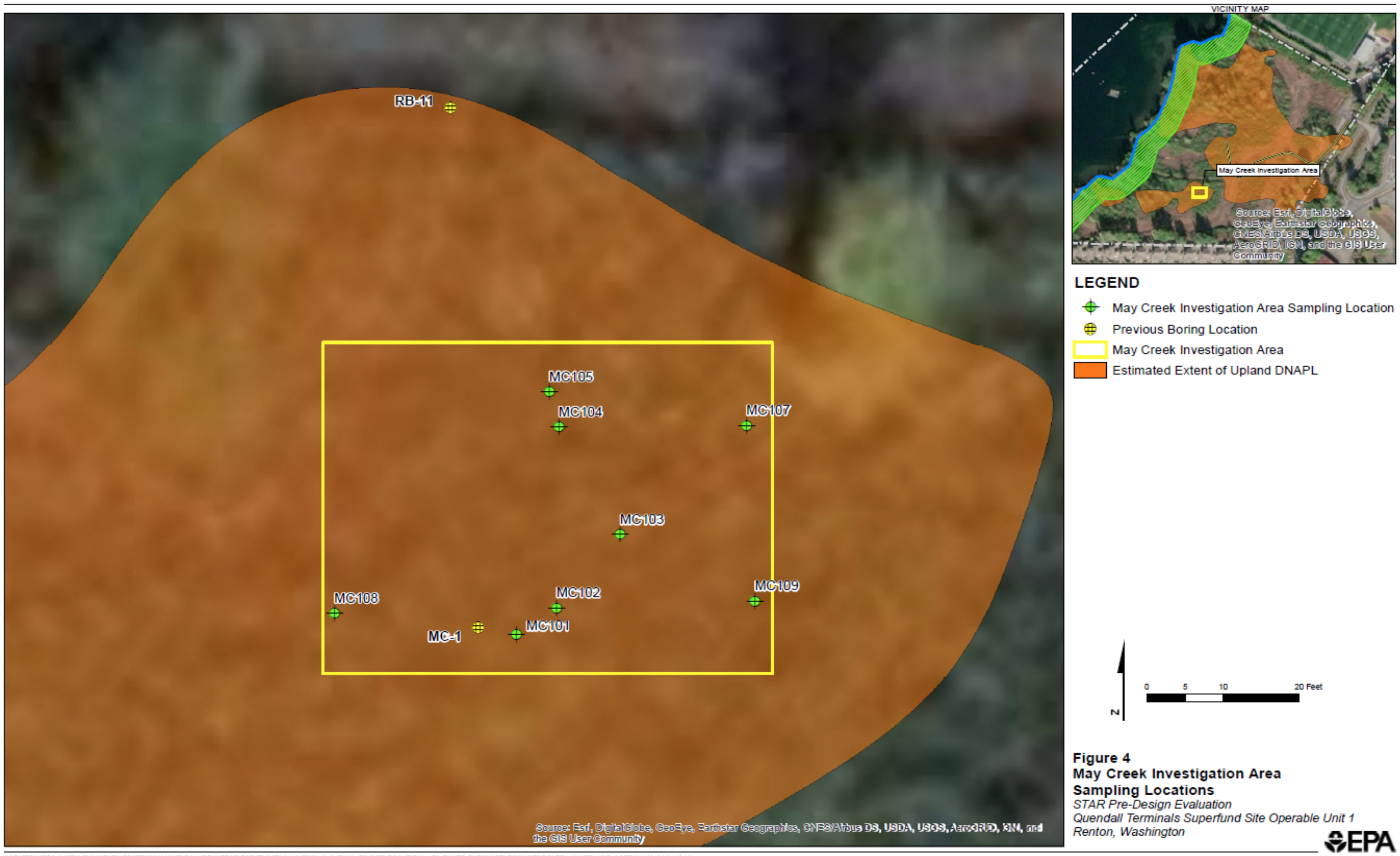
Notes:

Schematic not to scale.

Water elevation

Visual/analytical evidence of impacts amenable to STAR

Simplified Geologic Cross-Section in QP-1 Area Quendall Terminals, Renton, WA STAR PDE	
savron	**October 2018**
	Figure 24



Notes:

Figure obtained from CH2M/Jacobs (September, 2018).

MC-1 Area Sampling Locations

Quendall Terminals, Renton, WA

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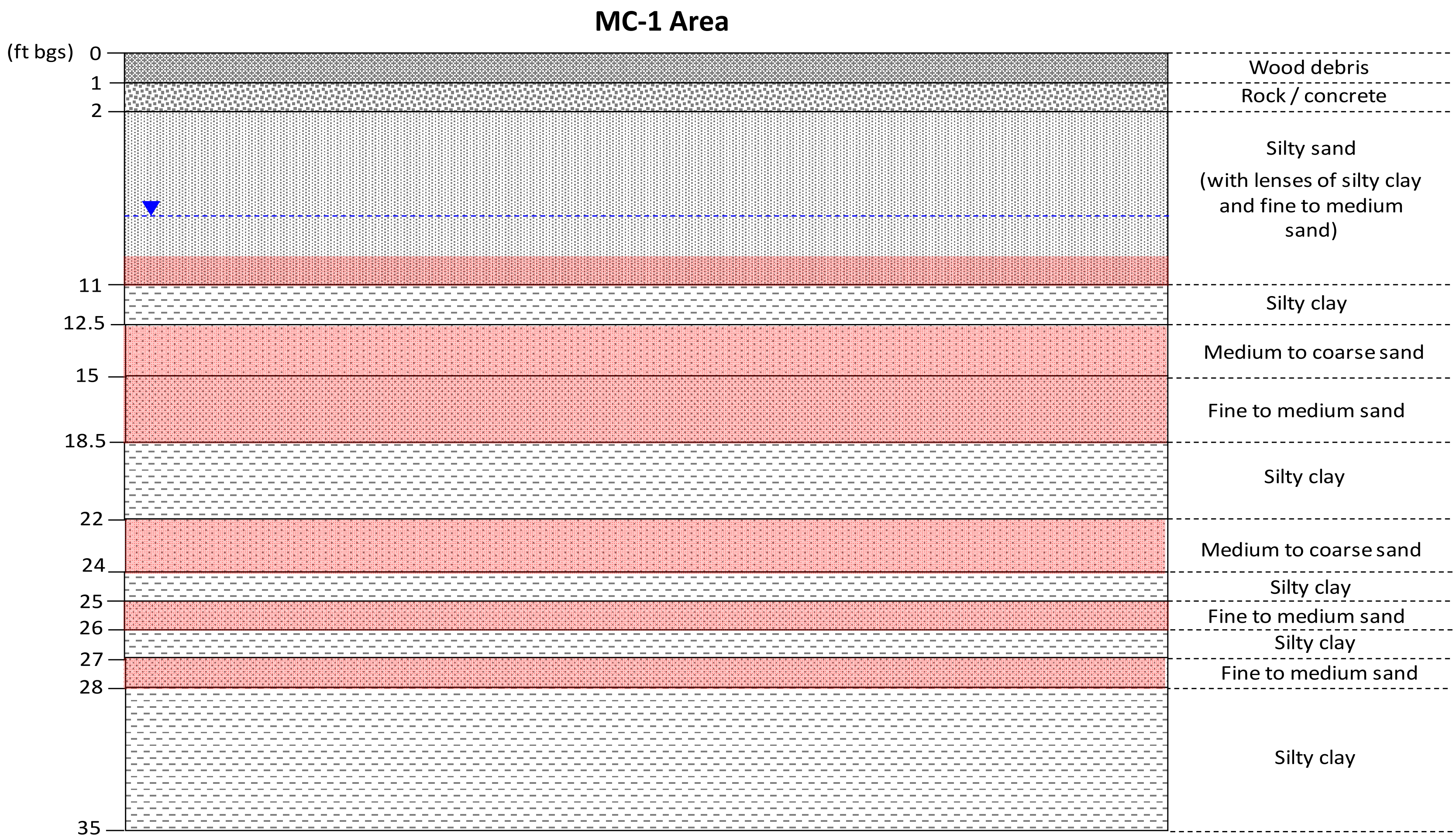
Figure 25



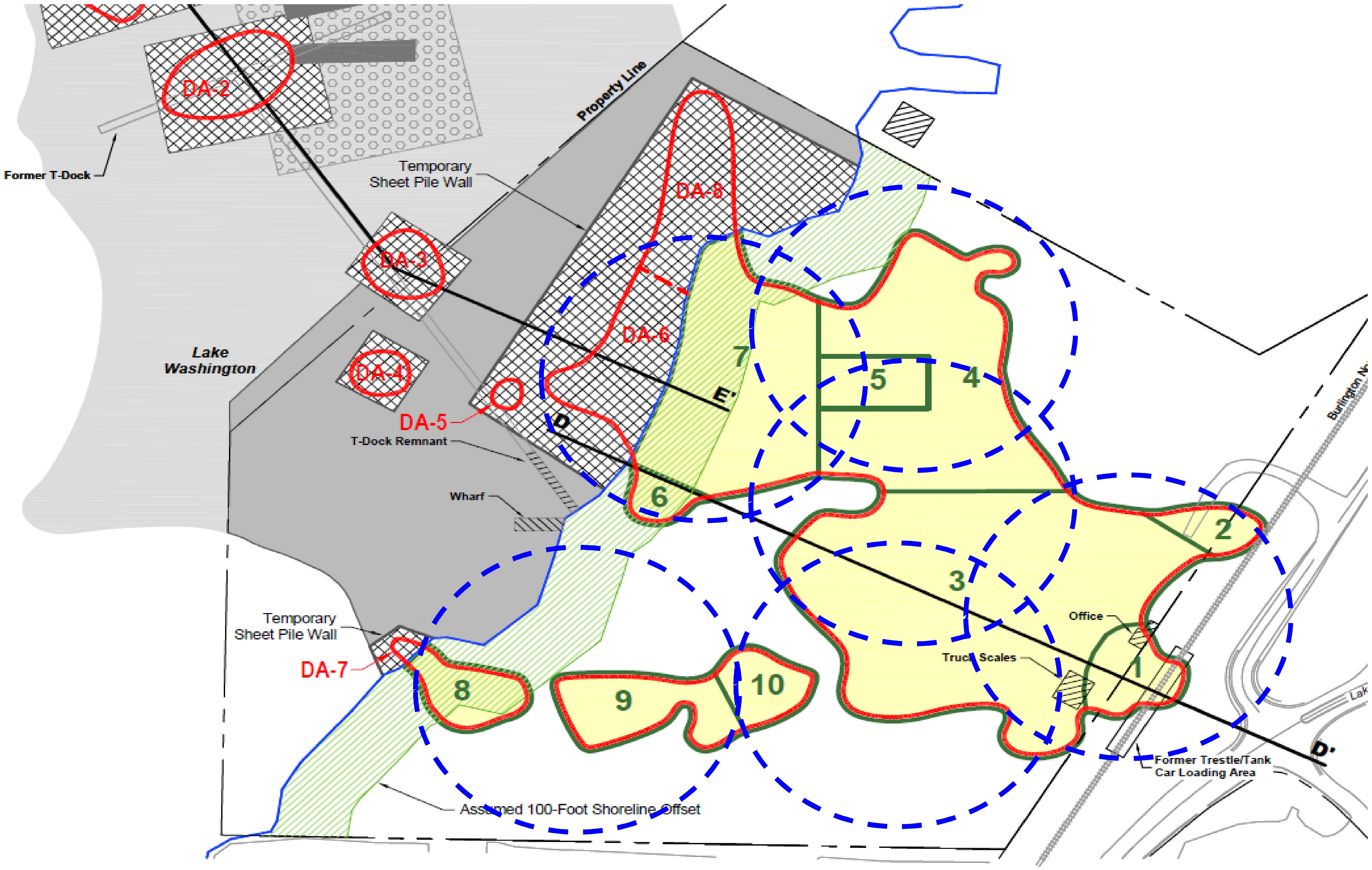
Notes:

Schematic not to scale.

Water elevation

Visual/analytical evidence of impacts amenable to STAR

Simplified Geologic Cross-Section in MC-1 Area Quendall Terminals, Renton, WA STAR PDE	
savron	**October 2018**
	Figure 26



Zone #	Area (ft^2)	Average Depth (ft)
1	15,672	25.5
2	10,105	20.6
3	164,325	9.1
4	86,433	14.2
5	12,616	24.0
6	5,773	26.5
7	74,327	14.1
8	14,529	16.6
9	24,276	11.7
10	12,809	24.5
Total	**420,865**	

Notes:

Figure obtained from Quendall Terminals Feasibility Study Report (Figure 6-18, Aspect Consulting).

Proposed STAR nodes (225 ft radius) shown as blue dashed circles.

0 200 400
Feet

Proposed Full Scale STAR Layout

Quendall Terminals, Renton, WA

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Figure 27

APPENDIX A

FIELD SCREENING DATA FROM VAPOR PROBES

Table A1
Field Screening Data from Vapor Probes during IP-2 Operations
Quendall Terminals
Renton, Washington

		VP-01 (NW)			VP-02 (NE)			VP-03 (Center)			VP-04 (SW)			VP-05 (SE)		
Date/Time	Elapsed Time (hrs)	CO_2 (%)	O_2 (%)	CO (ppm)	CO_2 (%)	O_2 (%)	CO (ppm)	CO_2 (%)	O_2 (%)	CO (ppm)	CO_2 (%)	O_2 (%)	CO (ppm)	CO_2 (%)	O_2 (%)	CO (ppm)
7/20/2018 13:00	-5	23.3	0.6	4	22.2	0.6	109	3.2	16.4	93	7.6	14.4	13	5.3	14.6	70
7/20/2018 18:00	0	23.3	0.5	70	22.2	0.8	176	1.5	18.6	62	11.1	11.3	10	7.6	13	62
7/20/2018 22:00	4	21.5	0.8	102	17.5	1.8	132	1.1	18.9	893	11.6	10.8	13	8.1	12.3	72
7/21/2018 2:00	8	19.7	0.7	772	11.5	7.1	1083	1.5	18.4	1904	13.4	9.8	9	9.2	11.6	75
7/21/2018 6:00	12	18.2	0.7	1343	7.8	11.2	1364	2.1	18.1	>2000	11	11.8	11	9.9	11	74
7/21/2018 10:00	16	17.1	0.5	1853	5.9	12.3	>2000	2.5	17.1	>2000	11.5	11.1	15	10.1	10.6	75
7/21/2018 14:00	20	15.2	0.9	>2000	5	13.3	>2000	2.3	17.3	>2000	18.1	6.1	10	9.8	10.8	65
7/21/2018 18:00	24	14.2	1.1	>2000	4.5	14.4	>2000	3.1	16.8	>2000	24.1	2.7	8	10.5	10.4	64
7/21/2018 22:00	28	11.7	3.9	1902	3.8	16.2	1318	1.4	19.3	1040	20.6	4.1	433	7	12.5	283
7/22/2018 2:00	32	10.8	5	1960	3.2	15.9	>2000	2.6	16.3	>2000	21.4	3	607	14.4	2.6	737
7/22/2018 10:00	40	9.2	6.2	>2000	3.4	16.2	>2000	1.7	18.5	>2000	20.3	2.6	634	16.8	2.4	1825
7/22/2018 14:00	44	8.3	7.7	>2000	3.5	16.6	>2000	1.2	18.7	1616	19.6	2.4	1072	14.6	2.2	>2000
7/22/2018 18:00	48	7.4	9.1	1689	2	17.8	1332	1.4	17.6	1841	16.4	4.6	1969	10.7	5.9	>2000
7/22/2018 22:00	52	6.5	11.1	1676	1.8	18.9	709	1.7	18.4	850	14.6	7.3	1344	6.3	12.8	535
7/23/2018 2:00	56	5.5	12.9	1114	1.5	19.1	1116	2	18.3	1072	16.7	5.5	1223	5.5	14	337
7/23/2018 6:00	60	4.9	14	305	1.2	19.5	177	1.6	19.4	139	16.3	6.6	973	4.2	15.6	112
7/23/2018 10:00	64	4.1	13.8	181	1.2	18.9	75	2.9	16.9	148	8.1	12.8	427	2.9	16	81
7/23/2018 14:00	68	3.6	14.6	115	0.9	19.3	38	1.4	18	65	17.5	14	789	2.3	16.6	73

Notes:
Samples collected at 7/20/2018 13:00 during preliminary in-well heater testing at IP-2
Maximum range for CO on GEM 5000 Plus field meter is 2000 ppm

Table A2
Field Screening Data from Vapor Probes during IP-1 Operations
Quendall Terminals
Renton Washington

		VP-01 (NW)			VP-02 (NE)			VP-03 (Center)			VP-04 (SW)			VP-05 (SE)		
Date/Time	**Elapsed Time (hrs)**	**CO_2 (%)**	**O_2 (%)**	**CO (ppm)**	**CO_2 (%)**	**O_2 (%)**	**CO (ppm)**	**CO_2 (%)**	**O_2 (%)**	**CO (ppm)**	**CO_2 (%)**	**O_2 (%)**	**CO (ppm)**	**CO_2 (%)**	**O_2 (%)**	**CO (ppm)**
7/24/2018 18:00	3	6.2	1.9	245	2.7	12.3	301	3.1	13.9	689	12.9	8.9	69	6	14.3	23
7/24/2018 22:00	7	6.6	7.6	>2000	2.5	16.8	>2000	3.8	15.5	1885	14.6	6.7	75	6.2	14.3	25
7/25/2018 2:00	11	6.3	10.8	1680	2.3	17.5	>2000	3.5	16.3	1370	16.2	5.6	49	6.8	13.7	20
7/25/2018 6:00	15	6.4	11.1	1375	2.3	18	1882	3.3	16.6	950	15.9	5.9	34	7.2	13.4	17
7/25/2018 10:00	19	5.6	11.7	1516	1.9	18.4	1322	2.5	17.5	564	17.6	4	29	7.1	13.3	15
7/25/2018 14:00	23	5	11.9	1608	1.7	17.9	1640	2.7	16.4	1127	16.1	5.2	24	6.7	13.3	16
7/25/2018 18:00	27	5.4	10.6	>2000	1.9	17.4	>2000	3.1	15.7	1477	22	1.3	36	9.1	10.6	20
7/25/2018 22:00	31	5.4	10.9	>2000	2.2	17.1	>2000	3.4	15.4	>2000	22.3	1.4	28	9.6	10.8	16
7/26/2018 2:00	35	5.1	12.9	>2000	2.3	18.6	1655	3.8	15.3	>2000	21.5	2.1	37	13.8	5.6	44
7/26/2018 6:00	39	4.7	13.4	>2000	2.1	18	>2000	4.1	15.6	>2000	20.5	2.3	309	10.1	9.7	>2000
7/26/2018 10:00	43	3.6	11.5	>2000	1.5	15.3	1603	3.3	12.2	>2000	17.6	2	770	3.3	11	1704
7/26/2018 14:00	47	3.9	13.8	>2000	1.5	18.8	1197	3.3	16.7	1550	18.2	1.7	1485	3.5	15.3	1564
7/26/2018 18:00	51	4.1	14.1	>2000	1.4	18.2	1915	3.2	16.7	1585	17.9	1.7	1826	2.6	16.9	860
7/26/2018 22:00	55	3.3	15.7	>2000	1.4	19.1	1901	2.7	17.9	1549	19.7	1.9	1214	2.1	17.6	1556
7/27/2018 2:00	59	3.6	15.6	>2000	1.1	19.5	1456	2.3	18.6	1302	19.9	2.4	1014	1.9	18.6	365
7/27/2018 6:00	63	3.5	15.3	>2000	0.9	19.7	853	1.7	19.3	676	20.4	2.6	1010	1.6	18.7	406
7/27/2018 10:00	67	3.2	15.2	>2000	0.8	18.6	684	1	18.7	246	16.8	5.5	787	1.3	18.2	533
7/27/2018 14:00	71	3	15.9	>2000	1	19	1943	0.7	19.8	189	6.8	14.3	209	1.1	18.7	99
7/27/2018 18:00	75	2.9	16.1	>2000	1.1	19	1416	0.5	19.8	202	--	--	--	1	18.8	219
7/27/2018 22:00	79	2.4	17.6	>2000	0.8	20.3	773	0.5	20.8	133	--	--	--	1	19.5	923
7/28/2018 2:00	83	2.7	17	>2000	0.9	20.1	523	0.7	20.3	104	--	--	--	1	19.9	47
7/28/2018 6:00	87	2.8	17.7	1058	0.9	20	392	0.9	20.2	79	--	--	--	0.8	19.9	38
7/28/2018 10:00	91	2.4	17.7	612	0.7	19.9	167	0.3	20.7	35	21.1	0.8	975	0.7	19.6	39
7/28/2018 14:00	95	1.8	18.6	168	0.1	20.6	15	0.1	20.7	12	19.1	3	606	0.6	19.6	34
7/28/2018 18:00	99	1.5	19	61	0.1	20.7	10	0.1	20.7	11	17.1	4.6	384	0.5	19.7	28
7/28/2018 22:00	103	1.4	19.9	36	0.1	21.5	6	0.1	20.5	8	18.1	3.7	312	0.6	20.4	24
7/29/2018 2:00	107	0.8	20.3	25	0.1	21.3	5	0.1	20.2	7	18.9	3.5	202	0.5	20.4	20
7/29/2018 6:00	111	1.2	19.5	36	0.1	21.5	5	0.1	21.5	6	17.7	3.7	174	0.5	20.7	17
7/29/2018 10:00	115	0.1	20.7	32	0.1	20.7	4	0.1	20.6	6	18.7	7	165	0.5	19.8	20
7/29/2018 14:00	119	1.1	18.6	32	0.1	20.4	6	0.1	20.3	7	11.9	8	166	0.5	19.4	25
7/29/2018 18:00	123	1	18.7	27	0.1	20.4	5	0.1	20.3	8	11.1	8.3	148	0.4	19.4	23
7/29/2018 22:00	127	1	19.6	21	0.1	21.1	5	0.1	21	7	10.3	9.7	138	0.4	20.3	17
7/30/2018 2:00	131	1	19.9	19	0.1	21.2	4	0.1	21.2	5	9.2	11.3	126	0.4	20.5	17
7/30/2018 6:00	135	1	19.8	19	0.1	21.2	3	0.1	21.2	4	4.7	15.4	88	0.4	20.5	17
7/30/2018 10:00	139	1	19.1	21	0.1	20	18	0.1	20.7	5	6	13.4	105	0.1	20.7	4
7/30/2018 14:00	143	0.9	18.9	18	0.1	20.5	5	0.1	20.4	7	6	12.9	109	0.4	19.6	20
7/30/2018 18:00	147	0.9	18.9	19	0.1	20.5	5	0.1	20.4	6	5.2	13.6	101	0.3	19.6	20
7/30/2018 22:00	151	0.9	19.3	17	0.1	20.9	4	0.1	20.8	6	4.7	14.7	90	0.3	20.2	17
7/31/2018 2:00	155	1	19.9	19	0.1	21.4	4	0.1	21.4	6	4.8	15.2	86	0.4	20.8	15
7/31/2018 6:00	159	1	19.8	17	0.1	21.1	3	0.1	21.1	4	4.5	15.5	80	0.4	20.5	15
7/31/2018 10:00	163	0.9	19.6	13	0.1	21.1	3	0.1	21	4	4.5	15.4	78	0.3	20.3	16
7/31/2018 14:00	167	1	20.7	7	0.1	20.6	6	0.1	20.7	7	4.5	14.9	86	0.3	20.1	18
7/31/2018 18:00	171	0.9	19.4	14	0.1	20.9	4	0.2	20.6	6	3.3	16.6	60	0.3	20.2	18
7/31/2018 22:00	175	0.9	19.8	14	0.1	20.3	3	0.2	21.2	5	3.2	17.2	54	0.3	20.6	16
8/1/2018 2:00	179	1	19.6	14	0.1	21.1	4	0.2	20.9	5	3.2	17.1	53	0.3	20.5	14
8/1/2018 6:00	183	0.9	19.7	13	0.1	21.2	3	0.2	21	6	2.9	17.5	48	0.3	20.6	13

Notes:
-- No sample collected due to water in vapor probe
Maximum range for CO on GEM 5000 Plus field meter is 2000 ppm

APPENDIX B

PRE-STAR BORING LOGS

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BORING LOG

Project No.:	**TS0034**	Page	1 of 1
Site Name:	Quendall Terminals	Date Started:	6/28/2018
Boring I.D.:	IP-1	Date Completed:	6/28/2018
Geologist/Eng.:	LK	Borehole Diameter:	2.25"
Drilling Company:	Cascade	Borehole Depth:	18'
Drilling Method:	DPT	Depth to Water:	7'6"
Comments:			

Depth	Sample Interval	Lithologic Description	% Recovery	PID Reading (ppm)	Comments
0–5		NO RECOVERY (0' to 5')	0	-- / -- / -- / -- / --	Vac cleared to 5' - no sample collected
5–10		SILTY CLAY (5'6" to 6'3"), brown, moist MEDIUM TO FINE SAND (6'3" to 7"), grey, moist, moderately stained SILTY CLAY (7' to 8'), dark brown, organics SILTY FINE SAND (8' to 10'), greyish brown, wet, very lightly stained	90	15.6 / 67.3 / 45.6 / 23.3 / 14.1	
10–15		FINE SAND (11' to 11'7"), grey, heavily stained, wet SILTY CLAY (11'7" to 13'6"), greyish brown MEDIUM TO FINE SAND (13'6" to 15'), grey, product stringers from 14' to 15'	85	6.4 / 28.9 / 22.6 / 16.6 / 247.6	
15–18		FINE SAND (16' to 17'), some silt, brownish grey, moderately stained SILTY CLAY (17' to 18'), brown	50	-- / 38.7 / 53.3	
18		END OF BORING			

INSTALL DETAILS:
Screen installed at 17 ft bgs
Sand to 15'4"
Bentonite to 14'8"
Grout to surface

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BORING LOG

Project No.:	**TS0034**	Page 1 of 1	
Site Name:	Quendall Terminals	Date Started:	6/28/2018
Boring I.D.:	IP-2	Date Completed:	6/28/2018
Geologist/Eng.:	LK	Borehole Diameter:	2.25"
Drilling Company:	Cascade	Borehole Depth:	18'
Drilling Method:	DPT	Depth to Water:	8'6"
Comments:			

Depth	Sample Interval	Lithologic Description	% Recovery	PID Reading (ppm)	Comments
0–5		NO RECOVERY (0' to 5')	0	-- / -- / -- / -- / --	Vac cleared to 5' - no sample collected
5–10		QUARRY SPALLS (5' to 6'4") SILTY CLAY (6'4" to 6'9"), dark brown MEDIUM TO FINE SAND (6'9" to 7'8"), greyish brown, heavily stained SILTY FINE SAND (7'8" to 10'), greyish brown, wet	90	5.1 / 29.6 / 95.2 / 24.2 / 21.1	
10–15		MEDIUM TO FINE SAND (10' to 11'), dark brown, lightly stained SILTY CLAY (11' to 13'3"), dark brown MEDIUM TO FINE SAND (13'3" to 15'), grey, stringers of product	95	69.6 / 39.6 / 35.1 / 20.1 / 84.9	
15–18		MEDIUM TO FINE SAND (15' to 17'3"), dark brown, wet, product SILTY CLAY (17'3" to 18'), dark brown	100	108.2 / 135.9 / 67.8	
18		END OF BORING			

INSTALL DETAILS:
Screen installed at 17.5 ft bgs
Sand to 16'
Bentonite to 15'2"
Grout to surface

BORING LOG

Project No.:	**TS0034**	Page	1 of 1
Site Name:	Quendall Terminals	Date Started:	6/29/2018
Boring I.D.:	TC-5	Date Completed:	6/29/2018
Geologist/Eng.:	LK	Borehole Diameter:	2.25"
Drilling Company:	Cascade	Borehole Depth:	17'
Drilling Method:	DPT	Depth to Water:	8'
Comments:			

Depth	Sample Interval	Lithologic Description	% Recovery	PID Reading (ppm)	Comments
0–5		TOP SOIL (2' to 3') QUARRY SPALLS (3' to 3'6") MEDIUM TO FINE SAND (3'6" to 4'3"), grey, trace pebbles, moist SILTY SAND WITH ORGANICS (4'3" to 5'), brown/grey	60	-- -- 0 0.4 3.1	
5–10		SLOUGH (5'6" to 6'6"), collapsed from above QUARRY SPALLS (6'6" to 7') SILT/QUARRY SPALLS (7' to 7'8"), product MEDIUM TO FINE SAND (7'8" to 8'4"), grey, wet, moderately stained PEAT (8'4" to 9') FINE SANDY SILT (9' to 10'), grey, wet	85	0.5 2.4 105.9 58.4 27.3	
10–15		SLOUGH (10' to 10'6"), collapsed from above MEDIUM TO FINE SAND (10'6" to 11'), brown wet, lightly stained SILTY CLAY (11' to 13'4"), grey, wet MEDIUM TO FINE SAND (13'4" to 15'), grey	100	37.1 11.8 7.4 5.2 15.8	
15–17	sampled (15'–17')	MEDIUM TO FINE SAND (15' to 16'), brown, wet, heavy product SILTY CLAY (16' to 17'), brown	>100	80.4 288	Some heaving sands at top of core (>100% recovery)
17		END OF BORING		95.3	

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BORING LOG

Project No.:	**TS0034**	Page	1 of 1
Site Name:	Quendall Terminals	Date Started:	6/29/2018
Boring I.D.:	TC-6	Date Completed:	6/29/2018
Geologist/Eng.:	LK	Borehole Diameter:	2.25"
Drilling Company:	Cascade	Borehole Depth:	17'
Drilling Method:	DPT	Depth to Water:	8'
Comments:			

Depth	Sample Interval	Lithologic Description	% Recovery	PID Reading (ppm)	Comments
0–5		TOP SOIL/WOOD CHIPS (1' to 2'2") MEDIUM TO FINE SAND (2'2" to 3'9"), grey, some pebbles, moist SILT (3'9" to 5'), dark brown, compact, some organics	80	-- 0 0 1.5 1.1	
5–10		FINE SAND/SILT (5' to 7'), light grey/brown, dry, some organics SILTY CLAY (7' to 8'), dark brown FINE SAND (8' to 9'), dark grey, wet, heavily stained FINE SILTY SAND (9' to 10'), grey, heavily stained	80	-- 2.2 41.5 68.2 62.2	
10–15	sampled (13.5'–15')	SILT (10'5" to 10'9"), dark grey, wet SILTY SAND (10'9" to 11'6"), compact SILTY CLAY (11'8" to 13'3"), grey/black banding, wet MEDIUM TO FINE SAND (13'3" to 15'), bands of product	90	13.6 168.5 39.8 45.7 243.8	
15–17	sampled (15.5'–17')	MEDIUM TO FINE SAND (15' to 16'), wet, product SILTY CLAY (16' to 17'), brown	>100	331.6 109.6	Heaving sands at top of core (>100% recovery)
17		END OF BORING		93.7	

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BORING LOG

Project No.:	**TS0034**	Page	1 of 1
Site Name:	Quendall Terminals	Date Started:	6/29/2018
Boring I.D.:	TC-9	Date Completed:	6/29/2018
Geologist/Eng.:	LK	Borehole Diameter:	2.25"
Drilling Company:	Cascade	Borehole Depth:	18'
Drilling Method:	DPT	Depth to Water:	8'
Comments:			

Depth	Sample Interval	Lithologic Description	% Recovery	PID Reading (ppm)	Comments
0–5		TOP SOIL/WOOD CHIPS (1' to 2'4") SILTY SAND/PEBBLES (2'4" to 2'8") SILTY SAND/WOOD CHIPS (2'8" to 3'2"), dark brown FINE SAND (3'2" to 4'1"), grey, trace pebbles SILTY SAND (4'1" to 5'), dark brown, organics	80	0 0 0 0 0	
5–10		FINE SAND (6' to 6'7"), grey, dry SILTY SAND/ORGANICS (6'1" to 7'4"), brown FINE SAND/PEBBLES (7'4" to 8'), compact SILTY SAND/PEBBLES (8' to 9'1"), compacy, wet, product MEDIUM TO FINE SAND (9' to 10'), dark grey, heavily stained	85	-- 0 9.4 89.4 136.8	
10–15	14–15 (sample)	SLOUGH (10'6" to 11'4"), collapsed from above SILTY CLAY (11'4" to 13'), grey, wet SILTY FINE SAND (13' to 14'2"), dark brown MEDIUM TO FINE SAND (14'2" to 15'), grey	90	19.7 10 6.7 3.3 18.9	
15–18	15–16 (sample)	FINE SAND (15' to 15'5"), grey SILTY CLAY (15'5" to 18')	100	23.9 12.9 3.9	Rock stuck in rod from 15' to 17' - stepped off and redrilled interval to 18'
18		END OF BORING			

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BORING LOG

Project No.:	**TS0034**	Page	1 of 1
Site Name:	Quendall Terminals	Date Started:	6/29/2018
Boring I.D.:	TC-10	Date Completed:	6/29/2018
Geologist/Eng.:	LK	Borehole Diameter:	2.25"
Drilling Company:	Cascade	Borehole Depth:	17'
Drilling Method:	DPT	Depth to Water:	8'
Comments:			

Depth	Sample Interval	Lithologic Description	% Recovery	PID Reading (ppm)	Comments
0–5		NO RECOVERY (0' to 5')	0	-- / -- / -- / -- / --	Rock stuck in sample rod - no recovery
5–10		WOOD DEBRIS (7' to 8'), product MEDIUM TO FINE SAND (8' to 8'8") grey, wet, moderately stained SILTY CLAY (8'8" to 10'), grey, lightly stained	60	-- / -- / 238.9 / 66.5 / 69.2	
10–15	14–15	CLAY (10' to 10'4") MEDIUM TO FINE SAND (10'4" to 11'), grey, heavily stained, strong odor SILTY CLAY (11' to 13'6"), stringers of product, strong odor MEDIUM TO COARSE SAND (13'6" to 15'), stringers of staining, wet	100	55.8 / 45.5 / 21 / 23.4 / 18.9	
15–17	15–16	MEDIUM TO FINE SAND (15' to 16'6"), wet, product, strong odor SILTY CLAY (16'6" to 17'), brown	>100	201.2 / 297.2 / 104	Heaving sands at top of core (>100% recovery)
17		END OF BORING			

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BORING LOG

Project No.:	**TS0034**	Page	1 of 1
Site Name:	Quendall Terminals	Date Started:	7/2/2018
Boring I.D.:	TC-11	Date Completed:	7/2/2018
Geologist/Eng.:	LK	Borehole Diameter:	2.25"
Drilling Company:	Cascade	Borehole Depth:	17'
Drilling Method:	DPT	Depth to Water:	8'
Comments:	Refusal at first 3 location attempts - shifted west of original location		

Depth	Sample Interval	Lithologic Description	% Recovery	PID Reading (ppm)	Comments
		TOP SOIL (1' to 1'6"), brown WOOD DEBRIS (1'6" to 2'2"), brown SILTY SAND (2'2" to 2'8"), dark brown, compact FINE SAND/PEBBLES (2'8" to 5'), grey transitioning to dark grey, some silt, compact	70	-- 0.0 0.0 10.4 1.9	
5		SLOUGH (5 to 8'6"), collapsed from above SILTY SAND (8'6" to 9'), dark grey, compact, product SILTY CLAY (9' to 9'4") MEDIUM TO FINE SAND (9'4" to 10'), grey, moderately stained	20	-- 0.0 0.0 45.0 74.8	
10		SLOUGH (10' to 11'), collapsed from above MEDIUM TO FINE SAND (11' to 12'), dark grey, product, wet SILTY CLAY (12' to 13'3"), brown MEDIUM TO FINE SAND (13'3" to 15'), grey, bands of heavy staining/product	100	38.0 345.8 147.9 128.9 304.9	
15		MEDIUM TO FINE SAND (15' to 16'), grey, product, wet SILTY CLAY (16' to 17'), brown	100	140.0 58.4	Heaving sands in top 2' of recovered soils
17		END OF BORING			

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BORING LOG

Project No.:	**TS0034**	Page	1 of 1
Site Name:	Quendall Terminals	Date Started:	7/2/2018
Boring I.D.:	TC-12	Date Completed:	7/2/2018
Geologist/Eng.:	LK	Borehole Diameter:	2.25"
Drilling Company:	Cascade	Borehole Depth:	17'
Drilling Method:	DPT	Depth to Water:	8'
Comments:			

Depth	Sample Interval	Lithologic Description	% Recovery	PID Reading (ppm)	Comments
0–5		TOPSOIL (1'4" to 2'3"), brown, wood chips QUARRY SPALLS (2'3" to 2'10"), light grey SILTY SAND (2'10" to 3'5"), grey brown, compact MEDIUM TO FINE SAND (3'5" to 4'), grey, moist SILTY SAND/PEAT (4' to 5'), dark brown/black	70	-- 0.0 0.0 0.0 3.9	
5–10	9–10	QUARRY SPALLS (6' to 6'11") MEDIUM TO FINE SAND (6'11" to 7'4"), dark brown, heavy staining PEAT (7'4" to 7'11"), dark brown SILTY CLAY (7'11" to 9'2"), grey, wet, light staining MEDIUM TO COARSE SAND (9'2" to 10'), grey, light staining	80	-- 0.0 149.1 22.8 20.3	
10–15	14–15	SILTY SAND/GRAVEL (10' to 11'4"), dark brown MEDIUM TO FINE SAND (11'4" to 11'7"), dark grey, gravel, stained stringers, wet SILTY CLAY (11'7" to 13'5"), brown MEDIUM TO FINE SAND (13'5" to 15'), grey, bands of staining/product	85	-- 14.9 13.6 10.1 156.1	
15–17		MEDIUM TO COARSE SAND (15' to 15'2"), product SILTY CLAY (15'2" to 17'), brown	100	134.5 21.8	No recover at initial location. Installed TC-12 and stepped off to recover sample.
17		END OF BORING		7.8	PID reading of 134.5 ppm in 2" sand layer

BORING LOG

Project No.:	**TS0034**	Page	1 of 1
Site Name:	Quendall Terminals	Date Started:	7/2/2018
Boring I.D.:	TC-16	Date Completed:	7/2/2018
Geologist/Eng.:	LK	Borehole Diameter:	2.25"
Drilling Company:	Cascade	Borehole Depth:	17'
Drilling Method:	DPT	Depth to Water:	8'
Comments:			

Depth	Sample Interval	Lithologic Description	% Recovery	PID Reading (ppm)	Comments
		TOPSOIL (1' to 2'), brown, wood chips QUARRY SPALLS (2' to 3'), light grey SILTY SAND (3' to 3'7"), grey, quarry spalls PEAT (3'7" to 4'), dark brown SILTY SAND (4' to 5'), grey, compact, moist	80	-- 0.0 0.0 9.4 6.3	
5		SILTY CLAY (7' to 7'11"), grey MEDIUM TO FINE SAND (7'11" to 8'5"), grey, moderately stained SILTY CLAY (8'5" to 9'6"), grey brown, lightly stained MEDIUM TO FINE SAND (9'6" to 10'), grey, moderately stained	60	-- -- 21.0 101.2 88.6	
10		SILTY CLAY (10'4" to 10'7"), dark grey PEAT (10'7" to 11'2"), brown SILTY CLAY (11'2" to 12'7"), grey brown MEDIUM TO FINE SAND (12'7" to 15'), grey, bands of heavy staining	95	31.0 96.7 42.6 197.1 129.3	
15		MEDIUM TO FINE SAND (15' to 15'5"), product, wet SILTY CLAY (15'5" to 17'), brown	100	120.4 79.6	
17		END OF BORING			

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BORING LOG

Project No.:	**TS0034**	Page	1 of 1
Site Name:	Quendall Terminals	Date Started:	7/2/2018
Boring I.D.:	TC-18	Date Completed:	7/2/2018
Geologist/Eng.:	LK	Borehole Diameter:	2.25"
Drilling Company:	Cascade	Borehole Depth:	17'
Drilling Method:	DPT	Depth to Water:	8'
Comments:			

Depth	Sample Interval	Lithologic Description	% Recovery	PID Reading (ppm)	Comments
0–5		TOPSOIL (1' to 1'9"), brown, wood chips SILTY SAND/QUARRY SPALLS (1'9" to 3'5") MEDIUM TO FINE SAND (3'5" to 3'11"), grey SILTY SAND (3'11" to 5'), dark brown some peat	80	-- 0.0 0.0 0.0 1.7	
5–10		SILTY SAND/PEBBLES (6' to 7'), compact PEBBLES (7' to 7'11), stringers of product MEDIUM TO FINE SAND (7'11" to 8'1"), heavily stained SILTY CLAY (8'1" to 10'), dark grey	70	-- 24.0 79.2 7.5 14.7	
10–15		SILTY CLAY (10'6" to 11'), grey brown, wet MEDIUM TO FINE SAND (11' to 11'5"), wet, visible product SILTY CLAY (11'10" to 14'), brown MEDIUM TO FINE SAND (14' to 15'), grey	100	8.4 159.4 53.8 21.3 11.7	Rock stuck in sample rod at original location - no recovery. Installed TC-18 and stepped off to recover soils for 10' to 15' interval.
15–17		SILTY CLAY (15' to 17'), brown	100	4.7 7.4	
17		END OF BORING			

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BORING LOG

Project No.: **TS0034**
Site Name: Quendall Terminals
Boring I.D.: TC-20
Geologist/Eng.: LK
Drilling Company: Cascade
Drilling Method: DPT
Comments:

Date Started: 7/2/2018
Date Completed: 7/2/2018
Borehole Diameter: 2.25"
Borehole Depth: 17'
Depth to Water: 8'

Depth	Sample Interval	Lithologic Description	% Recovery	PID Reading (ppm)	Comments
0–5		TOP SOIL (1' to 2'6"), brown, wood chips QUARRY SPALLS (2'6" to 3'8"), light grey MEDIUM TO FINE SAND (3'8" to 5'), grey transitioning to dark grey, compact, some silt, some organics	80	-- 7.4 1.0 3.5 7.1	
5–10		SILTY SAND/PEBBLES (7'8" to 8'10"), compact MEDIUM TO FINE SAND (8'10" to 9'4"), dark grey, heavy staining SILTY CLAY (9'4" to 10'), brown	60	-- -- 9.3 10.9 143.8	
10–15	(sample)	SILTY CLAY (10' to 10'9"), brown MEDIUM TO FINE SAND (10'9" to 11'7"), dark grey, visible product, wet SILTY CLAY (11'7" to 14'), brown MEDIUM TO FINE SAND (14' to 15'), grey, light staining	100	146.4 250.9 56.1 36.6 43.2	
15–17	(sample)	MEDIUM TO FINE SAND (15' to 15'6"), wet, visible product PEAT (15'6" to 15'8") SILTY CLAY (15'8" to 17'), brown	100	232.7 31.3	
17		END OF BORING			

APPENDIX C

POST-STAR BORING LOGS

2018.10.18

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BORING LOG

Project No.: **TS0034**
Site Name: Quendall Terminals
Boring I.D.: PT-01
Geologist/Eng.: LK
Drilling Company: Cascade
Drilling Method: DPT
Comments:

Page 1 of 1
Date Started: 8/1/2018
Date Completed: 8/1/2018
Borehole Diameter: 2.25"
Borehole Depth: 17'

Depth	Sample Interval	Lithologic Description	% Recovery	PID Reading (ppm)	Comments
		TOP SOIL (2' to 2'6") SILTY SAND (2'6" to 3'4"), compact QUARRY SPALLS (3'4" to 3'8") MEDIUM SAND (3'8" to 4'2"), light brown, moist SILT/PEAT (4'2" to 5'), dark brown	60	-- -- 0.0 0.0 8.3	
5		SLOUGH (7' to 8'), collapsed from above SILTY CLAY (8' to 8'4"), grey brown, moist MEDIUM TO COARSE SAND (8'4" to 9'), brown, moist SILTY SAND (9' to 10'), grey brown, moist	60	-- -- 0.0 99.4 36.4	
10		SILTY CLAY (12' to 14'), dark grey/brown with color banding MEDIUM TO FINE SAND (14' to 15'), light brown, loose, dry	60	-- -- 14.7 10.5 0.2	Poor recovery at initial location, stepped off and collected new sample for 10 to 15' interval
15		SILTY CLAY (15' to 15'2"), dark grey, moist FINE SAND (15'2" to 16'), light brown, dry SILTY CLAY (16' to 17'), brown, compact	100	1.5 42.4	
17		END OF BORING			

BORING LOG

Project No.:	**TS0034**	Page	1 of 1
Site Name:	Quendall Terminals	Date Started:	8/1/2018
Boring I.D.:	PT-02	Date Completed:	8/1/2018
Geologist/Eng.:	LK	Borehole Diameter:	2.25"
Drilling Company:	Cascade	Borehole Depth:	17'
Drilling Method:	DPT		
Comments:			

Depth	Sample Interval	Lithologic Description	% Recovery	PID Reading (ppm)	Comments
0–5		TOP SOIL (1' to 2'4"), brown QUARRY SPALLS (2'4" to 2'9") SAND/PEAT (2'9" to 3'8"), dark brown SILTY SAND (3'8" to 5'), dark grey, compact, stringer of hard tar	80	-- 0.0 0.0 11.3 2.5	
5–10		SLOUGH (7' to 7'8"), collapsed from above SILTY CLAY (7'8" to 10'), grey brown, some sand, slight sheen/staining, moist	60	-- -- 0.0 107.0 21.6	
10–12	sampled (approx. 11'–12')	SILTY SAND (10' to 12'), dark grey, moist, with some dry sand stringers; appear to have additional lost dry sand from bottom of liner	85	8.3 14.9	Poor recovery at initial location, stepped off and resampled from 10 to 12' and 12' to 17'
12–17	sampled (approx. 14.5'–15.5')	SILTY CLAY (13'6" to 14'6"), dark brown, some fine sand, moist MEDIUM TO FINE SAND (14'5" to 15'8"), light brown/pink, loose, dry SILTY CLAY (15'8" to 17'), brown, few sand	70	-- 2.1 1.4 0.3 --	
17		END OF BORING			

BORING LOG

Project No.:	**TS0034**	Page	1 of 1
Site Name:	Quendall Terminals	Date Started:	8/1/2018
Boring I.D.:	PT-03	Date Completed:	8/1/2018
Geologist/Eng.:	LK/AS	Borehole Diameter:	2.25"
Drilling Company:	Cascade	Borehole Depth:	17'
Drilling Method:	DPT		
Comments:	Changed DPT sampling intervals to improve recovery		

Depth	Sample Interval	Lithologic Description	% Recovery	PID Reading (ppm)	Comments
		TOPSOIL (0' to 1') WOODCHIPS (1' to 2')	100	0.0 0.0	
2		SLOUGH (2' to 3'), collapsed from above MEDIUM TO FINE SAND (3' to 4'2"), medium brown SILTY SAND (4'2" to 5'2"), dark grey to black, compact, some peat MEDIUM TO FINE SAND (6' to 7'), light staining, thin band of product at base of liner	80	-- 0.8 41.6 108.5 126.1	
7		SLOUGH (8' to 9'), collapsed from above SILTY CLAY (9' to 11'), slight sheen, wet from 9' to 10' SILTY SAND (11' to 12'), dark brown, light brown clean and dry lens at 11.5'	80	-- 2.2 20.3 5.1 5.5	
12		SILTY CLAY (14'6" to 15'2"), dark brown, transitioning to silty sand MEDIUM TO FINE SAND (15'2" to 16'), light brown, loose, dry SILTY CLAY (16' to 17'), dark brown, light staining	50	-- -- 43.4 0.4 90.8	
17		END OF BORING			

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BORING LOG

Project No.:	**TS0034**	Page	1 of 1
Site Name:	Quendall Terminals	Date Started:	8/1/2018
Boring I.D.:	PT-04	Date Completed:	8/1/2018
Geologist/Eng.:	LK/AS	Borehole Diameter:	2.25"
Drilling Company:	Cascade	Borehole Depth:	17'
Drilling Method:	DPT		
Comments:			

Depth	Sample Interval	Lithologic Description	% Recovery	PID Reading (ppm)	Comments
		TOPSOIL (0' to 2'), dark brown, organics	75	0.0 0.0	
2		SLOUGH (2' to 3'), collapsed from above SILTY SAND/PEBBLES (3' to 4'3"), brown, some organics SILTY SAND (4'3" to 5'5"), dark brown, compact SILTY CLAY (5'5" to 6') MEDIUM TO FINE SAND (6' to 6'4") SILTY CLAY (6'4" to 7')	95	0.0 0.8 11.7 27.7 96.5	
7		CLAY (7' to 8'), dark grey SLOUGH(8' to 8'4"), collapsed from above SILTY CLAY (8'4" to 9'4"), grey, wet, minor sheen FINE SAND (9'4" to 9'8"), dry SILTY CLAY (9'8" to 11'3"), brown MEDIUM TO FINE SAND (11'3" to 12'), light brown, dry	95	10.3 27.3 19.4 13.1 6.3	
12	14'–15' (shaded)	CLAY (13' to 13'7"), dark grey SLOUGH(13'7" to 13'10"), collaped from above MEDIUM TO FINE SAND (13'10" to 15'2"), light grey brown, some reddish coloring, dry, small lens of compact silt at 14'6" SILTY CLAY (15'2" to 17'), brown	80	-- 45.8 1.2 35.7 23.5	
17		END OF BORING			

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BORING LOG

Project No.: **TS0034**
Site Name: Quendall Terminals
Boring I.D.: PT-05
Geologist/Eng.: LK/AS
Drilling Company: Cascade
Drilling Method: DPT
Comments:

Page 1 of 1
Date Started: 8/1/2018
Date Completed: 8/1/2018
Borehole Diameter: 2.25"
Borehole Depth: 17'

Depth	Sample Interval	Lithologic Description	% Recovery	PID Reading (ppm)	Comments
		TOPSOIL (0' to 2'), brown to dark brown, organics	80	0.3 0.3	
2		SLOUGH (2' to 3'), collapsed from above SILTY SAND/QUARRY SPALLS (3' to 4'), compact SILTY SAND (4' to 5'4"), dark brown, compact SILTY SAND (5'4" to 5'10"), fine sand, moist MEDIUM TO FINE SAND (5'10" to 6'2") SILTY CLAY (6'2" to 7'), brown to dark brown	95	0.2 0.2 0.4 29.2 44.4	
7		CLAY (7' to 7'5"), dark brown SLOUGH (7'5" to 8'2"), light brown, collapsed from above SILTY CLAY (8'2" to 10'6"), grey, sheen, wet MEDIUM TO FINE SAND (10'6" to 10'8"), dark brown SILTY CLAY (10'8" to 11'1") MEDIUM TO FINE SAND (11'1" to 12'1"), light brown, dry	90	8.2 20.7 16.3 7.9 0.0	Collected colocated core from 9' to 14' to capture sand from 11' interval that was falling out of liner. No recovery 12' to 14' due to sand falling out.
12		CLAY (14' to 14'6"), dark grey SLOUGH (14'6" to 14'10"), collapsed from above MEDIUM TO FINE SAND (14'10" to 15'9"), light brown, dry SILTY CLAY (15'9" to 17'), brown	60	-- -- 27.7 0.2 69.8	
17		END OF BORING			

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BORING LOG

Project No.:	**TS0034**	Page	1 of 1
Site Name:	Quendall Terminals	Date Started:	8/1/2018
Boring I.D.:	PT-06	Date Completed:	8/1/2018
Geologist/Eng.:	LK/AS	Borehole Diameter:	2.25"
Drilling Company:	Cascade	Borehole Depth:	17'
Drilling Method:	DPT		
Comments:			

Depth	Sample Interval	Lithologic Description	% Recovery	PID Reading (ppm)	Comments
2		TOPSOIL (0' to 2'), brown, organics	90	0.0 0.0	
7		SILTY SAND/QUARRY SPALLS (2'5" to 3'5"), compact MEDIUM TO FINE SAND (3'5" to 3'11") SILTY SAND (3'11" to 5'1"), compact, little peat SILTY CLAY (5'1" to 5'10"), small stringers of minor staining FINE TO MEDIUM SAND (5'10" to 7'), minor staining, transitioning to silt at 6'10"	90	2.3 0.9 20.7 29.4 43.7	
12		SILTY CLAY (7' to 7'5"), thin stringer of product SLOUGH (7'5" to 7'10"), collapsedfrom above SILTY SAND (7'10" to 10'), grey, some clay, wet, sheen SILTY CLAY(10' to 11'), brown MEDIUM TO FINE SAND (11' to 12'), light to medium brown, dry to moist	100	77.2 18.6 8.4 8.9 1.2	
17		SILTY CLAY (12'6" to 13'6") SLOUGH (13'6" to 14'1"), collapsed from above MEDIUM TO FINE SAND (14'1" to 14'6"), light brown, dry SILTY SAND (14'6" to 14'8"), compact MEDIUM TO FINE SAND (14'8" to 15'6"), light brown, dry SILTY CLAY (15'6" to 17'), brown	95	36.0 21.5 0.4 7.0 57.6	
		END OF BORING			

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BORING LOG

Project No.: **TS0034**
Site Name: Quendall Terminals
Boring I.D.: PT-07
Geologist/Eng.: LK/AS
Drilling Company: Cascade
Drilling Method: DPT
Comments:

Date Started: 8/1/2018
Date Completed: 8/1/2018
Borehole Diameter: 2.25"
Borehole Depth: 17'

Depth	Sample Interval	Lithologic Description	% Recovery	PID Reading (ppm)	Comments
		TOPSOIL (0' to 2'), brown, wood chips	80	1.9 12.8	
2		SLOUGH (2' to 2'8"), brown, collapsed from above SILTY SAND/PEBBLES (2'8" to 4'), grey, compact PEAT (4' to 4'2") SILTY SAND/QUARRY SPALLS (4'2" to 5'5"), compact MEDIUM TO FINE SAND (5'5" to 5'9"), brown SILTY CLAY (5'9" to 7'), grey	100	0.4 2.1 2.6 134.3 21.9	
7		SAND/PEBBLES (7'6" to 8'2") SLOUGH (8'2" to 8'10"), collapsed from above SILTY CLAY (8'10" to 11'6"), grey, wet, medium to fine sand stringers from 9'6" to 9'11" and 11' to 11'1" MEDIUM TO FINE SAND (11'1" to 12'), fell out of liner	90	3.3 9.6 12.5 13.8 18.2	
12		SILTY CLAY (13' to 13'6") MEDIUM TO FINE SAND (13'6" to 14'6"), light brown, loose, dry SILTY CLAY (14'6" to 17'), brown, transitioning to grey at 16'	80	-- 24.5 0.9 28.9 11.1	
17		END OF BORING			

BORING LOG

Project No.: **TS0034**
Site Name: Quendall Terminals
Boring I.D.: PT-08
Geologist/Eng.: LK/AS
Drilling Company: Cascade
Drilling Method: DPT
Comments:

Page 1 of 1
Date Started: 8/2/2018
Date Completed: 8/2/2018
Borehole Diameter: 2.25"
Borehole Depth: 17'

Depth	Sample Interval	Lithologic Description	% Recovery	PID Reading (ppm)	Comments
2		NO RECOVERY (0' to 2')	0	-- --	Not sampled
7		SLOUGH (2' to 2'7"), collapsed from above SILTY SAND/QUARRY SPALLS (2'7" to 3'7"), compact MEDIUM TO FINE SAND (3'7" to 4'4"), some pebbles SILTY SAND (4'4" to 4'11"), compact, little peat SILTY SAND/PEBBLES/QUARRY SPALLS (4'11" to 7'), compact, product lens from 6'2" to 6'4"	100	0.2 0.0 9.6 10.5 14.7	
12		SLOUGH (7' to 7'8"), collapsed from above SILTY SAND/PEBBLES (7'8" to 7'11"), compact, slight staining MEDIUM TO FINE SAND (7'11" to 8'3") SILTY CLAY (8'3" to 8'10") SILTY FINE SAND (8'10" to 10'6"), wet SILTY CLAY (10'6" to 12')	100	2.7 23.7 5.2 12.7 13.2	
17		SILTY CLAY (12' to 12'4"), minor staining SILTY SAND (12'4" to 13'), compact SLOUGH (13' to 13'7"), collapsed from above SILTY CLAY (13'7" to 13'8") MEDIUM TO FINE SAND (13'8" to 14'6"), light brown, moist MEDIUM TO FINE SAND (14'6" to 15'4"), bands of dark brown MEDIUM TO FINE SAND (15'4" to 15'7"), peat, product SILT (15'7" to 17'), grey	100	8.0 1.2 2.9 107.5 30.5	
		END OF BORING			

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BORING LOG

Project No.:	**TS0034**	Page	1 of 1
Site Name:	Quendall Terminals	Date Started:	8/1/2018
Boring I.D.:	PT-09	Date Completed:	8/1/2018
Geologist/Eng.:	LK/AS	Borehole Diameter:	2.25"
Drilling Company:	Cascade	Borehole Depth:	17'
Drilling Method:	DPT		
Comments:			

Depth	Sample Interval	Lithologic Description	% Recovery	PID Reading (ppm)	Comments
2		TOPSOIL (0'6" to 1'8"), organics QUARRY SPALLS (1'8" to 2')	75	0.7 0.8	
7		SLOUGH (2' to 2'6"), collapsed from above QUARRY SPALLS (2'6" to 3') MEDIUM TO FINE SAND (3' to 4'), with pebbles SANDY SILT (4' to 5'), with peat and quarry spalls, visible product MEDIUM TO FINE SAND (5'10" to 7'), some staining	100	1.2 5.4 40.5 54.0 11.1	
12		SILTY SAND (7' to 7'4"), compact SLOUGH (7'4" to 7'8"), collapsed from above SILTY SAND (7'8" to 8'), compact, product stringers SILTY CLAY (8' to 10'), grey, wet SILTY CLAY (10' to 11'), brown MEDIUM TO FINE SAND (11' to 12'), light brown, dry to moist	100	2.5 4.5 4.4 3.7 1.1	
17		SILTY CLAY (12'4" to 12'11") SILTY SAND/PEBBLES (12'11" to 14'2"), comapct MEDIUM TO FINE SAND (14'2" to 14'7"), moist MEDIUM TO FINE SAND (14'7" to 15'), darker in color, wet, product stringer SILTY CLAY (15' to 17'), brown	95	1.7 20.8 0.7 42.7 37.9	
		END OF BORING			

BORING LOG

Project No.:	**TS0034**	Page	1 of 1
Site Name:	Quendall Terminals	Date Started:	8/2/2018
Boring I.D.:	PT-10	Date Completed:	8/2/2018
Geologist/Eng.:	LK/AS	Borehole Diameter:	2.25"
Drilling Company:	Cascade	Borehole Depth:	17'
Drilling Method:	DPT		
Comments:			

Depth	Sample Interval	Lithologic Description	% Recovery	PID Reading (ppm)	Comments
		NO RECOVERY (0' to 2')	0	-- --	Not sampled
2		SLOUGH (2' to 3'4"), collapsed from above QUARRY SPALLS (3'4" to 3'7") SILTY SAND (3'7" to 4'), some peat QUARRY SPALLS (4' to 4'3") SILTY SAND (4'3" to 5'8"), compact, product from 5'3" to 5'8" SILTY CLAY (5'8" to 6'4"), some staining MEDIUM TO FINE SAND (6'4" to 7'), staining	100	0.0 11.3 17.8 72.3 170.3	
7		SLOUGH (7' to 8'), collapsed from above SILTY CLAY (8' to 8'6") SLOUGH (8'6" to 9'1"), collapsed from above FINE SAND (9'1" to 9'8"), minor staining SILTY SAND (9'8" to 10'7"), product stringers FINE SAND (10'7" to 10'10"), staining SILTY CLAY (10'10" to 11'3"), bands of staining SILTY CLAY (11'3" to 12'), brown, some staining	80	-- 47.6 87.9 60.3 102.5	
12		SILTY CLAY (13' to 13'10"), slight staining SILTY SAND (13'10" to 14'1"), compact SLOUGH (14'1" to 14'5"), collapsed from above MEDIUM TO FINE SAND (14'5" to 14'8"), moist MEDIUM TO FINE SAND (14'8" to 15'3"), light brown, dry SILTY SAND (15'3" to 15'6"), compact, some peat MEDIUM TO FINE SAND (15'5" to 15'11"), light brown, dry SILTY CLAY (15'11" to 17'), brown	80	-- 33.3 2.1 3.6 49.9	
17		END OF BORING			

APPENDIX D

ADDITIONAL DRILLING INVESTIGATION BORING LOGS (QP-1 AREA)

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BORING LOG

Project No.:	**TS0034**	Page	1 of 1
Site Name:	Quendall Terminals	Date Started:	8/22/2018
Boring I.D.:	QP-1-01	Date Completed:	8/22/2018
Geologist/Eng.:	DJ	Borehole Diameter:	2.25"
Drilling Company:	Cascade	Borehole Depth:	25'
Drilling Method:	DPT		
Comments:			

Depth	Sample Interval / [TPH] in mg/kg	Lithologic Description	% Recovery	PID Reading (ppm)	Comments
0–5		SILTY SAND (0 to 3'4"), light brown, little fine gravel, dry SILTY SAND (3'4" to 5'), grey, little fine gravel, dry	70	0.0 0.0 0.0 0.2 --	
5–10		SILTY SAND (5' to 5'8"), grey, rock fragments SILTY CLAY (5'8" to 7'), grey green, little fine sand, dry to moist TAR SEAM (7' to 7'9"), hard, black, moderate odor CLAY (7'9" to 10'), wet	60	0.5 1.0 0.5 1.0 --	PID reading of 2.1 ppm in tar seam
10–15		CLAY (10' to 11'1"), some fine sand/silt FINE TO MEDIUM SAND (11'1" to 11'10"), grey, wet, trace clay/silt SILTY CLAY (11'10" to 14'), medium brown, trace fine sand, trace organics, wet CLAYEY SAND (14' to 15'), fine, wet, light odor at 14.5'	100	0.9 1.0 0.9 1.0 2.5	
15–20	9,300 Duplicate 10,800	CLAYEY SAND (15' to 17'2"), interbedded dark brown clay layers, wet, moderate odor, trace roots FINE TO MEDIUM SAND (17'2" to 19'4") grey, strong sheen and heavy oil staining, strong odor SILTY CLAY (19'4" to 20'), dark brown, some organics, heavy staining and strong odor, wet	100	5.0 7.3 351.9 368.5 351.3	
20–25	17,200	FINE TO MEDIUM SAND (20' to 22'9"), grey, trace silt and gravel, strong sheen and odor, heavy staining and product from 22 to 22'9" CLAY (22'9" to 25'), medium to dark brown, reduced odor and staining with depth, few organics	100	512.3 309.3 456.5 44.9 5.0	
25		END OF BORING			

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BORING LOG

Project No.: **TS0034**
Site Name: Quendall Terminals
Boring I.D.: QP-1-02
Geologist/Eng.: DJ
Drilling Company: Cascade
Drilling Method: DPT
Comments:

Date Started: 8/22/2018
Date Completed: 8/22/2018
Borehole Diameter: 2.25"
Borehole Depth: 25'

Depth	Sample Interval / [TPH] in mg/kg	Lithologic Description	% Recovery	PID Reading (ppm)	Comments
		SILTY SAND to SANDY SILT (0' to 1'1"), brown, tight, fine sand, rootlets, few fine gravels, dry SILTY SAND (1'1" to 3'), brown to reddish brown, hard nodules, little fine gravel SILTY CLAY (3' to 5'), grey, glass fragments, trace fine sand and gravel	65	1.0 1.2 0.5 -- --	
5		SILT (5' to 5'6"), light brown, trace roots, trace fine sand, dry SILTY SAND (5'6" to 6'4"), grey, little fine gravel, dry TAR/ASPHALT (6'4" to 7'8"), black, hard SILTY CLAY (7'8" to 10'), grey to dark brown, some organics, moist	80	1.0 1.5 1.0 0.3 --	
10		SILTY SAND (10' to 11'), dark grey green, wet, trace organics SILTY CLAY (11' to 13'7"), grey brown to medium brown, little organics, wet FINE TO MEDIUM SAND (13'7" to 15'), grey green, few clay, wet	100	0.3 1.1 0.6 0.7 1.0	
15	6,300	FINE TO MEDIUM SAND (15' to 16'), grey green, slight odor SILTY CLAY (16' to 16'9"), grey brown, trace roots, slight odor, wet FINE TO MEDIUM SAND (16'9" to 18'), grey green, odor CLAY (18' to 18'10"), with interbedded sand FINE TO MEDIUM SAND (18'10" to 20'), heavy oil staining, strong odor, few blebs, product at 19.5'	100	2.8 9.2 31.2 58.0 255.1	
20	7,110	FINE TO MEDIUM SAND (20' to 22'2"), product, heavily stained, strong odor CLAY (22'2" to 25'), medium to dark brown, few silt, wet, decreased odor, no staining	100	330.2 302.4 10.8 5.1 5.0	
25		END OF BORING			

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BORING LOG

Project No.:	**TS0034**	Page	1 of 1
Site Name:	Quendall Terminals	Date Started:	8/22/2018
Boring I.D.:	QP-1-03	Date Completed:	8/22/2018
Geologist/Eng.:	DJ	Borehole Diameter:	2.25"
Drilling Company:	Cascade	Borehole Depth:	25'
Drilling Method:	DPT		
Comments:			

Depth	Sample Interval / [TPH] in mg/kg	Lithologic Description	% Recovery	PID Reading (ppm)	Comments
0–5		SANDY SILT (0' to 2'), light brown, rootlets, trace fine gravel, dry SANDY SILT (2' to 4'), brown, few to little gravel TAR/ASPHALT (4' to 5'), black, hard	85	14.3 14.7 15.0 11.5 --	
5–10		SANDY SILT (5' to 5'9"), light brown SILTY CLAY (5'9" to 6'5"), grey, few fine gravel, moist TAR/ASPHALT (6'5" to 7'2"), black, hard, dry SILTY CLAY (7'2" to 8'9"), grey green to dark brown, some organics, trace fine sand and gravel SILTY SAND (8'9" to 10'), grey green, fine sand, wet	80	12.5 16.5 13.7 9.7 --	
10–15		SANDY SILT (10' to 10'7"), light brown FINE TO MEDIUM SAND (10'7" to 11'4"), grey green, few clay, wet SILTY CLAY (11'4" to 13'2"), brown, wet FINE TO MEDIUM SAND (13'2" to 15'), grey green, wet, interbedded silty clay, slight odor at 14.5'	100	11.5 14.6 10.2 9.6 7.9	
15–20	3,220 (19'–20')	FINE TO MEDIUM SAND (15' to 19'9"), grey, increasing odor with depth, heavy sheen and staining SILTY CLAY (19'9" to 20'), dark brown, strong odor, moderate staining, wet	100	7.9 21.2 20.2 16.7 58.9	
20–25	28 (21'–22')	FINE TO MEDIUM SAND (20' to 22'1"), strong odor, heavy sheen and oil staining at 21'6" to 22'1" CLAY (22'1" to 25'), brown to dark brown, few silt, trace medium to fine sand lenses, blebs and staining at 22.5' to 23', odor reducing with depth	100	11.9 160.7 87.8 47.9 19.1	
25		END OF BORING			

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BORING LOG

Project No.: **TS0034**
Site Name: Quendall Terminals
Boring I.D.: QP-1-04
Geologist/Eng.: DJ
Drilling Company: Cascade
Drilling Method: DPT
Comments:

Date Started: 8/23/2018
Date Completed: 8/23/2018
Borehole Diameter: 2.25"
Borehole Depth: 20'

Depth	Sample Interval / [TPH] in mg/kg	Lithologic Description	% Recovery	PID Reading (ppm)	Comments
0–5		SANDY SILT (0' to 2'1"), light brown, rootlets, few fine gravel, fine sand, dry SANDY SILT (2'1" to 3'1"), brown to grey, little to some fine gravel, few clay, dry TAR/ASPHALT (3'1" to 3'9"), black, hard SILTY SAND (3'9" to 5'), grey, little fine gravel, dry	80	10.5 10.5 12.3 12.5 --	Background PID reading = 10 ppm
5–10		SANDY SILT (5' to 5'5"), light brown, dry TAR/ASPHALT (5'5" to 5'7"), black, hard SILTY CLAY (5'7" to 7'), grey green to grey brown, few organics, wet FINE TO MEDIUM SAND (7' to 8'4"), grey green, interbedded silty clay, few organics, slight odor, wet SILTY CLAY (8'4" to 10'), brown, few organics, wet	100	12.5 13.0 13.0 15.5 16.3	
10–15	15	FINE TO MEDIUM SAND (10' to 11'1"), grey green, slight odor SILTY CLAY (11'1" to 13'), grey brown, few organics, wet FINE TO MEDIUM SAND (13' to 15'), few interbedded silty clay, few organics, slight odor	100	2.6 15.1 17.0 16.7 45.6	
15–20	780	FINE TO MEDIUM SAND (15' to 17'6"), increasing odor with depth, little clay at 17'3" to 17'6") CLAY (17'6" to 20'), brown to dark brown, few silt, few organics, wet	95	20.2 44.5 33.4 19.1 15.0	
20		END OF BORING			

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BORING LOG

Project No.: **TS0034**
Site Name: Quendall Terminals
Boring I.D.: QP-1-05
Geologist/Eng.: DJ
Drilling Company: Cascade
Drilling Method: DPT
Comments:

Page 1 of 1
Date Started: 8/23/2018
Date Completed: 8/23/2018
Borehole Diameter: 2.25"
Borehole Depth: 20'

Depth	Sample Interval / [TPH] in mg/kg	Lithologic Description	% Recovery	PID Reading (ppm)	Comments
0–5		SANDY SILT (0' to 2.3'), light brown, rootlets, few to little gravel, increasing with depth TAR/ASPHALT (2'3" to 2'6"), black, hard, dry SANDY SILT (2'6" to 3'2"), light brown SILTY SAND (3'2" to 5'), with hard tar, little fine gravel, dry	100	13.5 13.6 13.6 13.6 13.5	Background PID reading = 13.3 ppm
5–10		SILTY SAND (5' to 5'2"), light brown SANDY SILT (5'2" to 5'5"), light brown SILTY CLAY (5'5" to 6'4"), dark brown, few organics, moist to wet FINE TO MEDIUM SAND (6'4" to 9'2"), grey green, few silt and organics, interbedded silty clay, wet SILTY CLAY (8'3" to 10'), brown, wet	95	13.6 13.9 14.0 14.9 15.2	
10–15	ND (sample at ~14'–15')	FINE TO MEDIUM SAND (10' to 15'), grey green, slight odor	95	14.9 18.8 19.8 25.3 27.6	
15–20	7 (sample at ~17'–18')	FINE TO MEDIUM SAND (15' to 17'6"), grey green, slight to moderate odor, increasing with depth CLAY (17'6" to 20'), brown to dark brown, few silt, wet	100	28.7 50.0 19.5 15.0 18.1	
20		END OF BORING			

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BORING LOG

Project No.: **TS0034**
Site Name: Quendall Terminals
Boring I.D.: QP-1-06
Geologist/Eng.: DJ
Drilling Company: Cascade
Drilling Method: DPT
Comments:

Page 1 of 1
Date Started: 8/23/2018
Date Completed: 8/23/2018
Borehole Diameter: 2.25"
Borehole Depth: 20'

Depth	Sample Interval / [TPH] in mg/kg	Lithologic Description	% Recovery	PID Reading (ppm)	Comments
0–5		SANDY SILT (0' to 2'), light brown, rootlets, find sand and gravel increasing with depth, dry SILTY CLAY (2' to 5'), grey green, few fine sand and gravel, moist	65	6.5 7.0 7.0 -- --	Background PID reading = 4.0 ppm
5–10		SILTY CLAY (5' to 5'2"), grey green SANDY SILT (5'2" to 5'8"), light brown, few fine gravel SILTY SAND (5'8" to 6'5"), grey greeen, little to some fine gravel, fine sand, moist SILTY CLAY (6'5" to 8'3"), grey green, little organics, moist to wet FINE TO MEDIUM SAND (8'3" to 10'), grey green, few silt, wet	85	7.7 7.9 8.0 7.3 --	Background PID reading = 7.0 ppm
10–15	22 ND	FINE TO MEDIUM SAND (10' to 11'9"), grey green, slight odor, little to some clay SILTY CLAY (11'9" to 14'1"), brown, trace fine sand, few organics, wet FINE TO MEDIUM SAND (14'1" to 15'), grey green, slight odor	100	10.4 12.6 12.3 10.2 13.0	
15–20		FINE TO MEDIUM SAND (15' to 15'9"), grey green, slight odor CLAY (15'9" to 20'), brown to dark brown, little silt, trace organics, trance sand, wet	65	11.6 11.6 11.6 -- --	Background PID reading = 11.5 ppm
20		END OF BORING			

BORING LOG

Project No.:	**TS0034**
Site Name:	Quendall Terminals
Boring I.D.:	QP-1-07
Geologist/Eng.:	DJ
Drilling Company:	Cascade
Drilling Method:	DPT
Comments:	
Page	1 of 1
Date Started:	8/22/2018
Date Completed:	8/22/2018
Borehole Diameter:	2.25"
Borehole Depth:	20'

Depth	Sample Interval / [TPH] in mg/kg	Lithologic Description	% Recovery	PID Reading (ppm)	Comments
0–5		SANDY SILT (0 to 1'2"), light brown, rootlets, few fine sand and gravel, dry SANDY SILT (1'2" to 2'), light brown, little fine gravels, dark brown band and band of tar/asphalt SILTY CLAY (2' to 5'), grey green, dry to moist, trace fine sand and gravel, trace organics	70	20.5 21.2 18.5 -- --	Background PID reading = 3.5 ppm
5–10		SILTY CLAY (5' to 5'6"), grey green SANDY SILT (5'6" to 6'), light brown, some organics, dry, trace fine gravel SILTY CLAY (5'6" to 8'1"), brown to dark brown, few organics, wood fragments, moist to wet FINE TO MEDIUM SAND (8'1" to 10'), grey green, few silt, interbedded silty clay, wet trace organics	80	16.4 12.3 15.3 15.1 --	
10–15	14	FINE TO MEDIUM SAND (10' to 10'6"), grey green CLAY/SILTY SAND (10'6" to 11'8"), slight odor, wet SILTY CLAY (11'8" to 13'3"), brown, wet SILTY/CLAYEY SAND (13'3" to 15'), brown, wet	100	17.3 18.4 18.1 13.1 --	
15–20	9	SILTY/CLAYEY SAND (15' to 16'9"), brown, wet, slight odor CLAY (16'9" to 20'), brown to dark brown, little silt, little organics and wood mass, wet	100	12.8 13.8 16.8 17.7 23.3	
20		END OF BORING			

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BORING LOG

Project No.:	**TS0034**	Page	1 of 1
Site Name:	Quendall Terminals	Date Started:	8/22/2018
Boring I.D.:	QP-1-08	Date Completed:	8/22/2018
Geologist/Eng.:	DJ	Borehole Diameter:	2.25"
Drilling Company:	Cascade	Borehole Depth:	25'
Drilling Method:	DPT		
Comments:			

Depth	Sample Interval / [TPH] in mg/kg	Lithologic Description	% Recovery	PID Reading (ppm)	Comments
0–5		SANDY SILT (0' to 2'), light brown, few fine gravels, fine sand SANDY SILT (2' to 5'), dark brown, some fine gravel, trace organics, dry	70	13.1 12.1 9.7 -- --	Background PID reading = 3.3 ppm
5–10		SANDY SILT (5' to 5'8"), light brown SILTY CLAY (5'8" to 8'5"), grey green, some organics, few gravel decreasing to trace with depth, few dark brown layers, moist SILTY SAND (8'5" to 10'), grey green, fine sand, wet	80	12.9 13.0 12.2 8.5 --	
10–15		FINE TO MEDIUM SAND (10' to 11'4"), grey green, few silt, wet SILTY CLAY (11'4" to 13'1"), brown, little organics, wet FINE TO MEDIUM SAND (13'1" to 15'), brown, few thin interbedded silty clay seams, few organics, slight odor	100	6.8 11.1 10.9 11.3 9.5	
15–20	10,011 (19'–20')	FINE TO MEDIUM SAND (15' to 20'), grey green, slight odor increasing with depth, heavy staining and product 19'5" to 20'	100	12.0 15.0 11.9 12.0 379.2	
20–25	4,310 (21'–22')	FINE TO MEDIUM SAND (20' to 22'3"), grey green, strong odor, heavy sheen/staining and product 21' to 22;3" CLAY (22'3" to 25'), brown to dark brown, little silt, odor decreasing with depth (no odor 23' to 25'), wet	100	57.8 459.7 166.3 101.4 43.6	
25		END OF BORING			

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BORING LOG

Project No.: **TS0034**
Site Name: Quendall Terminals
Boring I.D.: QP-1-09
Geologist/Eng.: DJ
Drilling Company: Cascade
Drilling Method: DPT
Comments:

Date Started: 8/22/2018
Date Completed: 8/22/2018
Borehole Diameter: 2.25"
Borehole Depth: 20'

Depth	Sample Interval / [TPH] in mg/kg	Lithologic Description	% Recovery	PID Reading (ppm)	Comments
0–5		SANDY SILT (0' to 2'6"), light brown, rootlets, fine sand, little organics, trace fine gravel, dry SILTY SAND (2'6" to 3'6"), pale brown to grey, few fine gravel, dry SILTY CLAY (3'6" to 5'), grey green, little organics, trace fine sand, dry to moist	90	6.4 9.1 8.7 6.0 3.0	1" tar/asphalt (hard, black) layer at 3'
5–10		SANDY SILT (5' to 5'7"), slough from above SILTY CLAY (5'7" to 7'7"), grey green SILTY CLAY (7'7" to 8'2"), dark brown, few roots, thin 1" hard tar/asphalt layer SILTY SAND (8'3" to 10'), grey green, fine sand, trace roots, light sheen, slight odor, wet	80	3.1 2.9 13.2 12.1 --	
10–15	1,400	SILTY SAND (10' to 10'2"), grey green CLAY (10'2" to 10'7"), brown, some silt, trace roots, moist FINE SAND (10'7" to 11'5"), grey, little silt, strong sheen, strong odor, wet CLAY (11'5" to 13'6"), brown, little silt, wet FINE TO MEDIUM SAND (13'6" to 15'), grey green, little silt, wet	100	30.8 22.0 16.0 24.8 14.1	
15–20	110	FINE TO MEDIUM SAND (15' to 19'4"), grey green, wet, odor increasing with depth CLAY (19'4" to 20'), brown, some silt, wet, strong odor	100	10.1 14.7 12.1 5.2 15.1	
20		END OF BORING			

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BORING LOG

Project No.: **TS0034**
Site Name: Quendall Terminals
Boring I.D.: QP-1-10
Geologist/Eng.: DJ
Drilling Company: Cascade
Drilling Method: DPT
Comments:

Date Started: 8/22/2018
Date Completed: 8/22/2018
Borehole Diameter: 2.25"
Borehole Depth: 25'

Depth	Sample Interval / [TPH] in mg/kg	Lithologic Description	% Recovery	PID Reading (ppm)	Comments
0–5		SANDY SILT (0' to 2'), light brown, rootlets, few fine gravel, dry SILTY SAND (2' to 2'6"), light brown, fine sand, little fine gravel, dry SILTY CLAY (2'6" to 5'), grey brown to brown, few roots, trace fine gravel, moist	80	0.2 0.2 0.2 0.9 --	
5–10		SANDY SILT (5' to 5'5"), light brown SILTY SAND (5'5" to 7'), grey green, trace fine gravel, wet TAR/ASPHALT (7' to 7'4"), black, hard SILTY CLAY (7'4" to 8'1"), grey transitioning to dark brown, trace fine gravel, wet FINE TO MEDIUM SAND (8'1" to 10'), grey green, little silt, slight odor, slight staining	80	0.7 0.7 3.5 3.5 --	
10–15	1,827	SANDY SILT (10' to 10'3"), slough from above FINE TO MEDIUM SAND (10'3" to 11'5"), grey green, visible sheen/staining, moderate odor SILTY CLAY (11'5" to 13'2"), brown, moderate odor, wet FINE TO MEDIUM SAND (13'2" to 15'), grey green, light sheen/staining, moderate odor	100	1.6 4.6 9.1 4.1 2.9	
15–20	727	FINE TO MEDIUM SAND (15' to 19'6"), grey green, light sheen, light odor, heavy staining/product at 19' to 19.5' SILTY CLAY (19'6" to 20'), dark brown, trace fine sand, moderate odor, wet	100	2.7 2.2 3.5 3.8 4.6	
20–25	Duplicate 573 1,220	FINE TO MEDIUM SAND (20' to 21'10"), grey green, light odor/sheen, heavy sheen and product at 21'5" to 21'10", wet FINE TO MEDIUM SAND (21'10" to 22'8"), grey, some clay, little silt, reduced odor, wet CLAY (22'8" to 25'), dark brown transitioning to grey, little silt, wet	100	6.9 11.7 6.5 2.2 2.0	
25		END OF BORING			

APPENDIX E

ADDITIONAL DRILLING INVESTIGATION BORING LOGS (MC-1 AREA)

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BORING LOG

Project No.: **TS0034**
Site Name: Quendall Terminals
Boring I.D.: MC-1-01
Geologist/Eng.: DJ
Drilling Company: Cascade
Drilling Method: DPT
Comments:

Page 1 of 1
Date Started: 8/23/2018
Date Completed: 8/23/2018
Borehole Diameter: 2.25"
Borehole Depth: 35'

Depth	Sample Interval / [TPH] in mg/kg	Lithologic Description	% Recovery	PID Reading (ppm)	Comments
0–5		WOOD DEBRIS (0' to 1.1'), brown ROCK (1.1' to 1.4'), pink SILTY SAND (1.4' to 2.5'), brown to green, some gravel, some organics, cobbles, dry SILTY SAND (2.5' to 3.1'), greygreen, few fine gravel, dry SANDY SILT (3.1' to 5'), dark brown, some organics, dry to moist	95	0.0 0.0 0.0 0.5 0.5	
5–10		SANDY SILT (5' to 5.2'), dark brown *WOOD DEBRIS (5.2' to 6.2'), brown SILTY SAND (6.2' to 10'), dark brown, some organics, few gravel, few clay, moist to wet, strong odor and staining at 8.4' to 10'	80	10.4 0.9 4.2 58.1 18.4	*Wood debris is slough from above
10–15	118,000	*WOOD DEBRIS (10' to 11.7'), brown SILTY SAND (11.7' to 12.5'), grey, little clay, few organics, strong odor, slight sheen/staining WOOD DEBRIS (12.5' to 12.6') MEDIUM TO COARSE SAND (12.6' to 13'), grey, some silt and clay, product and heavy staining, wet	70	1.8 3.2 18.1 54.0 61.6	*Wood debris is slough from above
15–20	52,000 9,830	MEDIUM TO COARSE SAND (15' to 18.5'), grey, transititioning to sandy gravel with depth, heavy staining throughout, product above clay at 18.5' CLAY (18.5' to 20'), brown, staining and product at 18.5' to 19', decreasing odor below 19', wet	100	61.1 118.5 67.8 58.2 25.4	
20–25	Duplicate 9,400	*MEDIUM TO COARSE SAND (20' to 21.6'), grey, transitioning to sandy gravel with depth, strong odor and oil staining throughout, product above clay SILTY CLAY (21.6' to 23.6'), brown, trace gravel, staining/odor at sand interface	100	40.5 79.5 27.5 26.5 14.9	*Medium to coarse sand is slough from above
25–30		*CLAYEY/SILTY GRAVEL (25' to 25.8'), with coarse sand, wet, odor, some staining/sheen SILTY CLAY (25.8' to 26'), brown, little fine gravel, wet CLAYEY/SILTY GRAVEL (26' to 27.5'), dark brown, coarse sand, wet, staining/sheen FINE TO MEDIUM SAND (27.5' to 29.3'), grey, interbedded silty clay, sheen and odor, wet SILTY CLAY (29.3' to 30'), dark brown, wet, slight odor	75	48.2 91.8 40.1 41.6 20.0	*Clayey/silty gravel is slough from above
30–35		*FINE TO MEDIUM SAND (30' to 31'), slight odor and sheen, wet SILTY CLAY (31' to 35'), grey brown to grey, wet, trace fine sand and gravel	80	19.4 14.3 10.3 7.5 7.0	*Fine to medium sand is slough from above
35		END OF BORING			

BORING LOG

Project No.:	**TS0034**	Page	1 of 1
Site Name:	Quendall Terminals	Date Started:	8/23/2018
Boring I.D.:	MC-1-02	Date Completed:	8/23/2018
Geologist/Eng.:	DJ	Borehole Diameter:	2.25"
Drilling Company:	Cascade	Borehole Depth:	35'
Drilling Method:	DPT		
Comments:			

Depth	Sample Interval / [TPH] in mg/kg	Lithologic Description	% Recovery	PID Reading (ppm)	Comments
0–5		WOOD DEBRIS (0' to 1'), brown ROCK/CONCRETE (1' to 2'), pink/grey to green SILT (2' to 2.4'), brown, roots, dry SILTY SAND (2.1' to 3.5'), grey green, dry SILTY SAND (3.5' to 5'), brown, organics, few fine gravel	90	7.5 9.5 16.6 29.6 --	
5–10		*WOOD DEBRIS (5' to 5.8'), brown SILTY SAND (5.8' to 10'), grey green to grey brown, few clay, few gravel, moist to wet, slight odor below water table (~6'), some organics	80	1.4 6.7 5.2 12.5 35.6	*Wood debris is slough from above
10–15		*WOOD DEBRIS (10' to 11.7'), brown SILTY SAND (11.7' to 13.2'), heavy staining/product at 12.9' to 13.2' SILTY CLAY (13.2' to 13.6'), dark grey, product and heavy staining, wet MEDIUM TO COARSE SAND (13.6' to 15'), grey, gravel, oil stringers, strong odor, wet	70	4.2 7.7 105.5 93.1 69.5	*Wood debris is slough from above
15–20	36,400 (sample at ~18'–19')	SAND AND GRAVEL (15' to 19.3'), grey, medium to coarse sand coarsening with depth to gravel with sand, strong odor and product at 18' to 19'3 SILTY CLAY (19.3' to 20'), brown, slight odor, wet	100	61.7 144.1 21.4 119.1 12.1	
20–25		*SAND AND GRAVEL (20' to 21.7'), grey, coarsening with depth CLAYEY/SILTY GRAVEL (21.7 to 23.3'), oil staining, strong odor, wet SILTY CLAY (23.2' to 24'), brown, reduced odor and no stain FINE TO MEDIUM SAND (24' to 25'), grey green, no odor, wet	70	40.3 18.5 15.0 16.5 7.0	*Sand and gravel is slough from above
25–30	28,600 (sample at ~30'–31')	*CLAYEY GRAVEL (25' to 26.2'), product and oil staining FINE TO MEDIUM SAND (26.2' to 28.1'), grey green SILTY CLAY (28.1' to 29'), grey brown to brown, few fine sand layers FINE TO MEDIUM SAND (29' to 30'), grey green	80	8.4 4.4 6.0 0.7 5.4	*Clayey gravel is slough from above
30–35		*CLAYEY GRAVEL (30' to 31.6') *FINE TO MEDIUM SAND (31.6' to 35')	75	21.0 23.2 8.8 6.7 8.4	*Clayey gravel and fine to medium sand is slough from above
35		END OF BORING			

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BORING LOG

Project No.: **TS0034**
Page 1 of 1
Site Name: Quendall Terminals
Date Started: 8/24/2018
Boring I.D.: MC-1-03
Date Completed: 8/24/2018
Geologist/Eng.: DJ
Borehole Diameter: 2.25"
Drilling Company: Cascade
Borehole Depth: 35'
Drilling Method: DPT
Comments:

Depth	Sample Interval / [TPH] in mg/kg	Lithologic Description	% Recovery	PID Reading (ppm)	Comments
0–5		WOOD DEBRIS (0' to 0.8'), brown ROCK (0.8' to 1.0') SILT (1.0' to 1.6'), dark brown, organics, rock fragments, dry SILT (1.6' to 2.0'), dark brown, organics, no rock fragments, dry ROCK (2.0 to 2.3') SILTY SAND (2.3' to 5.0'), grey green, fine sand, low organics, dry	50	5.0 12.9 -- -- --	Background PID = 3.5 ppm
5–10		*WOOD DEBRIS (5.0' to 6.0') SILTY SAND (6.0' to 7.5'), grey green, some organics SILTY CLAY (7.5' to 8.1'), grey, moist to wet SILT (8.1' to 8.7'), dark brown, organics, wood, wet SILTY SAND (8.7' to 10'), grey, some organics, wet	80	11.5 13.4 13.5 5.5 11.0	*Wood debris is slough from above
10–15		*WOOD DEBRIS (10' to 12') SILTY SAND (12' to 14.4'), slight sheen, slight odor SILTY CLAY (14.4' to 15'), brown, wet	60	11.8 11.7 15.9 14.4 15.2	Background PID = 8-9 ppm *Wood debris is slough from above
15–20		*SILTY SAND (15' to 16') FINE TO MEDIUM SAND (15' to 18.8'), grey, slight sheen/staining and odor, few organics, wet SILTY CLAY (18.8' to 20'), brown, few organics, wet	80	11.9 20.9 13.5 13.9 10.7	*Silty sand is slough from above
20–25	14,600 (20'–21')	FINE TO MEDIUM SAND (20' to 21.5'), grey, little silt, product, oil sheen/staining and odor, wet SILTY CLAY (21.5' to 24.5'), dark brown to brown, few organics, wet SILTY CLAY (24.5' to 25')	100	58.3 20.9 17.3 18.4 14.0	
25–30	100,000 (25'–25.5')	FINE TO MEDIUM SAND (25' to 25.5'), heavy staining and product, few silt and clay, minimal slough material SILTY CLAY (25.5' to 26.5'), brown, moderate staining and odor at interface, wet FINE TO MEDIUM SAND (26.5' to 27.5'), slight sheen and slight odor SILTY CLAY (27.5' to 30'), trace interbedded fine sand	100	69.9 16.2 23.6 20.7 15.7	
30–35		SILTY CLAY (30' to 33.5'), grey green transitioning to brown, trace organics, wet FINE TO MEDIUM SAND (33.5' to 34.2'), grey, few silt, wet SILTY CLAY (34.2' to 35'), brown	100	8.9 10.2 10.0 10.0 9.8	
35		END OF BORING			

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BORING LOG

Project No.:	**TS0034**	Page	1 of 1
Site Name:	Quendall Terminals	Date Started:	8/24/2018
Boring I.D.:	MC-1-04	Date Completed:	8/24/2018
Geologist/Eng.:	DJ	Borehole Diameter:	2.25"
Drilling Company:	Cascade	Borehole Depth:	35'
Drilling Method:	DPT		
Comments:			

Depth	Sample Interval / [TPH] in mg/kg	Lithologic Description	% Recovery	PID Reading (ppm)	Comments
0–5		WOOD DEBRIS (0' to 0.8'), brown ROCK/CONCRETE (0.8' to 1.3') WOOD/SILT (1.3' to 1.4'), dark brown, organics ROCK (1.4' to 2.3') WOOD (2.3' to 2.8'), dark brown SILTY SAND (2.8' to 3.0'), grey, fine, dry SILTY SAND (3.0' to 5.0'), grey green, fine, organics/wood, dry	100	11.5 12.4 13.2 12.2 --	Background PID = 8.0 ppm
5–10	11,800	WOOD DEBRIS (5.0' to 5.2') SILTY SAND (5.2' to 8.2'), dark brown, some organics, slight sheen/light staining 7.0' to 8.2', wet SILTY CLAY (8.2' to 10'), brown, trace fine sand, wet	70	12.7 29.5 20.2 -- --	
10–15		SILTY CLAY (10' to 10.3') FINE TO MEDIUM SAND (10.2' to 11.2'), grey, few silt, moderate sheen and staining, wet SILTY CLAY (11.2' to 12.7'), brown, slight sheen/odor at interface FINE TO MEDIUM SAND (12.7' to 13.9'), grey, layers of silty sand, slight sheen, no staining, wet SILTY CLAY (13.9' to 14.4'), brown, few organics FINE TO MEDIUM SAND (14.4' to 15'), grey, few silt, slight odor, no sheen, wet	100	22.8 17.0 14.5 12.0 11.3	
15–20	58,830 Duplicate 92,000	MEDIUM TO COARSE SAND (15' to 19.4'), grey, few silt, moderate sheen/staining increasing with depth, wet, heavy staining and product at 18.3' to 19.4' SILTY CLAY (19.4' to 20'), brown, little sand, moderate sheen, odor and staining at interface, wet	100	15.0 16.4 17.0 45.5 20.0	
20–25		SILTY CLAY (20' to 23.4'), light brown to dark brown, some organics, wet MEDIUM TO COARSE SAND (23.4' to 23.7'), grey, few silt, wet SILTY CLAY(23.7' to 24.1') MEDIUM TO COARSE SAND (24.1' to 25'), slight odor	85	11.0 10.5 11.0 -- --	
25–30		FINE TO MEDIUM SAND (25' to 26.5'), grey, few silt, slight sheen and odor, wet SILTY CLAY (26.5' to 30'), brown to light brown, few bands of sand, some organics, wet	100	7.5 10.8 7.4 9.0 7.0	Background PID = 1.0 ppm
30–35		SILTY CLAY (30' to 35'), grey green	60	-- -- -- -- --	Broken liner - no PID readings
35		END OF BORING			

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BORING LOG

Project No.:	**TS0034**	Page	1 of 1
Site Name:	Quendall Terminals	Date Started:	8/24/2018
Boring I.D.:	MC-1-05	Date Completed:	8/24/2018
Geologist/Eng.:	DJ	Borehole Diameter:	2.25"
Drilling Company:	Cascade	Borehole Depth:	30'
Drilling Method:	DPT		
Comments:			

Depth	Sample Interval / [TPH] in mg/kg	Lithologic Description	% Recovery	PID Reading (ppm)	Comments
0–5		WOOD DEBRIS (0' to 1.2') ROCK (1.2' to 2.9') WOOD/SILT (2.9' to 5.0'), dark brown, some silty sand, dry, few organics	60	5.7 9.7 8.5 -- --	
5–10	1,948 (10'–11')	SILTY SAND (5' to 9.4'), grey green transitioning to dark brown, little to some organics, trace brick fragments, fine sand, slight odor, wet, moderate sheen and staining at 8.8' to 9.4' ROCK (9.4' to 10'), red, fragments, heavy staining and strong odor	100	11.8 12.8 11.7 17.2 159.1	
10–15		FINE TO MEDIUM SAND (10' to 11'), grey, few silt, moderate to heavy staining/sheen, wet SILTY CLAY (11' to 11.7'), brown, few organics, wet FINE TO MEDIUM SAND (11.7' to 15'), few interbedded silty clay, slight odor, wet	65	15.0 9.8 9.5 -- --	
15–20	8,300 (17'–18')	FINE TO MEDIUM SAND (15' to 18'), moderate staining and sheen increasing with depth, heavy staining at 17' to 18' SILTY CLAY (18' to 20'), dark brown, some organics, wet	70	9.5 21.5 7.2 -- --	
20–25		SILTY CLAY (20' to 23.8'), brown to dark brown FINE TO MEDIUM SAND (23.3' to 25'), no staining, slight odor	65	5.0 6.8 3.8 -- --	
25–30		FINE TO MEDIUM SAND (25' to 26'), no odor SILTY CLAY (26' to 30'), brown transitioning to grey, few organics, wet	100	5.0 3.5 6.0 1.2 1.0	
30		END OF BORING			

BORING LOG

Project No.: **TS0034**
Page 1 of 1
Site Name: Quendall Terminals
Date Started: 8/24/2018
Boring I.D.: MC-1-07
Date Completed: 8/24/2018
Geologist/Eng.: DJ
Borehole Diameter: 2.25"
Drilling Company: Cascade
Borehole Depth: 30'
Drilling Method: DPT
Comments:

Depth	Sample Interval / [TPH] in mg/kg	Lithologic Description	% Recovery	PID Reading (ppm)	Comments
0–5		NO RECOVERY (0' to 5')	0	--, --, --, --, --	No sample collected
5–10	420	FINE TO MEDIUM SAND (5' to 5.7'), grey, trace silt, moist SILTY SAND (5.7' to 6.3'), grey brown, fine sand, slight odor, moist to wet FINE TO MEDIUM SAND (6.3' to 10'), grey, few interbedded silty sand, slight odor, wet	60	2.5, 5.8, 9.7, --, --	
10–15		FINE TO MEDIUM SAND (10' to 10.4'), slight sheen/staining SILTY CLAY (10.4' to 11.6'), brown to dark brown, some organics, wet FINE TO MEDIUM SAND (11.6' to 15'), no staining, slight odor	95	4.4, 2.3, 3.7, 3.3, 4.7	
15–20		FINE TO MEDIUM SAND (15' to 19'), little coarse sand SILT (19' to 20'), wood fibres/organics, some clay, wet	100	3.9, 4.3, 4.3, 4.7, 2.2	
20–25		SILTY CLAY (20' to 21.8'), brown to dark brown, some organics, wet FINE TO MEDIUM SAND (21.8' to 22.2'), grey, few silt, wet SILTY CLAY (22.2' to 23.7') FINE TO MEDIUM SAND (23.7' to 25'), few interbedded silty clay with organics	100	5.4, 5.2, 4.3, 4.3, 5.1	
25–30		FINE TO MEDIUM SAND (25' to 26') SILTY CLAY (26' to 26.6') FINE TO MEDIUM SAND (26.6' to 27.5') SILTY CLAY (27.5' to 30'), grey to dark brown, little organics, wet	100	4.7, 3.8, 3.9, 4.6, 3.2	
30		END OF BORING			

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BORING LOG

Project No.:	**TS0034**	Page	1 of 1
Site Name:	Quendall Terminals	Date Started:	8/24/2018
Boring I.D.:	MC-1-08	Date Completed:	8/24/2018
Geologist/Eng.:	DJ	Borehole Diameter:	2.25"
Drilling Company:	Cascade	Borehole Depth:	20'
Drilling Method:	DPT		
Comments:			

Depth	Sample Interval / [TPH] in mg/kg	Lithologic Description	% Recovery	PID Reading (ppm)	Comments
0–5		NO RECOVERY (0' to 5')	0	-- / -- / -- / -- / --	No sample collected
5–10	39,900	NO RECOVERY (5' to 10')	0	-- / -- / -- / -- / --	No sample collected
10–15	11,500	COARSE SAND/GRAVEL (10' to 11.4'), grey, strong odor, heavy staining and product, wet FINE TO MEDIUM SAND (11.4' to 15'), strong odor, heavy staining, wet	70	50.7 / 40.7 / 49.6 / -- / --	
15–20	9,200	FINE TO MEDIUM SAND (15' to 15.5'), heavy staining and product SILTY CLAY (15.5' to 15.8'), brown, some organics, slight odor, wet FINE TO MEDIUM SAND (15.8' to 18.9'), grey, few silt, heavy staining and sheen, visible product throughout SILTY CLAY (18.9' to 20'), dark brown, some organics, moderate odor, wet	100	63.9 / 25.5 / 48.0 / 76.3 / 16.4	
20		END OF BORING			

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BORING LOG

Project No.:	**TS0034**	Page	1 of 1
Site Name:	Quendall Terminals	Date Started:	8/24/2018
Boring I.D.:	MC-1-09	Date Completed:	8/24/2018
Geologist/Eng.:	DJ	Borehole Diameter:	2.25"
Drilling Company:	Cascade	Borehole Depth:	30'
Drilling Method:	DPT		
Comments:			

Depth	Sample Interval / [TPH] in mg/kg	Lithologic Description	% Recovery	PID Reading (ppm)	Comments
0–5		NO RECOVERY (0' to 5')	0	-- / -- / -- / -- / --	No sample collected
5–10	1,350	SILTY SAND (5' to 6.2'), grey green, moist, few organics BRICK (6.2' to 7.5'), orange red to red fragments, medium to coarse sand, moist SILTY SAND (7.5' to 8.0'), dark brown, wood fragments, wet FINE TO MEDIUM SAND (8.0' to 10'), grey, few silt, wet	60	2.4 / 3.6 / 3.6 / -- / --	
10–15		FINE TO MEDIUM SAND (10' to 10.6'), slight odor, slight staining SILTY CLAY (10.6' to 12.1'), brown, some organics, wet FINE TO MEDIUM SAND (12.1' to 14'), grey, interbedded silty sand, slight odor, wet SILTY CLAY (14' to 15'), brown to grey brown	100	5.3 / 3.1 / 4.0 / 3.3 / 4.5	
15–20	ND	FINE TO MEDIUM SAND (15' to 17.5'), grey, few silt, slight odor, slight sheen and staining at 17 to 17.5', wet SILTY CLAY (17.5' to 20'), brown to dark brown, some organics, wet	100	5.2 / 4.3 / 4.8 / 3.4 / 4.8	
20–25		FINE TO MEDIUM SAND (20' to 20.6'), grey, few silt, wet SILTY CLAY (20.6' to 21'), brown, some organics, thin interbedded sand FINE TO MEDIUM SAND (21.8' to 24.1') SILTY CLAY (24.1' to 25'), dark brown	100	5.1 / 4.3 / 1.9 / 4.0 / 3.0	
25–30		FINE TO MEDIUM SAND (25' to 26.1') SILTY CLAY (26.1' to 27.8'), grey brown to brown, little organics, wet FINE TO MEDIUM SAND (27.8' to 28.6'), few coarse sand bands SILTY CLAY (28.6' to 30'), grey brown, trace fine sand	100	4.0 / 4.9 / 5.1 / 4.4 / 5.1	
30		END OF BORING			