Draft
Site Wide Feasibility Study Report

PSC Georgetown

Seattle, Washington

Prepared for:

Philip Services Corporation
18000 72nd Avenue South
Suite 217
Kent, Washington 98032

September 2005

Project No. 8770

Geomatrix

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Geomatrix

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DRAFT
SITE WIDE FEASIBILITY STUDY REPORT
PSC Georgetown
Seattle, Washington

1.0 INTRODUCTION

Geomatrix Consultants, Inc. (Geomatrix) prepared this Draft Site Wide Feasibility Study (SWFS) on behalf of Philip Services Corporation (PSC) for PSC's former dangerous waste treatment and storage (TSD) facility located at 734 Lucille Avenue (the "Facility") in the Georgetown neighborhood of Seattle (see Figure 1-1). The property on which the Facility is located and the Facility have a long history of industrial use, and during the past industrial activities at the property and the Facility, releases of hazardous constituents have occurred, affecting soil and groundwater. For the purposes of this SWFS, constituents of concern (COCs) are defined as constituents that were released to soil and groundwater at the Facility and that are covered by the corrective action provisions of the Facility's Resource Conservation and Recovery Act (RCRA) Part B Permit (Permit). The specific chemical compounds defined as COCs have also been released to soil and groundwater by non-PSC sources; however, only constituents released by PSC at the Facility and covered under the Permit are addressed by this SWFS. The areas addressed by this SWFS include soil and groundwater affected with Facility COCs at concentrations exceeding clean-up levels established in accordance with the Model Toxics Control Act (MTCA) regulations (Washington Administrative Code [WAC] 173-340). The areas affected by Facility COCs at concentrations exceeded these cleanup levels extending from and including the Facility are collectively referred to as the Site. In accordance with the corrective action provisions of the Permit, PSC completed characterization of the Site, and presented the results to Ecology in the Final Comprehensive Remedial Investigation Report (RI) and subsequent Addenda (PSC, 2003; PSC, 2004a, b, c, d), referred to herein as the RI Report. In February 2004, Ecology approved the RI Report and, in accordance with the Permit, required PSC to complete a SWFS for the Site. This report presents the results of the SWFS.

1.1 SWFS OBJECTIVES AND SCOPE

The objective of the SWFS is to identify and evaluate potential remedial alternatives for the Site. This SWFS is focused to evaluate only appropriate and proven remediation technologies capable of attaining remediation objectives within constraints of the Site.

The scope of the SWFS is defined by the requirements of the Permit and other applicable regulations and by the Site characterization results as presented in the RI report. The scope of the SWFS includes:

- Presenting remediation objectives and media cleanup levels;
- Presenting, analyzing and screening applicable remediation technologies and remedial alternatives capable of achieving the SWFS remediation objectives and clean-up levels;
- Estimating costs associated with the remedial alternatives, and
- Identifying the preferred remedial alternative which best meets the approved remediation objectives and clean-up levels.

1.1.1 Areas Included in the SWFS

The Permit requires that the SWFS address all areas affected by releases from the Facility. The area addressed by the FS includes the properties currently owned by PSC (the Facility and the adjacent TASCO property, collectively referred to as the PSC properties); properties adjacent to the PSC properties (UPRR, Aronson, and SAD properties); and the contiguous areas affected by releases from the facility extending downgradient (west) to Fourth Avenue South (see Figure 1-2). This area is referred as the SWFS Area. After the RI Report was completed, additional releases to soil and groundwater were identified within the area downgradient from the Facility. The specific chemicals released in these downgradient areas include many of the Facility COCs. These downgradient releases have resulted in an area of co-mingled releases that extend from approximately Fourth Avenue South to the Duwamish Waterway. Due to the presence of these downgradient source areas and the complexity of dealing with impacted groundwater from multiple sources, the scope of the SWFS has been limited, with Ecology concurrence, to the SWFS Area.

The SWFS Area has been further separated into two remediation areas for performance of this SWFS: (1) the area enclosed by the Hydraulic Control Interim Measure (HCIM) barrier wall (the HCIM Area) and (2) the portion of the SWFS Area outside the barrier wall (the Outside Area) (see Figure 1-3). The HCIM Area is inside the HCIM barrier wall and is either owned by PSC or PSC has secured a subsurface easement to that property. The Outside Area is outside the barrier wall, including the groundwater hydraulically downgradient of the HCIM barrier wall, a portion of the Facility, and the adjacent properties. The Outside Area has multiple owners, both public and private. The remediation technologies and institutional controls appropriate for the HCIM Area are expected to be substantially different from those appropriate for the Outside Area. For these reasons, separate remedial alternatives are developed for these two areas in this FS. The preferred remedial alternatives for the two areas are combined to develop a comprehensive remedial alternative addressing the entire SWFS Area.

The HCIM Area and Outside Area are described in more detail below:

- HCIM Area – The HCIM Area comprises portions of the areas referred to in the RI Report as Area 1 and Area 2 and is defined as the area contained by the HCIM barrier wall (Figure 1-3). This area includes the source areas, the Facility, and near-facility areas where groundwater is affected by high concentrations of COCs. The HCIM Area has historically been used for industrial purposes. Considerations affecting remediation of the HCIM Area are substantially different from considerations for the area located outside the barrier wall.

- Outside Area – The Outside Area is defined as the portions of RI Areas 1, 2, and 3 located outside of the HCIM barrier wall, extending downgradient to Fourth Avenue South. This remediation area includes the mixed industrial/commercial/residential area immediately surrounding the HCIM Area, including the downgradient groundwater plume extending west from Denver Avenue South to Fourth Avenue South. Although there are a few locations of impacted soil in the Outside Area, the primary impacted environmental medium is groundwater. Groundwater contamination has led to the contamination of soil gases and indoor air within the Outside Area.

Remedial alternatives are developed in this FS for both the HCIM Area and the Outside Area. This FS report identifies and evaluates potential remedial alternatives for the two impacted areas.

1.2 REPORT ORGANIZATION

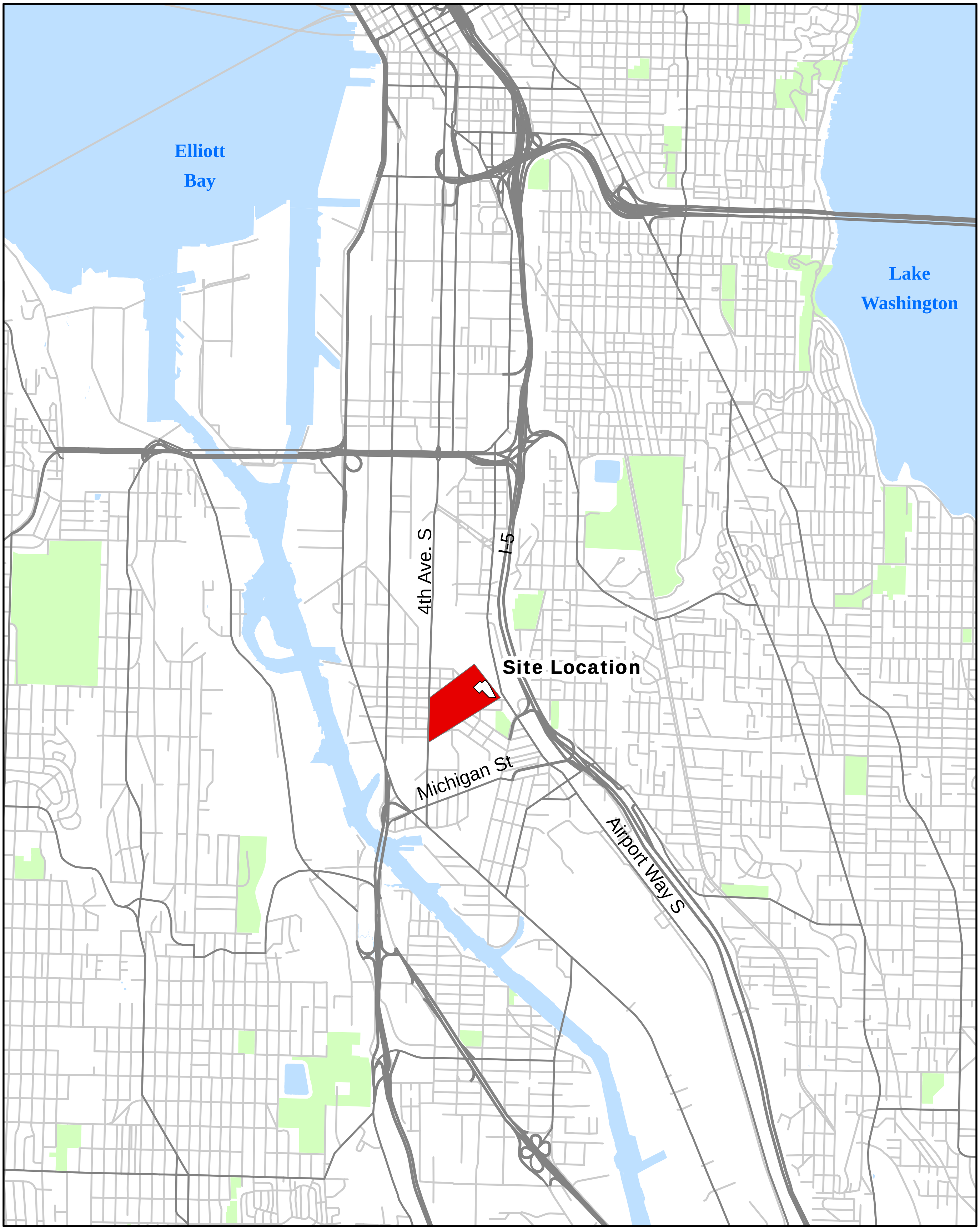
This FS report is organized as follows:

- Section 1 - Introduction. This section briefly describes the scope and objectives for the FS, the approach used to prepare the FS, and considerations specific to the area that are expected to affect remediation.

- Section 2 – FS Background and Setting. This section outlines the background for the SWFS, including site history, previous investigations, the previously implemented interim actions completes, and the regulatory framework. The hydrogeological setting for the SWFS Area is also described.

- Section 3 – Cleanup Levels and Remediation Levels. The cleanup levels taken from the RI Report are summarized for use in this FS. Remediation levels are also proposed in this section.
- Section 4 – Nature and Extent. Characterization results obtained from the RI Report that describe the known nature and extent of contaminated soil and groundwater in the Site area are summarized and the conceptual site model is described.
- Section 5 – Remediation Considerations and Objectives. Factors that could affect the implementation of remedial alternatives are identified. The remediation objectives are also defined.
- Section 6 – Potentially Applicable Remediation Technologies. The identification and screening of remediation technologies for potential use in the FS are described in this section.
- Section 7 – Remedial Alternative Evaluation Criteria. This section describes the criteria that have been used to assess and evaluate the remedial alternatives in this FS.
- Section 8 – Development and Evaluation of Remedial Alternatives: HCIM Area. This section describes each of the remediation alternatives addressed by this FS for the HCIM Area. The preliminary conceptual design used in the FS is described and potential issues specific to each alternative are identified, discussed, and evaluated.
- Section 9 – Development and Evaluation of Remedial Alternatives: Outside Area. This section describes each of the remediation alternatives addressed by this FS for the Outside Area. The preliminary conceptual design used in the FS is described, and potential issues specific to each alternative are identified, discussed, and evaluated.
- Section 10 – Site Wide Remediation. This section summarizes the evaluation of alternatives for the two areas and describes how the preferred alternatives will be implemented as a single combined alternative.
- Section 11 –References.

Appendices have been included to evaluate the fate and transport of COCs for various alternatives, provide technical details for establishing remediation levels, and support cost estimates.



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SITE VICINITY
PSC Georgetown
Seattle, Washington

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Figure
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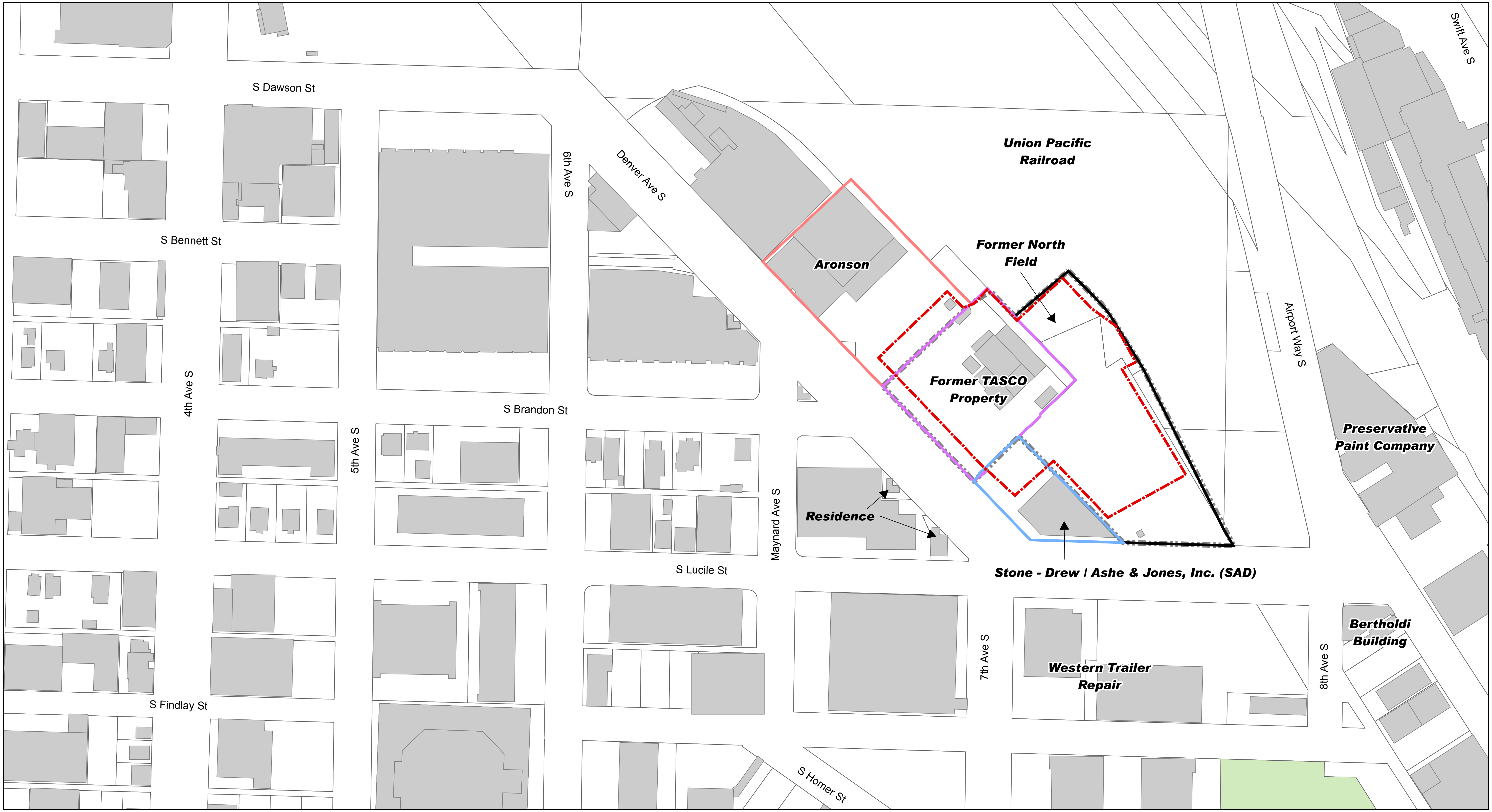

EXPLANATION

- Facility
- PSC Property
- Former TASCO
- Stone-Drew / Ashe & Jones, Inc (SAD) Property
- Aronson Property
- HCIM Area
- Building
- Parcel

0 200 Feet

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PSC PROPERTIES AND ADJACENT PROPERTIES
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Seattle, Washington

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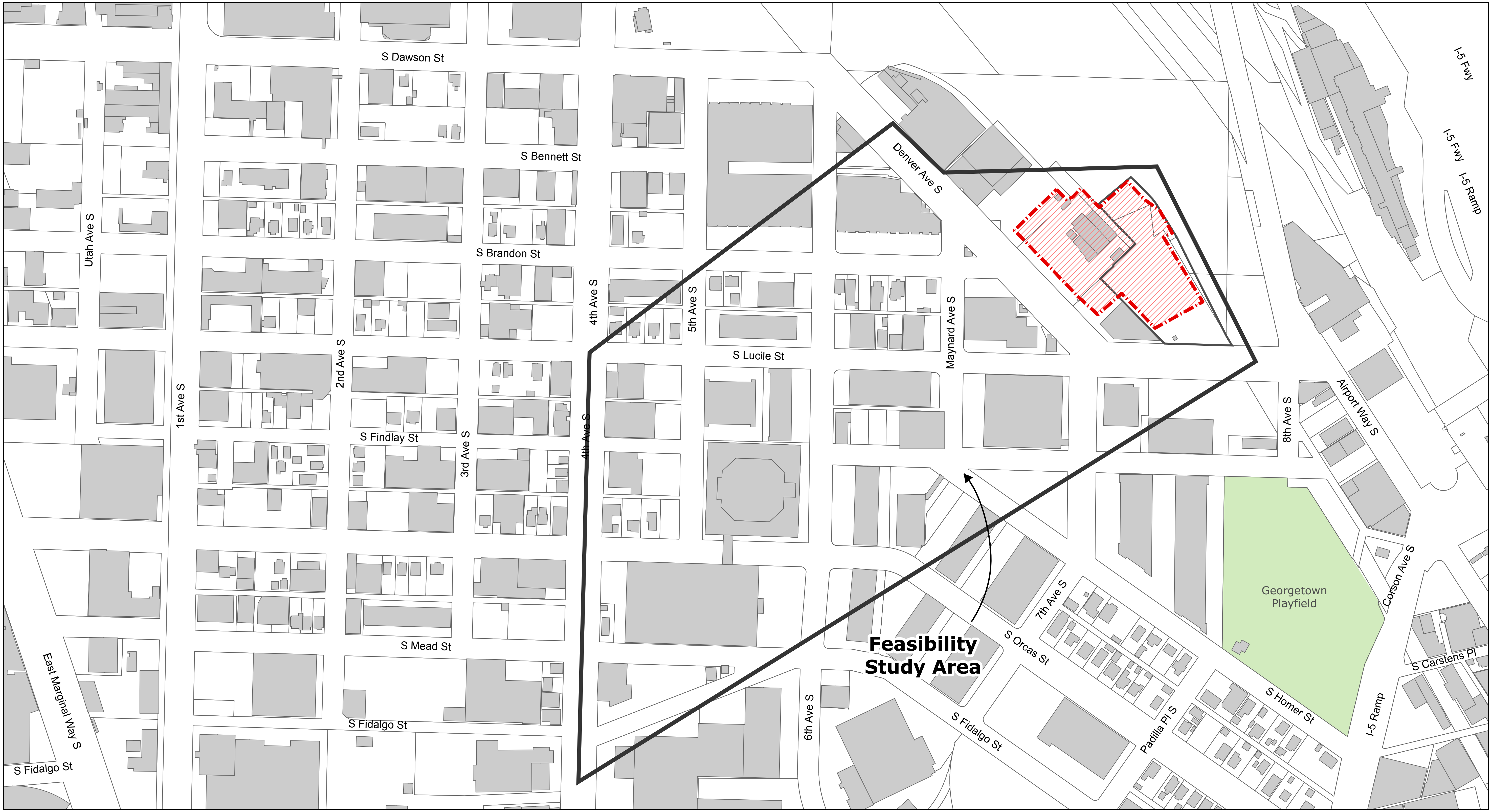

EXPLANATION

🟥 HCIM Area

▭ Outside Area

▭ Facility

▨ Building

▭ Parcel

0 200 Feet

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SITE WIDE FEASIBILITY STUDY AREA
PSC Georgetown
Seattle, Washington

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2.0 FEASIBILITY STUDY BACKGROUND AND SETTING

This section briefly summarizes the background for the SWFS including history of the Facility and surrounding property, the regulatory background, and previous interim actions. The general setting for the SWFS is also described.

2.1 BACKGROUND

The Facility has a long history and has been used for industrial and waste management purposes. Adjacent properties have and continue to be used for industrial and commercial purposes. Additionally, nearby properties include private residences. Extensive investigations and interim remedial measures have been completed to address historic releases from the Facility. This background information is summarized presented in the following subsections. Additional details are presented in the RI Report.

2.1.1 Historical, Present, and Future Facility Uses

Based on historical information collected during the RI, the Facility has been used for industrial purposes since at least 1936. Past Facility uses have included a distillation plant for reclaiming waste solvents; a paints and resins manufacturing facility; a wood shingle staining operation; a storage, solvent recycling, and treatment of dangerous wastes facility; and, most recently, as a RCRA-permitted hazardous waste management site that is the Facility. The Facility was permitted in 1991 (jointly by EPA and Ecology) to manage hazardous waste under a RCRA Part B Permit. Between 1991 and 1993, in accordance with Permit requirements, a microsilica concrete containment pad and storm water containment system were installed on the entire Facility. The Facility closed in December 2002, and Ecology approved the above-ground closure certification in August 2003. PSC currently conducts no activities at the Facility, although the corrective action process continues.

Figure 1-2 shows the Facility layout and the neighboring properties. The Facility is bordered on the east and north by UPRR property and rail lines. The Preservative Paint Company operates a plant to the east of the rail lines, across Airport Way South. The Bertholdi Building, which is used as office space, is located to the southeast of the Facility, on the southeast corner of Airport Way South and South Lucile Street. Western Trailer Repair Inc. is located south of the Facility across South Lucile Street. Immediately to the west of the southern part of the Facility is Stone-Drew/Ashe & Jones, Inc., a plumbing supply warehouse owned by SAD Properties LLC (SAD). PSC owns the adjacent TASCO property west of the Facility, which was formerly owned by the Amalgamated Sugar Company. Directly northwest of the Facility, to the northwest of the TASCO property, is property owned by Aronson Investment Company (Aronson), which is leased as a warehouse with office space. Three residences are located southwest of the Facility on the west side of Denver Avenue South.

The SWFS Area is entirely within an urban industrial/commercial/residential setting and has a long history of industrial, commercial, and residential use. This area is densely developed and includes private and public land owners. Land uses are varied and include residences and businesses, both commercial and industrial. Fourth Avenue South, a major arterial roadway for north-south traffic, defines the western extent of the SWFS Area. The nature and level of development in this part of Georgetown will have substantial effects on any remedial measures considered for the Outside Area. Private ownership limits access for conducting investigations and remediation in the area, as was the case during the RI. Remedial measures considered in this SWFS must be compatible with existing development and use in the Georgetown area.

Figure 2-1 shows zoning for the SWFS Area and vicinity. The Facility and adjacent properties are zoned General Industrial 1 (IG1), which allows the heaviest degree of industrial use and typically relies on rail and marine transportation (City of Seattle, 2002). The portions of the SWFS Area west of Denver Avenue South and south of South Lucile Street are zoned General Industrial 2 (IG2), indicating it is limited to mixed industrial and commercial use. Commercial development in areas zoned as IG2 is allowed to the extent that it does not interfere with industrial use. A small area located on both sides of Fourth Avenue South and extending east to Fifth Avenue South (except for the block between South Orcas and South Mead Streets) is zoned Commercial 1 (C1), which consists primarily of auto-oriented service commercial use. According to the zoning standards, limited residential development is allowed within areas zoned C1.

Substantial surface and subsurface utilities are present within the SWFS Area to service the heavy industrial, commercial, and residential development. Most of the utilities are located beneath the roads and adjacent sidewalks. The major north-south arterial, Fourth Avenue South, is heavily used by truck traffic. The location of these utilities can significantly affect permitting and engineering for remediation of the downgradient groundwater. The utility locations will likely affect the remediation implementation schedule because of the necessity of ensuring that proper access is obtained and that any work is protective of public safety.

2.1.2 Facility Investigations and Regulatory Oversight

Remedial investigation activities have been ongoing at the Facility since 1988. Section 2.4.3 of the RI Report provides a complete description of investigations performed to date.

A complete review of the regulatory history of the Facility is presented in Section 2.3 of the RI Report. In 1988, the EPA (the lead regulatory agency at the time) prepared a RCRA Facility Assessment and produced a Solid Waste Management Unit Report to evaluate whether there had been any releases to the environment, and issued a 3008(h) Order with corrective action requirements. As stated above, the Facility received a RCRA permit from the EPA and Ecology in August 1991, which replaced the corrective action requirements from the 3008(h) Order and included provisions to conduct a RCRA Facility Investigation (RFI) to determine the nature and extent of contamination and to install an interim measure to address the interim remedial measure requirements.

PSC conducted three major phases of a remedial investigation under the guidance of EPA and Ecology and on June 29, 2001, submitted a Draft Comprehensive RFI report. As part of the Draft RFI, a Draft Human Health and Environmental Risk Assessment (HHERA) (PSC, 2001), which characterized the potential risks and provided preliminary pathway-specific remedial action levels for the areas potentially affected by the Facility, was submitted to Ecology on August 10, 2001. In January 2002, EPA provided comments to PSC on the draft RFI and HHERA reports and requested additional work prior to resubmitting the reports. In response to EPA's and Ecology's comments, PSC submitted work plans and completed field work to address the data gaps identified in the RFI and HHERA. Most of the field work was completed during the summer of 2002 and spring of 2003 and included multiple rounds of groundwater sampling.

Ecology became the lead agency for the RCRA corrective actions related to the Facility in March 2002 and currently enforces the Permit's corrective action requirements. Ecology manages RCRA corrective actions under the MTCA, which uses different terminology than the EPA RCRA regulations. The RFI under RCRA is referred to as an RI under MTCA. The Draft Comprehensive RFI Report was revised and reissued as the Draft Comprehensive RI Report. Following approval of the RI Report by Ecology, the cleanup phase of the corrective action process began with implementation of this SWFS.

The RI Report presented detailed information on the Facility history, the SWFS Area, and surrounding area geology and hydrology; investigations completed; facility-related COCs and cleanup levels; and the nature and extent of contamination emanating from the Facility. In addition, details of the exposure pathways and identification of the COCs and human health and ecological risks were provided in the November 2003 Final Human Health and Ecological Risk Assessment (PTC, 2003). Ecology provided PSC with comments on the RI Report in February 2004; based on these comments, portions of the report were revised.

2.1.3 Interim Measures

PSC has previously performed three interim remedial actions within the SWFS Area, including a soil vapor extraction (SVE) system that was installed on the Facility in the former North Field area, the HCIM surrounding much of the PSC properties and a portion of neighboring properties, and vapor mitigation systems in several residences and businesses west of Denver Avenue South to eliminate the groundwater to indoor air pathway (referred to as the inhalation pathway interim measures or IPIMs). These three remedial actions are described in the following sections, and the location of each is shown on Figure 2-2.

2.1.3.1 Soil Vapor Extraction Interim Measure

An interim measure to address soil contamination in the Facility was installed in accordance with the requirements of the Permit. In 1993, an SVE Interim Measures Design and Implementation Work Plan (BEI, 1993) addressing the Facility was submitted to EPA. This work plan provided plans and specifications for the construction of an SVE system. In March 1994, an SVE system was installed in the former North Field area of the Facility, with the following objectives:

- Reduce the volatile organic compound (VOC) concentrations within the vadose zone just above the groundwater table;
- Prevent or minimize the further spread of contamination, thereby stabilizing conditions at the facility while long-term remedies are pursued; and
- Reduce the contaminant concentrations of preformed vapors that may be migrating offsite.

SVE systems are designed to desorb volatile contaminants from unsaturated soil by vacuum extraction. The extracted air is treated to break down or remove the contaminants before being released into the environment. The SVE system consisted of four SVE wells (V1, V2, V3, and V4) and originally included a catalytic oxidation unit, which was the air treatment system. The SVE wells are screened in the vadose zone.

The SVE system showed the highest removal rate during the first year of operation, after which time the removal rate dropped gradually, showing a tailing effect (PSC, 1998a). Approximately 19,000 pounds of VOCs have been removed using the system. The SVE system was turned off from February to August 1996 to allow the vadose zone to re-equilibrate; however, after resuming system operations, no increase in contaminant removal was observed. EPA and Ecology did not approve PSC's May 1998 request to turn the system off. Therefore, in 2000, PSC redeveloped the SVE wells to determine whether the well screens could be cleaned and performance of the system could be improved. However, this did not make a significant impact on the system's performance. The SVE system operated sporadically over the next two years and was found to be only marginally effective at removing additional contaminant mass.

When the SVE had reached the point of minimal additional effectiveness and after discussion with Ecology, operation of the SVE system was suspended February 1, 2004, and performance data from this system were not collected during the first quarter of 2004. With the completion of the HCIM barrier wall and associated groundwater withdrawal, a more effective source control measure is now in place to address the releases from the Facility. Therefore, PSC submitted a letter to Ecology pursuant to Section VII.C.4 of the Permit requesting official authorization to cease operation of the SVE interim measure (PSC, 2004e).

2.1.3.2 Hydraulic Control Interim Measure

In June 2001, EPA and Ecology required that PSC implement groundwater interim measures, including a measure that would establish hydraulic control of non-aqueous phase liquid (NAPL) and dissolved plumes emanating from the Facility. The RI Report indicated that groundwater affected by Facility constituents extends downgradient of the Facility, with high concentrations of constituents present on three neighboring properties to the west (TASCO, Aronson, and SAD). In order to address the areas of highest groundwater impacts associated with the Facility, PSC purchased the TASCO property and the associated rail spur in 2003 and gained a permanent subsurface easement access to relevant portions of Aronson and SAD properties in October and December 2003, respectively.

Between October 2003 and January 2004, a low-permeability barrier wall was installed to surround the contamination source areas and near-facility impacted groundwater. The barrier wall is coupled with groundwater extraction on the inside of the wall to provide hydraulic containment by maintaining an inward-directed hydraulic gradient. The barrier wall surrounds the source areas as well as areas of the most highly impacted groundwater as identified in the

RI Report, which includes a large portion of the Facility and portions of neighboring properties (Figure 2-2). Along with the barrier wall, the HCIM includes a system of groundwater extraction wells and a groundwater pretreatment system. The purpose of the barrier wall is to restrict groundwater influx to the HCIM area so that hydraulic control is achievable at lower groundwater extraction rates than by simply pumping groundwater without the barrier wall. The inward-directed gradient minimizes the potential for migration of groundwater through the barrier wall. The permeability of the barrier wall is very low, on the order of 10^{-8} centimeters per second (cm/sec). As a result, the barrier wall is also acting as a hydraulic containment system for both groundwater and soil vapors. A system of monitoring wells inside and outside the barrier wall are monitored for water levels, general water quality parameters, and COCs to ensure that the HCIM is performing properly. Figure 2-3 shows the location of monitoring wells located near the HCIM barrier wall.

The pretreated groundwater discharges into the King County Department of Natural Resources and Parks (King County) sewer system, in accordance with the PSC revised Permit No. 7670-4 issued on February 27, 2004. The final discharge of water from the pretreatment system is permitted under the Clean Water Act. The air stream that is discharged at the air stripper is sent through permanganate and granular-activated carbon units for treatment prior to atmospheric discharge.

2.1.3.3 Inhalation Pathway Interim Measures

COC-impacted groundwater has been detected in the water table sample interval downgradient of the HCIM Area. COCs can be transferred from contaminated groundwater or soil by volatilization to soil vapor. Soil vapor is the air residing in the interstitial spaces of the porous granular soil, below ground surface and above the saturated soil zone. Once volatilized, the constituents in soil vapor can migrate in the vadose zone via diffusion and/or gas-phase advection to the ground surface or into overlying buildings. Gas-phase advection results primarily from differences in air pressure in the subsurface and above-ground air or in buildings. Cracks or other openings in a building’s foundation may serve as entry points for impacted soil vapor via diffusion or pressure-gradient driven advection. Similar to the differences in pressure above and below ground, pressure differentials often exist between the inside and outside of buildings due to wind, building ventilation systems (including heating and air conditioning, bathroom, and kitchen fans), and household appliances (e.g., clothes dryers or cooling fans). These pressure differentials also result in ambient air being drawn into buildings.

Because exposure to volatile COCs in indoor air has been identified as a potentially complete exposure pathway, the indoor air concentrations that may result from migration from impacted groundwater are of interest. One of the objectives of the interim measures required by EPA and Ecology in June 2001 was to prevent indoor inhalation exposure of residents and workers located between the Facility and the Duwamish Waterway (well beyond the limits of the SWFS Area) in areas known or reasonably expected to have VOCs in the upper portion of the shallow aquifer. However, the concentration of a compound detected in indoor air may be attributed to a number of sources, including unrelated contamination in soil vapor, ambient air, and other household or industrial sources. For instance, household products containing the same VOCs as those that constitute the affected groundwater plume (e.g., solvents) are ubiquitous. As a result, concentrations detected in indoor air samples should be considered in conjunction with groundwater, soil vapor, and ambient air concentrations to determine the likely source of the constituents in indoor air.

PSC developed a tiered approach for evaluating specific locations and buildings in the affected area on a quarterly basis. The buildings that were evaluated by this tiered approach are shown on Figure 2-2. The approach consisted of three steps:

1. developing site-specific groundwater to indoor air volatilization factors (GIVFs) that represent the relationship of concentrations of VOCs in groundwater and concentrations in indoor air;

2. using the GIVFs to develop site-specific risk-based inhalation pathway interim measure action levels (IPIMALs) for each constituent of concern in groundwater throughout the affected area; and

3. using the IPIMALs and the decision tree to determine if indoor air concentrations of VOCs would potentially be above levels of concern for the various buildings.

Regardless of the source of the detected concentrations, buildings that were identified in the third step as potentially having indoor air concentrations above levels of concern are being evaluated. Depending on results of that further evaluation, mitigation systems including depressurization systems and/or vapor barriers have been (and continue to be) installed in the buildings to prevent indoor inhalation exposure.

2.2 SITE WIDE FEASIBILITY STUDY REGULATORY REQUIREMENTS

Regulatory and Permit requirements provide the framework for conducting the SWFS for the Facility. The applicable regulatory requirements are summarized in this section. Section 2.2.1 describes RCRA requirements under the provisions of the Permit. Section 2.2.2 describes the relevant requirements of MTCA. Section 2.2.3 summarizes the requirements from regulations other than MTCA or RCRA that apply to the SWFS.

2.2.1 RCRA/Permit Requirements

The Permit requires this SWFS to be completed. Because Ecology uses MTCA for RCRA corrective actions, this SWFS follows the MTCA regulations. The Permit also requires the SWFS to include analyses and predictions of future groundwater movement and the risks to receptors potentially exposed to the groundwater (and/or surface water, soil gas, and indoor/outdoor air contaminated by groundwater). These analyses may be limited to scenarios based on implementation of appropriate remediation alternatives.

In the Permit, PSC is specifically required to submit a draft FS report. The submittal must include remedial action objectives and media cleanup levels as well as remediation technologies, screening of those technologies, and remedial alternatives capable of achieving the remedial action objectives and cleanup levels. The SWFS must identify a preferred remedial alternative that best meets the preliminary remedial action objectives approved in the RI Report and a cost estimate for completing the design, implementation, monitoring, and closure of the preferred remedy. Additional general requirements of the SWFS are listed in Sections VII.D.1 and VII.D.2 of the Permit and include threshold criteria for all potential cleanup alternatives and remedial action selection factors.

2.2.2 MTCA Requirements

Regulations issued pursuant to MTCA (WAC 173-340) specify the requirements for completing an FS and selecting a cleanup action. Each remedial alternative considered must be designed to comply with MTCA regulations, which specify the procedures for establishing cleanup levels and points of compliance and for risk assessment. In addition, the regulations provide minimum requirements for establishing controls and for selecting the preferred cleanup actions. The MTCA regulations contain specific requirements for developing and applying cleanup standards that are protective of human health and the environment, and provisions for the use of remediation levels to develop and evaluate cleanup action alternatives.

Cleanup levels are applied at a specific location to assess compliance with the MTCA cleanup standard. The location where the cleanup level must be met is known as the Point of Compliance (POC). Procedures for establishing risk-based cleanup levels are established in the MTCA regulations. These cleanup levels are specific to the COCs, the affected media, the exposure pathway, and the receptor. Cleanup levels were presented for Facility COCs in the RI Report and are summarized in Section 3 of this report. Under MTCA regulations, the POC may be a standard POC (SPOC) or a conditional POC (CPOC). The SPOC for soil or groundwater is defined in the MTCA regulations as applying throughout a site (i.e., for the Facility, the SPOC would apply to all soil or groundwater present within the SWFS Area). A CPOC is defined as a POC located at a specified distance from the source of the contamination. If it can be demonstrated in accordance with MTCA regulations that it is not practicable to meet the cleanup level at the SPOC within a reasonable timeframe, Ecology may approve a CPOC. Establishing a POC is specific to the site at which the release occurred. The SWFS will assess the practicability of attaining the SPOC for the SWFS Area. If it is determined that attaining the SPOC is impracticable, CPOCs will be proposed as appropriate. The POC proposed for the SWFS is presented in Section 5 of this report.

In general, MTCA requires final cleanup action plans to comply with applicable state and federal laws and regulations in the FS. WAC 173-340-350 (8) specifies general requirements and guidelines for conducting an FS. Ecology also has defined expectations regarding cleanup action alternatives that are documented in WAC 173-340-370. As noted in these regulations, “these expectations represent the types of cleanup actions the department considers likely results of the remedy selection process….” These expectations are addressed in the SWFS.

2.2.3 Other Requirements (ARARs)

The remedial alternatives discussed in detail in the SWFS will comply with all applicable or relevant and appropriate regulations (ARARs), including state and federal laws, in accordance with WAC 173-340-350, WAC 173-340-710, and the requirements of the Permit. “Applicable” requirements mean those regulatory cleanup standards; standards of control; and other substantive environmental protection requirements, criteria, or limitations promulgated under federal or state law that specifically address a COC, remedial action, location, or other circumstance at the facility and that are applicable to the facility under law. “Relevant and appropriate” requirements are regulatory requirements or regulatory guidance that do not apply to the facility under law but have been determined to apply by Ecology in accordance with WAC 173-340-710(3). ARARs are often identified as chemical-specific, location-specific, or remedial action-specific. A number of regulations include requirements in more than one of these three categories.

The operational portions of the Facility are considered closed under RCRA; however, corrective actions are ongoing and require compliance with the Washington Dangerous Waste Regulations (WAC 173-303) and federal RCRA regulations (40 CFR Parts 240-299). Any remedial action taken must comply with other applicable laws and regulations (42 U.S.C. Ch. 6901 et seq.). The applicable requirements under the Dangerous Waste and RCRA regulations pertain primarily to management of remediation wastes and general compliance issues with the Permit. Corrective action requirements under RCRA and the Dangerous Waste regulations are addressed under the Permit and the MTCA regulations, which include very specific and extensive requirements for the SWFS.

2.3 SITE HYDROGEOLOGY

The RI Report identified five hydrogeologic units that occur with increasing depths within the Site. These hydrogeologic units are described below in descending order:

- The *shallow sand unit* (including fill) is the uppermost hydrogeologic unit in the study area and consists of poorly graded, fine to medium sand with fine gravel and varies from 21 to 46 feet in thickness. The upper portions of the unit may be composed of fill including material dredged from the Duwamish Waterway. The shallow sand unit grades into the intermediate sand and silt unit. PSC estimates a hydraulic conductivity of 3.2×10^{-2} cm/sec for the shallow sand unit based on grain size, slug test, and pumping test data.

- The *intermediate sand and silt unit* underlies the shallow sand and consists of discontinuous interbedded silty sand and sandy silt lenses with shell fragments. The unit ranges in thickness from 13 to 68 feet and is often indistinguishable from the overlying shallow sand unit. PSC estimates a hydraulic conductivity of 5.1×10^{-3} cm/sec for the intermediate sand and silt unit based on grain size, slug test, and pumping test data. The lower hydraulic conductivity as compared to the overlying shallow sand unit is consistent with the finer-grained nature of the intermediate unit.

- The *silt unit* at the Facility underlies the intermediate sand and silt unit and consists predominately of silt and very fine sand ranging in thickness from 11 to 50 feet. Clam shells and shell fragments are commonly present. Some borings encountered worm burrows, mud cracks, and occasional fine laminations. Laboratory triaxial tests indicated a vertical hydraulic conductivity of 10^{-7} cm/sec to 5×10^{-6} cm/sec.

- The *deep sand and silt unit* consists of sandy silt, fine sand, and interbedded lenses of silty sand. The top of the unit lies at depths of between approximately 84 and 128 feet below the ground surface (bgs). PSC estimates a hydraulic conductivity of

3×10^{-3} cm/sec for the deep sand and silt unit based on grain size, slug test, and pumping test data.

- The *bedrock* consists of consolidated sedimentary sandstone and siltstone. At a boring east of the Facility, bedrock was encountered at a depth of approximately 56 feet bgs. The depth to bedrock increases to the west and is estimated to be about 330 to 660 feet near the Duwamish Waterway (PSC, 2003).

Review of groundwater quality data indicate that the hydrogeologic units of primary interest include the shallow sand unit, intermediate sand and silt unit, and silt unit. These units have been grouped into three hydrogeologic units including a shallow zone that includes the water table and shallow sample intervals, an intermediate zone that includes the intermediate sample interval, and silt aquitard.

2.3.1 Hydrostratigraphy

Hydrogeologic cross sections were created using the lithologic data collected during the installation of selected reconnaissance borings and groundwater monitoring wells (Dalton, Olmsted, & Fuglevand, 2005; PSC, 2003). Groundwater levels and geology are depicted on the cross sections SW-A-NE (shown on Figure 2-4 as A-NE and on Figure 2-5 as SW-A, respectively) and B-B' (Figure 2-6). Cross section locations are shown on Figure 2-7. The location of the cross section SW-A-NE was chosen based on the areal extent of the primary COCs. Cross section SW-A-NE was oriented along the direction of groundwater flow so that it is representative of the trends and distribution of COCs along a transport pathway. Cross section B-B' is oriented perpendicular to the direction of groundwater flow, extending north-south along the west side of the Facility.

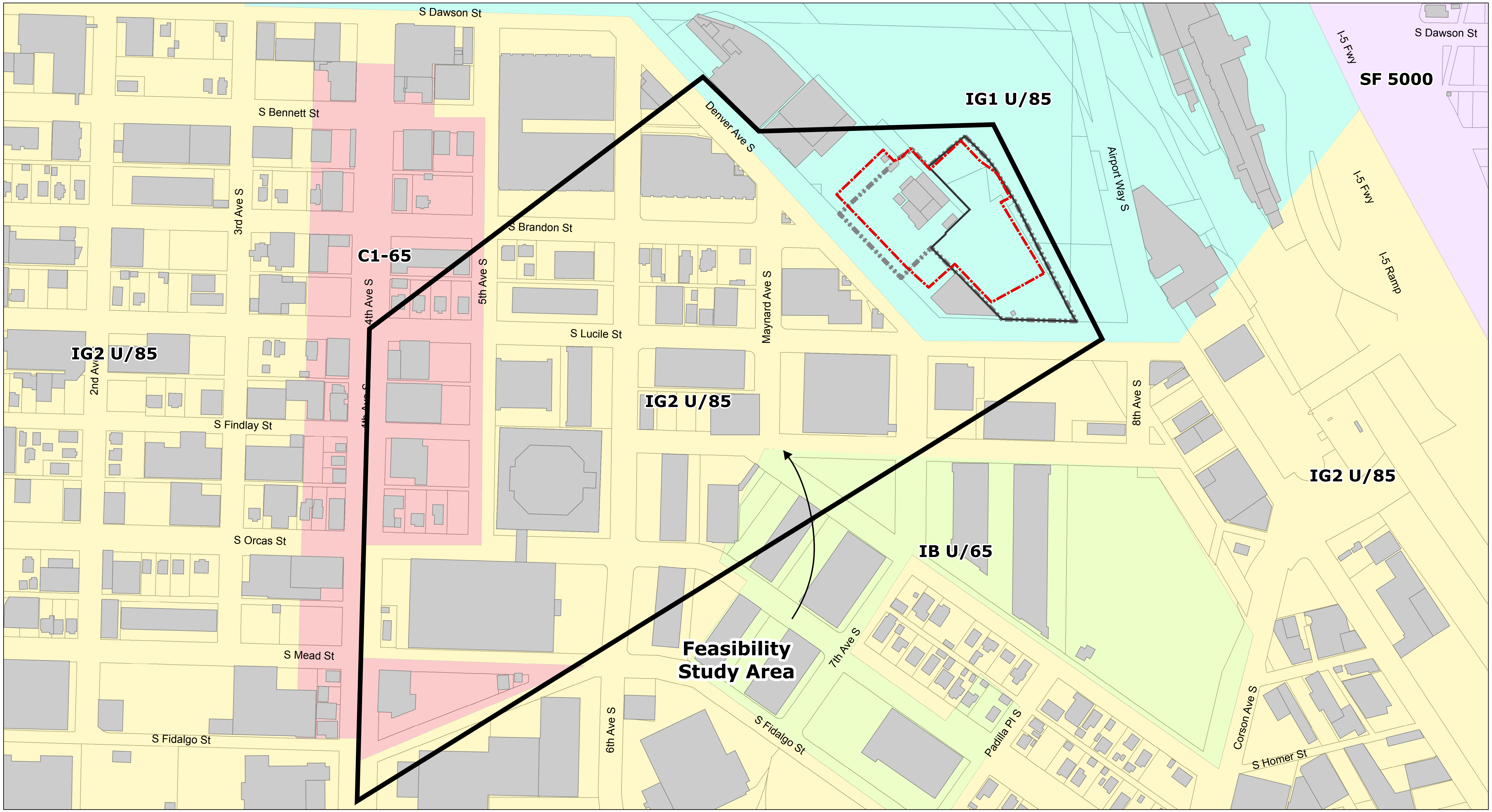
The water table defines the top of the water-saturated zone of interest. The top of the silt aquitard defines the bottom of the water-saturated zone of interest for the SWFS and appears to decline in elevation in a southwesterly direction from the Facility. The water-saturated zone of interest ranges in thickness from approximately 45 to 50 feet near the Facility to 105 to 110 feet toward the Duwamish Waterway and includes the shallow sand unit and the intermediate sand and silt unit sample intervals.

The shallow sand unit at the Facility is quite distinct from the intermediate sand and silt unit. The shallow sand unit is a relatively clean sand, whereas the intermediate sand and silt unit is recognizable by the numerous silt layers. Groundwater velocities in the intermediate sand and silt unit are much slower than those in the shallow sand unit, with velocities in the intermediate sand and silt unit on the order of 25 feet per year compared to velocities in the shallow sand unit of 180 to 190 feet per year. However, the intermediate sand and silt unit becomes much sandier, with very few silt layers identified in the boring logs west of the SWFS Area along East Marginal Way South. This suggests that in the more western portion of the SWFS Area, the shallow sand and the intermediate sand and silt units may be acting as a single hydrogeologic unit.

2.3.2 Groundwater Elevations and Gradient

The general direction of groundwater flow within the SWFS Area is west-southwest from the HCIM Area towards the Duwamish Waterway, and shows seasonal fluctuations that are moderately well correlated to precipitation. Mean groundwater levels were calculated in the RI Report using data collected from the PSC monitoring well network over the course of one year (2002-2003), prior to installation of the HCIM barrier wall. These mean groundwater levels were used to construct the contour maps presented in the RI Report of the groundwater elevations for the water table, the shallow zone (30 to 40 feet bgs), and the intermediate zone (wells 40 to 90 feet bgs). Water levels measured in the shallow zone are similar to those in the intermediate zone, suggesting that the two zones are hydraulically well connected. Average horizontal hydraulic gradients in the water table, shallow, and intermediate zones were all about 0.0016.

Groundwater elevation data from January 2005 for the water table, shallow, and intermediate zones are shown on Figures 2-8 through 2-10, respectively. The influence of the barrier wall on groundwater flow near the Facility can be seen in the groundwater elevation contours. Higher than average hydraulic gradients are observed along the northwestern and southeastern sides of the wall, and lower than average gradients are observed in a “stagnation” zone along the southwestern side of the wall. A more typical gradient, within the range of historical average gradients, appears to be reestablished within a few hundred feet downgradient of the barrier wall.



EXPLANATION

- 🟥 Commercial C1-65
- 🟩 Industrial Buffer IB U/65
- 🟦 General Industrial IG1 U/85
- 🟨 General Industrial IG2 U/85
- 🟪 Single Family SF 5000
- HCIM Area
- OutsideArea
- Facility
- PSC Property
- Building
- Parcel

0 200 Feet

N

CITY OF SEATTLE LAND USE ZONING
PSC Georgetown
Seattle, Washington

GEOMATRIX

Project No.	Figure
8770	2-1

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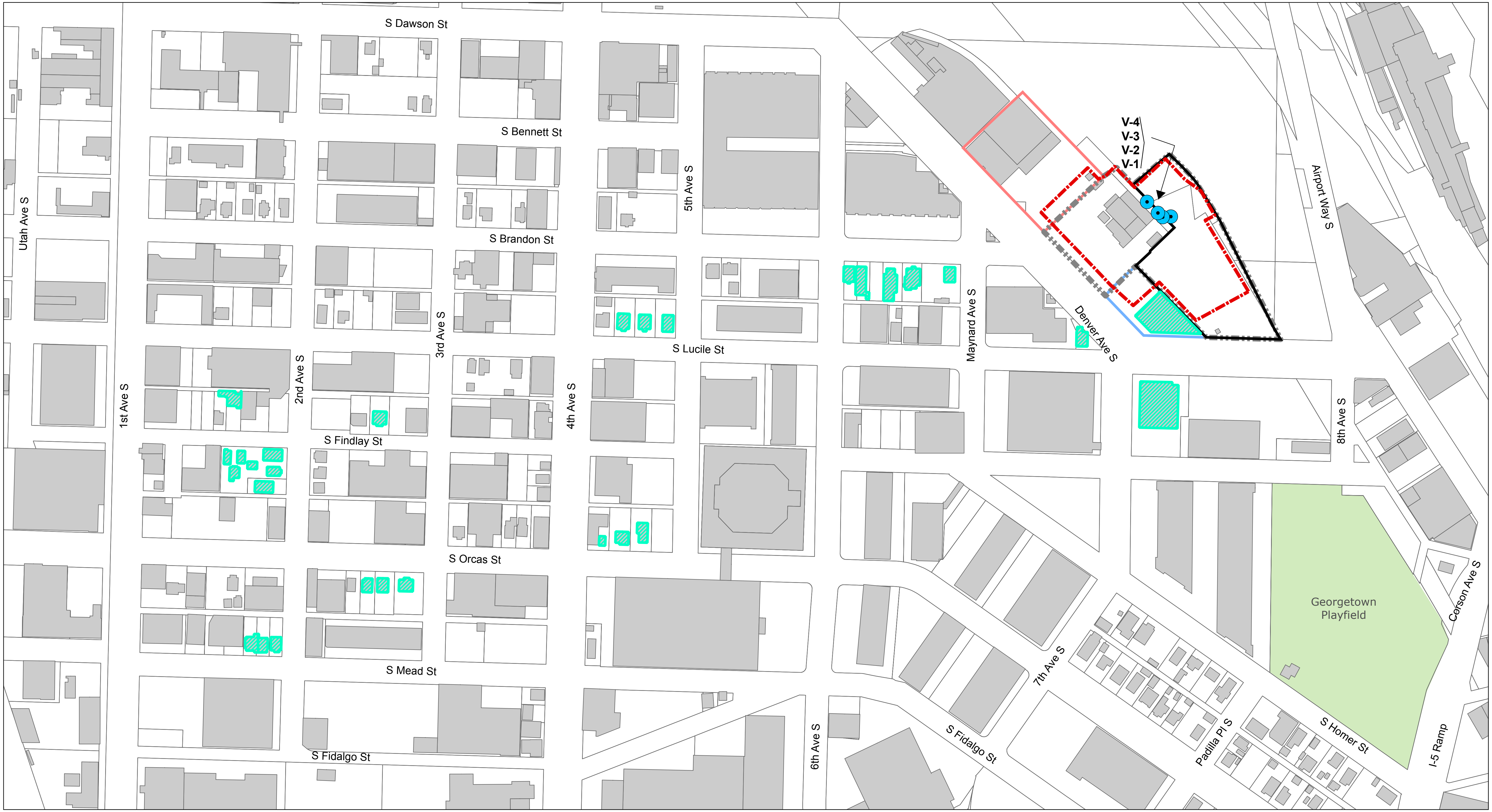

EXPLANATION

▬ · ▬	HCIM Area	☐	Facility	☐	Stone-Drew / Ashe & Jones, Inc. (SAD) Property
▨	IPIM	⬚	PSC Property	☐	Aronson Property
●	SVE Well	☐	Parcel	■	Building

0 200 Feet

N

INTERIM MEASURE LOCATIONS
PSC Georgetown
Seattle, Washington

GEOMATRIX

Project No. 8770

Figure 2-2

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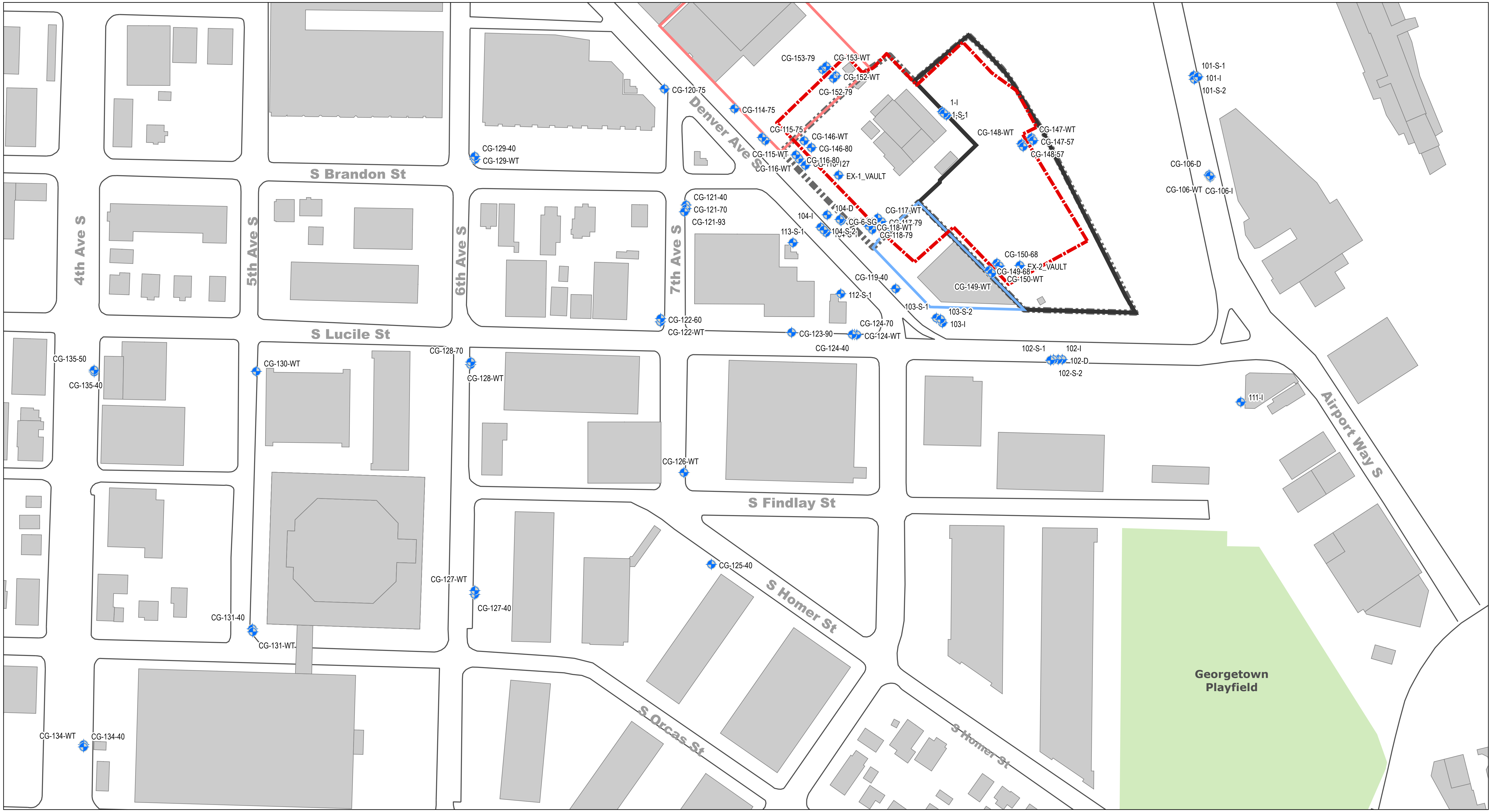

EXPLANATION

- ⯐ Current Monitoring Well
- HCIM Area
- Facility
- PSC Property
- Stone-Drew / Ashe & Jones, Inc (SAD) Property
- Aronson Property
- Building

CURRENT HCIM
MONITORING WELL LOCATIONS
PSC Georgetown
Seattle, Washington

GEOMATRIX

Project No.	Figure
8770	2-3

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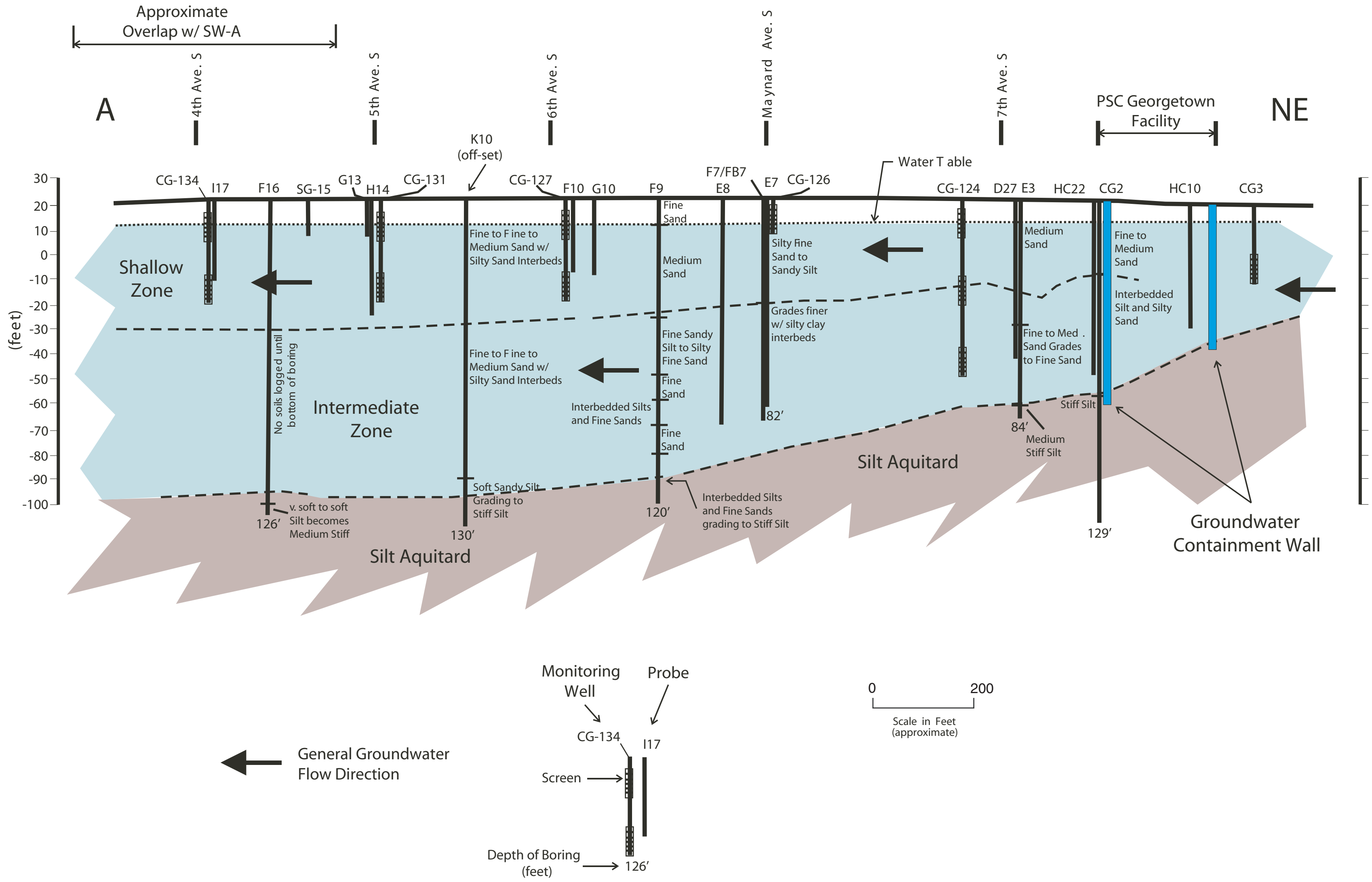


Note: This figure is from *Report on Solvent Sources Downgradient of PSC-Georgetown Facility*, March 2005: Dalton, Olmsted & Fuglevand, Inc.

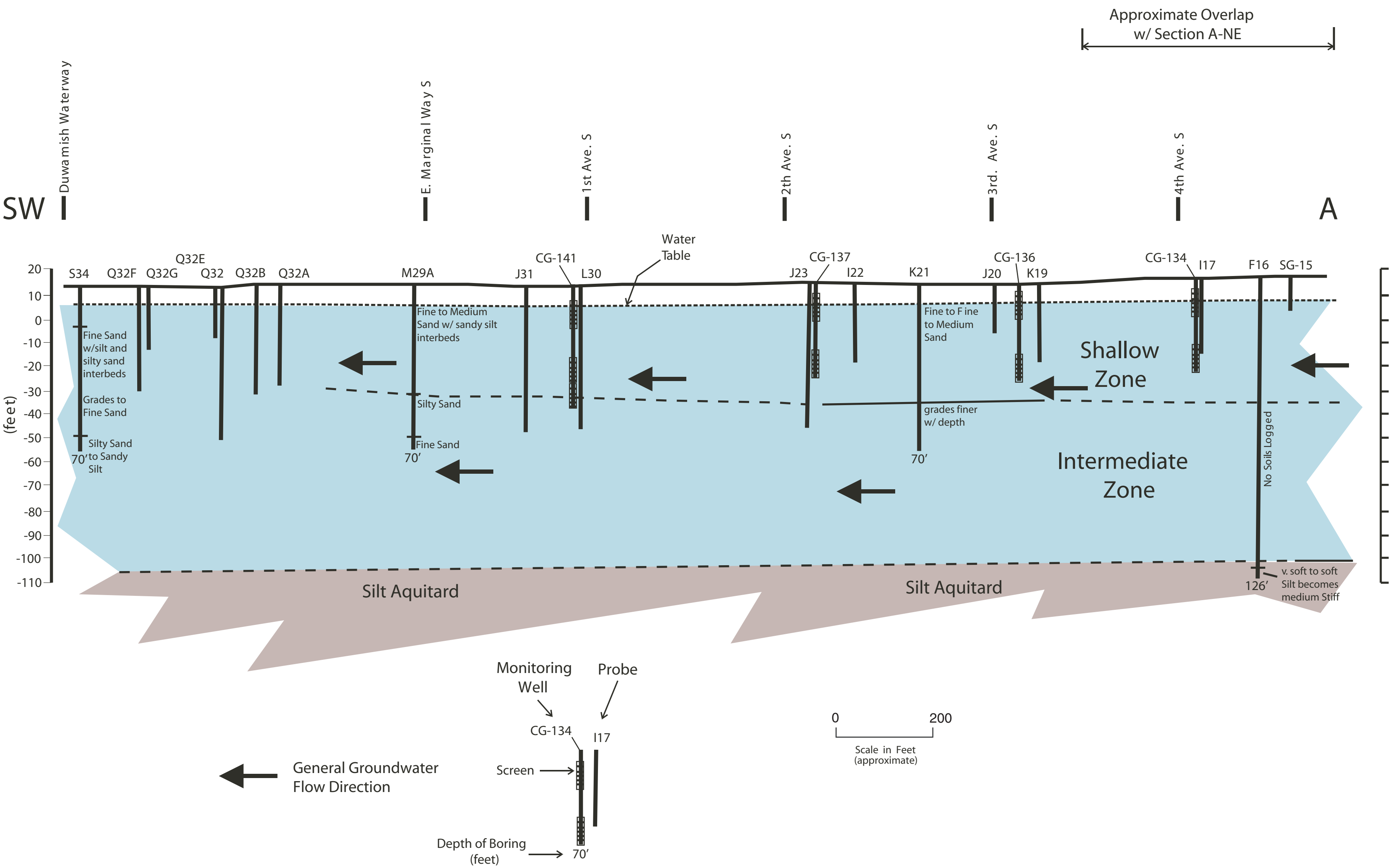
GEOMATRIX

GEOLOGIC CROSS SECTION A-NE
PSC Georgetown
Seattle, Washington

Project No.
8770

Figure
2-4

S:\8770\027_DSiteWideFS\Illustrator\Fig2-5_Geo-section SW-A.ai



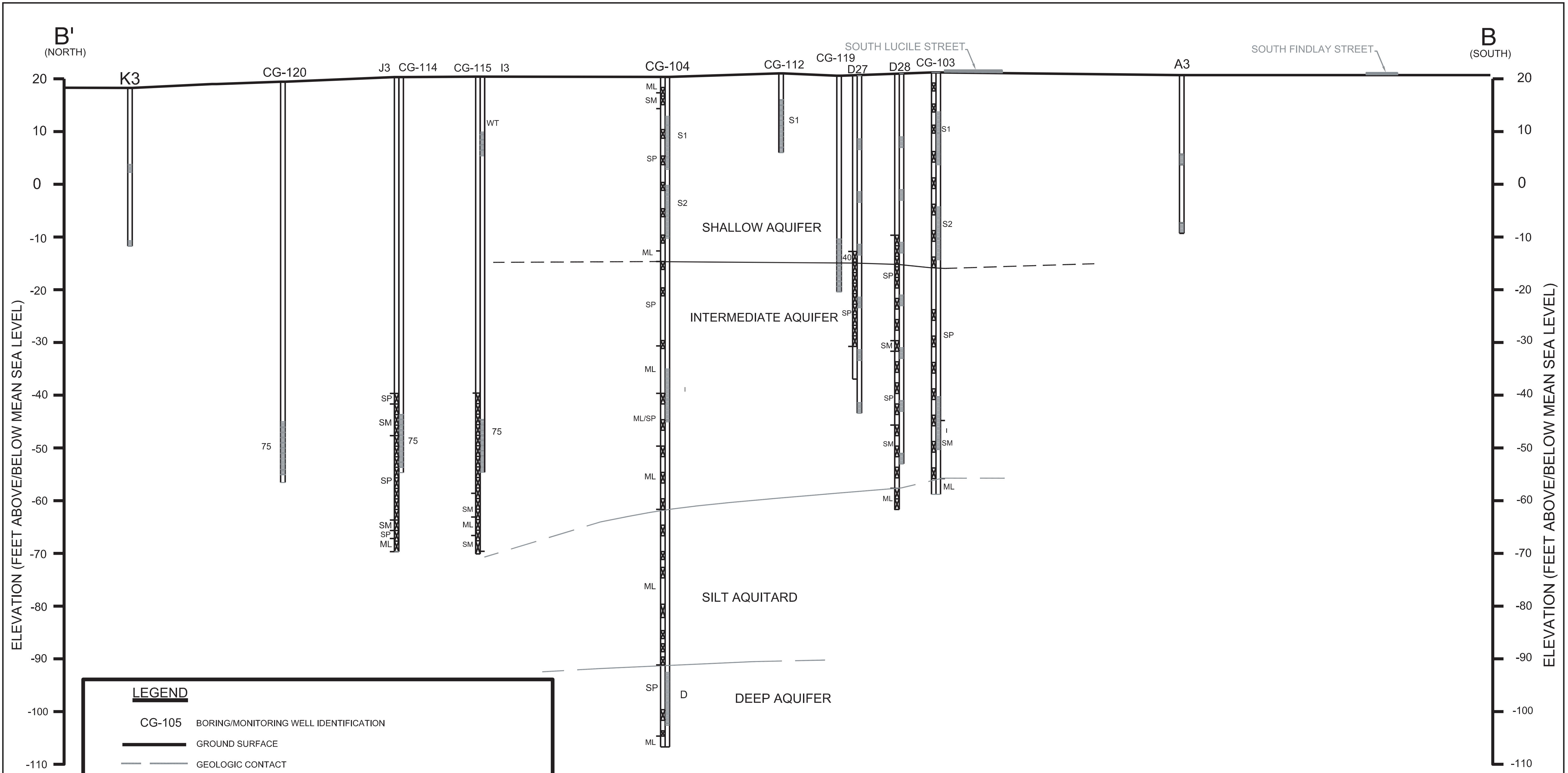
Note: This figure is from *Report on Solvent Sources Downgradient of PSC-Georgetown Facility,* March 2005: Dalton, Olmsted & Fuglevand, Inc.

GEOMATRIX

GEOLOGIC CROSS SECTION SW-A
PSC Georgetown
Seattle, Washington

Project No.
8770

Figure
2-5



LEGEND

CG-105	BORING/MONITORING WELL IDENTIFICATION
▬	GROUND SURFACE
— — —	GEOLOGIC CONTACT
▬	INDICATES CROSS-SECTION LINE CROSSING CITY STREETS
⊠	SAMPLE INTERVAL FOR LITHOLOGIC DESCRIPTION
▤	SCREENED INTERVAL FOR GROUNDWATER SAMPLE COLLECTION
WT, S1, S2, 40, I, 75, D	INDICATES WELL SCREENED IN THE WATER TABLE SAMPLE INTERVAL (WT OR S1), SHALLOW SAMPLE INTERVAL (S2 OR 40), INTERMEDIATE SAMPLE INTERVAL (I OR 75), AND DEEP (D) AQUIFERS
ML	SILT, SANDY SILT, GRAVELLEY SILT
SM	SILTY SAND, SILTY SAND WITH GRAVEL
SP	SAND, POORLY GRADED
SW	SAND WITH GRAVEL, WELL GRADED
GP	GRAVEL WITH SAND, POORLY GRADED

1. VERTICAL DATUM FOR GROUNDWATER LEVEL IS BASED ON NAVD88

2. SOIL TYPES SHOWN FOR BORING CG-104 COMBINED FROM CG-104-S2, CG-104-I, AND CG-104-D

CROSS SECTION B - B'
PSC Georgetown
Seattle, Washington

GEOMATRIX

Project No.	Figure
8770	2-6

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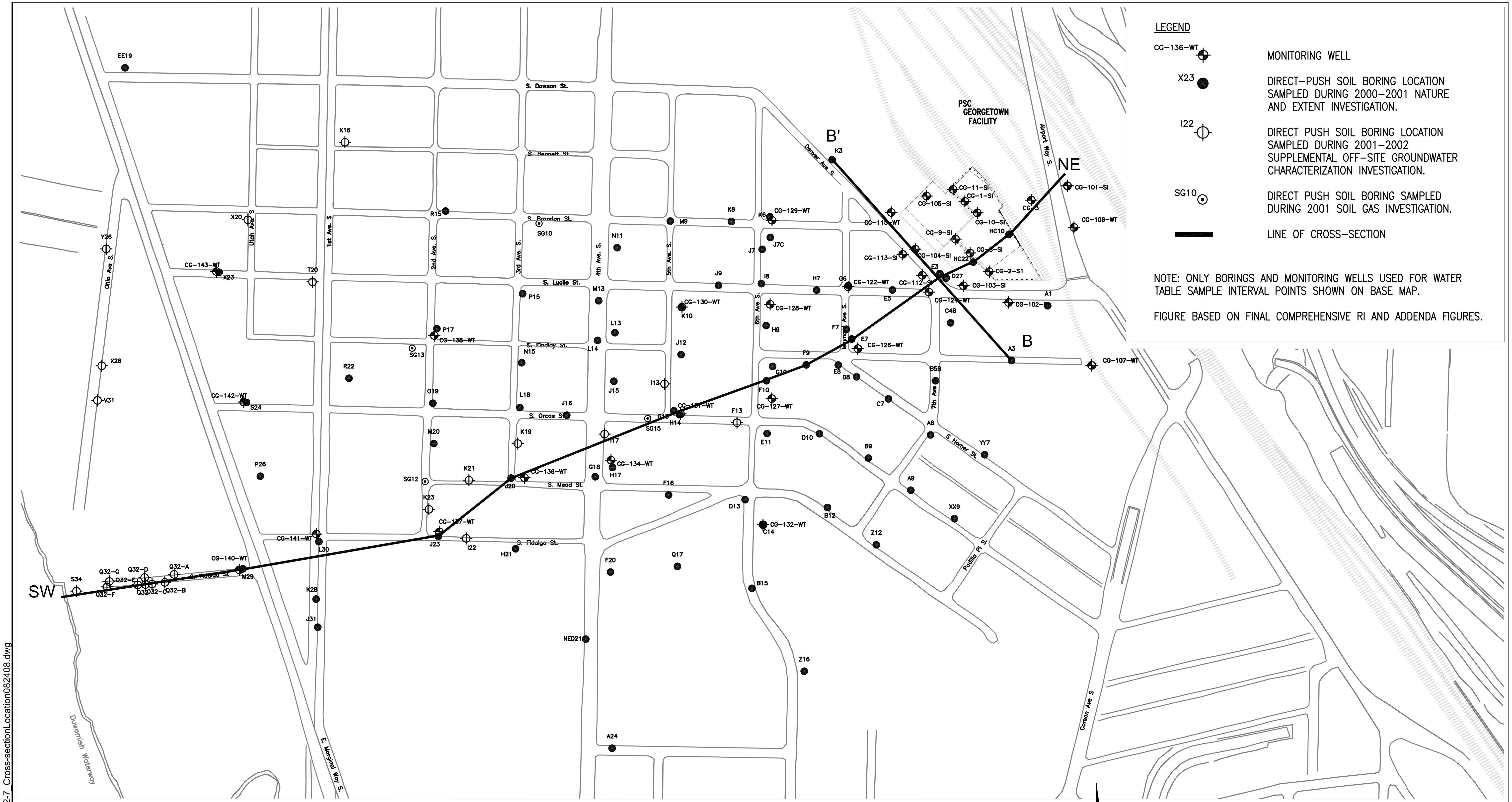

NOTE: ONLY BORINGS AND MONITORING WELLS USED FOR WATER TABLE SAMPLE INTERVAL POINTS SHOWN ON BASE MAP.

FIGURE BASED ON FINAL COMPREHENSIVE RI AND ADDENDA FIGURES.

0 400
APPROXIMATE SCALE (FEET)

CROSS SECTION LOCATION
PSC Georgetown
Seattle, Washington

GEOMATRIX

Project No.
8770

Figure
2-7

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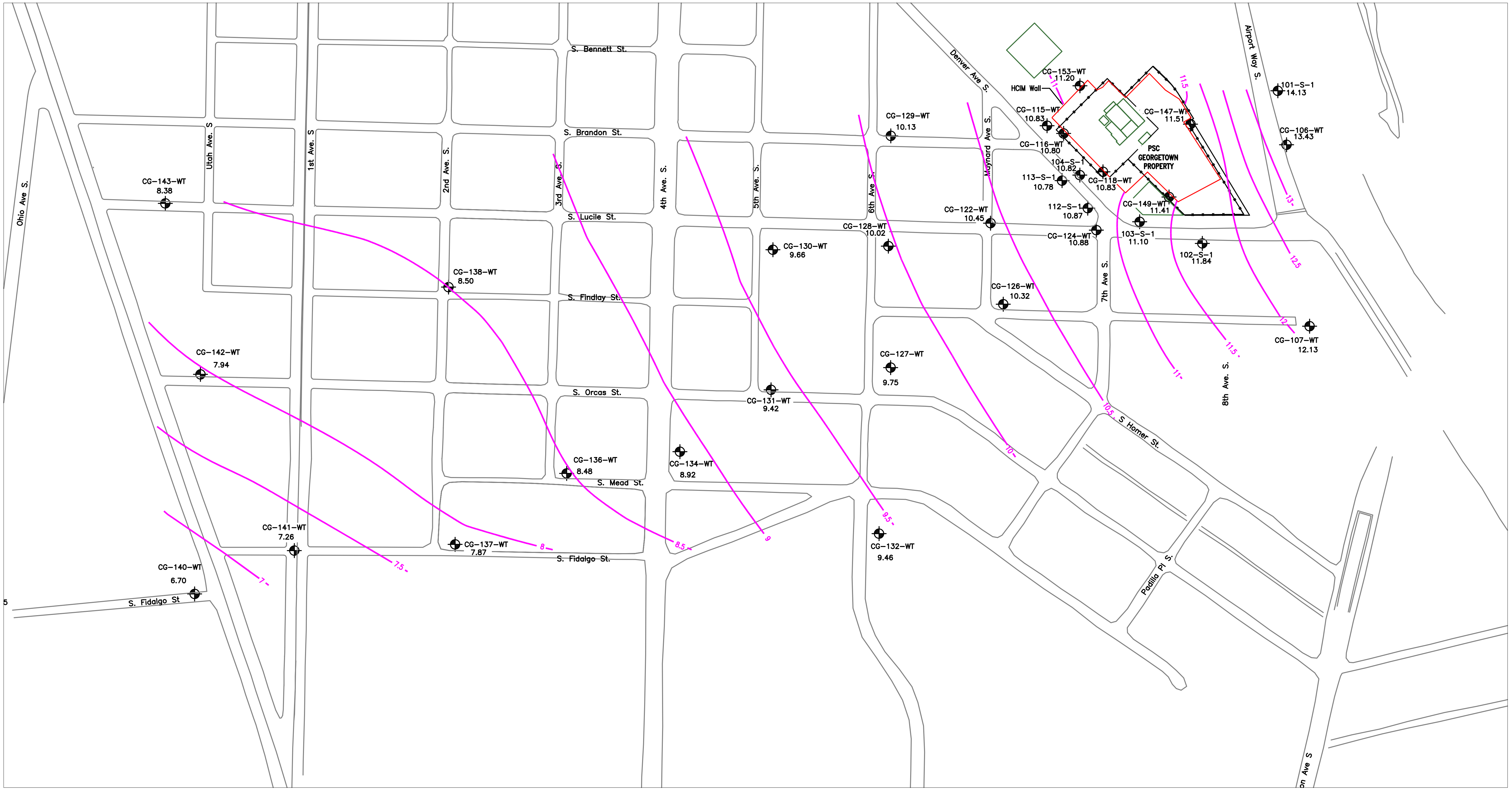

Legend

⊕ Shallow Aquifer Monitoring Well with Water Level (feet)

Water Elevation Contour

Contour Interval = 0.5 (feet)
Vertical Datum is based on NAVD88

N

0 300
APPROXIMATE SCALE (FEET)

GROUNDWATER ELEVATIONS, JANUARY 31, 2005
WATER TABLE SAMPLE INTERVAL

PSC Georgetown
Seattle, Washington

GEOMATRIX

Project No.	Figure
8770	**2-8**

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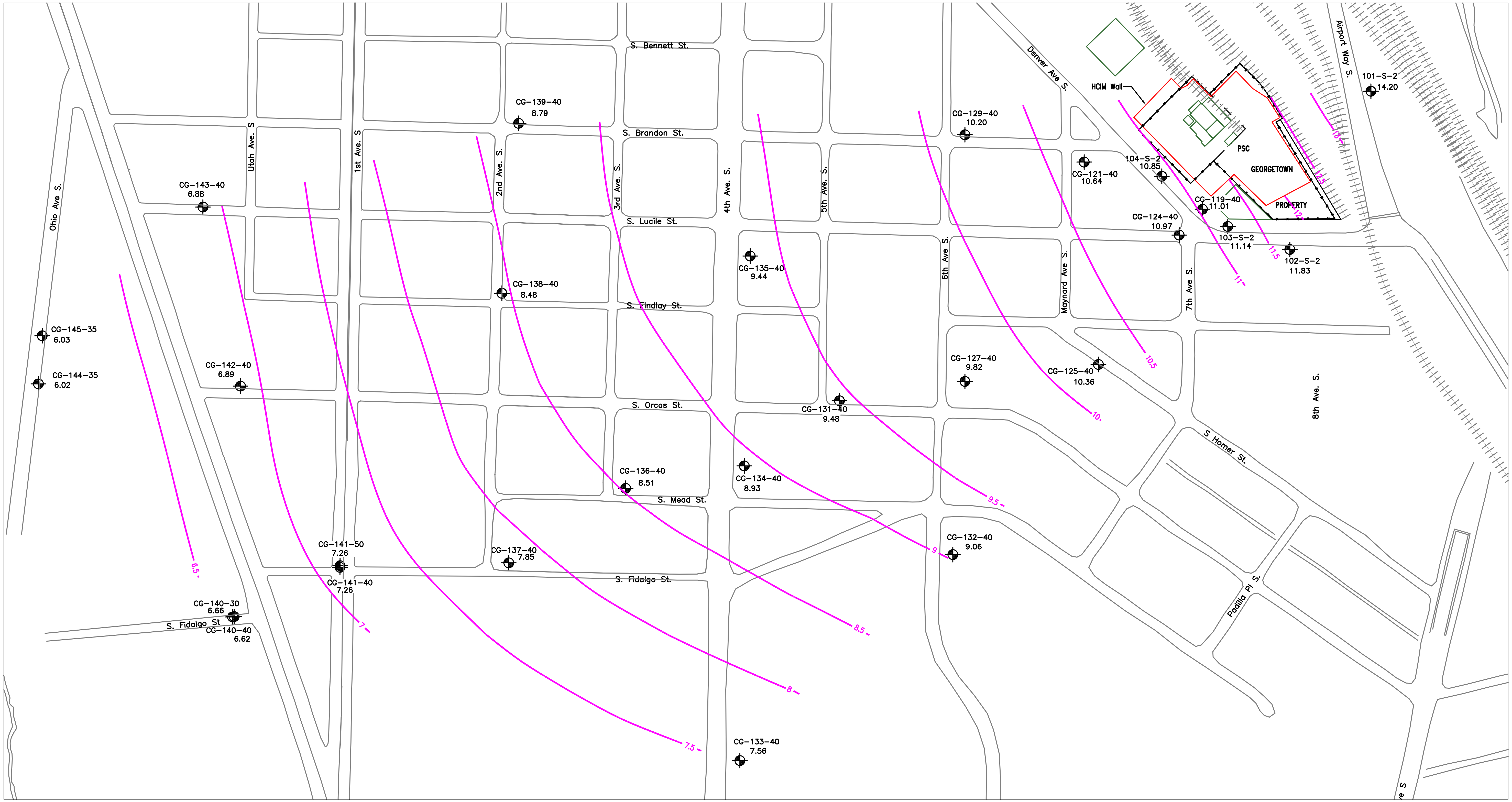
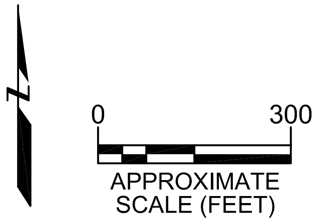


Legend

⊕ Shallow Aquifer Monitoring Well with Water Level (feet)

Water Elevation Contour

Contour Interval = 0.5 (feet)
Vertical Datum is based on NAVD88



GROUNDWATER ELEVATIONS, JANUARY 31, 2005
SHALLOW SAMPLE INTERVAL

PSC Georgetown
Seattle, Washington

GEOMATRIX

Project No.	Figure
8770	2-9

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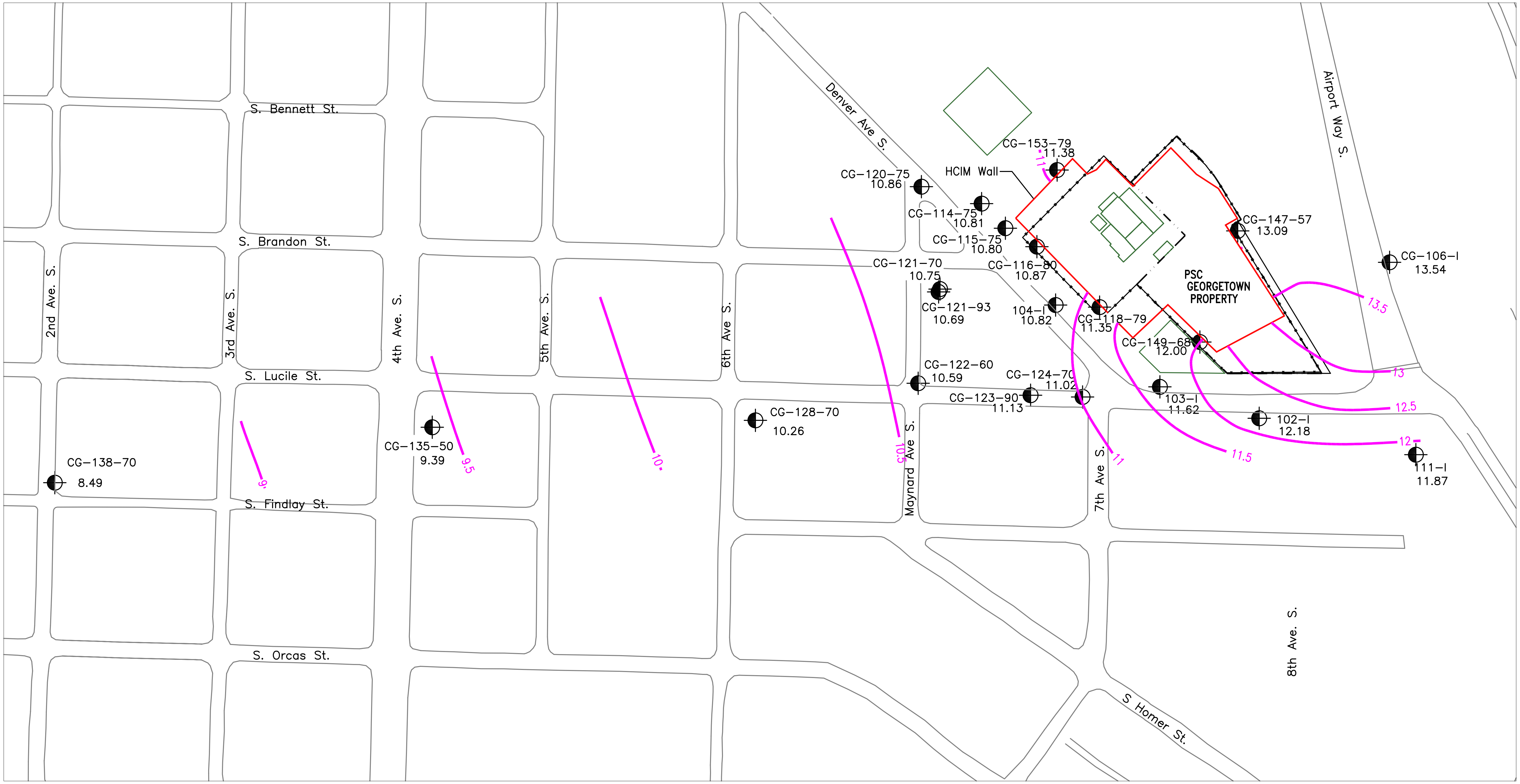

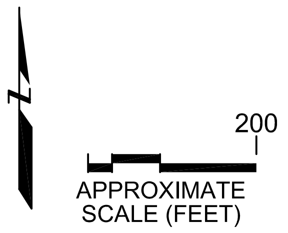

APPROXIMATE SCALE (FEET)

Legend

⊕	Intermediate Aquifer Monitoring Well with Water Level (feet)
〰	Water Elevation Contour

Contour Interval = 0.5 (feet)
Vertical Datum is based on NAVD88

GROUNDWATER ELEVATIONS, JANUARY 31, 2005
INTERMEDIATE SAMPLE INTERVAL
PSC Georgetown
Seattle, Washington

GEOMATRIX

Project No.
8770

Figure
2-10

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3.0 CLEANUP LEVELS

Cleanup levels, as defined in the MTCA regulations, are media-specific criteria determined by Ecology to be protective of human health and the environment under specified exposure conditions, and must be achieved at the SPOC or CPOC within an acceptable timeframe. For the area addressed by this SWFS, the cleanup levels must be protective of the pathways described in the conceptual site model (CSM).

Cleanup levels protective of consumers of fish from surface water must be achieved at the point at which groundwater discharges to the Duwamish Waterway. Cleanup levels protective of indoor air must be achieved at the point of vapor intrusion, i.e., in soil gas and groundwater beneath buildings within the Site. Remedial measures must be capable of achieving these cleanup levels at these points. The cleanup levels must also be achieved within an acceptable time frame. Since under MTCA the POC cannot (practically speaking) be located at the actual locations of vapor intrusion or groundwater discharge to the Duwamish Waterway, remediation levels will need to be established that are protective of the two exposure pathways related to groundwater. The cleanup standard consists of the cleanup levels and the location or POC where the cleanup levels must be attained.

The RI Report identified cleanup levels that are protective of human health and the environment based on the groundwater to surface water pathway and the inhalation pathway. These cleanup levels are described in the following sections and are used for this SWFS. However, the cleanup levels developed in the RI Report have also been refined in this SWFS to include consideration of area background levels discussed in the RI Report and laboratory practical quantitation levels (PQLs).

3.1 SOIL CLEANUP LEVELS

Soil cleanup levels calculated during the RI are included in Table 3-1. Final RI cleanup levels for soil were calculated based on a Commercial Worker Exposure Scenario (i.e., MTCA Method C) for the following exposure pathways:

- Dermal Contact with Soil (745-4 and 745-5),
- Incidental Soil Ingestion (745-1 and 745-2),
- Inhalation of Particulates (750-1 and 750-2), and
- Inhalation of Indoor Air (750-1 and 750-2).

A cancer risk goal of 10^{-6} and a hazard quotient of 0.1 were used to develop the Final RI cleanup levels. The Final RI cleanup levels were adjusted downward so that the "Minimum Commercial Final RI Cleanup Level" for each COC would not result in a cancer risk greater than 1×10^{-6} or a hazard index of 0.1 when the risks are totaled for the COC for all exposure pathways.

MTCA considers potential risks from affected soils based on soil depth. For soil samples collected less than or equal to 15 feet bgs, the Final RI cleanup level for each COC was selected by choosing the minimum of the following MTCA cleanup levels:

- Minimum Commercial Cleanup Level;
- MTCA Method A Table Values for Industrial Purposes (Table 745-1);
- Soil to Groundwater Cleanup Levels (WAC 173-340-747 (4)); and
- Soil to Surface Water Cleanup Levels (WAC 173-340-747 (4)).

For soil samples collected greater than 15 feet bgs, the Final RI cleanup level for each COC was selected by choosing the minimum of the following MTCA cleanup levels:

- MTCA Method A Table Values for Industrial Purposes (Table 745-1);
- Soil to Groundwater Cleanup Levels (WAC 173-340-747 (4)); and
- Soil to Surface Water Cleanup Levels (WAC 173-340-747 (4)).

However, for SWFS Area, soil depths below 15 feet bgs are all below the water table and addressed as a groundwater issue. Soil to groundwater and soil to surface water Final RI cleanup levels were calculated using the minimum Final RI cleanup levels for groundwater and surface water using WAC 173-340-747 (4), fixed parameter three-phase partitioning model. MTCA Equation 747-1 default input parameters were used to calculate the soil to groundwater concentrations except for the dry soil bulk density, which was set at 1.32 kilograms per liter (kg/L), based on site-specific geotechnical data.

The interim measure work already conducted within the SWFS Area will also be accounted for in this SWFS since it impacts the potential exposure pathways. This SWFS addresses two separate and distinct areas within the SWFS Area: (1) the HCIM Area and (2) the Outside Area. The HCIM (barrier wall, groundwater pump and treat, and the cap) addresses all the pathways within the HCIM Area; therefore, the primary concern is to address soil and groundwater outside of the barrier wall.

The HCIM barrier wall, combined with the groundwater withdrawal system to induce an inward gradient, prevents contaminants present in groundwater within the barrier wall from migrating to downgradient portions of the SWFS Area. This area is contained and the HCIM addresses most off-site risks posed by groundwater contamination. The soil to surface water (via groundwater) pathway is not complete. This area is also completely industrial and will continue to be used so in the future. Therefore, the Final RI Soil cleanup levels that were based on the soil to groundwater/surface water pathway or residential levels apply to the HCIM area but are being addressed by the HCIM through control of the groundwater to surface water pathway. The Final RI Soil cleanup levels also apply to all areas evaluated in this SWFS outside of the barrier wall (i.e., the Outside Area).

3.2 GROUNDWATER CLEANUP LEVELS

Groundwater cleanup levels applied in the SWFS are based on groundwater cleanup levels calculated during the RI and adjusted for background concentrations and PQLs, as appropriate. Final RI Groundwater cleanup levels were calculated based on a Residential Exposure Scenario (i.e., MTCA Method B) for the inhalation of indoor air (750-1 and 750-2) exposure pathway. Final RI groundwater cleanup levels protective of the groundwater to surface water pathway were calculated based on an Asian Pacific Islander (API) Exposure Scenario (i.e., Modified MTCA Method B) for the Consumption of Fish (Modified 730-1 and Modified 730-2) exposure pathway. A cancer risk goal of 10^{-6} and a hazard quotient of 0.1 were used to develop the Final RI cleanup levels. The Final RI cleanup levels were adjusted downward so that the "Minimum Commercial Final RI Cleanup Level" for each COC would not result in a total cancer risk greater than 10^{-6} or a hazard index of 0.1 when the risks are totaled for the COC for all exposure pathways for each receptor (i.e., the Resident or the API Fisher).

For monitoring wells and direct push samples where the bottom of the screen interval is less than or equal to 20 feet bgs, the Final RI cleanup level for each COC was selected by choosing the minimum of the following MTCA cleanup levels:

- Residential Exposure Scenario;
- API Fisher Exposure Scenario;

- Ambient Water Quality Criteria (AWQC), based on Human Health Consumption of Organisms only;
- Ecological Risk Assessment Surface Water Screening Levels;
- AWQC Freshwater and Marine Criteria Maximum Concentration, Criteria Continuous Concentration, and Organoleptic Effects;
- State of Washington Freshwater and Marine Acute and Chronic effects (WAC 173-201A); and
- MTCA Method A cleanup levels (WAC 173-340 - Table 720-1).

For monitoring wells and direct push samples where the bottom of the screen interval is greater than 20 feet bgs, the Final RI cleanup level for each COC was selected by choosing the minimum of the following MTCA cleanup levels:

- API Fisher Exposure Scenario;
- AWQC based on Human Health Consumption of Organisms only;
- Ecological Risk Assessment Surface Water Screening Levels;
- AWQC Freshwater and Marine Criteria Maximum Concentration, Criteria Continuous Concentration, and Organoleptic Effects;
- State of Washington Freshwater and Marine Acute and Chronic effects (WAC 173-201A); and
- MTCA Method A cleanup levels (WAC 173-340 - Table 720-1).

Groundwater cleanup levels for the water table and shallow zones, the intermediate zone, and the deep zone are shown on Tables 3-2 through 3-4. Cleanup levels presented on these tables are limited to constituents detected in groundwater since February 2004, after the HCIM was installed. The final cleanup levels for use in the SWFS have been revised upward for certain metals and semi-volatile organic compounds (SVOCs) to account for the lab-established PQLs and area background concentrations calculated in the RI Report.

3.2.1 HCIM Area Groundwater Cleanup Levels

The barrier wall surrounding the HCIM Area, combined with the groundwater withdrawal system to induce an inward gradient, prevents contaminants present in groundwater from migrating to the Outside Area. Since the HCIM Area is contained and the HCIM addresses the most risks posed by groundwater contamination, the groundwater to surface water pathway is not complete. This area is also completely industrial and will continue to be so in the future. Therefore, the RI cleanup levels that were based on the groundwater to surface water or residential levels will not be met inside the barrier wall, although the HCIM has addressed the pathways to receptors

3.2.2 Outside Area Groundwater Cleanup Levels

The Final RI cleanup levels, as originally established in the RI Report and modified as described above, apply to all areas evaluated in this SWFS in the Outside Area. The IPIM currently addresses the indoor air inhalation pathway in the Outside Area downgradient of the barrier wall. As long as the inhalation pathway is being addressed by the IPIMs, the only remaining pathway to address is the groundwater to surface water pathway.

3.3 REMEDIATION LEVELS

The MTCA regulations [WAC 173-340-720(8)(e)(ii)] state that when monitoring is performed upgradient of a point of discharge to surface water, Ecology should consider an estimate of the natural attenuation that occurs between the monitoring wells and the surface water in assessing compliance with the cleanup levels. Since the Facility is located well upgradient of the Duwamish Waterway, it is expected that substantial attenuation will occur prior to discharge to the waterway. The magnitude of this attenuation will be estimated downgradient of the monitoring wells, and that this estimated attenuation may used to establish remediation cleanup levels for some alternatives considered in this SWFS. Remediation levels used in the SWFS will be established in accordance with the requirements of WAC 173-340-355.

The remediation levels used in this SWFS are groundwater concentrations that would be attained at a specified monitoring location upgradient from the Duwamish Waterway by implementation of a remedial alternative. The remediation levels were established to consider natural attenuation of groundwater constituents downgradient from the monitoring location so that cleanup levels would be attained prior to discharge to the Duwamish Waterway (assuming no other constituent source is present between the monitoring point for the remediation level and the waterway). As described generally in WAC 173-340-420 (8) (e), Ecology should allow for attenuation of groundwater constituents downgradient of the monitoring location and prior to discharge of the groundwater to the Duwamish Waterway. Fate and transport modeling were used to estimate attenuation and support establishment of the remediation levels and the monitoring locations. Conservative modeling parameters were used to estimate levels protective of the Duwamish Waterway.

PSC and Ecology have completed extensive assessments of groundwater flow within the SWFS Area, and have evaluated the results of fate and transport modeling to assess natural attenuation of groundwater constituents. This work has established a common understanding of groundwater flow paths, groundwater chemistry, and expected rates of natural attenuation. The parameters that were used to estimate attenuation downgradient from the monitoring locations and establish remediation levels were generally consistent with this common understanding. Values for these parameters, including degradation half lives, are presented in Appendix A. Groundwater velocities were based on hydraulic conductivity and gradient values for the shallow sand unit measured during investigations near the Facility. These investigations indicate that estimated groundwater velocities in the shallow sand unit are about 30 times higher than estimated velocities in the finer-grained intermediate sand and silt unit (as opposed to the intermediate sample interval). West of SWFS Area, in the vicinity of East Marginal Way South, the intermediate sand and silt unit is less distinct from the shallow hydrogeologic unit, although it is still generally siltier than shallower soils.

An evaluation was performed as part of the fate and transport modeling for each remedial alternative to assess whether implementation of remedial measures would alter conditions for biodegradation downgradient of proposed monitoring locations. For each alternative, any potential effects on biodegradation conditions are not expected to extend significantly past the proposed monitoring locations along Denver Avenue South and S. Lucile Street. As such, attenuation processes occurring downgradient from the monitoring locations would be the same for all alternatives. In general, the modeling parameters agreed upon from prior modeling were used for modeling in areas not directly influenced by implementation of the remediation technologies included in the alternatives developed for this SWFS.

Based on the fate and transport modeling presented in Appendix B, remediation levels applied at Denver Avenue South that are predicted to be protective of the Duwamish Waterway for groundwater are as follows:

- Trichloroethene (TCE) – 40 micrograms per liter (μg/L)
- Vinyl chloride (VC) – 1,000 μg/L
- 1,4 Dioxane – 100 μg/L

The modeling results indicate that groundwater COC concentrations that were released from the Facility and are either at or below these concentrations at Denver Avenue South would attenuate to attain cleanup levels protective of surface water prior to reaching the Duwamish Waterway. Current groundwater monitoring data indicate that groundwater along this monitoring location meet these remediation levels. No other remediation levels were established for this SWFS. It should be noted that since the remediation levels are currently being met at the proposed Condition Point of Compliance, the groundwater migration from the Facility is under control.

Since remediation levels protective of the groundwater to surface water pathway are currently being met, the other potential exposure pathway in the Outside Area is the groundwater to vapor pathway (inhalation pathway). The IPIMs are currently addressing the inhalation pathway within the SWFS Area; therefore, releases from the Facility are currently all being controlled and there is no risk to human health or the environment.

TABLE 3-1

SOIL CLEANUP LEVELS

PSC Georgetown
Seattle, Washington

Cas_No	COPC	Datagroup	Final RI CULs[1] (mg/kg)	Final RI CULs[1] Basis	Puget Sound Ecology Background Levels (mg/kg)	FS CULs (mg/kg)
7440-38-2	Arsenic	Inorganic	0.030	Minimum Soil to SW CUL	7.3	7.3
7440-39-3	Barium	Inorganic	3.3	Minimum Soil to SW CUL	--	3.3
7440-47-3	Chromium	Inorganic	200	Minimum Soil to SW CUL	48.2	200
7440-50-8	Copper	Inorganic	1.4	Minimum Soil to SW CUL	36.4	36.4
57-12-5	Cyanide	Inorganic	0.0045	Minimum Soil to SW CUL	--	0.0045
7439-92-1	Lead	Inorganic	500	Minimum Soil to SW CUL	16.8	500
7439-97-6	Mercury	Inorganic	2.0	MTCA Method A Industrial CUL	0.07	2
7440-02-0	Nickel	Inorganic	10.7	Minimum Soil to SW CUL	38.2	38.2
7440-22-4	Silver	Inorganic	0.32	Minimum Soil to SW CUL	--	0.32
7440-66-6	Zinc	Inorganic	101	Minimum Soil to SW CUL	85.1	101
1336-36-3	Aroclor 1016/1242	PCB	1.56	Minimum Commercial CUL	--	1.56
11097-69-1	Aroclor 1254	PCB	1.56	Minimum Commercial CUL	--	1.56
11096-82-5	Aroclor 1260	PCB	1.56	Minimum Commercial CUL	--	1.56
105-67-9	2,4-Dimethylphenol	Semi-Volatile	0.25	Minimum Soil to SW CUL	--	0.25
95-48-7	2-Methylphenol	Semi-Volatile	0.083	Minimum Soil to SW CUL	--	0.083
106-44-5	4-Methylphenol	Semi-Volatile	1.4	Minimum Soil to SW CUL	--	1.42
67-64-1	Acetone	Semi-Volatile	70,000	Minimum Commercial CUL	--	70,000
56-55-3	Benzo(a)anthracene	Semi-Volatile	0.00008	Minimum Soil to SW CUL	--	0.00008
50-32-8	Benzo(a)pyrene	Semi-Volatile	2.0	MTCA Method A Industrial CUL	--	2
205-99-2	Benzo(b)fluoranthene	Semi-Volatile	0.00008	Minimum Soil to SW CUL	--	0.00008
191-24-2	Benzo(ghi)perylene	Semi-Volatile	--	--	--	--
207-08-9	Benzo(k)fluoranthene	Semi-Volatile	0.00008	Minimum Soil to SW CUL	--	0.00008
65-85-0	Benzoic acid	Semi-Volatile	0.19	Minimum Soil to SW CUL	--	0.19
117-81-7	Bis(2-ethylhexyl) phthalate	Semi-Volatile	554	Minimum Soil to SW CUL	--	554
218-01-9	Chrysene	Semi-Volatile	0.00008	Minimum Soil to SW CUL	--	0.00008
53-70-3	Dibenzo(a,h)anthracene	Semi-Volatile	0.00008	Minimum Soil to SW CUL	--	0.00008
193-39-5	Indeno(1,2,3-cd)pyrene	Semi-Volatile	0.00008	Minimum Soil to SW CUL	--	0.00008
87-86-5	Pentachlorophenol	Semi-Volatile	0.041	Minimum Soil to SW CUL	--	0.041
108-95-2	Phenol	Semi-Volatile	0.60	Minimum Soil to SW CUL	--	0.60
71-55-6	1,1,1-Trichloroethane	Volatile	0.091	Minimum Soil to SW CUL	--	0.091
75-34-3	1,1-Dichloroethane	Volatile	0.14	Minimum Commercial CUL	--	0.14
75-35-4	1,1-Dichloroethylene	Volatile	0.017	Minimum Commercial CUL	--	0.017
95-50-1	1,2-Dichlorobenzene	Volatile	0.24	Minimum Soil to SW CUL	--	0.24
107-06-2	1,2-Dichloroethane	Volatile	0.0060	Minimum Commercial CUL	--	0.0060
591-78-6	2-Hexanone	Volatile	0.50	Minimum Soil to SW CUL	--	0.50
91-57-6	2-methylnaphthalene	Volatile	0.13	Minimum Soil to SW CUL	--	0.13
71-43-2	Benzene	Volatile	0.010	Minimum Commercial CUL	--	0.010
67-66-3	Chloroform	Volatile	0.0013	Minimum Commercial CUL	--	0.0013
156-59-2	cis-1,2-Dichloroethylene	Volatile	0.0099	Minimum Commercial CUL	--	0.0099
98-82-8	Cumene	Volatile	0.015	Minimum Commercial CUL	--	0.015
132-64-9	Dibenzofuran	Volatile	--	--	--	--
100-41-4	Ethylbenzene	Volatile	0.091	Minimum Soil to SW CUL	--	0.091
108-10-1	Methyl Isobutyl Ketone	Volatile	0.81	Minimum Soil to SW CUL	--	0.81
75-09-2	Methylene chloride	Volatile	0.020	MTCA Method A Industrial CUL	--	0.02
91-20-3	Naphthalene	Volatile	0.26	Minimum Commercial CUL	--	0.26
85-01-8	Phenanthrene	Volatile	--	--	--	--
100-42-5	Styrene	Volatile	0.0014	Minimum Soil to SW CUL	--	0.0014
127-18-4	Tetrachloroethylene	Volatile	0.0019	Minimum Soil to SW CUL	--	0.0019

TABLE 3-1

SOIL CLEANUP LEVELS

PSC Georgetown
Seattle, Washington

Cas_No	COPC	Datagroup	Final RI CULs[1] (mg/kg)	Final RI CULs[1] Basis	Puget Sound Ecology Background Levels (mg/kg)	FS CULs (mg/kg)
108-88-3	Toluene	Volatile	0.086	Minimum Soil to SW CUL	--	0.086
156-60-5	trans-1,2-Dichloroethylene	Volatile	0.0097	Minimum Commercial CUL	--	0.0097
79-01-6	Trichloroethylene	Volatile	0.00062	Minimum Commercial CUL	--	0.00062
75-01-4	Vinyl chloride	Volatile	0.0012	Minimum Commercial CUL	--	0.0012
108-38-3, 1	Xylenes (Total)	Volatile	0.18	Minimum Commercial CUL	--	0.18
95-63-6	1,2,4-Trimethylbenzene	Volatile/Semi-Volatile	0.15	Minimum Commercial CUL	--	0.15
108-67-8	1,3,5-Trimethylbenzene	Volatile/Semi-Volatile	0.024	Minimum Commercial CUL	--	0.024
99-87-6	p-Isopropyltoluene	Volatile/Semi-Volatile	6.5	Minimum Soil to GW CUL	--	6.5
103-65-1	Propylbenzene	Volatile/Semi-Volatile	0.22	Minimum Commercial CUL	--	0.22
135-98-8	sec-Butylbenzene	Volatile/Semi-Volatile	0.15	Minimum Commercial CUL	--	0.15

Notes:

1. Final RI CULs - Applicable to Soil <= 15 feet bgs: Based on the Minimum of the Commercial Soil, Soil to Groundwater/Surface Water, and MTCA Method A Soil CULs. Cumulative COPC Cancer Risk Goal = 1E-06 and Hazard Index Goal = 0.1
2. -- = No value was available.
3. CR = Cancer Risk
4. CUL = Cleanup Level
5. Eco = Ecological
6. GW = Groundwater
7. HQ = Hazard Quotient
8. MTCA = Model Toxics Control Act (WAC 173-340)
9. No IAVF = No indoor air volatilization factor was available to calculate the cleanup level
10. No RfD = No Reference Dose was available to calculate the cleanup level
11. No SF = No Slope Factor was available to calculate the cleanup level
12. Not a GW COPC = Not a groundwater COPC
13. No GW CUL = No groundwater cleanup level was calculated for this COPC
14. Not a SW COPC = Not a surface water COPC
15. PAHs = Polycylic Aromatic Hydrocarbons
16. PCBs = Polychlorinated Biphenyls
17. Final RI CULs = These are the most stringent applicable CULs and are the initial CULs that will be considered in the Feasibility Study (FS). As such, they may be adjusted upward or downward based on area background concentrations, practical quantitation limits, or other information, as appropriate, in the FS.
18. RA = Risk Assessment
19. RI = Remedial Investigation
20. SW = Surface Water

TABLE 3-2

GROUNDWATER CLEANUP LEVELS - WATER TABLE AND SHALLOW

PSC Georgetown
Seattle, Washington

			Final RI CULs[1]				
Cas_No	**COPC**	**Datagroup**	**(ug/L)**	**Basis**	**Area Backgound Levels for Water Table and Shallow Aquifers (mg/L)**	**Practical Quantitation Limits (mg/L)**	**Final Cleanup Level (mg/L)**
7440-38-2	Arsenic	Inorganic	0.051	API Fisher	1.98	0.5	1.98
7440-39-3	Barium	Inorganic	4	Ecological RA: ORNL	9.75	0.05	9.75
7440-50-8	Copper	Inorganic	3.1	Ecological RA: State AWQC	1.63	0.1	3.1
57-12-5	Cyanide	Inorganic	1	Ecological RA: State AWQC	7.08	3	7.08
18540-29-9	Hexavalent Chromium	Inorganic	10	Ecological RA: State AWQC	5	0.02	10
7439-89-6	Iron	Inorganic	1000	AWQC Ecological	394	4	1000
7439-92-1	Lead	Inorganic	2.5	Ecological RA: State AWQC	1.13	0.02	2.5
7439-96-5w	Manganese	Inorganic	100	AWQC Human Health Consumption Organism Only	151		151
7440-02-0	Nickel	Inorganic	8.2	Ecological RA: State AWQC	1.95	0.2	8.2
12674-11-2	Aroclor 1016	PCB	6.4E-05	AWQC Human Health Consumption Organism Only	--	0.005	0.005
106-46-7	1,4-Dichlorobenzene	Semi-Volatile	2.5	API Fisher	--	0.12	2.5
123-91-1	1,4-Dioxane	Semi-Volatile	94.9	API Fisher	--	0.47	94.9
105-67-9	2,4-Dimethylphenol	Semi-Volatile	28.5	API Fisher	--	0.32	28.5
95-48-7	2-Methylphenol	Semi-Volatile	13	Ecological RA: ORNL	--	0.06	13
56-55-3	Benzo(a)anthracene	Semi-Volatile	0.018	AWQC Human Health Consumption Organism Only	--	0.591	0.591
205-99-2	Benzo(b)fluoranthene	Semi-Volatile	0.018	AWQC Human Health Consumption Organism Only	--	0.584	0.584
207-08-9	Benzo(k)fluoranthene	Semi-Volatile	0.018	AWQC Human Health Consumption Organism Only	--	0.872	0.872
117-81-7	Bis(2-ethylhexyl) Phthalate	Semi-Volatile	1.83	API Fisher	--	0.27	1.83
Gis-c10-are	C10-c12 (eph) Aromatics	Semi-Volatile	528	Residential GW to Air	--	0.05	528
Gis-c8-are	C8-c10 (eph) Aromatics	Semi-Volatile	120	Residential GW to Air	--	0.08	120
Gis-c8-arv	C8-c10 (vph) Aromatics	Semi-Volatile	120	Residential GW to Air	--	50	120
218-01-9	Chrysene	Semi-Volatile	0.018	AWQC Human Health Consumption Organism Only	--	0.0029	0.018
53-70-3	Dibenzo(a,h)anthracene	Semi-Volatile	0.018	AWQC Human Health Consumption Organism Only	--	0.0018	0.018
193-39-5	Indeno(1,2,3-cd)pyrene	Semi-Volatile	0.018	AWQC Human Health Consumption Organism Only	--	0.0016	0.018
1319-77-3	Methylphenol	Semi-Volatile	1650	Ecological RA: AQUIRE	--	0.478	1650
87-86-5	Pentachlorophenol	Semi-Volatile	2.53	API Fisher	--	0.029	2.53
Gis-teph	Totalextractablepetroleum Hc	Semi-Volatile	--	--	--	0.08	--
Gis-tvph	Totalvolatilepetroleum Hc	Semi-Volatile	--	--	--	50	--
108-90-7	Chlorobenzene	Voaltile	51.9	Residential GW to Air	--	0.14	51.9
71-55-6	1,1,1-Trichloroethane	Volatile	11	Ecological RA: ORNL	--	0.12	11
76-13-1	1,1,2-Trichlorotrifluoroethane	Volatile	1209	Residential GW to Air	--	0.14	1209
75-34-3	1,1-Dichloroethane	Volatile	47	Ecological RA: ORNL	--	0.11	47
75-35-4	1,1-Dichloroethylene	Volatile	3.2	AWQC Human Health Consumption Organism Only	--	0.0047	3.2
95-50-1	1,2-Dichlorobenzene	Volatile	14	Ecological RA: ORNL	--	0.12	14
107-06-2	1,2-Dichloroethane	Volatile	12.9	Residential GW to Air	--	0.0045	12.9
90-12-0	1-Methyl naphthalene	Volatile	2.1	Ecological RA: ORNL	--	1	2.1
71-43-2	Benzene	Volatile	9.6	Residential GW to Air	--	0.14	9.6
75-00-3	Chloroethane	Volatile	461	API Fisher	--	0.23	461
67-66-3	Chloroform	Volatile	4.1	Residential GW to Air	--	0.14	4.1
156-59-2	cis-1,2-Dichloroethylene	Volatile	72.7	Residential GW to Air	--	0.12	72.7
74-84-0	Ethane	Volatile	--	--	--	0.35	--
74-85-1	Ethene	Volatile	--	--	--	0.55	--
100-41-4	Ethylbenzene	Volatile	7.3	Ecological RA: ORNL	--	0.13	7.3

TABLE 3-2

GROUNDWATER CLEANUP LEVELS - WATER TABLE AND SHALLOW

PSC Georgetown
Seattle, Washington

			Final RI CULs[1]				
Cas_No	**COPC**	**Datagroup**	**(ug/L)**	**Basis**	**Area Backgound Levels for Water Table and Shallow Aquifers (mg/L)**	**Practical Quantitation Limits (mg/L)**	**Final Cleanup Level (mg/L)**
74-82-8	Methane	Volatile	--	--	--	0.3	--
75-09-2	Methylene Chloride	Volatile	321	Residential GW to Air	--	0.2	321
91-20-3	Naphthalene	Volatile	12	Ecological RA: ORNL	--	0.29	12
110-54-3	n-Hexane	Volatile	0.45	Residential GW to Air	--	0.18	0.45
127-18-4	Tetrachloroethylene	Volatile	0.20	API Fisher	--	0.13	0.20
108-88-3	Toluene	Volatile	9.8	Ecological RA: ORNL	--	0.11	9.8
156-60-5	trans-1,2-Dichloroethylene	Volatile	65.3	Residential GW to Air	--	0.15	65.3
79-01-6	Trichloroethylene	Volatile	0.40	Residential GW to Air	--	0.14	0.40
75-01-4	Vinyl Chloride	Volatile	1.28	Residential GW to Air	--	0.0081	1.28
108-38-3, 1	Xylene (total)	Volatile	141	API Fisher	--	0.22	141
95-63-6	1,2,4-Trimethylbenzene	Volatile/Semi-Volatile	13	Residential GW to Air	--	0.15	13
108-67-8	1,3,5-Trimethylbenzene	Volatile/Semi-Volatile	9.8	Residential GW to Air	--	0.13	9.8
99-87-6	p-Isopropyltoluene	Volatile/Semi-Volatile	75	Residential GW to Air	--	0.13	75
103-65-1	Propylbenzene	Volatile/Semi-Volatile	7.3	Ecological RA: ORNL	--	0.098	7.3
135-98-8	sec-Butylbenzene	Volatile/Semi-Volatile	4.6	API Fisher	--	0.13	4.6

Notes:

1. Final RI CULs - Applicable to the Water Table and Shallow Aquifers: Based on the Minimum of the Residential Vapor Intrusion to Indoor Air, API Fisher, AWQC, Ecological RA, and MTCA Method A GW CULs. Cumulative COPC Cancer Risk Goal = 1E-06 and Hazard In
2. -- = No value was available
3. API Fisher = Asian Pacific Islander Fisherman
4. AQUIRE = U.S. EPA AQUIRE Database - available on-line at http://www.epa.gov/ecotox/
5. AWQC = Federal Ambient Water Quality Criteria (Section 304 of the Clean Water Act)
6. CUL = Cleanup Level
7. GW = Groundwater
8. MTCA = Model Toxics Control Act (WAC 173-340)
9. ORNL = Oak Ridge Nation Laboratory Toxicological Benchmarks for Screening Potential Contaminants of Concern for Effects on Aquatic Biota - http://www.esd.ornl.gov/programs/ecorisk/ecorisk.html and go to screening benchmark reports
10. Final RI CULs = These are the most stringent applicable CULs and are the initial CULs that will be considered in the Feasibility Study (FS). As such, they may be adjusted upward or downward based on area background concentrations, practical quantitation limits, or other information, as appropriate, in the FS.
11. RA = Risk Assessment
12. RI = Remedial Investigation

TABLE 3-3

GROUNDWATER CLEANUP LEVELS - INTERMEDIATE
PSC Georgetown
Seattle, Washington

Cas_No	COPC	Datagroup	Final RI CULs[1]		Area Backgound Levels for Intermediate Aquifer (mg/L)	Practical Quantitation Limits (mg/L)	Final Cleanup Level for Intermediate Aquifer (mg/L)
			(ug/L)	Basis			
7440-38-2	Arsenic	Inorganic	0.051	API Fisher	1.16	0.5	1.16
7440-39-3	Barium	Inorganic	4	Ecological RA: ORNL	30	0.05	30
7440-47-3	Chromium	Inorganic	10	Ecological RA: State AWQC	10.2	0.2	10.2
7440-50-8	Copper	Inorganic	3.1	Ecological RA: State AWQC	6.16	0.1	6.16
57-12-5	Cyanide	Inorganic	1	Ecological RA: State AWQC	9.76	3	9.76
7439-89-6	Iron	Inorganic	1000	AWQC Ecological	6667	4	6667
7440-02-0	Nickel	Inorganic	8.2	Ecological RA: State AWQC	3.11	0.2	8.2
7440-62-2	Vanadium	Inorganic	20	Ecological RA: ORNL	15.3	0.03	20
7440-66-6	Zinc	Inorganic	81	Ecological RA: State AWQC	52	0.5	81
123-91-1	1,4-Dioxane	Semi-Volatile	94.9	API Fisher	--	0.47	94.9
56-55-3	Benzo(a)anthracene	Semi-Volatile	0.018	AWQC Human Health Consumption Organism Only	--	0.591	0.591
205-99-2	Benzo(b)fluoranthene	Semi-Volatile	0.018	AWQC Human Health Consumption Organism Only	--	0.584	0.584
207-08-9	Benzo(k)fluoranthene	Semi-Volatile	0.018	AWQC Human Health Consumption Organism Only	--	0.872	0.872
117-81-7	Bis(2-ethylhexyl) Phthalate	Semi-Volatile	1.83	API Fisher	--	0.27	1.83
218-01-9	Chrysene	Semi-Volatile	0.018	AWQC Human Health Consumption Organism Only	--	0.0029	0.018
53-70-3	Dibenzo(a,h)anthracene	Semi-Volatile	0.018	AWQC Human Health Consumption Organism Only	--	0.0018	0.018
193-39-5	Indeno(1,2,3-cd)pyrene	Semi-Volatile	0.018	AWQC Human Health Consumption Organism Only	--	0.0016	0.018
87-86-5	Pentachlorophenol	Semi-Volatile	2.53	API Fisher	--	0.029	2.53
75-34-3	1,1-Dichloroethane	Volatile	47	Ecological RA: ORNL	--	0.11	47
75-35-4	1,1-Dichloroethylene	Volatile	3.2	AWQC Human Health Consumption Organism Only	--	0.0047	3.2
107-06-2	1,2-Dichloroethane	Volatile	30.6	API Fisher	--	0.0045	30.6
71-43-2	Benzene	Volatile	11.7	API Fisher	--	0.14	11.7
75-00-3	Chloroethane	Volatile	461	API Fisher	--	0.23	461
156-59-2	cis-1,2-Dichloroethylene	Volatile	165	API Fisher	--	0.12	165
74-84-0	Ethane	Volatile	--	--	--	0.35	--
74-85-1	Ethene	Volatile	--	--	--	0.55	--
100-41-4	Ethylbenzene	Volatile	7.3	Ecological RA: ORNL	--	0.13	7.3
74-82-8	Methane	Volatile	--	--	--	0.3	--
75-09-2	Methylene Chloride	Volatile	495	API Fisher	--	0.2	495

TABLE 3-3

GROUNDWATER CLEANUP LEVELS - INTERMEDIATE

PSC Georgetown
Seattle, Washington

Cas_No	COPC	Datagroup	Final RI CULs[1] (ug/L)	Final RI CULs[1] Basis	Area Backgound Levels for Intermediate Aquifer (mg/L)	Practical Quantitation Limits (mg/L)	Final Cleanup Level for Intermediate Aquifer (mg/L)
91-20-3	Naphthalene	Volatile	12	Ecological RA: ORNL	--	0.29	12
108-88-3	Toluene	Volatile	9.8	Ecological RA: ORNL	--	0.11	9.8
156-60-5	trans-1,2-Dichloroethylene	Volatile	1691	API Fisher	--	0.15	1691
79-01-6	Trichloroethylene	Volatile	0.79	API Fisher	--	0.14	0.79
75-01-4	Vinyl Chloride	Volatile	2.04	API Fisher	--	0.0081	2.04
95-63-6	1,2,4-Trimethylbenzene	Volatile/Semi-Volatile	78	API Fisher	--	0.15	78

Notes:

1. Final RI CULs - Applicable to the Intermediate Aquifer: Based on the Minimum of the API Fisher, AWQC, Ecological RA, and MTCA Method A GW CULs. Cumulative COPC Cancer Risk Goal = 1E-06 and Hazard Index Goal = 0.1
2. -- = No value was available
3. API Fisher = Asian Pacific Islander Fisherman
4. AWQC = Federal Ambient Water Quality Criteria (Section 304 of the Clean Water Act)
5. CUL = Cleanup Level
6. GW = Groundwater
7. MTCA = Model Toxics Control Act (WAC 173-340)
8. ORNL = Oak Ridge Nation Laboratory Toxicological Benchmarks for Screening Potential Contaminants of Concern for Effects on Aquatic Biota - http://www.esd.ornl.gov/programs/ecorisk/ecorisk.html and go to screening benchmark reports
9. Final RI CULs = These are the most stringent applicable CULs and are the initial CULs that will be considered in the Feasibility Study (FS). As such, they may be adjusted upward or downward based on area background concentrations, practical quantitation limits, or other information, as appropriate, in the FS.
10. RA = Risk Assessment
11. RI = Remedial Investigation

TABLE 3-4

GROUNDWATER CLEANUP LEVELS - DEEP

PSC Georgetown
Seattle, Washington

Cas_No	Datagroup	Final RI CULs[1]		Area Backgound Levels for Deep Aquifer (mg/L)	Practical Quantitation Limits (mg/L)	Final Cleanup Level for Deep Aquifer (mg/L)
		(ug/L)	Basis			
7440-38-2	Inorganic	0.051	API Fisher	15.6	0.5	15.6
7440-39-3	Inorganic	4	Ecological RA: ORNL	24.5	0.05	24.5
7440-47-3	Inorganic	10	Ecological RA: State AWQC	15.8	0.2	15.8
18540-29-9	Inorganic	10	Ecological RA: State AWQC	55.9	0.02	55.9
7439-89-6	Inorganic	1000	AWQC Ecological	510	4	1000
7440-66-6	Inorganic	81	Ecological RA: State AWQC	52	0.5	81
117-81-7	Semi-Volatile	1.83	API Fisher	--	0.27	1.83
75-15-0	Semi-Volatile	0.92	Ecological RA: ORNL	--	0.16	0.92
107-06-2	Volatile	30.6	API Fisher	--	0.0045	30.6
74-82-8	Volatile	--	--	--	0.3	--
79-01-6	Volatile	0.79	API Fisher	--	0.14	0.79
75-01-4	Volatile	2.04	API Fisher	--	0.0081	2.04

Notes:

1. Final RI CULs - Applicable to the Deep Aquifer: Based on the Minimum of the API Fisher, AWQC, Ecological RA, and MTCA Method A GW CULs. Cumulative COPC Cancer Risk Goal = 1E-06 and Hazard Index Goal = 0.1
2. -- = No value was available
3. API Fisher = Asian Pacific Islander Fisherman
4. AWQC = Federal Ambient Water Quality Criteria (Section 304 of the Clean Water Act)
5. CUL = Cleanup Level
6. GW = Groundwater
7. MTCA = Model Toxics Control Act (WAC 173-340)
8. ORNL = Oak Ridge Nation Laboratory Toxicological Benchmarks for Screening Potential Contaminants of Concern for Effects on Aquatic Biota - http://www.esd.ornl.gov/programs/ecorisk/ecorisk.html and go to screening benchmark reports
9. Final RI CULs = These are the most stringent applicable CULs and are the initial CULs that will be considered in the Feasibility Study (FS). As such, they may be adjusted upward or downward based on area background concentrations, practical quantitation limits, or other information, as appropriate, in the FS.
10. RA = Risk Assessment
11. RI = Remedial Investigation

4.0 NATURE AND EXTENT

PSC has completed extensive characterization of the environmental conditions in soil, groundwater, and the vapor pathway for the SWFS Area. This characterization work has been documented in the RI Report. The nature and extent of soil and groundwater impacted by COCs released from the Facility has been delineated for both soil and groundwater.

4.1 SOIL

Only soil samples collected above 15 feet bgs were evaluated to assess soil contamination for this SWFS. Deeper soil samples are likely to have been impacted by groundwater concentrations, which are evaluated in Section 4.2.

Historically, a number of soil investigations have been conducted within the SWFS Area. Soil samples were collected as part of the RI between 1987 and the present. Most soil samples were collected as part of the RI on the Facility within the area currently enclosed by the HCIM barrier wall. Several test pits and soil samples were collected in 2005 along the east side of the Facility on the UPRR property (Kennedy/Jenks, 2005). Figure 4-1 shows the soil sample locations from the RI. Few soil samples have been collected outside the HCIM barrier wall because the source area is located on the Facility. Therefore, RI investigations focused on the Facility. The most recent proposed investigation, the Off-Site Soil Investigation (PSC, 2005), will collect soil data at off-site locations near the Facility boundary to further evaluate soil contamination to the east and west.

VOCs, SVOCs, metals, and polychlorinated biphenyls (PCBs) have been detected in soil samples collected within the SWFS Area at levels above the RI cleanup levels and Ecology background levels for metals in the Puget Sound region. Figure 4-2 shows the location of soil samples where COC concentrations exceeded cleanup levels. The highest concentrations were generally detected in samples collected in the northern portion of the Facility, within the barrier wall, where USTs were formerly located. In the northern portion of the Facility and in several other locations within the HCIM Area, there are localized areas with high concentrations of COCs that indicate that dense, non-aqueous phase liquids (DNAPLs) may be present in the subsurface. The released solvents and DNAPLs migrated down through the unsaturated soils to the underlying aquifer. While these DNAPLs would pool temporarily and spread out on the capillary fringe and on fine grained soil layers, these liquids eventually migrated vertically through the subsurface, eventually reaching the low permeability silty layers and silt aquitard under the Facility. There has not been any primary documentation that DNAPL is present at the Facility from the various investigations performed on the Facility; only secondary evidence has been found. Therefore, it is likely that the DNAPL exists as widely dispersed fingers of free product over a fairly substantial vertical and horizontal profile. This impacted area is within the HCIM Area and is currently contained and capped.

The vast majority of COC exceedances for soil are found within the HCIM Area. Some soil exceedances are located outside the HCIM Area (in the Outside Area) but most of these are on PSC properties and are contained under the microsilica concrete cap or pavement. The exceptions to this are:

- A few scattered locations under Denver Avenue South (beneath the road pavement) where COCs in soil exceed CLs that do not appear to be related to the Facility. These soil impacts are not considered to be related to the Facility impacts and are not addressed by this SWFS.

- A recent investigation on UPRR property (Kennedy/Jenks 2005) identified COCs that could be related to the Facility. PSC is currently investigating the UPRR property to characterize the nature and extent of the COCs. Since the characterization work was not complete at the time this report was prepared, this SWFS will not be able address these impacts.

4.2 AFFECTED GROUNDWATER

This section presents an overview of the known nature and extent of COC-impacted groundwater detected within the SWFS Area during PSC's environmental investigations. The data suggest that impacted groundwater originated from a source area in the HCIM Area that has been cut off by installation of the barrier wall, thereby minimizing future source contribution to the Outside Area. For this reason, the nature and extent discussions are focused primarily on the Outside Area.

To aid in the evaluation of the nature and extent of COC-impacted groundwater across the SWFS Area, isoconcentration maps from recent quarterly corrective action reports were used for evaluation of cis-1,2-dichloroethene (DCE), trichloroethene (TCE), and VC, the VOCs that are the key indicator COCs for the FS (see Figures 4-3 through 4-11). Isoconcentration maps depict lines of equal concentrations while also considering the direction of groundwater flow. These maps are helpful in evaluating the current conditions in the Outside Area since installation of the HCIM barrier wall was completed in early 2004.

4.2.1 Distribution of Constituents of Concern in Groundwater in the Outside Area

This section presents a general description of the nature and extent of COCs detected in groundwater throughout the SWFS Area, regardless of the source of the COCs. The discussion of the nature and extent of groundwater COCs is presented based on the groundwater cleanup levels presented in Section 3. Groundwater cleanup levels protective of vapor intrusion into indoor air were used to evaluate groundwater concentrations in the water table sample interval. Groundwater cleanup levels protective of exposure of humans and ecological receptors to surface water (WAC 173-340-730), the groundwater to surface water pathway, were used to evaluate groundwater concentrations in all sampling intervals.

Groundwater data collected since installation of the HCIM, beginning in first quarter 2004 and collected quarterly through the second quarter 2005, were reviewed to evaluate COC concentrations in groundwater. COCs identified in the RI, including VOCs, SVOCs, metals, PCBs, and volatile petroleum hydrocarbons (VPH), have been detected above cleanup levels within the SWFS Area since installation of the HCIM. Groundwater wells and associated constituents detected above cleanup levels from first quarter 2004 through second quarter 2005 for the HCIM Area and the water table, shallow, intermediate, and deep zone intervals the Outside Area are included in Tables 4-1 through 4-5, respectively. These tables include the concentration and date of the most recent cleanup level exceedance at each well and the associated exceedance ratio (i.e., the detected concentration divided by the cleanup level). The majority of cleanup level exceedances occurred in the HCIM Area and the area immediately downgradient of the HCIM, to Denver Avenue South. Between Denver Avenue South and Fourth Avenue South COCs include the following:

- VOCs – benzene, ethylbenzene, toluene, total xylenes, naphthalene, TCE, VC, 1,1,1-trichloroethane, 1,1-dichloroethane, 1,1-dichloroethene, cis-1,2-DCE, and tetrachloroethene
- SVOCs – 1,2,4-trimethylbenzene, 1,3,5-trimethylbenzene, 1,4-dioxane, dibenzo(a,h)anthracene, bis(2-ethylhexyl)phthalate (BEHP), chrysene, indeno(1,2,3-cd)pyrene, and C8-C10 (VPH) Aromatics
- Inorganics – arsenic, iron, copper, barium, hexavalent chromium, and cyanide

Other COCs that exceed cleanup levels only within the HCIM Area or between the HCIM Area and Denver Avenue South include chloroethane, n-hexane, n-propylbenzene, sec-butylbenzene, and 1,2-dichlorobenzene. 2-methylphenol, Aroclor 1016, and lead exceed cleanup levels only within the HCIM Area. Chloroform and manganese have also been detected at concentrations above cleanup levels downgradient of Fourth Avenue South, west of the SWFS Area. Chloroform, BEHP, TCE, and iron have also been detected above cleanup levels in one or more monitoring wells along Airport Way South, upgradient of the Facility.

4.2.1.1 Water Table Sample Interval

In the water table sample interval, concentrations of tetrachloroethene (PCE), TCE, VC, and to a lesser extent, cis-1,2-DCE exceeding applicable cleanup levels were detected throughout the HCIM Area and in the Outside Area. As shown on the isoconcentration maps (Figures 4-3, 4-6, and 4-9), the highest concentrations of cis-1,2-DCE, TCE, and VC were not necessarily located closest to the HCIM Area; several of these VOCs were detected at the highest concentration at well CG-131-WT near the intersection of Fifth Avenue South and South Orcas Street.

BEHP was detected above cleanup levels upgradient of the Facility, between the HCIM Area and the east side of Denver Avenue South, and at two locations (CG-128-WT and CG-129-WT) along Sixth Avenue South. BEHP was not detected at concentrations above cleanup levels along Maynard Avenue, between Denver and Sixth Avenues South. Other VOCs and SVOCs (such as 1,1,1-trichloroethane, 1,1-dichloroethane, toluene, ethylbenzene, total xylenes, naphthalene, dibenzo(a,h)anthracene, indeno(1,2,3-cd)pyrene, 1,2,4-trimethylbenzene, 1,3,5-trimethylbenzene, and C8-C10 (VPH) aromatics) were detected above cleanup levels only as far west as the west side of Denver Avenue South. The VOC 1,1-dichloroethene was detected above cleanup levels at two locations along Denver Avenue South and at one location further downgradient (at Fifth Avenue South) but not at intervening locations.

Arsenic concentrations exceeded cleanup levels at several locations downgradient of the HCIM Area. Concentrations decrease to the west and are below calculated background concentrations at Fourth Avenue South. Iron exceeds the cleanup levels along Denver Avenue South. Copper exceeded the cleanup level at one location (CG-127-WT) along Sixth Avenue South.

4.2.1.2 Shallow Sample Interval

In the shallow sample interval, benzene, 1,1-dichloroethane, TCE, and VC were the only VOCs exceeding applicable cleanup levels within the SWFS Area. Isoconcentration maps for cis-1,2-DCE, TCE, and VC are shown in Figures 4-4, 4-7, and 4-10. Of these, benzene exceeded cleanup levels at two locations between Denver Avenue South and Sixth Avenue South, and 1,1-dichloroethane exceeded cleanup levels at only one location, which was between the HCIM Area and Denver Avenue South. TCE exceeded cleanup levels along both sides of Denver

Avenue South. VC exceeded cleanup levels at locations throughout the SWFS Area and to the west of Fourth Avenue South.

SVOCs 1,4-dioxane, dibenzo(a,h)anthracene, BEHP, chrysene, and indeno(1,2,3-cd)pyrene were all detected above cleanup levels in the shallow sample interval. Naphthalene was detected above cleanup levels in one location (CG-137-40) west of Fourth Avenue South. BEHP was detected above cleanup levels at two locations between the HCIM Area and Denver Avenue South, and one other location (CG-134-40) along Fourth Avenue South approximately 1,600 feet downgradient of the Facility. Dibenzo(a,h)anthracene, indeno(1,2,3-cd)pyrene, and chrysene were detected above cleanup levels at one or both of two locations west of Denver Avenue South (CG-132-40 and CG-138-40). These wells are 1,000 feet and 2,100 feet downgradient of the Facility, respectively. Concentrations of 1,4-dioxane in groundwater are not above cleanup levels near the HCIM Area along Denver Avenue South. Concentrations of 1,4-dioxane exceed groundwater cleanup levels between approximately Maynard Avenue and Second Avenue South, where it only slightly exceeds the cleanup level, which is based on protection of surface water.

Inorganics barium, hexavalent chromium, and iron were detected above cleanup levels within the Site. Barium was detected above cleanup levels at one location (CG-127-40) at Sixth Avenue South. Hexavalent chromium was detected above cleanup levels at two locations along Sixth Avenue South (CG-127-40 and CG-129-40). Iron was detected above cleanup levels at two locations along Denver Avenue and at six locations along and west of Sixth Avenue South.

4.2.1.3 Intermediate Sample Interval

In the intermediate sample interval, ethylbenzene, 1,1-dichloroethane, and vinyl chloride are the only VOCs that have been detected above applicable cleanup levels. Isoconcentration maps for cis-1,2-DCE, TCE, and VC are presented in Figures 4-5, 4-8, and 4-10. Ethylbenzene and 1,1-dichloroethane were detected above cleanup levels at one location each, both of which are between Denver Avenue South and the HCIM barrier wall. VC was detected above cleanup levels at six locations between Denver Avenue South and the HCIM barrier wall, and again at three locations (CG-135-50, CG-138-70, and CG-141-50) within and downgradient of the SWFS Area.

SVOCs in the intermediate sample interval were limited to areas near the Facility, with the exceptions of BEHP, which was detected once at CG-123-90, and 1,4-dioxane, which was detected at concentrations slightly above cleanup levels as far west as Second Avenue South.

Inorganics arsenic, cyanide, and iron were detected above cleanup levels. Arsenic was detected at concentrations slightly above cleanup levels based on background concentrations at two locations between Denver and Maynard Avenue South. Cyanide and iron exceedances were also limited to the area between Denver and Maynard Avenues South.

4.2.1.4 Selection of Indicator COCs

As noted above, a number of different COCs were detected in groundwater at concentrations exceeding applicable cleanup levels. The majority of the exceedances were limited to areas in the HCIM Area immediately downgradient of the HCIM barrier wall. Most exceedances were in the water table and shallow sample intervals.

MTCA (WAC 173-340-703) allows cleanup evaluations to select "indicator hazardous substances" for sites that are contaminated with a large number of COCs and eliminate other COCs that "contribute a small percentage of the overall threat to human health and the environment." Due to the large number of COCs present within the SWFS Area groundwater and because detected constituents include volatile, semi-volatile, and inorganic species, the SWFS Area qualifies for use of indicator COCs. To select indicator COCs that are the primary focus of the FS, several factors were considered, including the downgradient extent and persistence of COCs, the number and magnitude of exceedances, and the potential risk to receptors. This evaluation will focus on the Outside Area because constituents present in the HCIM Area are effectively contained and have limited risk potential.

Most COCs near the HCIM Area showed significant decreases in concentration between the east side and the west side of Denver Avenue South, with concentrations on the west side of Denver Avenue South below or approaching cleanup levels in many cases. Relatively few COCs were detected above cleanup levels in areas downgradient from Denver Avenue South, indicating that most constituents are either relatively immobile or are rapidly attenuating as they migrate. The COCs that exceed cleanup levels in the area downgradient of Denver Avenue South include PCE, TCE, VC, 1,1-dichloroethene, benzene, 1,4-dioxane, BEHP, a few scattered exceedances of SVOCs, and various inorganic constituents (arsenic, copper, barium, hexavalent chromium, iron, and cyanide).

Of these constituents, TCE, VC, 1,4-dioxane, and arsenic are the most widespread and exhibit the highest exceedances of their respective cleanup levels. The remaining COCs are either limited to a few scattered location,, have low exceedance ratios, indicating concentrations are close to the cleanup levels; or are associated with the reducing conditions in the groundwater (i.e., iron). COCs with low exceedance ratios are considered to have low risk. Downgradient exceedances of 1,1-dichloroethene, copper, barium, and hexavalent chromium were limited to one or two locations each, with exceedance ratios less than 1.3. Downgradient benzene exceedances were limited to three locations east of Sixth Avenue South, with exceedance ratios ranging from 1.1 to 2.9. COCs with limited distribution are considered to have a lower potential for causing risk than more widely distributed COCs.

BEHP exceedances were scattered at four downgradient locations, a location upgradient of the Facility, and in the deep zone, where no Facility-related impacts have been observed. Based on the scattered nature of these exceedances and elevated upgradient concentrations, BEHP was not included as an indicator COC.

The four downgradient locations with PCE exceedances coincide with much greater TCE exceedances. The potential risk associated with TCE at these locations is much greater, and any efforts to address TCE contamination will also address areas with PCE contamination. As such, PCE was not included as an indicator COC.

Arsenic occurrence appears to be associated with reducing conditions in the water table and intermediate zones that appear to result from the urban hydrogeologic setting and the groundwater. Arsenic concentrations generally decrease downgradient of the areas with the highest organic VOC concentrations as conditions become less reducing. Arsenic concentrations are at background concentrations west of Fourth Avenue South. Arsenic concentrations downgradient from the HCIM Area are expected to decline as the VOC plume is addressed. Due to the limited risk potential and observed natural attenuation, arsenic was not included as an indicator COC.

Based on this evaluation, TCE, VC, and 1,4-dioxane were selected as indicator COCs for the Outside Area. Development and evaluation of remediation technologies and alternatives in the FS are focused on these constituents.

4.3 FATE AND TRANSPORT OF INDICATOR COCS

A number of factors, including chemical-physical properties, local geochemical conditions, local hydrogeological conditions, and potential natural attenuation processes, can influence the migration of groundwater COCs within the Site. The RI Report presents a detailed overview of the potential fate and transport processes. For the indicator COCs, which are the focus of this investigation, the primary fate and transport issue is the natural attenuation of these compounds in groundwater within the SWFS Area. TCE and VC are both subject to biodegradation in natural groundwater conditions. TCE biodegrades most rapidly under anaerobic conditions; whereas VC biodegrades anaerobically via cometabolism with other carbon sources. When other carbon sources or electron donors are not available, VC will biodegrade faster aerobically. 1,4-dioxane is used in chlorinated solvents as a stabilizer because it is not prone to biodegradation. As a result, the primary process of natural attenuation for 1,4-dioxane is simply dispersion. Since both TCE and VC are biodegradable and since both are risk drivers in the SWFS, the understanding of the factors that are important to their biodegradation are pertinent to this SWFS.

The geochemical conditions that could enhance or retard natural biodegradation in groundwater in the water table, shallow, and intermediate sample intervals are described in the following subsections. The description of the geochemical environment is based on the evaluation of the natural attenuation water quality parameters monitored during quarterly groundwater monitoring. These parameters include redox potential, dissolved oxygen, nitrate/nitrite, Fe(III)/Fe(II), Mn(IV)/Mn(II), sulfate/sulfide, carbon dioxide, and methane. Dissolved oxygen levels less than 0.5 mg/L, redox potentials of less than 750 millivolts (mV), and the presence of reduced species such as nitrite, Fe(II), Mn(II), sulfide, and methane indicate an anaerobic or reducing environment (Wiedemeier et al., 1999).

The description of the geochemical environment is based on the evaluation of a number of water quality parameters rather than consideration of a single analysis/measurement. Groundwater geochemistry is complex and the scale on which the reactions occur is different than that on which samples are collected. For example, the redox potential measured for a groundwater sample presents the average or dominant conditions within the well area, although reactions associated with multiple redox potentials may be occurring within microsites within the area sampled.

4.3.1 Water Table Sample Interval

The geochemical data and water quality parameters within the SWFS Area indicate that the water table sample interval is generally a mildly anaerobic environment, with an area of stronger reducing conditions apparently present in the area near the Duwamish Waterway downgradient from the SWFS Area. The stronger reducing conditions are indicated by the presence of reduced iron (Fe(II)), sulfide, and methane and the depletion of nitrate, sulfate, and dissolved oxygen.

4.3.2 Shallow Sample Interval

The geochemical data and water quality parameters in the shallow sample interval indicate that anaerobic conditions exist throughout the SWFS Area, as supported by average redox potential measurements below 100 mV. The other geochemical data that support a reducing environment include the depletion of nitrate and sulfate and production of ferrous iron, sulfide, and methane.

4.3.3 Intermediate Sample Interval

Groundwater geochemical parameters indicate an area of strong reducing conditions in the intermediate sample interval and near the Facility. The concentrations of metabolic byproducts, including methane and carbon dioxide, are similar throughout the SWFS Area, indicating that the reducing conditions detected in the intermediate sample interval are related at least in part to natural conditions in the interval.

4.4 INFLUENCE OF NATURAL ATTENUATION ON PLUME MIGRATION

Although many COCs have been detected at concentrations exceeding cleanup levels in groundwater in the water table, shallow, and intermediate sample intervals at and near the Facility, the concentrations of these COCs are significantly lower toward the west portion of the SWFS Area. The lower downgradient concentrations of biodegradable COCs are attributed to natural attenuation, including biodegradation.

Biodegradation appears to be active for chlorinated ethenes in the water table, shallow, and intermediate sample intervals. Conditions are conducive to the biodegradation of chlorinated solvent COCs in the water table, shallow, and intermediate sample intervals for the entire SWFS Area. In the water table and shallow sample intervals, biodegradation appears to be limiting the migration of chlorinated solvent COCs and their breakdown products, and the conditions for continued COC biodegradation exist. In the intermediate sample interval, biodegradation also appears to be limiting the migration of chlorinated ethenes from areas near the Facility. Potential biodegradation products of chlorinated ethenes have also been detected in areas where no petroleum-related compounds have been detected, suggesting that biodegradation of chlorinated solvents is not solely dependent on the presence of petroleum-related compounds. These observations are consistent with the reducing conditions found throughout Site.

Appendix A describes the approach used to evaluate natural attenuation of TCE and VC in the groundwater plume downgradient of the barrier wall. Geomatrix used a mass flux approach to calculating biodegradation of these compounds downgradient of the barrier wall. Two hydrogeological cross sections were constructed both across (perpendicular) to groundwater flow direction. The first cross section was established on the Facility and represents the highest COC concentrations. The second cross section was established downgradient of the Facility at a point where data on TCE and VC concentrations is dense. Calculating the total mass of COC in each cross sectional area and subtracting cross section A from cross section B resulted in a loss in total mass between the two sections. This loss in mass of COC was attributed to biodegradation of the COC. Using this mass flux approach, the biodegradation rates were established for each COC, and these biodegradation rates were used in the fate and transport modeling (Appendix B) to assess the various remedial alternatives.

4.5 INHALATION PATHWAY CHARACTERIZATION

COC-impacted groundwater has been detected in the water table sample interval downgradient of the HCIM Area, as discussed in Section 4.2. COCs can be transferred from contaminated groundwater or soil by volatilization to soil vapor. Once volatilized, the constituents in soil vapor can migrate in the vadose zone via diffusion and/or gas-phase advection to the ground surface or into overlying buildings.

Because exposure to volatile COCs in indoor air has been identified as a potentially complete exposure pathway, the indoor air concentrations that may result from migration from impacted groundwater are of interest for the SWFS. However, the concentration of a compound detected in indoor air may be attributed to a number of sources, including unrelated contamination in soil vapor, ambient air, and other household or industrial sources.

Indoor air, ambient air, and soil vapor samples were collected as part of several investigations conducted near the Facility since 2000. Locations where soil gas, indoor air, and ambient air samples have been collected between 2000 and 2005 are shown in Figure 4-12. Several compounds were detected in the indoor air of local buildings at concentrations exceeding the applicable MTCA Method B air cleanup levels. Many uncertainties exist in indoor air data collection, resulting in difficulties interpreting sampling data. For this reason, the concentrations of these compounds detected in indoor air may be attributed, at least in part, if not entirely, to sources other than the groundwater plume emanating from the Facility. It is highly unlikely that the detected concentrations in ambient air are the result of volatilization from groundwater because the concentrations detected in groundwater would need to be several orders of magnitude higher to result in ambient air concentrations on the order of those detected, as indicated by screening level modeling (PSC, 2004a). Detected concentrations are more likely a result of vapor releases from normal traffic and business operations. Regardless of the source of the detected concentrations, as discussed in Section 2 of this report, PSC has been conducting the IPIMs to prevent unacceptable human exposure to compounds that may migrate from groundwater into the indoor air of area buildings. In addition, the cleanup levels established in the RI for water table and shallow sample groundwater intervals are protective of the inhalation pathway (vapor intrusion) into indoor air. Currently the inhalation pathway is being addressed by the IPIMs.

4.6 CONCEPTUAL SITE MODEL

For the purposes of the SWFS, the CSM was developed considering the HCIM Area and the Outside Area. Figure 4-13 summarizes the CSM that identifies the human and ecologic exposure pathways that is used for the FS. Section 4.6.1 describes the human health exposure CSM for the HCIM Area, while Section 4.6.2 presents the human health exposure and ecologic exposure CSMs for the Outside Area.

4.6.1 HCIM Area Conceptual Site Model

The human health exposure CSM for the HCIM Area is shown in Figure 4-13. Past Facility operations within the HCIM Area have contaminated soil and groundwater. The CSM for the HCIM Area is summarized as follows:

- Facility operations are known to have affected the soils and groundwater with VOCs, SVOCs, total petroleum hydrocarbons (TPH), metals, and PCBs. Areas where wastes were treated, stored, disposed, or released are source areas for these COCs. Facility operations included storage and handling of materials containing these COCs in aboveground and underground tanks, piping, and drums.

- Releases from these operations migrated into the soil through uncovered soils and/or cracked or missing pavement and then into the unsaturated zone soils and the underlying groundwater.

- The released solvents and dense, non-aqueous phase liquids (DNAPLs) migrated down through the unsaturated soils to the underlying aquifer. While these solvents and DNAPLs would pool temporarily and spread out on the capillary fringe, these liquids eventually migrated vertically through the subsurface, eventually reaching the low permeability silty layers and silt aquitard under the Facility.

- These DNAPLs migrated laterally past the Facility property boundary and under the adjacent TASCO property, dissolving into groundwater as the liquid migrated through the subsurface.

- The installation of the HCIM established hydraulic control of source areas, impacted soil, and the near-facility contaminated saturated zones, thereby preventing off-site migration of Facility contaminants to the extent practicable.

- Groundwater extraction within the HCIM barrier wall maintains an inward-directed hydraulic gradient for the shallow and intermediate aquifer zones, as well as the underlying deep aquifer.

- The HCIM barrier wall isolates site contaminants, including DNAPL, from the regional groundwater flow and also limits potential lateral migration of soil vapors from inside the COC-affected soils remaining within it. The barrier wall consists of a mixture of cement and highly-plastic clay resulting in a wall that is very low in permeability and, due to the clay content, is unlikely to crack including desecration cracks that are typical of concrete. This clay/cement wall, therefore, is ideally suited to containing both groundwater and soil vapors.

- After construction of the HCIM, surface drainage was restored and surficial debris was removed from the Facility. There is currently no exposed soil within the HCIM Area.

- Human receptors on the Facility may include office workers, industrial workers, temporary construction workers, and site visitors.

- The complete exposure pathways within the HCIM Area include potential worker ingestion and dermal exposure to COC-affected subsurface soils and inhalation of soil vapors, which may migrate from the soil into occupied buildings.

- The temporary construction worker could be exposed to affected soil during installation of underground utilities. None of the other receptors would ingest or have dermal contact with affected soils in the HCIM Area. The temporary construction worker could also be exposed to soil vapors from affected soils within any utility trenches.

- Office workers and visitors could be exposed to soil vapors in buildings located within the HCIM Area. While none of the HCIM Area buildings are currently used regularly by workers or visitors, these activities may take place in the future.

- A potentially complete exposure pathway in the HCIM Area is inhalation of fugitive dusts from affected soils. None of the COC-affected soil is exposed within the HCIM Area, and it is not expected that affected soil will be exposed except during construction; construction activities may expose industrial and temporary construction workers to HCIM Area COCs.

- The HCIM Area is entirely paved/developed and, therefore, has no pathways to ecological receptors.

The FS addresses each of the complete and potentially complete exposure pathways for the human receptors and the proposed remedial alternatives will reduce the potential risks associated with these pathways to acceptable levels.

4.6.2 Outside Area Conceptual Site Model

The CSM for human health and ecologic exposures for the Outside Area is shown in Figure 4-13. The human health CSM for the Outside Area is summarized below:

- Soil and groundwater contamination from Facility operations have created source areas currently located within the HCIM Area. There are a few known exceedances of cleanup levels for soil outside the wall. With the exception of some exceedances on UPRR property to the east of the Facility, all the soil exceedances are either on PSC property and capped or are located under roadways owned by the City of Seattle. The UPRR soil exceedances are in the process of being evaluated and are not being addressed by this FS.

- COC-affected groundwater migrated away from the Facility prior to HCIM installation. This large area of dissolved COCs in groundwater will continue to affect areas downgradient of the HCIM for the foreseeable future.

- The only complete exposure pathway in the Outside area is the inhalation of soil vapors, which migrate from the groundwater up through the soil into occupied buildings. This pathway is currently being addressed by the IPIMs

- A potentially complete pathway is groundwater migration to surface water (the Duwamish Waterway) with human potential exposure based on ingestion of fish under the API risk model (TCE and VC) and potential exposure of ecological receptors to 1,4-dioxane. Groundwater modeling to calculate remediation levels for groundwater that are protective of the surface water pathway indicates that the COCs from the Facility will not migrate to the Duwamish River.

- The temporary construction worker might be exposed to soil vapors (inhalation pathway) during installation of underground utilities in the Outside Area

The SWFS addresses each of the complete and potentially complete exposure pathways for the human and ecological receptors and the proposed remedial alternatives will**]** reduce the risks associated with these pathways to acceptable levels.

TABLE 4-1

GROUNDWATER EXCEEDANCES - HCIM AREA

PSC Georgetown
Seattle, Washington

Sample Location	Constituent	Cleanup Level (mg/L)	Concentration of Most Recent Exceedance (mg/L)	Date of Most Recent Exceedance
CG-150-WT	1,1,1-Trichloroethane	11	22.4	16-Nov-04
1-S-1	1,1-Dichloroethane	47	213	16-Nov-04
CG-150-WT	1,1-Dichloroethane	47	197	16-Nov-04
1-S-1	1,2,4-Trimethylbenzene	13	236	16-Nov-04
CG-146-WT	1,2,4-Trimethylbenzene	13	167	16-Nov-04
CG-150-WT	1,2,4-Trimethylbenzene	13	169	16-Nov-04
CG-150-WT	1,2-Dichlorobenzene	13	30.8	16-Nov-04
1-S-1	1,3,5-Trimethylbenzene	9.8	116	16-Nov-04
CG-146-WT	1,3,5-Trimethylbenzene	9.8	27	16-Nov-04
CG-150-WT	1,3,5-Trimethylbenzene	9.8	51.6	16-Nov-04
CG-150-WT	1,4-Dichlorobenzene	2.5	25	16-Nov-04
CG-150-WT	1,4-Dioxane	2.5	207	16-Nov-04
1-S-1	2-Methylphenol	13	32	16-Nov-04
1-S-1	Aroclor 1016	0.005	1.95	16-Nov-04
CG-146-80	Arsenic	1.16	2.48	17-Nov-04
CG-146-WT	Arsenic	1.98	6.76	16-Nov-04
CG-150-WT	Arsenic	1.98	1.73	16-Nov-04
1-S-1	Chloroethane	461	505	16-Nov-04
CG-150-WT	Chloroethane	461	834	16-Nov-04
1-S-1	Chrysene	0.018	0.0312	16-Nov-04
CG-146-80	Chrysene	0.018	0.023	17-Nov-04
1-S-1	cis-1,2-Dichloroethylene	72.7	223	16-Nov-04
CG-150-WT	cis-1,2-Dichloroethylene	72.7	234	16-Nov-04
CG-146-WT	Cyanide	7.08	53	16-Nov-04
CG-146-80	Dibenzo(a,h)anthracene	0.018	0.0239	17-Nov-04
1-S-1	Ethylbenzene	7.3	1670	16-Nov-04
CG-146-WT	Ethylbenzene	7.3	55	16-Nov-04
CG-150-WT	Ethylbenzene	7.3	1190	16-Nov-04
1-S-1	Indeno(1,2,3-cd)pyrene	0.018	0.0217	16-Nov-04
CG-146-80	Indeno(1,2,3-cd)pyrene	0.018	0.0215	17-Nov-04
CG-146-80	Lead	2.5	2.61	17-Nov-04
1-S-1	Xylenes (Total)	141	5900	16-Nov-04
CG-150-WT	Xylenes (Total)	141	1069	16-Nov-04
1-S-1	Naphthalene	12	55	16-Nov-04
CG-146-WT	Naphthalene	12	14.5	16-Nov-04
CG-150-WT	Naphthalene	12	58.4	16-Nov-04
1-S-1	Toluene	9.8	24600	16-Nov-04
CG-150-WT	Toluene	9.8	607	16-Nov-04
CG-146-80	trans-1,2-Dichloroethene	65.3	438	17-Nov-04
1-I	Trichloro-ethene	0.79	1.62	16-Nov-04
1-I	Vinyl chloride	2.04	3.87	16-Nov-04
CG-146-80	Vinyl chloride	2.04	4130	17-Nov-04
CG-150-WT	Vinyl chloride	1.28	106	16-Nov-04

TABLE 4-2

GROUNDWATER EXCEEDANCES - WATER TABLE
PSC Georgetown
Seattle, Washington

Sample Location	Constituent	Cleanup Level (mg/L)	Concentration of Most Recent Exceedance (mg/L)	Date of Most Recent Exceedance	Upgradient	HCIM to Denver Avenue	West Side of Denver Avenue	Between Denver Avenue and 4th Avenue	Downgradient of 4th Avenue
102-S-1	1,1,1-Trichloroethane	11	11.4	19-Aug-04		X			
112-S-1	1,1,1-Trichloroethane	11	26	17-May-05			X		
CG-118-WT	1,1,1-Trichloroethane	11	18	16-May-05		X			
CG-124-WT	1,1,1-Trichloroethane	11	21.3	05-Nov-04			X		
CG-149-WT	1,1,1-Trichloroethane	11	26	17-May-05		X			
112-S-1	1,1-Dichloroethane	47	116	10-Feb-05			X		
CG-118-WT	1,1-Dichloroethane	47	100	16-May-05		X			
CG-124-WT	1,1-Dichloroethane	47	81.1	07-May-04			X		
CG-149-WT	1,1-Dichloroethane	47	47	17-May-05		X			
112-S-1	1,1-Dichloroethene	3.2	3.7	03-Nov-04			X		
CG-131-WT	1,1-Dichloroethene	3.2	3.3	13-May-04				X	
CG-149-WT	1,1-Dichloroethene	3.2	4.31	10-Mar-04		X			
104-S-1	1,2,4-Trimethylbenzene	13	156	10-Feb-05		X			
112-S-1	1,2,4-Trimethylbenzene	13	20	03-Nov-04			X		
113-S-1	1,2,4-Trimethylbenzene	13	19.8	10-Feb-05			X		
CG-115-WT	1,2,4-Trimethylbenzene	13	21	18-May-05		X			
CG-118-WT	1,2,4-Trimethylbenzene	13	330	16-May-05		X			
CG-149-WT	1,2,4-Trimethylbenzene	13	39	17-May-05		X			
CG-153-WT	1,2,4-Trimethylbenzene	13	450	16-May-05		X			
CG-118-WT	1,2-Dichlorobenzene	14	14	16-May-05		X			
CG-153-WT	1,2-Dichlorobenzene	14	26	16-May-05		X			
104-S-1	1,3,5-Trimethylbenzene	9.8	50.1	10-Feb-05		X			
113-S-1	1,3,5-Trimethylbenzene	9.8	17.8	01-Nov-04			X		
CG-115-WT	1,3,5-Trimethylbenzene	9.8	13.9	11-Feb-05		X			
CG-118-WT	1,3,5-Trimethylbenzene	9.8	70	16-May-05		X			
CG-149-WT	1,3,5-Trimethylbenzene	9.8	13	17-May-05		X			
CG-153-WT	1,3,5-Trimethylbenzene	9.8	97.6	01-Feb-05		X			
CG-153-WT	1,3,5-Trimethylbenzene	9.8	190	16-May-05		X			
CG-118-WT	1,4-Dichlorobenzene	2.5	3.2	16-May-05		X			
104-S-1	Arsenic	1.98	11.5	29-Oct-04		X			
112-S-1	Arsenic	1.98	16	03-Nov-04			X		
113-S-1	Arsenic	1.98	12	01-Nov-04			X		
CG-115-WT	Arsenic	1.98	2.14	02-Nov-04		X			
CG-122-WT	Arsenic	1.98	21	04-Nov-04				X	
CG-124-WT	Arsenic	1.98	8.51	05-Nov-04			X		
CG-127-WT	Arsenic	1.98	2.95	05-Nov-04				X	
CG-128-WT	Arsenic	1.98	4.16	09-Nov-04				X	
CG-129-WT	Arsenic	1.98	2.02	08-Nov-04				X	
CG-131-WT	Arsenic	1.98	2.5	09-Nov-04				X	
104-S-1	Benzene	9.6	13.5	10-Feb-05		X			
CG-118-WT	Benzene	9.6	13	16-May-05		X			
CG-122-WT	Benzene	9.6	10.3	10-Feb-05				X	

TABLE 4-2

GROUNDWATER EXCEEDANCES - WATER TABLE

PSC Georgetown
Seattle, Washington

Sample Location	Constituent	Cleanup Level (mg/L)	Concentration of Most Recent Exceedance (mg/L)	Date of Most Recent Exceedance	Upgradient	HCIM to Denver Avenue	West Side of Denver Avenue	Between Denver Avenue and 4th Avenue	Downgradient of 4th Avenue
104-S-1	Bis(2-ethylhexyl)phthalate	1.83	4.97	09-Feb-04		X			
CG-106-WT	Bis(2-ethylhexyl)phthalate	1.83	2.06	28-Oct-04	X				
CG-128-WT	Bis(2-ethylhexyl)phthalate	1.83	14	11-Feb-04				X	
CG-129-WT	Bis(2-ethylhexyl)phthalate	1.83	8.93	11-Feb-04				X	
104-S-1	C8-C10 (VPH) Aromatics	120	17000	29-Oct-04		X			
113-S-1	C8-C10 (VPH) Aromatics	120	3000	01-Nov-04			X		
CG-115-WT	C8-C10 (VPH) Aromatics	120	120	18-May-05		X			
104-S-1	Chloroethane	461	666	09-Feb-04		X			
CG-118-WT	Chloroethane	461	1300	16-May-05		X			
101-S-1	Chloroform	4.1	18.2	28-Oct-04	X				
CG-106-WT	Chloroform	4.1	13.1	28-Oct-04	X				
CG-141-WT	Chloroform	4.1	7.08	13-May-04					X
112-S-1	cis-1,2-Dichloroethylene	72.7	117	03-Nov-04			X		
CG-124-WT	cis-1,2-Dichloroethylene	72.7	72.8	12-Feb-04			X		
CG-131-WT	cis-1,2-Dichloroethylene	72.7	73.6	09-Nov-04				X	
CG-136-WT	cis-1,2-Dichloroethylene	72.7	104	04-Feb-05					X
CG-149-WT	cis-1,2-Dichloroethylene	72.7	85.5	11-May-04		X			
CG-127-WT	Copper	3.1	4.05	05-Nov-04				X	
113-S-1	Dibenzo(a,h)anthracene	0.018	0.0667	01-Nov-04			X		
CG-124-WT	Dibenzo(a,h)anthracene	0.018	0.018	05-Nov-04			X		
104-S-1	Ethylbenzene	7.3	3900	10-Feb-05		X			
112-S-1	Ethylbenzene	7.3	26.7	03-Nov-04			X		
113-S-1	Ethylbenzene	7.3	741	10-Feb-05			X		
CG-115-WT	Ethylbenzene	7.3	9.77	20-Aug-04		X			
CG-118-WT	Ethylbenzene	7.3	1600	16-May-05		X			
CG-149-WT	Ethylbenzene	7.3	8	17-May-05		X			
CG-153-WT	Ethylbenzene	7.3	760	16-May-05		X			
113-S-1	Indeno(1,2,3-cd)pyrene	0.018	0.0616	01-Nov-04			X		
104-S-1	Iron	1000	20700	10-Feb-05		X			
CG-124-WT	Iron	1000	5840	09-Feb-05			X		
CG-141-WT	Iron	1000	1850	11-Nov-04					X
104-S-1	Xylenes (Total)	141	1000	10-Feb-05		X			
113-S-1	Xylenes (Total)	141	382	01-Nov-04			X		
CG-115-WT	Xylenes (Total)	141	247	20-Aug-04		X			
CG-118-WT	Xylenes (Total)	141	620	16-May-05		X			
CG-153-WT	Xylenes (Total)	141	4400	16-May-05		X			
CG-142-WT	Manganese	151	876	11-Nov-04					X
CG-143-WT	Manganese	151	346	12-Nov-04					X
104-S-1	Naphthalene	12	27.7	10-Feb-05		X			
112-S-1	Naphthalene	12	13.3	03-Nov-04			X		
113-S-1	Naphthalene	12	13.1	10-Feb-04			X		
CG-115-WT	Naphthalene	12	14.7	04-May-04		X			

TABLE 4-2

GROUNDWATER EXCEEDANCES - WATER TABLE

PSC Georgetown
Seattle, Washington

Sample Location	Constituent	Cleanup Level (mg/L)	Concentration of Most Recent Exceedance (mg/L)	Date of Most Recent Exceedance	Upgradient	HCIM to Denver Avenue	West Side of Denver Avenue	Between Denver Avenue and 4th Avenue	Downgradient of 4th Avenue
CG-118-WT	Naphthalene	12	89	16-May-05		X			
CG-149-WT	Naphthalene	12	13	10-Mar-04		X			
CG-153-WT	Naphthalene	12	19	16-May-05		X			
104-S-1	n-Hexane	0.45	2.31	09-Feb-04		X			
104-S-1	n-Propylbenzene	7.3	31.5	10-Feb-05		X			
CG-115-WT	n-Propylbenzene	7.3	12	18-May-05		X			
CG-118-WT	n-Propylbenzene	7.3	32	16-May-05		X			
CG-153-WT	n-Propylbenzene	7.3	190	16-May-05		X			
CG-118-WT	sec-Butylbenzene	4.6	7.4	16-May-05		X			
CG-153-WT	sec-Butylbenzene	4.6	10	16-May-05		X			
103-S-1	Tetrachloroethene	0.2	15.5	05-May-04		X			
104-S-1	Tetrachloroethene	0.2	0.36	09-Feb-04		X			
112-S-1	Tetrachloroethene	0.2	1.1	17-May-05			X		
113-S-1	Tetrachloroethene	0.2	1.5	10-Feb-05			X		
CG-118-WT	Tetrachloroethene	0.2	2.1	16-May-05		X			
CG-124-WT	Tetrachloroethene	0.2	7.7	19-May-05			X		
CG-126-WT	Tetrachloroethene	0.2	1.51	03-Feb-05				X	
CG-127-WT	Tetrachloroethene	0.2	0.383	02-Feb-05				X	
CG-128-WT	Tetrachloroethene	0.2	0.431	03-Feb-05				X	
CG-132-WT	Tetrachloroethene	0.2	0.392	03-Feb-05				X	
CG-136-WT	Tetrachloroethene	0.2	1.61	04-Feb-05					X
CG-138-WT	Tetrachloroethene	0.2	0.282	02-Feb-05					X
CG-149-WT	Tetrachloroethene	0.2	0.92	17-May-05		X			
104-S-1	Toluene	9.8	866	06-May-04		X			
113-S-1	Toluene	9.8	199	04-May-04			X		
CG-118-WT	Toluene	9.8	120	16-May-05		X			
CG-149-WT	Toluene	9.8	10	11-May-04		X			
CG-153-WT	Toluene	9.8	1300	18-Aug-04		X			
103-S-1	Trichloroethene	0.4	17.2	05-May-04		X			
104-S-1	Trichloroethene	0.4	0.568	09-Feb-04		X			
112-S-1	Trichloroethene	0.4	2.8	17-May-05			X		
113-S-1	Trichloroethene	0.4	1.14	10-Feb-05			X		
CG-106-WT	Trichloroethene	0.4	2.37	28-Oct-04	X				
CG-118-WT	Trichloroethene	0.4	1.2	16-May-05		X			
CG-122-WT	Trichloroethene	0.4	0.473	06-May-04				X	
CG-124-WT	Trichloroethene	0.4	17	19-May-05			X		
CG-126-WT	Trichloroethene	0.4	16.4	03-Feb-05				X	
CG-127-WT	Trichloroethene	0.4	11.7	02-Feb-05				X	
CG-128-WT	Trichloroethene	0.4	0.576	03-Feb-05				X	
CG-130-WT	Trichloroethene	0.4	1.2	03-Feb-05				X	
CG-131-WT	Trichloroethene	0.4	44.9	03-Feb-05				X	
CG-132-WT	Trichloroethene	0.4	5.03	03-Feb-05				X	

TABLE 4-2

GROUNDWATER EXCEEDANCES - WATER TABLE
PSC Georgetown
Seattle, Washington

Sample Location	Constituent	Cleanup Level (mg/L)	Concentration of Most Recent Exceedance (mg/L)	Date of Most Recent Exceedance	Upgradient	HCIM to Denver Avenue	West Side of Denver Avenue	Between Denver Avenue and 4th Avenue	Downgradient of 4th Avenue
CG-136-WT	Trichloroethene	0.4	28.4	04-Feb-05					X
CG-137-WT	Trichloroethene	0.4	269	01-Feb-05					X
CG-138-WT	Trichloroethene	0.4	0.611	11-Nov-04					X
CG-149-WT	Trichloroethene	0.4	7.3	17-May-05		X			
103-S-1	Vinyl chloride	1.28	3.07	05-May-04		X			
104-S-1	Vinyl chloride	1.28	3.01	10-Feb-05		X			
112-S-1	Vinyl chloride	1.28	1.5	17-May-05			X		
113-S-1	Vinyl chloride	1.28	2.47	10-Feb-05			X		
CG-118-WT	Vinyl chloride	1.28	4.9	16-May-05		X			
CG-122-WT	Vinyl chloride	1.28	1.37	16-Feb-04				X	
CG-124-WT	Vinyl chloride	1.28	9.5	19-May-05			X		
CG-126-WT	Vinyl chloride	1.28	2.48	05-Nov-04				X	
CG-131-WT	Vinyl chloride	1.28	5.76	03-Feb-05				X	
CG-137-WT	Vinyl chloride	1.28	2.02	01-Feb-05					X
CG-149-WT	Vinyl chloride	1.28	36	17-May-05		X			
CG-153-WT	Vinyl chloride	1.28	8.52	11-Mar-04		X			

TABLE 4-3

GROUNDWATER EXCEEDANCES - SHALLOW

PSC Georgetown
Seattle, Washington

Sample Location	Constituent	Cleanup Level (mg/L)	Concentration of Most Recent Exceedance (mg/L)	Date of Most Recent Exceedance	Upgradient	HCIM to Denver Avenue	West Side of Denver Avenue	Between Denver Avenue and 4th Avenue	Downgradient of 4th Avenue
CG-119-40	1,1-Dichloroethane	47	62	17-May-05		X			
CG-125-40	1,4-Dioxane	94.9	195	08-Nov-04				X	
CG-127-40	1,4-Dioxane	94.9	414	05-Nov-04				X	
CG-129-40	1,4-Dioxane	94.9	233	08-Nov-04				X	
CG-131-40	1,4-Dioxane	94.9	500	09-Nov-04				X	
CG-134-40	1,4-Dioxane	94.9	249	04-Feb-05				X	
CG-135-40	1,4-Dioxane	94.9	300	06-Feb-04				X	
CG-139-40	1,4-Dioxane	94.9	109	08-Nov-04					X
CG-127-40	Barium	9.75	10.3	05-Nov-04				X	
CG-121-40	Benzene	9.6	28	17-May-05				X	
CG-129-40	Benzene	9.6	23.2	08-Nov-04				X	
104-S-2	Bis(2-ethylhexyl)phthalate	1.83	5.72	09-Feb-04		X			
CG-119-40	Bis(2-ethylhexyl)phthalate	1.83	7.11	10-Feb-04		X			
CG-134-40	Bis(2-ethylhexyl)phthalate	1.83	2.97	10-Nov-04				X	
CG-127-40	Chromium (Hexavalent)	10	13.4	05-Nov-04				X	
CG-129-40	Chromium (Hexavalent)	10	10	08-Nov-04				X	
CG-141-40	Chromium (Hexavalent)	10	17.1	11-Nov-04					X
CG-132-40	Chrysene	0.018	0.0338	08-Nov-04				X	
103-S-2	Dibenzo(a,h)anthracene	0.018	0.0255	01-Nov-04		X			
CG-132-40	Dibenzo(a,h)anthracene	0.018	0.0272	08-Nov-04				X	
CG-138-40	Dibenzo(a,h)anthracene	0.018	0.0291	02-Feb-05					X
103-S-2	Indeno(1,2,3-cd)pyrene	0.018	0.0238	01-Nov-04		X			
CG-132-40	Indeno(1,2,3-cd)pyrene	0.018	0.0254	08-Nov-04				X	
CG-138-40	Indeno(1,2,3-cd)pyrene	0.018	0.0218	02-Feb-05					X
104-S-2	Iron	1000	16600	10-Feb-05		X			
CG-124-40	Iron	1000	4380	09-Feb-05			X		
CG-127-40	Iron	1000	19000	02-Feb-05				X	
CG-134-40	Iron	1000	24200	04-Feb-05				X	
CG-135-40	Iron	1000	37900	06-Feb-04				X	
CG-141-40	Iron	1000	16400	04-Feb-05					X
CG-143-40	Iron	1000	4700	02-Feb-05					X
CG-144-35	Iron	1000	7970	09-Feb-05					X

TABLE 4-3

GROUNDWATER EXCEEDANCES - SHALLOW

PSC Georgetown
Seattle, Washington

Sample Location	Constituent	Cleanup Level (mg/L)	Concentration of Most Recent Exceedance (mg/L)	Date of Most Recent Exceedance	Upgradient	HCIM to Denver Avenue	West Side of Denver Avenue	Between Denver Avenue and 4th Avenue	Downgradient of 4th Avenue
CG-140-30	Manganese	151	397	12-Nov-04					X
CG-141-40	Manganese	151	782	11-Nov-04					X
CG-142-40	Manganese	151	503	11-Nov-04					X
CG-143-40	Manganese	151	526	12-Nov-04					X
CG-145-35	Manganese	151	206	12-Nov-04					X
CG-151-25	Manganese	151	275	18-Nov-04					X
CG-137-40	Naphthalene	12	15.1	12-May-04					X
103-S-2	Trichloroethene	0.4	1.72	14-Feb-05		X			
CG-119-40	Trichloroethene	0.4	0.407	10-Feb-04		X			
CG-124-40	Trichloroethene	0.4	1.2	19-May-05			X		
CG-137-40	Trichloroethene	0.4	0.55	12-May-04					X
102-S-2	Vinyl chloride	1.28	15	19-May-05		X			
103-S-2	Vinyl chloride	1.28	9.95	14-Feb-05		X			
CG-119-40	Vinyl chloride	1.28	3.8	17-May-05		X			
CG-124-40	Vinyl chloride	1.28	5.77	12-Feb-04			X		
CG-124-40	Vinyl chloride	1.28	3.4	19-May-05			X		
CG-125-40	Vinyl chloride	1.28	5.61	08-Nov-04				X	
CG-127-40	Vinyl chloride	1.28	13.2	02-Feb-05				X	
CG-129-40	Vinyl chloride	1.28	2	08-Nov-04				X	
CG-131-40	Vinyl chloride	1.28	10.2	03-Feb-05				X	
CG-132-40	Vinyl chloride	1.28	3.44	08-Nov-04				X	
CG-133-40	Vinyl chloride	1.28	51.8	09-Feb-05				X	
CG-134-40	Vinyl chloride	1.28	18.1	04-Feb-05				X	
CG-135-40	Vinyl chloride	1.28	4.88	12-May-04				X	
CG-136-40	Vinyl chloride	1.28	38.7	04-Feb-05					X
CG-137-40	Vinyl chloride	1.28	68.2	01-Feb-05					X
CG-139-40	Vinyl chloride	1.28	1.83	08-Nov-04					X
CG-140-30	Vinyl chloride	1.28	76.9	09-Feb-05					X
CG-140-40	Vinyl chloride	1.28	2.32	14-May-04					X
CG-141-40	Vinyl chloride	1.28	362	04-Feb-05					X
CG-144-35	Vinyl chloride	1.28	2.92	12-Nov-04					X
CG-151-25	Vinyl chloride	1.28	49.4	18-Nov-04					X

TABLE 4-4

GROUNDWATER EXCEEDANCES - INTERMEDIATE

PSC Georgetown
Seattle, Washington

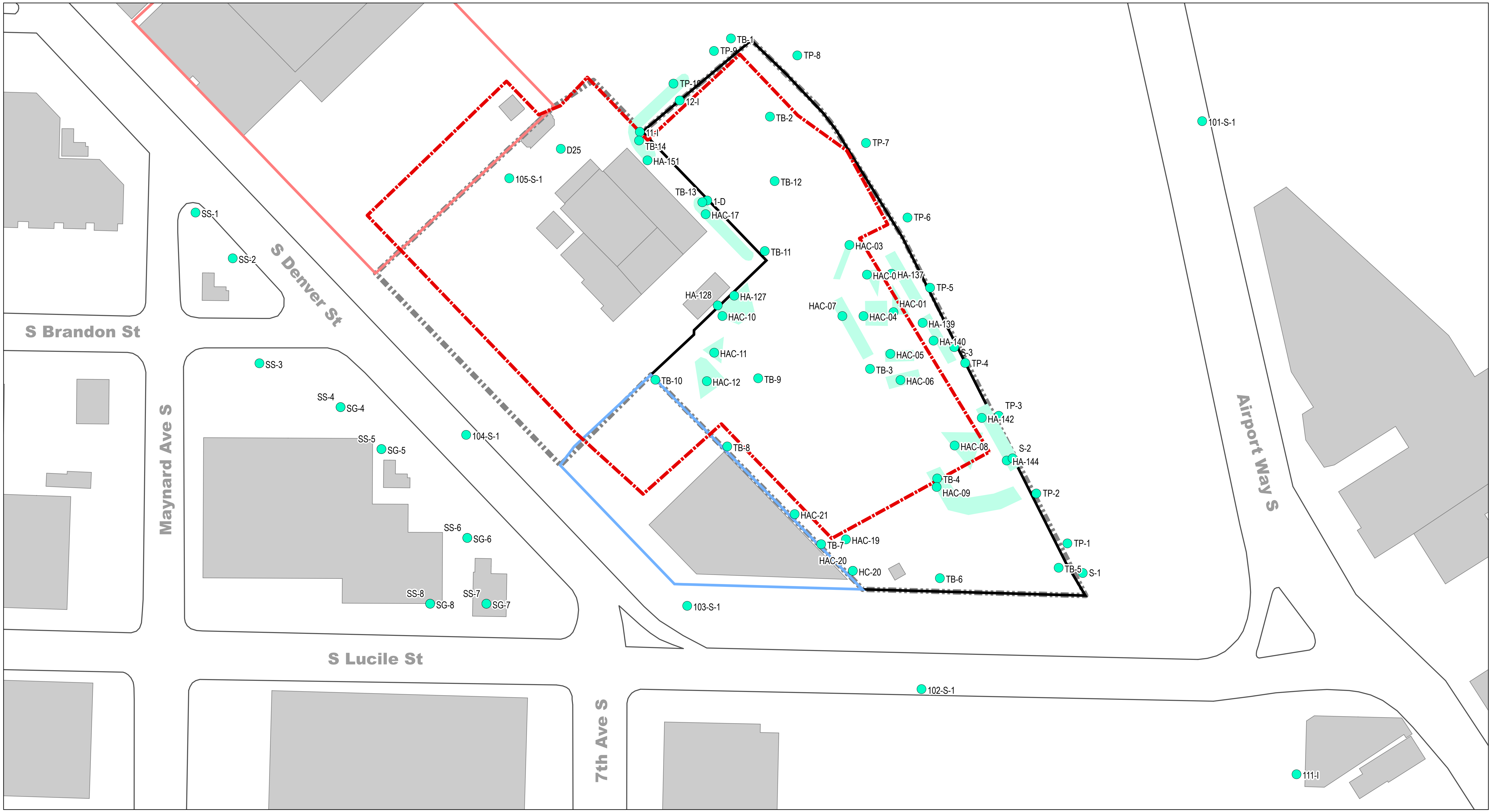
Sample Location	**Constituent**	**Cleanup Level (mg/L)**	**Concentration of Most Recent Exceedance (mg/L)**	**Date of Most Recent Exceedance**	**Upgradient**	**HCIM to Denver Avenue**	**West Side of Denver Avenue**	**Between Denver Avenue and 4th Avenue**	**Downgradient of 4th Avenue**
104-I	1,1-Dichloroethane	47	51.6	11-Feb-05		X			
CG-122-60	1,4-Dioxane	94.9	355	04-Nov-04				X	
CG-124-70	1,4-Dioxane	94.9	127	05-Nov-04			X		
CG-128-70	1,4-Dioxane	94.9	158	11-Feb-04				X	
CG-135-50	1,4-Dioxane	94.9	530	02-Feb-05				X	
CG-138-70	1,4-Dioxane	94.9	107	02-Feb-05					X
CG-121-93	Arsenic	1.16	1.38	04-Nov-04				X	
CG-124-70	Arsenic	1.16	1.19	05-Nov-04			X		
104-I	Bis(2-ethylhexyl)phthalate	1.83	9.51	09-Feb-04		X			
CG-120-75	Bis(2-ethylhexyl)phthalate	1.83	5.96	10-Feb-04			X		
CG-123-90	Bis(2-ethylhexyl)phthalate	1.83	5.57	04-Nov-04				X	
CG-120-75	Chrysene	0.018	0.0451	10-Feb-04			X		
CG-115-75	Cyanide	9.76	34	11-Feb-05		X			
CG-121-70	Cyanide	9.76	28	14-Feb-05				X	
103-I	Dibenzo(a,h)anthracene	0.018	0.0425	01-Nov-04		X			
CG-115-75	Dibenzo(a,h)anthracene	0.018	0.0317	02-Nov-04		X			
CG-118-79	Ethylbenzene	7.3	36.4	09-Mar-04		X			
103-I	Indeno(1,2,3-cd)pyrene	0.018	0.0431	01-Nov-04		X			
CG-115-75	Indeno(1,2,3-cd)pyrene	0.018	0.0343	02-Nov-04		X			
CG-120-75	Indeno(1,2,3-cd)pyrene	0.018	0.0239	10-Feb-04			X		
CG-124-70	Iron	6667	8180	09-Feb-05			X		
102-I	Vinyl chloride	2.04	6.4	18-May-05		X			
103-I	Vinyl chloride	2.04	2.9	14-Feb-05		X			
104-I	Vinyl chloride	2.04	1000	11-Feb-05		X			
CG-115-75	Vinyl chloride	2.04	3.98	11-Feb-05		X			
CG-116-80	Vinyl chloride	2.04	840	16-May-05		X			
CG-118-79	Vinyl chloride	2.04	80.2	09-Mar-04		X			
CG-135-50	Vinyl chloride	2.04	7	02-Feb-05					X
CG-138-70	Vinyl chloride	2.04	16.9	02-Feb-05					X
CG-141-50	Vinyl chloride	2.04	18.6	13-May-04					X

TABLE 4-5

GROUNDWATER EXCEEDANCES - DEEP

PSC Georgetown
Seattle, Washington

Sample Location	Constituent	Cleanup Level (mg/L)	Concentration of Most Recent Exceedance (mg/L)	Date of Most Recent Exceedance	Upgradient	HCIM to Denver Avenue	West Side of Denver Avenue	Between Denver Avenue and 4th Avenue	Downgradient of 4th Avenue
102-D	Arsenic	15.6	16.4	01-Nov-04		X			
1-D	Arsenic	15.6	19	18-Nov-04		X			
102-D	Barium	24.5	97.4	01-Nov-04		X			
104-D	Barium	24.5	52.2	29-Oct-04		X			
104-D	Bis(2-ethylhexyl)phthalate	1.83	20.6	10-Feb-05		X			
CG-116-	Carbon disulfide	0.92	5.7	16-May-05		X			
102-D	Chromium	15.8	28.6	01-Nov-04		X			
104-D	Iron	1000	6730	10-Feb-05		X			
CG-106-D	Iron	1000	1340	16-Feb-05	X				



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EXPLANATION

●	Historical Soil Sample Location < 15'
🟩	Composite Soil Sample
-·-·-	HCIM Area
☐	Facility
▨	PSC Property
☐	Stone-Drew / Ashe & Jones, Inc. (SAD) Property
☐	Aronson Property
▨	Building

0 100 Feet

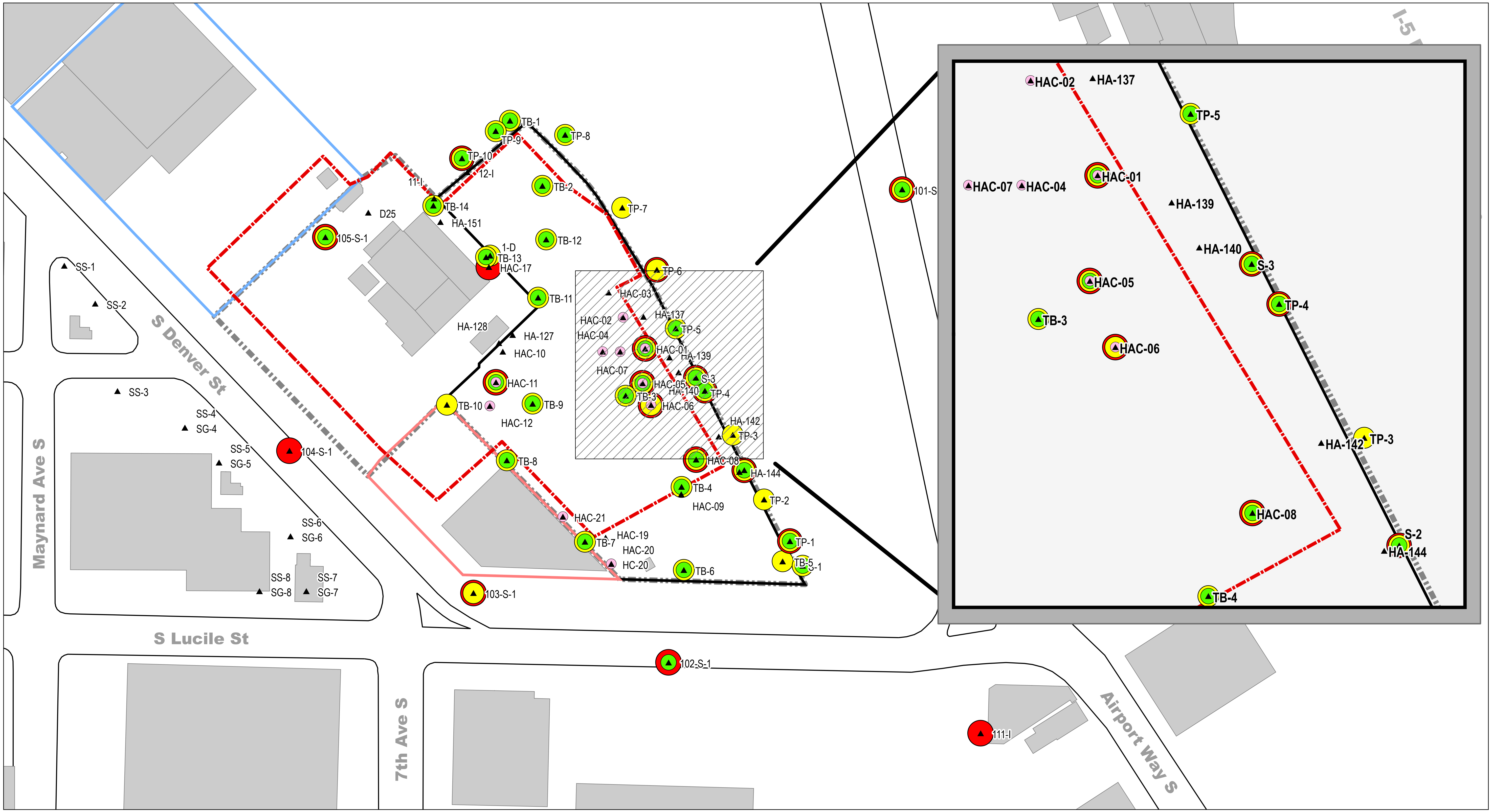
N

HISTORICAL SOIL SAMPLE LOCATIONS
PSC Georgetown
Seattle, Washington

GEOMATRIX

Project No.
8770

Figure
4-1



EXPLANATION

- ○ PCBs
- 🟢 SVOCs
- 🟡 VOCs
- 🔴 Metals
- ▲ Historical Soil Sample Location <15'
- HCIM Area
- ☐ Facility
- PSC Property
- ☐ Stone-Drew / Ashe & Jones, Inc. (SAD) Property
- ☐ Aronson Property
- ▨ Building

0 100 Feet

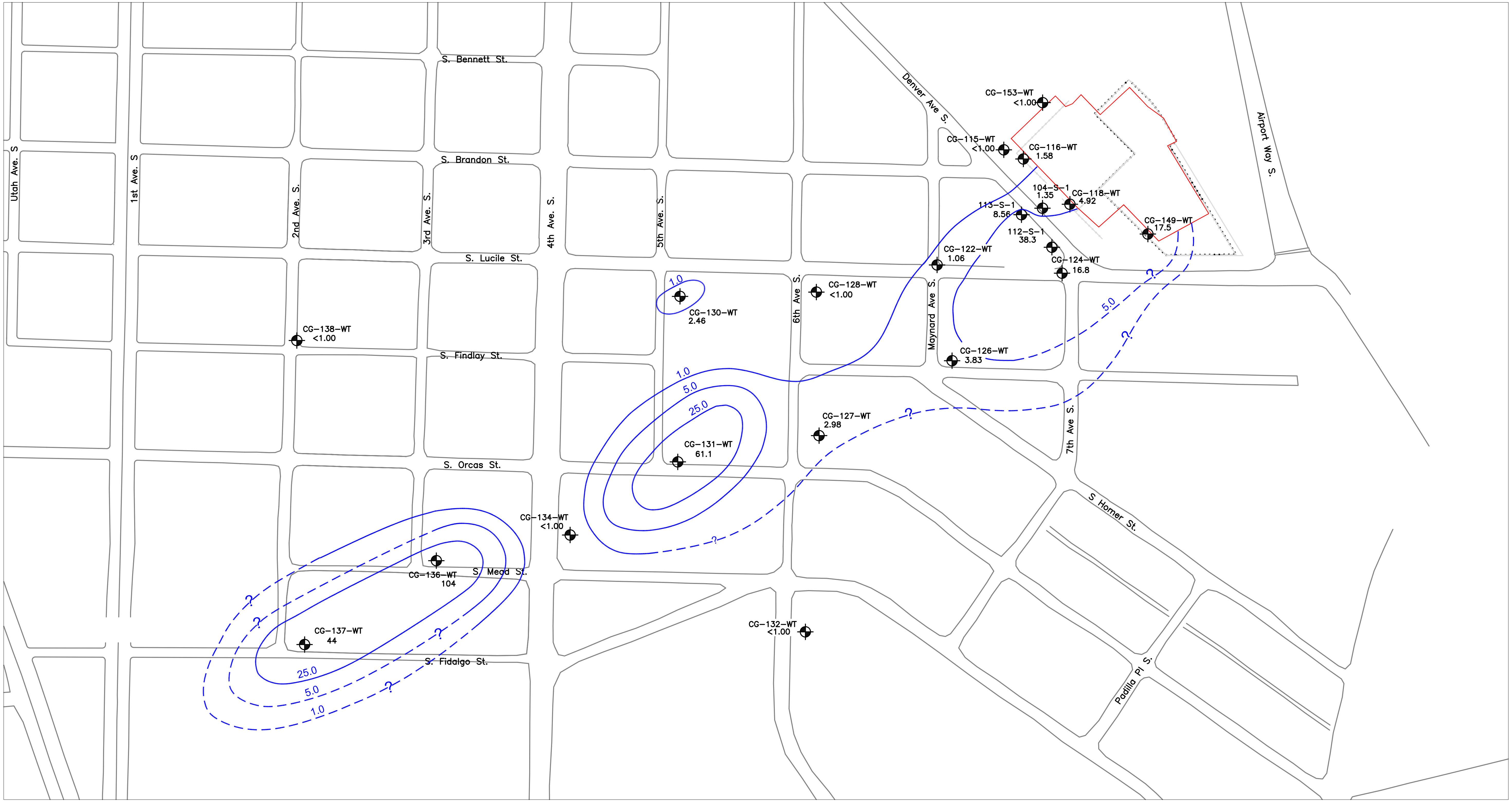
N

SOIL CLEANUP LEVEL EXCEEDANCES
PSC Georgetown
Seattle, Washington

GEOMATRIX

Project No.	Figure
8770	4-2

S:\8770\027_DSiteWideFS\mxds\Fig4-2_SoilHitsAboveCUL081705.mxd



LEGEND

⊕	MONITORING WELL
0.02	CONCENTRATION OF DCE IN MICROGRAMS PER LITER (µg/L)
0.02	DCE ISOCONCENTRATION CONTOUR IN µg/L
<1	CONCENTRATION NOT DETECTED ABOVE THE REPORTING LIMIT IN µg/L SHOWN
🟥	APPROXIMATE LOCATION OF BARRIER WALL

APPROXIMATE
SCALE (FEET)

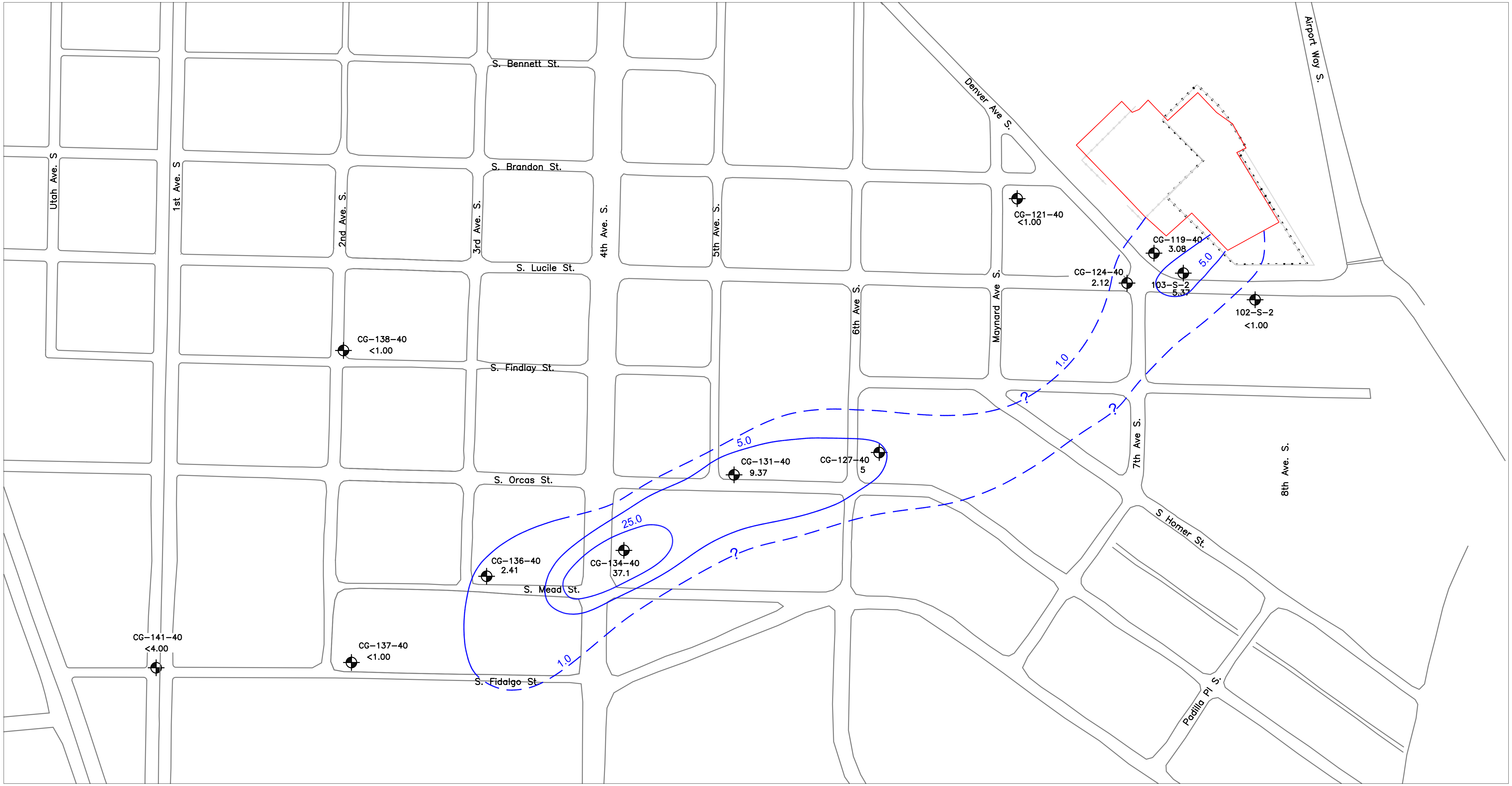
CIS-1,2-DICHLOROETHENE
WATER TABLE SAMPLE INTERVAL

PSC Georgetown
Seattle, Washington

GEOMATRIX

Project No.	Figure
8770	**4-3**

S:\8770\027_DSiteWideFS\CAD\Fig4-3_cis12DCE_WT_1Q05_090105.dwg



LEGEND

⊕ MONITORING WELL

0.02 CONCENTRATION OF DCE IN MICROGRAMS PER LITER (µg/L)

0.02 DCE ISOCONCENTRATION CONTOUR IN µg/L

<1 CONCENTRATION NOT DETECTED ABOVE THE REPORTING LIMIT IN µg/L SHOWN

APPROXIMATE LOCATION OF BARRIER WALL

N

0 260

APPROXIMATE SCALE (FEET)

CIS-1,2-DICHLOROETHENE
SHALLOW SAMPLE INTERVAL

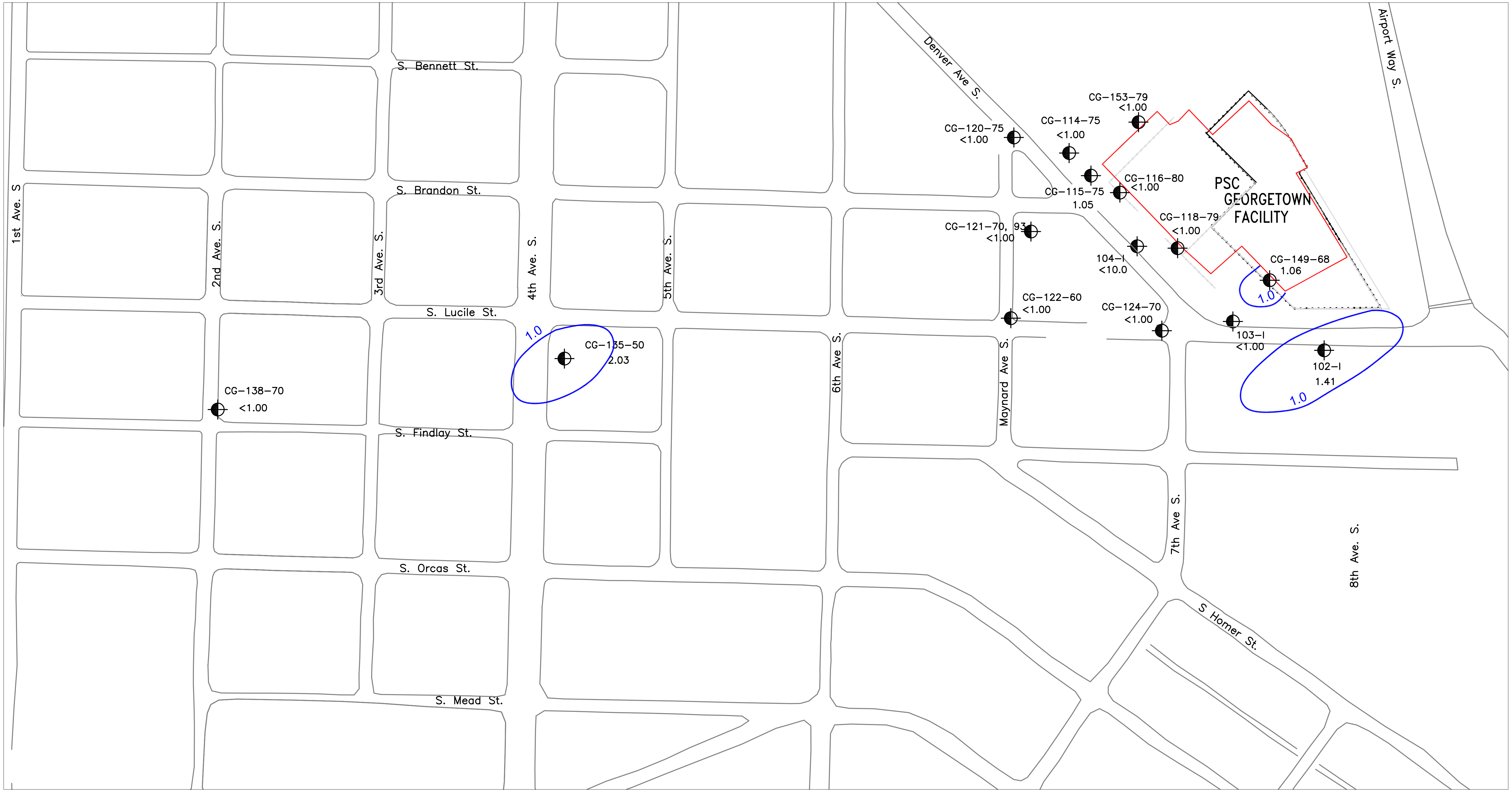
PSC Georgetown
Seattle, Washington

GEOMATRIX

Project No.
8770

Figure
4-4

S:\8770\027_DSiteWideFS\CAD\Fig4-4_cis12DCE_Sh2_1stQtr05.dwg



LEGEND

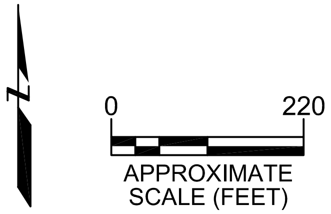
⊕ MONITORING WELL

0.02 CONCENTRATION OF DCE IN MICROGRAMS PER LITER (µg/L)

0.02 DCE ISOCONCENTRATION CONTOUR IN µg/L

<1 CONCENTRATION NOT DETECTED ABOVE THE REPORTING LIMIT IN µg/L SHOWN

APPROXIMATE LOCATION OF BARRIER WALL



APPROXIMATE SCALE (FEET)

CIS-1,2-DICHLOROETHENE
INTERMEDIATE SAMPLE INTERVAL
PSC Georgetown
Seattle, Washington

GEOMATRIX

Project No.	Figure
8770	4-5

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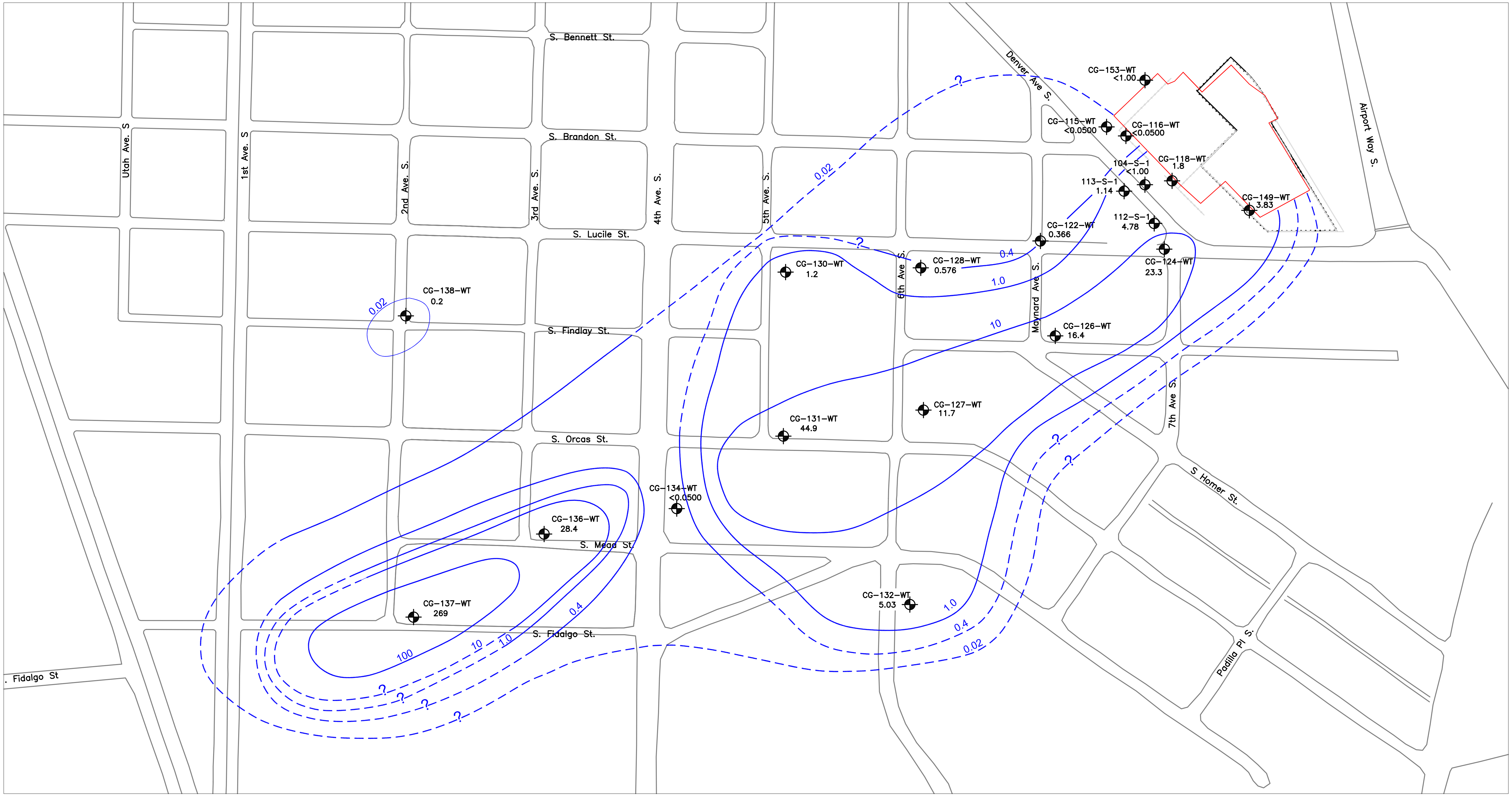


LEGEND

⌖ MONITORING WELL

0.02 CONCENTRATION OF TCE IN MICROGRAMS PER LITER (µg/L)

0.02 TCE ISOCONCENTRATION CONTOUR IN µg/L

<1 CONCENTRATION NOT DETECTED ABOVE THE REPORTING LIMIT IN µg/L SHOWN

APPROXIMATE LOCATION OF BARRIER WALL

N

0 275

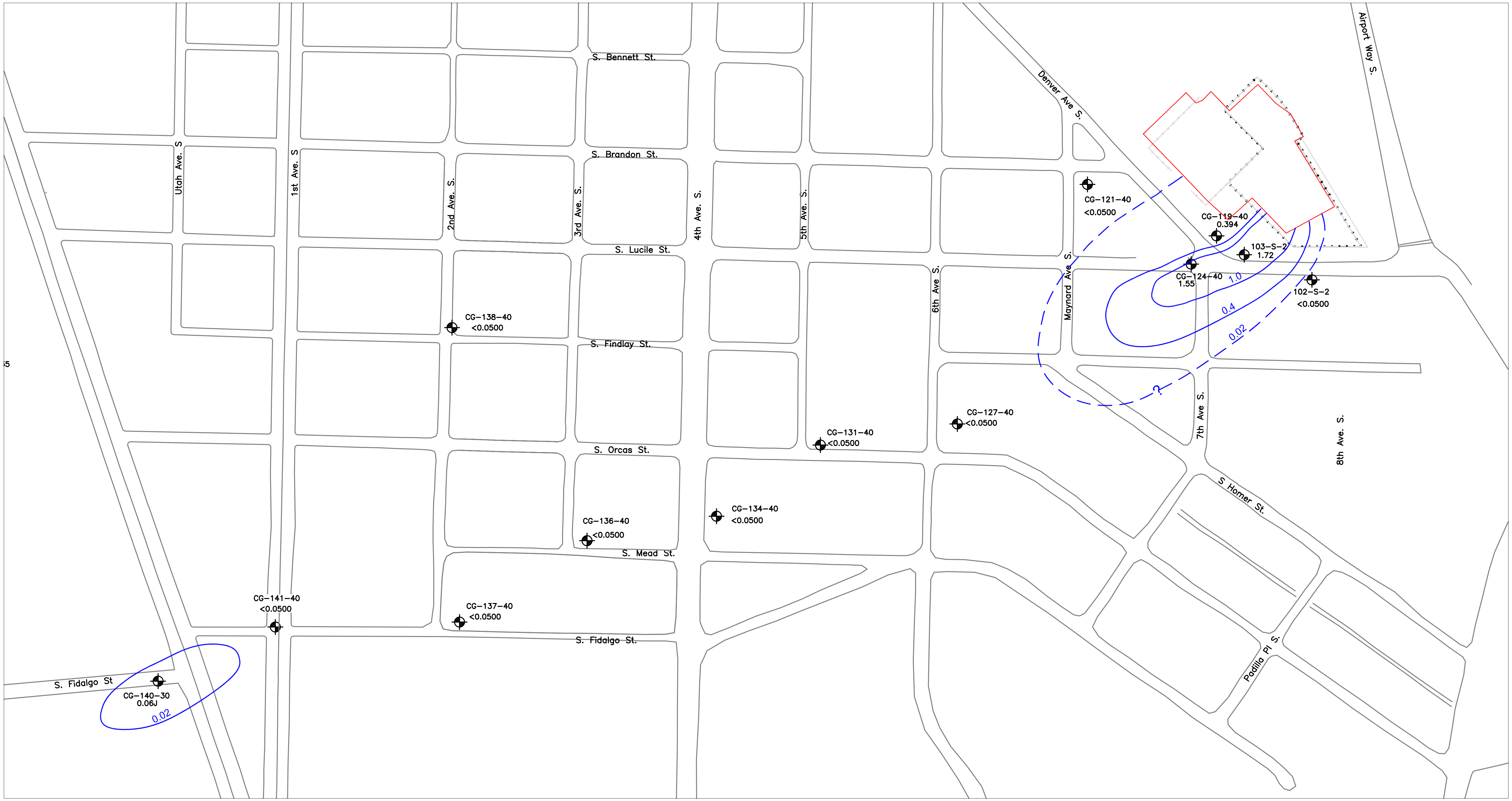
APPROXIMATE SCALE (FEET)

TRICHLOROETHENE
WATER TABLE SAMPLE INTERVAL
PSC Georgetown
Seattle, Washington

GEOMATRIX

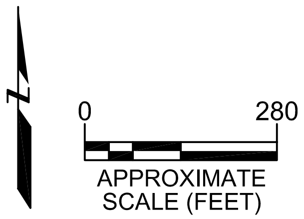
Project No.	Figure
8770	4-6

S:\8770\027_DSiteWideFS\CAD\Fig4-6_TCE_WT_1stQtr05.dwg



LEGEND

⌖	MONITORING WELL
0.02	CONCENTRATION OF TCE IN MICROGRAMS PER LITER (μg/L)
0.02	TCE ISOCONCENTRATION CONTOUR IN μg/L
<1	CONCENTRATION NOT DETECTED ABOVE THE REPORTING LIMIT IN μg/L SHOWN
🟥	APPROXIMATE LOCATION OF BARRIER WALL

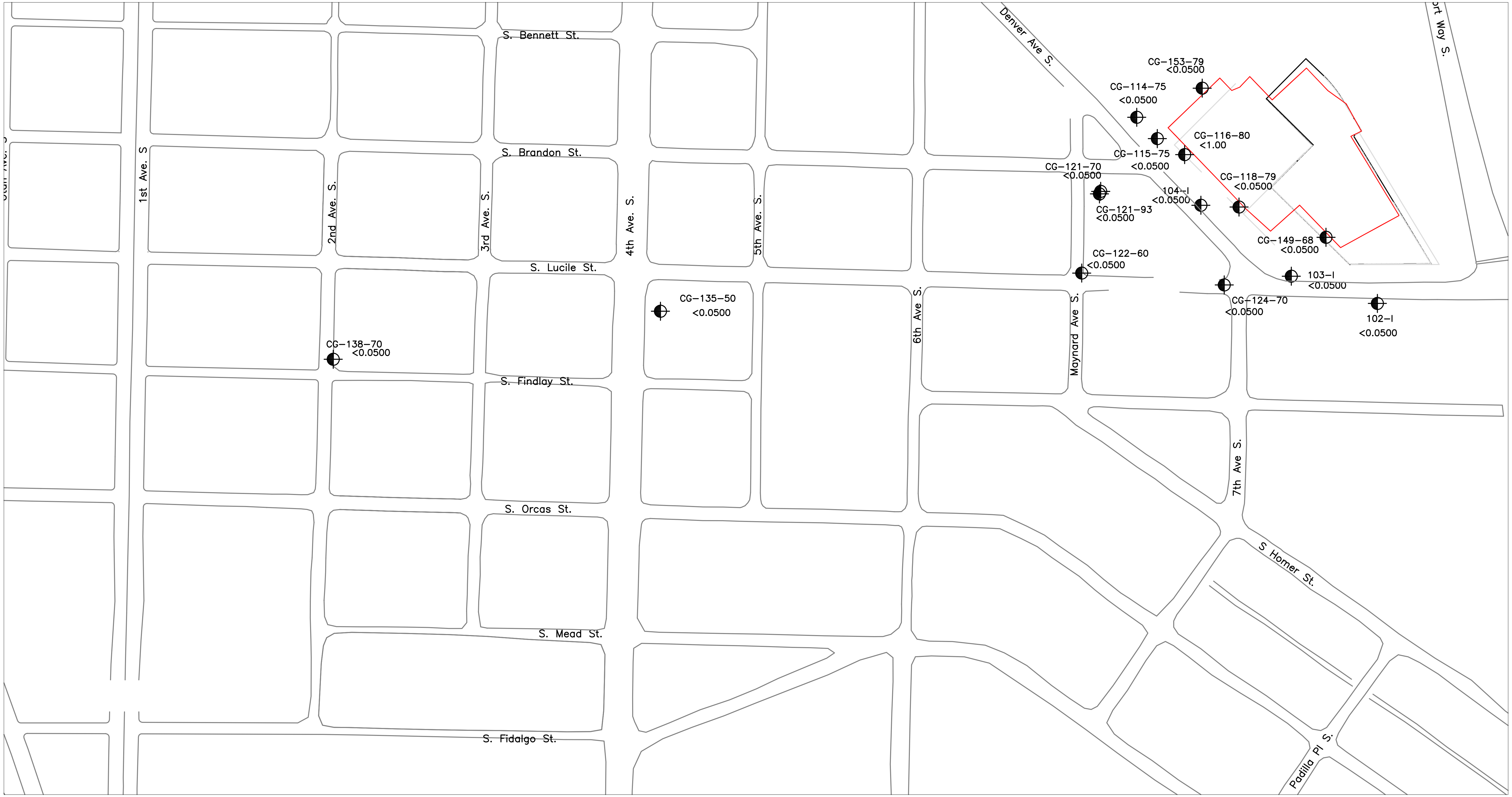


TRICHLOROETHENE
SHALLOW SAMPLE INTERVAL
PSC Georgetown
Seattle, Washington

GEOMATRIX

Project No.	Figure
8770	4-7

S:\8770\027_DSiteWideFS\CAD\Fig4-7_TCE_SH2_1stQtr05.dwg



LEGEND

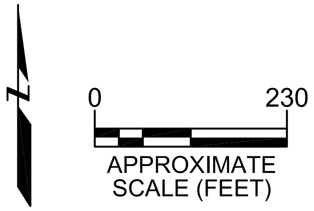
⌖ MONITORING WELL

0.02 CONCENTRATION OF TCE IN MICROGRAMS PER LITER (µg/L)

0.02 TCE ISOCONCENTRATION CONTOUR IN µg/L

<1 CONCENTRATION NOT DETECTED ABOVE THE REPORTING LIMIT IN µg/L SHOWN

APPROXIMATE LOCATION OF BARRIER WALL



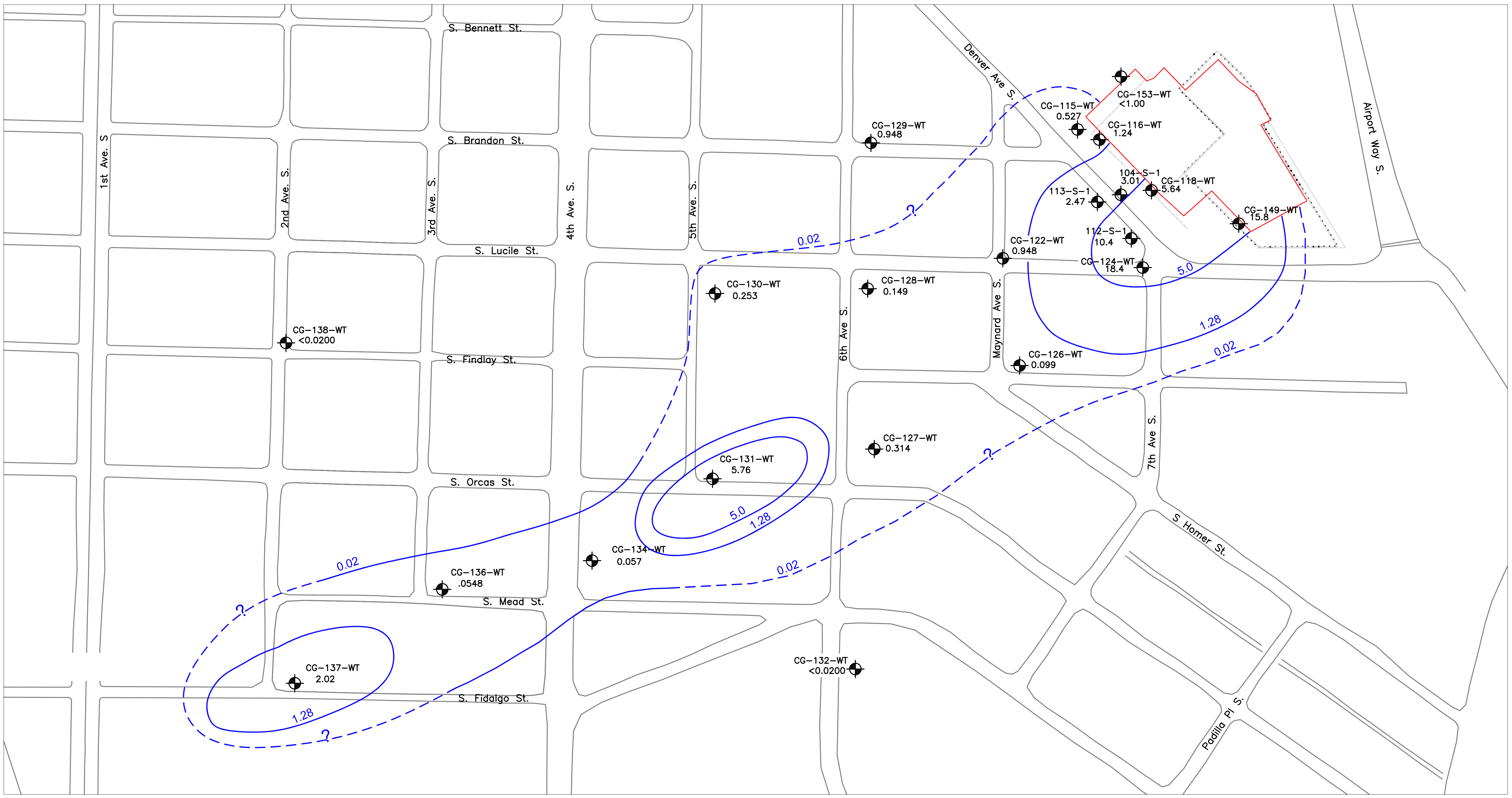
TRICHLOROETHENE
INTERMEDIATE SAMPLE INTERVAL

PSC Georgetown
Seattle, Washington

GEOMATRIX

Project No.	Figure
8770	**4-8**

S:\8770\027_DSiteWideFS\CAD\Fig4-8_TCE_Int_1stQtr05.dwg



LEGEND

⌖	MONITORING WELL	<1	CONCENTRATION NOT DETECTED ABOVE THE REPORTING LIMIT IN µg/L SHOWN
0.02	CONCENTRATION OF VC IN MICROGRAMS PER LITER (µg/L)	—	APPROXIMATE LOCATION OF BARRIER WALL
0.02 ╱	VC ISOCONCENTRATION CONTOUR IN µg/L		

N

0 235
APPROXIMATE SCALE (FEET)

VINYL CHLORIDE
WATER TABLE SAMPLE INTERVAL

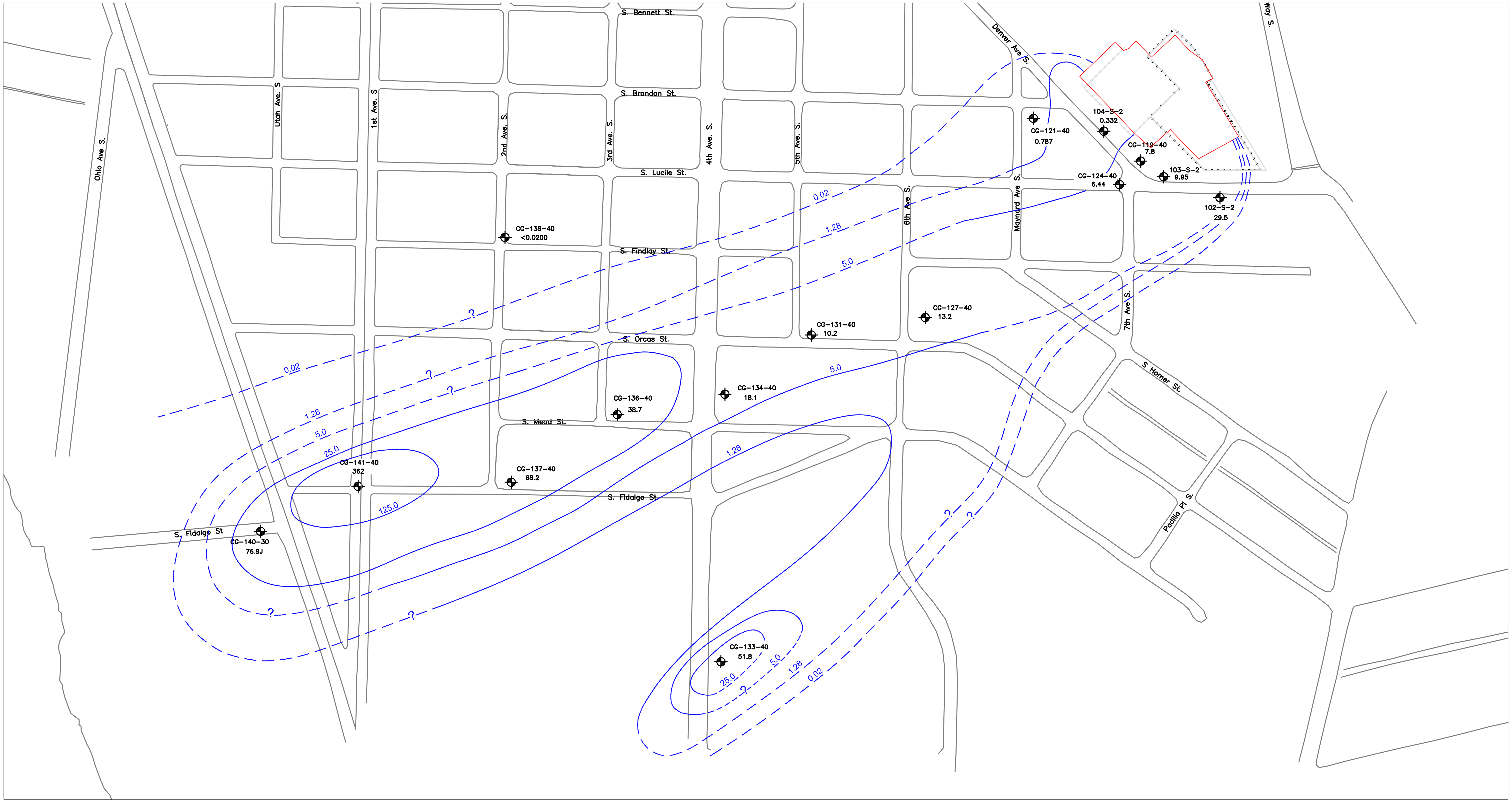
PSC Georgetown
Seattle, Washington

GEOMATRIX

Project No.
8770

Figure
4-9

S:\8770\027_DSiteWideFS\CAD\Fig4-9_VC_WT_1stQtr05.dwg



LEGEND

⊕	MONITORING WELL
0.02	CONCENTRATION OF VC IN MICROGRAMS PER LITER (µg/L)
0.02	VC ISOCONCENTRATION CONTOUR IN µg/L
<1	CONCENTRATION NOT DETECTED ABOVE THE REPORTING LIMIT IN µg/L SHOWN
	APPROXIMATE LOCATION OF BARRIER WALL

N

0 330

APPROXIMATE SCALE (FEET)

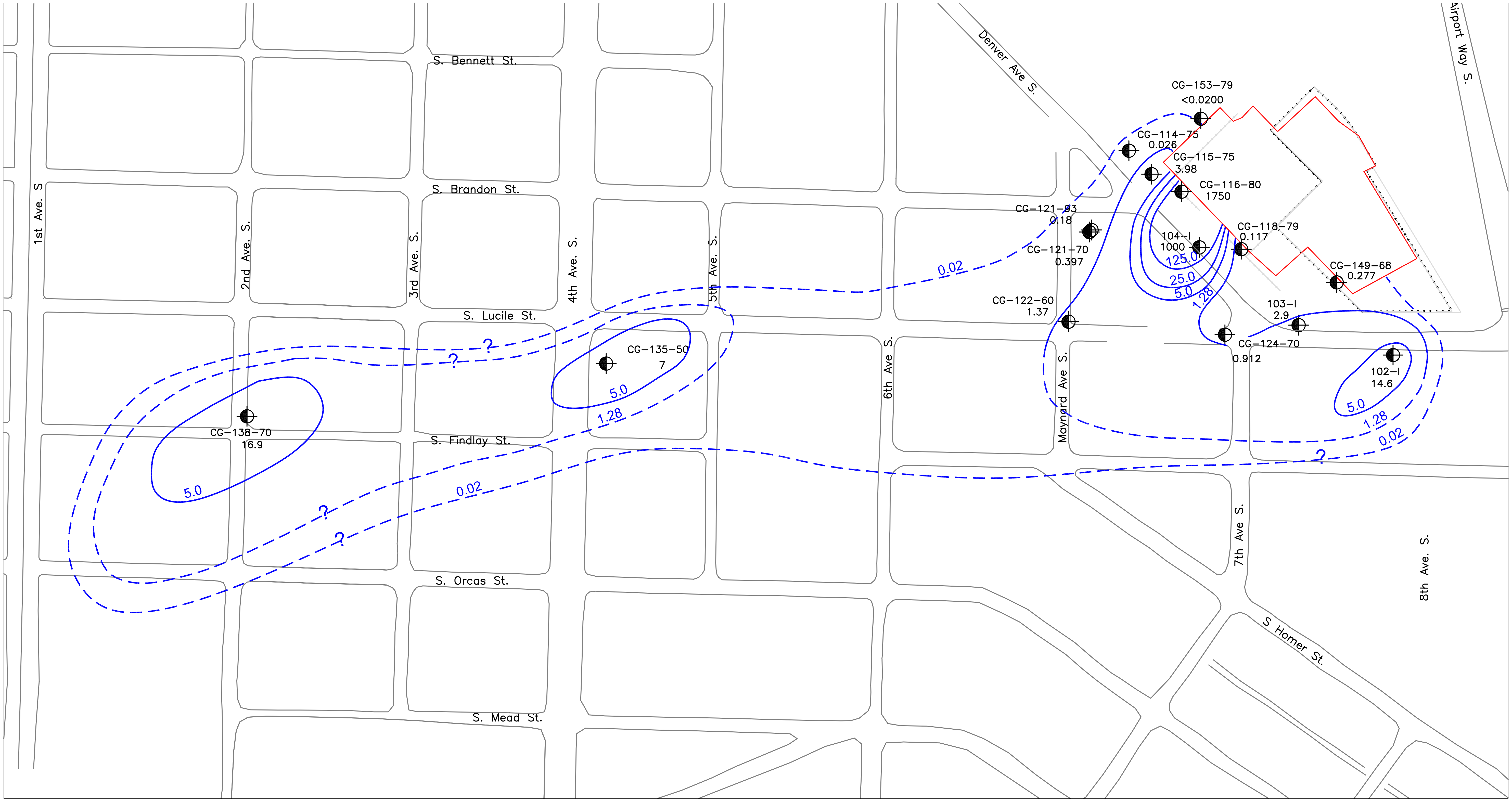
VINYL CHLORIDE
SHALLOW SAMPLE INTERVAL
PSC Georgetown
Seattle, Washington

GEOMATRIX

Project No.
8770

Figure
4-10

S:\8770\027_DSiteWideFS\CAD\Fig4-10_VC_SH2_1stQtr05.dwg



LEGEND

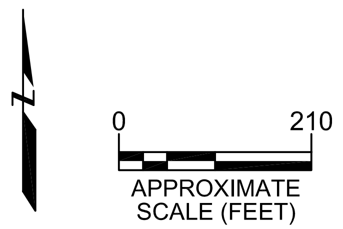
MONITORING WELL

0.02 CONCENTRATION OF VC IN MICROGRAMS PER LITER (µg/L)

0.02 VC ISOCONCENTRATION CONTOUR IN µg/L

<1 CONCENTRATION NOT DETECTED ABOVE THE REPORTING LIMIT IN µg/L SHOWN

APPROXIMATE LOCATION OF BARRIER WALL



APPROXIMATE SCALE (FEET)

VINYL CHLORIDE
INTERMEDIATE SAMPLE INTERVAL
PSC Georgetown
Seattle, Washington

GEOMATRIX

Project No.	Figure
8770	**4-11**

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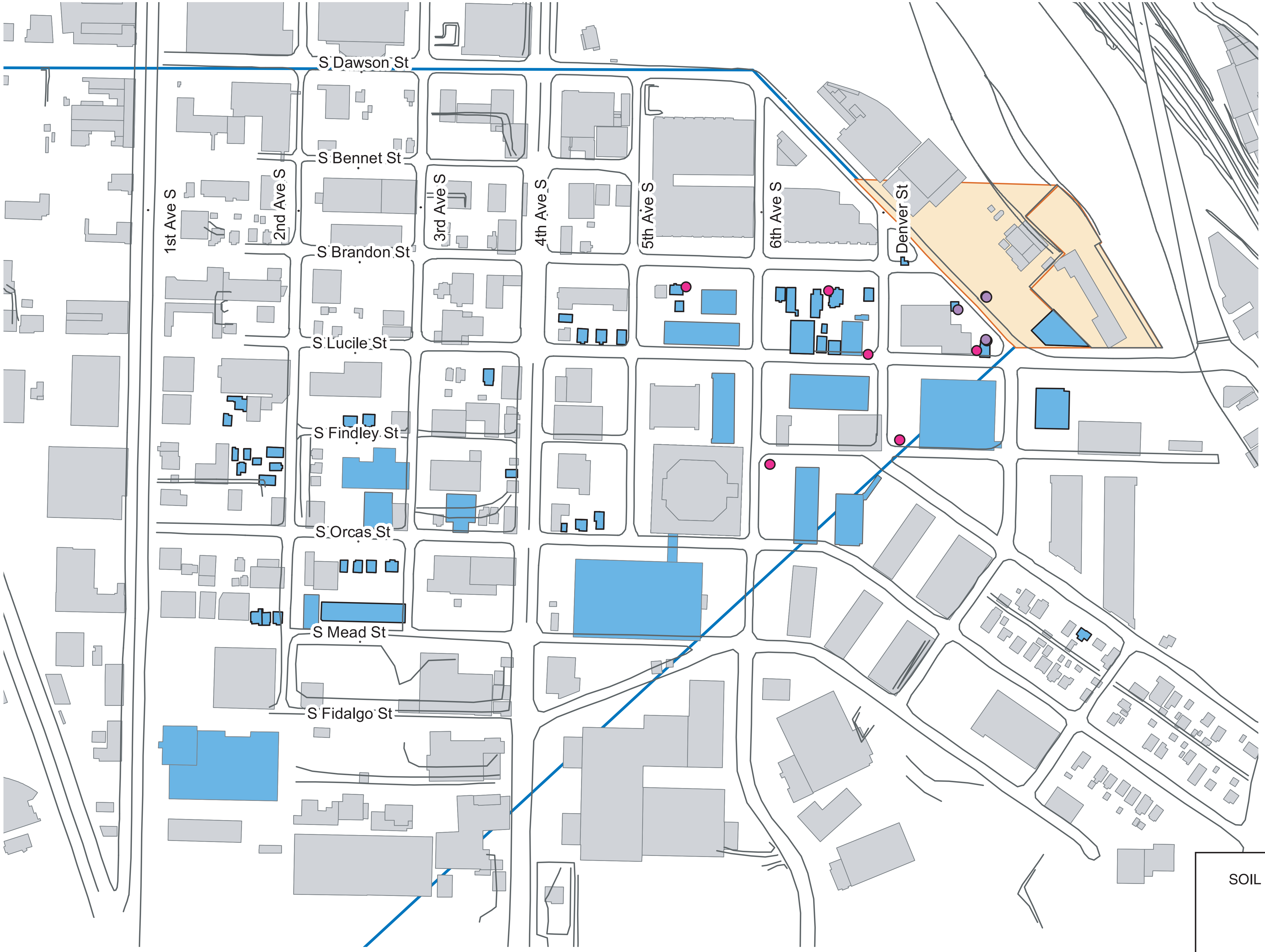


Legend

— Roads
🟧 Areas 1 and 2
▭ Area 3

Buildings

▨ All Other Buildings
🟦 Building With Sample Collected

GIVF Data (collected outside of buildings)

● Soil Gas (Permanent Port)
● Sample Collected During GIVF Investigation

N

0 85 170 340 510 680 Feet
Approximate Scale in Feet

Notes

- Field reconnaissance performed by Tasya Gray from PSC and Jenifer Hill from PTC to validate buildings and addresses on January 27th and February 7th 2003.

- PSC - Philip Services Corporation

- PTC - Pioneer Technologies Corporation

- Based on IPIM Tech Memos 1, 2, 3 and 4 (PSC, 2003).

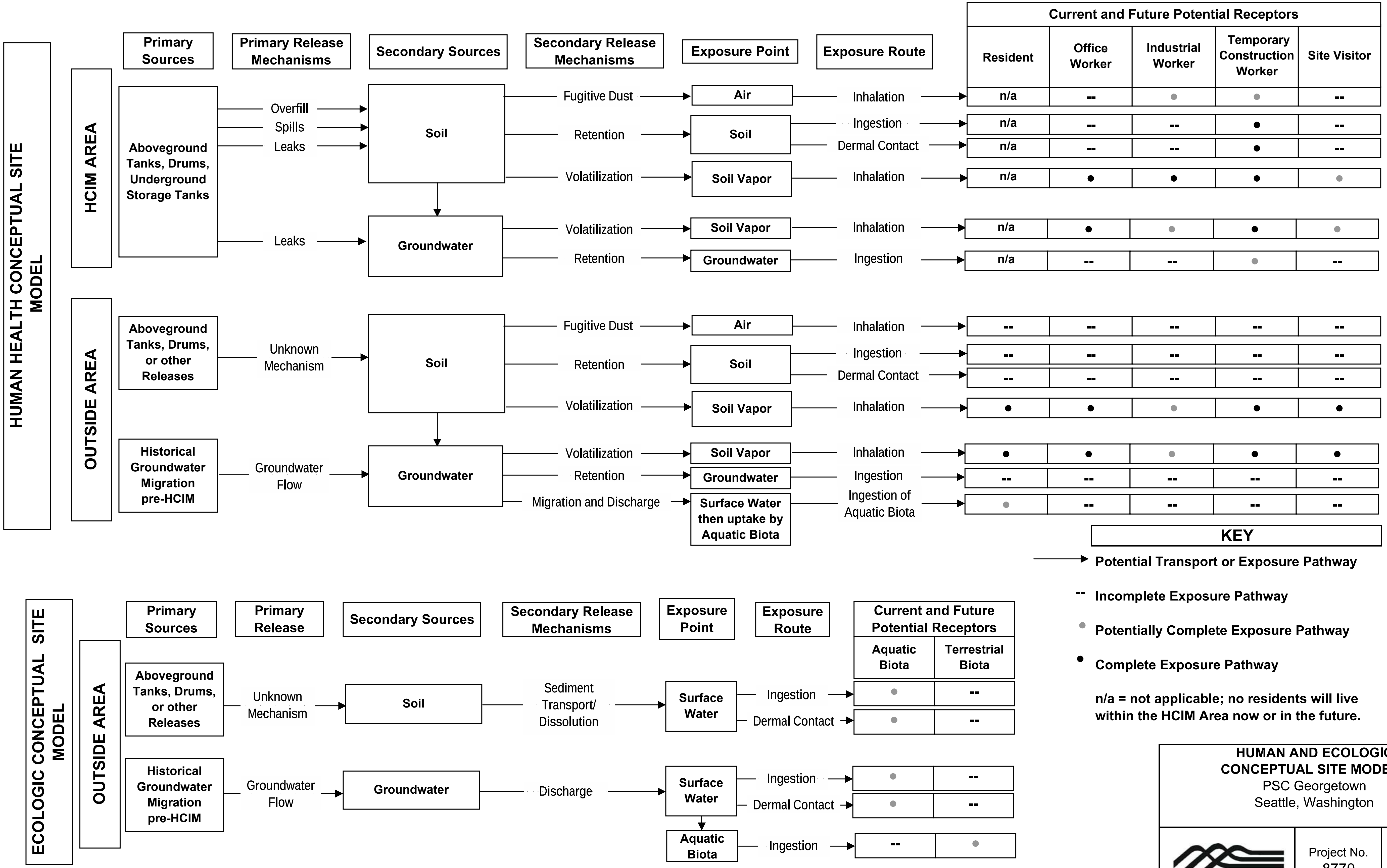
* Buildings noted as "Addresss Not Field Verified" have addresses associated with them from the City of Seattle, but have not been field checked by PSC and PTC.

SOIL GAS, INDOOR AIR, AND AMBIENT AIR
SAMPLING LOCATIONS
PSC Georgetown
Seattle, Washington

GEOMATRIX

Project No.	Figure
8770	4-12

S:\8770\027_DSiteWideFS\Illustrator\Figure 4-12_Soil Gas_Air Locatoins



HUMAN HEALTH CONCEPTUAL SITE MODEL

Area	Primary Sources	Primary Release Mechanisms	Secondary Sources	Secondary Release Mechanisms	Exposure Point	Exposure Route	Resident	Office Worker	Industrial Worker	Temporary Construction Worker	Site Visitor
HCIM AREA	Aboveground Tanks, Drums, Underground Storage Tanks	Overfill Spills Leaks	Soil	Fugitive Dust	Air	Inhalation	n/a	--	○	○	--
				Retention	Soil	Ingestion	n/a	--	--	●	--
						Dermal Contact	n/a	--	--	●	--
				Volatilization	Soil Vapor	Inhalation	n/a	●	●	●	○
		Leaks	Groundwater	Volatilization	Soil Vapor	Inhalation	n/a	●	○	●	○
				Retention	Groundwater	Ingestion	n/a	--	--	○	--
OUTSIDE AREA	Aboveground Tanks, Drums, or other Releases	Unknown Mechanism	Soil	Fugitive Dust	Air	Inhalation	--	--	--	--	--
				Retention	Soil	Ingestion	--	--	--	--	--
						Dermal Contact	--	--	--	--	--
				Volatilization	Soil Vapor	Inhalation	●	●	○	●	●
	Historical Groundwater Migration pre-HCIM	Groundwater Flow	Groundwater	Volatilization	Soil Vapor	Inhalation	●	●	○	●	●
				Retention	Groundwater	Ingestion	--	--	--	--	--
				Migration and Discharge	Surface Water then uptake by Aquatic Biota	Ingestion of Aquatic Biota	○	--	--	--	--

Current and Future Potential Receptors

ECOLOGIC CONCEPTUAL SITE MODEL

Area	Primary Sources	Primary Release	Secondary Sources	Secondary Release Mechanisms	Exposure Point	Exposure Route	Aquatic Biota	Terrestrial Biota
OUTSIDE AREA	Aboveground Tanks, Drums, or other Releases	Unknown Mechanism	Soil	Sediment Transport/ Dissolution	Surface Water	Ingestion	○	--
						Dermal Contact	○	--
	Historical Groundwater Migration pre-HCIM	Groundwater Flow	Groundwater	Discharge	Surface Water	Ingestion	○	--
						Dermal Contact	○	--
					Aquatic Biota	Ingestion	--	○

Current and Future Potential Receptors

KEY

- → **Potential Transport or Exposure Pathway**
- -- **Incomplete Exposure Pathway**
- ○ **Potentially Complete Exposure Pathway**
- ● **Complete Exposure Pathway**

n/a = not applicable; no residents will live within the HCIM Area now or in the future.

HUMAN AND ECOLOGIC
CONCEPTUAL SITE MODELS
PSC Georgetown
Seattle, Washington

GEOMATRIX

Project No.
8770

Figure
4-13

5.0 REMEDIATION CONSIDERATIONS AND OBJECTIVES

Because the SWFS for the Facility must address two very different areas (the enclosed HCIM Area and the Outside Area), remedial alternatives for these two areas will need to consider a number of factors specific to each particular area. This section briefly outlines these remediation considerations.

5.1 HCIM AREA REMEDIATION CONSIDERATIONS

Several features specific to the HCIM Area will affect remediation and development of alternatives. The considerations for the HCIM Area are discussed in the following subsections based on the various physical, land use, chemical, interim measure, regulatory, and technology related considerations.

5.1.1 Physical, Chemical, and Land Use Characteristics

The HCIM Area is enclosed by a low-permeability subsurface barrier wall and a groundwater recovery system (the HCIM). The HCIM includes proven engineering controls that will prevent migration of groundwater from the HCIM Area. Remediation technologies and alternatives for the HCIM Area must be compatible with the HCIM.

This remediation area includes the source areas associated with the Facility and also has the highest observed constituent concentrations in both soil and groundwater. Groundwater concentrations suggest that DNAPL may be present within the HCIM Area, although DNAPL has not been observed in any of the many borings or monitoring wells installed as part of the extensive RI efforts. The site conceptual model indicates that DNAPL likely is distributed throughout the soil profile as small localized concentrations of product associated with the numerous silt lenses within the HCIM Area. Remediation experience at numerous DNAPL sites has shown that, except under special circumstances, it is not practicable to remediate DNAPL (EPA, 1993) to low cleanup levels (e.g., to levels protective of drinking water uses). In addition, within the HCIM Area there are numerous COCs, including VOCs, SVOCs, TPH, PCBs, and metals. Any remedial alternatives considered must address the full range of COCs and the risks associated with them. For example, a technology designed to address VOCs may not address or be compatible with PCBs.

The HCIM Area has a long history of industrial land use and is expected to continue to be used for either industrial or commercial use in the foreseeable future. The HCIM Area currently is capped with either low-permeability microsilica concrete (the Facility) or asphalt. Practicable remedial alternatives, including an alternative limited to maintenance of the existing cap and institutional controls, are evaluated in this SWFS to ensure that risks associated with HCIM Area soils are reduced or controlled to acceptable levels.

5.1.2 Interim Measures

Two interim measures have been conducted for the Facility. The COCs within the HCIM Area currently are being hydraulically controlled and contained by a combination of the subsurface barrier wall, a groundwater extraction and treatment system, and a low-permeability cap. The broad range of COCs within the HCIM Area are distributed over a large portion of the HCIM Area, a considerable thickness of surficial soils, and the entire thickness of the aquifer above the silt unit aquitard. SVE was conducted for several years on the limited vadose zone soils, and it was successful in removing approximately 19,000 pounds of VOCs before its effectiveness diminished to a point of limited returns. It is likely that DNAPL remains in source areas but as diffused stringers or blebs of product adsorbed or perched on the numerous discontinuous silt stringers found throughout the shallow sand and the intermediate sand and silt units above the silt aquitard. Concentrations of TCE have been found that indicate DNAPL could be present at depths of 90 feet in the northwestern portion of the HCIM Area.

Few, if any, remediation technologies are capable of effectively addressing the breadth and depth of COCs present in the HCIM Area. With the barrier wall, cap and pump and treatment system in place, COCs within the HCIM Area are effectively contained and migration pathways have been controlled. The groundwater withdrawal is removing COCs from this source area; however, reduction in COCs within the HCIM Area due to groundwater pumping will be a very slow process.

5.1.3 Regulatory Considerations

MTCA (173-340-360) requires that source areas be addressed using permanent solutions to the extent practicable. Permanent solutions are further defined as “the degree to which the [remediation] alternative permanently reduces the toxicity, mobility or volume of hazardous substances, including the adequacy of the alternative in destroying the hazardous substance releases and sources of releases …”. Stated in simple terms, Ecology’s goal in obtaining a permanent solution is to eliminate the potential risk that a hazardous substance can remobilize in the future if a non-permanent remedy fails. However, Ecology recognizes that permanent solutions are not always practical, and MTCA has provided for “exceptions” to the goal of permanent solutions to allow for non-permanent remedies.

MTCA 173-340-360 (3) outlines the identification of permanent solutions and provides a framework for exceptions, including conducting a disproportionate cost analysis (173-340-360 (3) (e)). A classic example of a site that would use a disproportionate cost argument is a landfill. Landfills contain large quantities of waste material and the waste is typically highly variable. The only permanent solution for a landfill site is excavation and off-site disposal at another landfill. The cost of doing a complete landfill excavation and removal is disproportionate to any benefit gained over simply capping and permanently containing the landfill materials. As a result, EPA has recognized that landfill removals are not practical and have adopted a "presumptive remedy" for all landfill sites that assumes containment by capping, combined, if necessary, with groundwater/leachate control and landfill gas management.

5.1.4 Disproportionate Cost Analysis

The MTCA regulations will be followed to determine whether further remediation is warranted inside the HCIM Area following the disproportionate cost analysis. The HCIM Area is similar to the landfill example. As outlined above, the COCs within the HCIM Area are highly varied in nature and broadly distributed over the entire HCIM Area and to a depth of approximately 90 feet, of which about 80 feet are below the water table. This results in on the order of 300,000 cubic yards of soil that are impacted with a broad range of COCs having substantially different characteristics. The soil has been impacted either directly (from soil contamination or DNAPL) or indirectly in that the soil contains contaminated groundwater.

A variety of technologies could be applied to soils and groundwater within the HCIM Area; however, there is not a single technology or even combination of technologies that would successfully reduce concentrations of the broad range of COCs to attain below cleanup levels over the full areal and vertical extent of impacted soils. Implementation of any of these technologies would be difficult, be extremely costly, and result in potential for short term risks to on- site workers and the public. Unless cleanup levels can be met, there would only be nominal gain in risk reduction over the existing HCIM. Arguments can be made that some reduction in contaminant concentrations would be beneficial, but the key risk drivers at the Facility are the halogenated VOCs, which may be distributed throughout a broad cross section of the hydrostratigraphy in DNAPL form. EPA has shown that diffuse DNAPLs in heterogeneous soils, such as the interbedded silts and sands at the Facility, cannot be effectively remediated. As long as DNAPL exists within the subsurface, concentrations of VOCs in the groundwater will continue to be elevated and the HCIM will need to remain in place. In other words, even an extremely costly and disruptive remediation approach inside the HCIM would not significantly reduce COC concentrations and resultant risks to the point that the HCIM can be removed. As a result, there is nothing to be gained by implementation of any additional remedy inside the barrier wall area even at a very high cost. Ultimately, the HCIM is critical to long-term control of COC migration from the Facility.

MTCA's disproportionate cost analysis can be performed quantitatively or qualitatively. For this SWFS, the qualitative approach to evaluating a case for a disproportionate cost analysis is appropriate. To help in this analysis, the EPA guidance (EPA, 1993) on technical impracticability in evaluating reduction in DNAPL was also used. EPA has developed guidance to evaluating the potential benefits of source removal, including DNAPL. The criteria for evaluating DNAPL removal benefits are outlined below.

- Reduction of DNAPL mobility – It is beneficial to perform DNAPL reduction if the DNAPL is mobile and leaving it in place results in an increase risk that the DNAPL will continue to migrate. At the Facility, DNAPL migration appears to have stabilized prior to the construction of the subsurface barrier wall. With the wall in place, there is no risk of DNAPL migration or migration of any other Facility contaminants.

- Reduced Longevity – EPA guidance says that the up-front costs and effectiveness of source removal must be compared to the long-term costs (O&M costs) of controls without source removal. This estimate can use the net-present worth cost basis to determine if a true benefit can be realized by upfront source removal. For the SWFS, the technology to treat COCs within the barrier wall to cleanup levels is not available. The best scenario would be a partial reduction in concentrations; however, after implementing any technology, halogenated VOCs would still remain in the subsurface as DNAPL and groundwater impacts would still present a risk of migration. Completing extensive and costly source reduction would not be sufficient to allow removal of any of the HCIM measures; therefore, the costs of implementing such source removal would add costs without any benefit of reduced costs of the HCIM operation.

- Reduction of contaminant mass discharge to receptors – The HCIM already addresses migration of COCs to receptors. Because of the widespread nature of the DNAPL, partial source removal would not be effective in reducing concentrations of COCs in groundwater significantly; therefore, there would be no net gain in benefits for the dollars spent.

- Enhanced efficiency of complementary remediation technologies – If the HCIM did not exist, there might have been some benefit if source reduction could reduce groundwater concentrations to levels that could be addressed by another remediation alternative such as monitored natural attenuation (MNA). However, partial source reduction would not reduce COCs sufficient to use complementary technologies other than containment; the existing HCIM would still be needed, thereby providing no benefit. In fact, the analysis indicates that the barrier wall combined with MNA in the area outside the wall is effective in controlling groundwater migration without the need for the groundwater pump and treatment technology. Therefore long-term operating costs for the existing HCIM can be minimized with the existing system. Source removal would not have any impact on these long-term operation costs.

- Economic benefits – EPA further provides guidance on evaluating other potential economic benefits including:
    - Can you obtain earlier site closure and return of groundwater to beneficial use? – As outlined above, there is no technology that will allow the HCIM Area to be "clean closed" in the foreseeable future.
    - Can you lower annual overall life cycle costs? – All potential source reduction technologies are costly, and none of them would result in any reduction in life cycle costs.
    - Can long-term liability and accrued environmental reserves be removed? – Since there is not a technology or group of technologies that could clean up the HCIM Area, the long-term liability would not be reduced significantly.
    - Will the land value be enhanced? – The HCIM Area will remain environmentally tainted for a very long time with or without additional source removal. No increase in value or decrease in liability would result from partial source removal.
    - Will future land use transaction be easier due to fewer encumbrances? – Performing costly source removal would not be successful in meeting cleanup goals or in reducing any institutional controls on the HCIM Area, nor would future land use transactions become easier.
- Environmental Stewardship – From a stewardship basis, it would seem that reduction in COC concentrations should be considered the "right thing to do" and is consistent with Ecology policy. However, at the HCIM Area, source concentration reduction would not have an appreciable positive impact to the environment or provide reduction in long-term risk even if extremely costly remedial measures were implemented. In fact, implementation of source control/reduction technologies would greatly increase the risk of accidents, spills, and releases during the implementation period, and some technologies could risk the barrier wall integrity or upset natural degradation processes that are occurring. For this case, like the landfill example, further remediation of the source would provide no appreciable benefits.

The existing HCIM at the Facility is the best long-term remediation option to address the broad range of COCs found throughout the areal and vertical extent of the HCIM Area. Subsurface barrier walls are true long-term solutions and have proven effective for the entire period of their use as containment features, which is at least 50 years. Caps have an equally long life span and can be adapted to a variety of site uses. The benefits of the groundwater extraction are questionable at the Facility because the primary migration pathway of VOCs with the barrier wall in place is by vapor diffusion. Since the halogenated VOCs primarily degrade by anaerobic processes, shutting down the groundwater extraction system would enhance the reducing conditions in the HCIM Area and could be the best and most efficient approach to long-term reductions in VOC concentrations. Any COC reductions would be slow and not result in cleanup levels being met in a reasonable time frame.

5.1.5 Point of Compliance

For contaminated soils, the default MTCA POCs are as follows:

- Soils <u>throughout the site</u> for cleanup levels[1] based on the protection of groundwater;
- Soils <u>throughout the site</u>, for cleanup levels based on the protection of indoor air (via vapor intrusion);
- Soils <u>throughout the site to 15 feet bgs</u>, for cleanup levels based on protection of the direct contact pathway.

However, according to WAC 173-340-740(6)(f), cleanup action alternatives for contaminated soils may be judged to attain cleanup standards even if cleanup levels are not met at these POCs, if:

- The alternatives are permanent to the maximum extent practicable;
- The alternatives protect human health and the environment;
- Institutional controls are included as part of the alternatives, which prohibit or limit activities that could interfere with the long-term integrity of any containment system; and
- Compliance monitoring is included as part of the alternatives and is designed to ensure the long-term integrity of any containment systems.

As discussed above, it is not practicable to remediate soils throughout the HCIM Area. Costs associated with remediation are disproportionate with potential benefits. Alternatives, or components of alternatives, evaluated in the SWFS include:

---

[1] For the FS, it will be assumed that the cleanup levels for contaminated site soils will be Method C, as described in WAC 173-340-745(5).

- Capping to protect workers from direct contact with contaminated soils;
- Capping to protect groundwater from additional contamination due to infiltration through the on-site vadose zone;
- A monitoring program to assess the effectiveness of the engineered components;
- Institutional controls to require vapor intrusion mitigation systems for any occupied buildings on the Facility;
- Institutional controls to prevent residential use of the Facility; and
- Institutional controls to prevent interference with the functioning of the barrier wall.

These components are permanent to the extent practicable, given the issues specific to the HCIM Area identified above. These components also are protective of human health and the environment because they contain affected soil and groundwater and provide physical barriers to prevent direct contact. These components will include institutional controls designed to prohibit direct contact and to maintain the integrity of engineered controls, and a monitoring program to ensure the effectiveness of the engineered controls would be maintained.

In addition, the HCIM Area is located in a vital economic center of Seattle, and the property has numerous future commercial/industrial uses. Therefore, remedial alternatives for the HCIM Area must be compatible with active, ongoing industrial land use.

5.2 OUTSIDE AREA REMEDIATION CONSIDERATIONS

Remedial alternatives for the Outside Area must address many complex issues. The area is densely developed and includes private and public landowners. Land uses are varied and include many residences and both commercial and industrial businesses. Many active subsurface utilities are present in this area. The large number of independent property owners and tenants significantly complicates gaining access to the properties in order to perform remediation. Access agreements typically require extended negotiations, significantly increase costs, and prevent timely implementation of any remedial action requiring extensive access to the properties. Remedial alternatives which rely on less or fewer property-owner approvals for access will be generally preferred over those which require more.

5.2.1 Non-PSC Source Areas

Characterization data presented in the RI Report indicate that the plume emanating from releases that occurred at the Facility intermingle with other plumes originating from non-PSC source areas downgradient of Fourth Avenue South. Many of the constituents detected in these non-PSC plumes are the same as those released from the Facility and include TCE and its breakdown products. The presence of these downgradient sources areas further complicates the remediation of the Facility releases. Based on discussions with Ecology, the scope of the SWFS has been limited to the area hydrogeologically upgradient of Fourth Avenue South. Limiting the scope to this area removes several non-Facility source areas from this SWFS; however, groundwater characterization data collected between the Facility and Fourth Avenue South appear to show that there may be non-Facility source areas present within the scope of the SWFS.

The presence of the non-Facility sources can affect the quality of groundwater discharged to the Duwamish Waterway. As discussed in Section 3, groundwater remediation levels have been established for use in this SWFS. These remediation levels address only releases from the Facility, and were established to ensure that releases from the Facility do not adversely affect surface water. The remediation levels do not consider the presence of non-Facility source areas downgradient from the Facility. Available groundwater monitoring data indicate that these remediation levels have already been attained for releases from the Facility, thereby indicating that the Facility releases do not adversely affect nearby surface water. Remedial alternatives considered for the SWFS will not consider any effects non-Facility source areas would have on groundwater quality.

5.2.2 Point of Compliance

In accordance with state regulations, a permanent groundwater alternative will be chosen in the SWFS to achieve cleanup levels at the standard POC if a permanent action is deemed practicable.[2] If no permanent action at the standard POC is practicable, alternatives must be shown to meet WAC 173-340-360(2)(c)(ii). These alternatives must not rely primarily on dilution and dispersion unless the incremental costs of any active measures implemented, over the costs of dilution/dispersion, grossly exceed the incremental degree of benefit.

As established in the RI Report, groundwater within the SWFS Area is nonpotable. Therefore, cleanup levels for the Outside Area need to be protective of surface water, direct contact, and the inhalation pathway. The SPOC for the Outside Area would encompass all groundwater within the Outside Area. In order to establish a CPOC for groundwater in the Outside Area, it must be demonstrated that the following requirements of WAC 173-340-720(8)(d)(ii) are met:

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[2] or otherwise determined to be in the public interest.

- that a demonstration must be made in the FS report that it is not practicable to meet cleanup levels at points upgradient of the CPOC;
- that monitoring is conducted to assess the long-term performance of the selected cleanup action using this CPOC;
- that notification of such a proposed CPOC is mailed to natural resource trustees, the Washington State Department of Natural Resources, and the U.S. Army Corps of Engineers. The notification shall solicit comments; and
- that all affected property owners between the source of contamination and the CPOC agree to the location in writing.

It is not practicable to attain groundwater cleanup levels adjacent to or immediately downgradient of the barrier wall for the following reasons:

- affected groundwater within the Outside Area lies beneath numerous different property owners, severely restricting access to implement remediation;
- portions of the barrier wall are located on non-PSC property, limiting the potential to install and sample monitoring wells; and
- areas with elevated COC concentrations in groundwater are present outside the barrier wall and beneath non-PSC properties (including occupied buildings).

For these reasons, it is anticipated that a CPOC will be established along the west side of Denver Avenue South and the south side of South Lucile Street. This location is within a public thoroughfare, which simplifies access for installation and sampling of monitoring wells. Several wells are already present at this CPOC location, and it is expected that access for installation of additional wells can be obtained within a reasonable time. Additionally, the two private property owners located between the Facility and the proposed CPOC have already agreed to this location for a CPOC. The remaining notifications required under MTCA will be done as part of the CAP, after approval of the final SWFS Report.

Groundwater cleanup action alternatives, therefore, will be designed to attain remediation levels (based on protection of surface water) and cleanup levels (based primarily on protection of surface water and, for shallow groundwater, indoor air[3]) at the proposed CPOC. Prospective alternatives that are incapable of attaining cleanup levels throughout this area within a reasonable timeframe must be considered interim action alternatives, or simply components of more comprehensive alternatives that attain the cleanup standards.

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[3] via vapor intrusion

5.2.3 Interim Measures

One of the two primary exposure pathways of concern for the Outside Area is migration of VOCs in vapors released from affected groundwater. Vapors can accumulate within surface structures, potentially resulting in exposure via inhalation. PSC is currently implementing IPIMs downgradient of the Facility. These IPIMs, in conjunction with other remedial measures, would meet the remedial objectives (if the measures continue to be implemented, as needed, in the future). As noted above, other potential remedial alternatives considered for the Outside Area will be evaluated against one another to identify the preferred remedial alternative.

5.2.4 General Considerations

Data presented in the RI Report indicate that natural degradation and attenuation of groundwater COCs is active within the groundwater plume downgradient of the Facility. Due to the nature and extent of affected groundwater, the complexity in gaining access for remediation, and the potential presence of co-mingled plumes originating from other sources, natural attenuation or enhanced natural attenuation of groundwater constituents is expected to be a significant component of the remediation approach. Therefore, remediation technologies are assessed and judged as to their respective abilities to enhance, or at least not interfere with, remediation in areas where natural attenuation is effectively reducing the concentrations of the most critical COCs.

Future land use in the Outside Area is expected to remain mixed. Therefore, the remediation technologies considered for this remediation area must be compatible with residential, commercial, and industrial land use in an urban environment. The potentially applicable remediation technologies considered for the Outside Area will be combined with appropriate institutional controls to develop remedial alternatives for the Outside Area that will address remedial objectives as well as the significant constraints described above.

5.3 REMEDIATION OBJECTIVES

The remediation objectives presented in the RI Report and approved by Ecology are used for the SWFS. A summary of the remediation objectives presented in the RI Report follows:

- Prevent direct contact with surface or subsurface soil and inhalation of dust from surface soil affected with COCs at concentrations that exceed cleanup levels in the HCIM Area or reduce the risks associated with these exposure pathways to acceptable levels.

- Reduce risks associated with inhalation of vapors from affected soil or groundwater to acceptable levels established in accordance with MTCA regulations.

- Protect human and ecological receptors by reducing COC concentrations in affected groundwater to cleanup levels based on protection of surface water.

6.0 POTENTIALLY APPLICABLE REMEDIATION TECHNOLOGIES

Section 6 presents the potentially applicable remediation technologies considered in this SWFS to address the COCs in soil, groundwater, and vapor pathways for the HCIM and Outside Areas. These remediation technologies have been selected for potential implementation within the SWFS Area, and are not intended for potential implementation in the co-mingled plume area downgradient of the SWFS Area. Because of the similarities in Facility COCs and applicable remediation technologies, the technologies are described for both the HCIM Area and the Outside Area together. Institutional controls for both soil and groundwater are discussed in Section 6.3. Technologies were selected and evaluated relative to the specific remediation considerations for the two remediation areas and were screened against the evaluation criteria listed in Section 6.5. Section 6.6 discusses the results of the screening process and lists the retained technologies. Because this is intended to be a focused FS effort, only those technologies that show the greatest potential to satisfy the Site remediation objectives were retained for inclusion in the development of remedial alternatives. Tables 6-1 through 6-6 present the remediation technologies that were considered for the SWFS and the technology screening results.

6.1 SOIL REMEDIATION TECHNOLOGIES

Several proven remediation technologies have been considered as appropriate candidates for remediation of the HCIM and Outside Area soils. These technologies include both in situ and ex situ biological, chemical, and physical processes that would result in either destruction, removal, or containment of contaminants. In situ remediation technologies for soil are described in Section 6.1.1 and ex situ technologies in Section 6.1.2. These potentially applicable remediation technologies are described in the subsections below and listed in Tables 6-1 and 6-2.

6.1.1 In Situ Soil Remediation Technologies

In situ technologies for remediation of soil are implemented without excavation and with minimal disturbance to soil. These technologies rely upon techniques to alter subsurface conditions and promote remediation of contaminants present in the subsurface. In situ technologies are generally better suited for remediation in highly developed areas, active production facilities, and areas with deep or widely distributed contaminants.

6.1.1.1 Bioventing

Bioventing is an in situ technology that stimulates the natural biodegradation of aerobically degradable compounds in soil by providing oxygen to existing soil microorganisms. In contrast to SVE, bioventing uses low air flow rates to provide only enough oxygen to sustain microbial activity. Oxygen is most commonly supplied through direct air injection into residual contamination in soil, frequently through a system of small-diameter wells or permanent injection points. In addition to degradation of adsorbed fuel residuals, volatile compounds are biodegraded as vapors move slowly through biologically active soil.

Soil permeability to air must be adequate to permit the flow of oxygen throughout the contaminated soil mass. Excess soil moisture or a high water table can inhibit this movement of air. Soil must also contain the basic nutrients necessary to sustain an active microbial culture necessary to degrade contaminants. Bioventing is most effective on fuel hydrocarbons and non-halogenated volatile organic compounds. Its applicability to halogenated hydrocarbons, high molecular weight SVOCs, PCBs, and inorganics is very limited. Monitoring for soil vapors must be conducted to ensure that volatile compounds do not migrate into basements or living spaces. Within the HCIM Area, there is very little available vadose zone to implement bioventing, and the technology will not address the key COCs (the halogenated VOCs). In addition, within the HCIM Area the vadose zone soils also contain PCBs, metals, and SVOCs, which would not be degraded by bioventing.

6.1.1.2 Enhanced Bioremediation

Enhanced bioremediation is an in situ process in which indigenous microorganisms (e.g., existing soil fungi, bacteria, and other microbes) degrade organic contaminants found in site soil, converting them to innocuous end products. Nutrients, oxygen, or other amendments may be used to enhance bioremediation and contaminant desorption from subsurface materials. In the presence of sufficient oxygen (aerobic conditions) and other nutrient elements, microorganisms will ultimately convert many organic contaminants to carbon dioxide, water, and microbial cell mass.

Enhanced bioremediation of soil typically involves the percolation or injection of groundwater or uncontaminated water mixed with nutrients and saturated with dissolved oxygen. Sometimes acclimated microorganisms (bioaugmentation) and/or alternative oxygen sources such as hydrogen peroxide or above-ground aeration chambers are also used. An infiltration gallery or spray irrigation is typically used to address shallow impacted soils, and injection wells are frequently used for deeper contaminated soils.

Enhanced bioremediation is a long-term technology that may require several years to accomplish remedial goals. In some cases, bioremediation rates diminish before remediation goals are met, leaving lower concentration residuals in place. Enhanced bioremediation has been demonstrated effective for non-halogenated VOCs and non-halogenated SVOCs as well as fuel hydrocarbons. It has not been proven effective on chlorinated compounds in soil. Frequently, groundwater capture systems are required to capture infiltrating aqueous solutions that are applied to stimulate biological activity.

6.1.1.3 Chemical Oxidation

In situ chemical oxidation involves the application of chemical oxidizing compounds such as permanganate, ozone, Fenton’s Reagent, or hydrogen peroxide onto contaminated soils and directly oxidizing the organic contaminants, thereby converting the organics to nonhazardous compounds that are more stable, less mobile, and/or inert. These oxidants have been able to cause the rapid and complete chemical destruction of many toxic organic chemicals; other organics are amenable to partial degradation as an aid to subsequent bioremediation. In general, the oxidants have been capable of achieving high treatment efficiencies (e.g., > 90 percent) for unsaturated aliphatic (e.g., TCE) and aromatic compounds (e.g., benzene), with rapid reaction rates in ideal conditions and in homogeneous soils. Field applications have clearly affirmed that matching the oxidant and in situ delivery system to the COCs and the site hydrogeologic conditions is the key to successful implementation and achieving performance goals.

The rate and extent of oxidation of a target COC are dictated by the properties of the chemical itself and its susceptibility to oxidative degradation as well as the matrix conditions, most notably pH, temperature, the concentration of oxidant, and the concentration of other oxidant-consuming substances such as natural organic matter and reduced minerals as well as carbonate and other free radical scavengers. Given the relatively indiscriminant and rapid rate of reaction of the oxidants with reduced substances, the method of delivery and distribution throughout a subsurface region is of paramount importance. Complicated hydrostratigraphic conditions within the HCIM Area, such as interbedded silts and sands, make delivery and distribution more difficult. Oxidant delivery systems often employ vertical or horizontal injection wells or direct push injection points with forced advection to rapidly move the oxidant into the subsurface.

Oxidation reactions can decrease the soil pH if the system is not buffered effectively. Other potential oxidation-induced effects include colloid genesis leading to reduced permeability, mobilization of redox-sensitive and exchangeable sorbed metals, possible formation of toxic byproducts, evolution of heat and gas, and interference with biological activity.

6.1.1.4 Soil Flushing

In situ soil flushing is the extraction of contaminants from the soil with water or other suitable aqueous solutions. Soil flushing is accomplished by passing the extraction fluid through in-place soils using injection wells, an injection gallery, or other infiltration process. Extraction fluids must be recovered from the underlying aquifer and treated, recycled, or disposed as waste. Flushing can be accomplished using water mixed with a variety or extracting fluids such as surfactants or organic solvents. A groundwater recovery system to capture the extraction fluid as well as desorbed contaminants must be operated in conjunction with this flushing operation. This technology has been proven most effective on inorganics, with some limited success on VOCs and SVOCs.

Recovered groundwater and flushing fluids with the desorbed contaminants would need treatment to meet appropriate pretreatment standards prior to discharge to the King County POTW. To the maximum extent practical, recovered fluids are typically reused in the flushing process. The separation of surfactants or organic solvents from recovered flushing fluid for reuse in the process is a major factor in the cost of soil flushing. Treatment of the recovered fluids results in process sludge and residual solids, such as spent carbon and spent ion exchange resin, which must be appropriately treated before disposal. Air emissions of volatile contaminants from recovered flushing fluids should be collected and treated, as appropriate, to meet applicable regulatory standards. Residual flushing additives in the soil may be a concern.

Soil flushing has been successfully applied on only a few sites and is not generally commercially available. The duration of soil flushing process is generally short to medium term. For the HCIM, this technology does not have much application due to the fact that the key COCs are contaminants not particularly amenable to soil flushing.

6.1.1.5 Soil Vapor Extraction

The use of in situ SVE has a long and successful history for remediation of source area soils within the vadose zone. SVE has been proven to reduce volatile constituent levels in the subsurface by removal of soil gas, desorption of VOCs from soil and NAPL, and volatilization of constituents from groundwater. Systems for implementing SVE typically consist of several vapor extraction wells installed in the source area vadose zone to collect soil gas. The soil gas is usually drawn from the vapor extraction wells to a manifold using a blower, with the blower discharge typically treated by carbon adsorption or thermal oxidation.

In the HCIM Area soil, SVE would target the residual vadose zone VOC source to remove TCE, which is likely a continuing source of groundwater contamination for both TCE and VC. Removal of TCE from the vadose zone can be rapid, usually being complete within one to two years for a properly designed SVE system. Implementation of SVE is intrusive in that many wells and a gas collection manifold are typically required. Off-gas treatment is typically included to limit emissions and potential exposure of on-site workers and off-site receptors. An air permit may be required to install and operate an SVE system. The vadose zone in the HCIM Area is generally less than 10 feet thick, which limits the effectiveness of this technology in addressing the source area. This technology was successfully implemented within the HCIM Area as an interim measure until the effectiveness of the SVE decreased to the point that the system was finally shut down. Since this technology has already been implemented for the HCIM Area, it would not be effective for future remediation.

6.1.1.6 Solidification/Stabilization

Solidification/stabilization (S/S) reduces the mobility of hazardous substances and contaminants in the environment through both physical and chemical means. Unlike other remediation technologies, S/S seeks to trap or immobilize contaminants within the soil instead of removing them through chemical or physical treatment. Treatability studies are typically performed to measure the effectiveness of the contaminant immobilization and develop design data.

Auger/caisson systems and injector head systems are techniques used for in situ S/S. They apply S/S agents to soils to trap or immobilize contaminants. The target contaminant group for in situ S/S is generally inorganics. These systems have limited effectiveness against SVOCs and PCBs and no expected effectiveness against VOCs.

Solidification/stabilization processes result in a significant increase in volume (up to double the original volume). Reagent delivery and effective mixing are typically the biggest challenge for this technology. After treatment, the remaining solidified soil can hinder future site use and create structural challenges for future site development.

At the HCIM Area, stabilization would result in excess soil, which could need to be disposed of as a hazardous waste. In addition, S/S is minimally effective on VOCs and as a result would not meet site clean-up levels. Finally, S/S could not be completed near the barrier wall without risking the integrity of the existing containment.

6.1.1.7 Steam Injection

Using steam injection, hot air or steam is injected below the contaminated zone to heat up contaminated soil. This heating can also be achieved by radio frequency heating and electrical resistance heating. The heating enhances the release of contaminants from the soil matrix. Some VOCs and SVOCs are stripped from the contaminated zone and brought to the surface through SVE. This process is effective for VOCs and many SVOCs; however, it has limited effectiveness on PCBs and little effect on inorganics. High soil moisture content or low-permeability soils tend to hinder this process, requiring significantly more energy to achieve the desired soil temperatures. Because the technology requires SVE for off-gas collection and treatment, air permitting would be required to govern the off-gas abatement process. Treatment residuals include accumulated liquid (soil moisture and contaminants) and spent granular - activated carbon (GAC), if that is used to manage SVE emissions.

6.1.1.8 Cap/Surface Cover

Various caps and surface covers can be used to minimize exposure at the surface to waste materials, prevent vertical infiltration of surface water into wastes that could generate contaminated leachate, and control gas emissions from waste containing VOCs. Caps can also provide a useful surface for various land uses such as golf courses, parking, and warehouses.

Typical cap designs for industrial facilities include Portland cement concrete, asphalt pavement and asphalt concrete pavement. These cover systems effectively convey surface water to collection systems and definitively prevent runoff and human exposure to underlying soil or waste. These rigid or semi-rigid caps allow the site to be maintained in productive use by allowing for structures to be constructed and vehicles and equipment to be operated. Flexible membrane liners and compacted clay or bentonite liners are more conventionally applied to landfill caps, where large areas which are prone to differential settlement, must be graded, sloped, covered, vegetated, and managed over the long term with limited use of the area after capping.

Much of the HCIM Area soil currently has a microsilica concrete cap over the former asphalt, asphalt cap, or concrete cap. The total thickness of this existing cover system is as much as approximately 3 feet. Microsilica concrete is a special mix of concrete that is extremely hard and durable and has a much lower permeability than standard mix Portland cement concrete.

The pavement is sloped and storm water capture and conveyances (swales and drain inlets) are installed to reduce surface water ponding. Periodic maintenance would be conducted to fill cracks and reduce the potential for surface water infiltration. Other portions of the HCIM Area are capped with asphalt. This cover system prevents human exposure to underlying waste materials, minimizes the infiltration of surface water (thus reducing the potential for formation of leachate) and limits erosion and runoff of impacted soil.

6.1.2 Ex Situ Soil Remediation Technologies

Remediation of soil using ex situ technologies requires excavation of affected soil for treatment using above-grade techniques. Due to the need to excavate affected soil, ex situ technologies are highly invasive and create significant disturbance of affected areas. These technologies are typically used only for remediation of shallow hot spots rather than widely distributed or deep contamination.

6.1.2.1 Biopiles

Biopile treatment is a full-scale technology in which excavated soils are mixed with soil amendments and placed on a treatment area that includes leachate collection systems and some form of aeration. It is primarily used to reduce concentrations of petroleum constituents in excavated soils through the use of biodegradation. Moisture, heat, nutrients, oxygen, and pH can be controlled to enhance biodegradation.

The treatment area will generally be covered or contained with an impermeable liner to minimize the risk of contaminants leaching into uncontaminated soil. The drainage itself may be treated in a bioreactor before recycling. Vendors have developed proprietary nutrient and additive formulations and methods for incorporating the formulation into the soil to stimulate biodegradation. The formulations are usually modified for site-specific conditions.

Biopile treatment has been applied to treatment of nonhalogenated VOCs and fuel hydrocarbons. Halogenated VOCs, SVOCs, and pesticides also can be treated, but the process effectiveness will vary and may be applicable only to some compounds within these contaminant groups.

6.1.2.2 Soil Washing

Contaminants sorbed onto fine soil particles are separated from bulk soil in an aqueous-based system on the basis of particle size. The wash water may be augmented with a basic leaching agent, surfactant, pH adjustment, or chelating agent to help remove organics and heavy metals. The process removes contaminants from soils in one of the following two ways:

- by dissolving or suspending them in the wash solution, or
- by concentrating them into a smaller volume of soil through particle size separation, gravity separation, and attrition scrubbing (similar to those techniques used in sand and gravel operations).

A complex mixture of contaminants in the soil (such as a mixture of metals, nonvolatile organics, and SVOCs) and heterogeneous contaminant compositions throughout the soil mixture make it difficult to formulate a single suitable washing solution that will consistently and reliably remove all of the different types of contaminants. In addition, it may be difficult to remove organics adsorbed onto silt or clay-size particles, thus limiting the potential effectiveness of this technology.

Soil washing is generally considered a media transfer technology. The contaminated water generated from soil washing must be ultimately treated and disposed. This process may also create concentrated treatment residuals that require land disposal.

6.1.2.3 Solidification/Stabilization

Similar to in situ S/S, ex situ S/S contaminants are physically bound or enclosed within a stabilized mass (solidification), or chemical reactions are induced between the stabilizing agent and contaminants to reduce their mobility. Some of the most successful and commonly used stabilization agents are pozzolans (primarily of silicates from pozzolanic-based materials like fly ash, kiln dust, pumice, or blast furnace slag) and Portland cement. These materials chemically react with water to form a solid cementious matrix that improves the handling and physical characteristics of the waste. They also raise the pH of the water, which may help precipitate and immobilize some heavy metal contaminants. Pozzolanic and cement-based binding agents are typically appropriate for inorganic contaminants. This binding agent has limited effectiveness with organic contaminants, especially VOCs. Additionally, nuisance conditions (dust, noise, odors) and loss of VOCs to air may occur from this technology.

6.1.2.4 Thermal Desorption

Thermal desorption is a physical separation process and is not designed to destroy organics. Wastes (excavated soil) are heated to volatilize water and organic contaminants. A carrier gas or vacuum system transports volatilized water and organics to the gas treatment system. The bed temperatures and residence times designed into these systems will volatilize selected contaminants but will typically not oxidize them.

Two common thermal desorption designs are the rotary dryer and thermal screw. Rotary dryers are horizontal cylinders that can be indirect- or direct-fired. The dryer is normally inclined and rotated. For the thermal screw units, screw conveyors or hollow augers are used to transport the medium through an enclosed trough. Hot oil or steam circulates through the auger to indirectly heat the medium. All thermal desorption systems require treatment of the off-gas to control emission of particulates and volatilized contaminants. Particulates are removed by conventional particulate removal equipment, such as wet scrubbers or fabric filters. Contaminants can be removed through condensation followed by carbon adsorption, or they are destroyed in a secondary combustion chamber or a catalytic oxidizer. Most thermal desorption units are transportable. This technology can be operated as either low or high temperature thermal desorption.

The target contaminant groups for low temperature thermal desorption systems are usually nonhalogenated VOCs and fuels, although chlorinated VOCs can be treated. The technology can be used to treat SVOCs at reduced effectiveness. The target contaminants for high temperature thermal desorption are SVOCs, PAHs, PCBs, and pesticides. Volatile metals may be removed by high temperature thermal desorption systems, complicating emission control. The presence of chloride can affect the volatilization of some metals, such as lead.

The potential for application of this technology to the SWFS is low due to the variety of COCs that need to be treated and the fact that the HCIM Area cannot be easily excavated.

6.1.2.5 Off-Site Disposal

Excavation and off-site disposal is a technology that involves excavation of all soil within the HCIM Area above the water table that exceeds the cleanup levels. This would include removal for the presence of VOCs, SVOCs, TPH, PCBs, and inorganics (metals). The excavated soil would be stockpiled, characterized, and transported and disposed off site. New clean fill would be brought to the HCIM Area and placed and compacted to restore the site. It is likely that some dewatering would be required or a rock ballast layer with geotextile fabric would need to be installed to stabilize the soft wet bottom of the excavation prior to backfilling. Contaminated soil beneath the water table could not be excavated without extensive dewatering of the area.

Excavation of the HCIM Area would be extremely difficult. First, the cap (estimated to be approximately 3 feet thick) would have to be saw cut, broken, and removed from the site. Excavation near the HCIM perimeter would threaten the integrity of the existing barrier wall. Due to the frequent railroad traffic on the east side of the Facility, excavation would likely be prohibited adjacent to the railroad tracks. The dynamic loads caused the train traffic would preclude this excavation. Also, excavation would require obtaining access or easements from private property owners of contiguous parcels where soil removal would also need to be conducted.

HCIM Area soil would likely be classified as dangerous waste and would have to be transported by licensed haulers to appropriately permitted treatment disposal facilities. Due to the RCRA Land Disposal Restrictions, certain soils would likely require treatment either on site or at the disposal facility prior to landfilling. The costs related to this treatment and disposal of dangerous waste are extremely high, and very significant short-term risks would be created due to dust generation, volatilization, and transportation.

6.2 HCIM AND OUTSIDE AREAS GROUNDWATER REMEDIATION TECHNOLOGIES

Several general technologies have been considered for groundwater remediation within the HCIM and Outside Areas. These general response actions include institutional controls; containment; and biological, physical, and chemical treatment options. Numerous remediation technologies within these general response actions have been evaluated in this SWFS. The potentially applicable remediation technologies are described below and listed in Tables 6-3 and 6-4.

6.2.1 Enhanced Biodegradation with Biosparging

Enhanced biodegradation by biosparging involves the injection of air into groundwater to provide oxygen and increase the aerobic biological activity of the indigenous microorganisms. Compressed air is supplied to groundwater using vertical or horizontal wells screened below the depth of affected groundwater. The injected air forms bubbles in the groundwater, which then rise to the unsaturated zone, effectively delivering oxygen to the entire column of groundwater above the injection depth. This technology can be implemented either as a biobarrier, providing a reactive zone within the groundwater flow path, or as a distributed system addressing source areas and the aerial extent of impacted groundwater. Horizontal wells are best suited for implementation as a biobarrier, while vertical wells could be used for a biobarrier or for a distributed approach. Both horizontal and vertical wells must be placed appropriately to span the target area for affected groundwater. The placement of vertical wells is typically determined by the aeration radius determined during pilot testing.

This technology performs well for organic compounds that can be readily degraded aerobically, including VC. Potential problems associated with biosparging include possible volatilization of constituents that may affect air quality in surrounding buildings, the potential for chemical fouling due to high iron concentrations in groundwater that may precipitate upon oxidation, and/or fouling by excessive biological growth adjacent to the aeration well(s). The presence of natural iron in SWFS Area groundwater would create an oxygen demand that would increase the amount of air that must be supplied to the groundwater to successfully degrade VC. Aerobic biodegradation is not known to be effective for TCE without the addition of a co-metabolic inducer; aerobic conditions may actually slow the degradation rate for TCE. This technology does not have an application within the HCIM Area due to the multitude of COCs, most of which are not addressed by this technology. Outside the HCIM Area, this technology could only be applied farther downgradient where only VC remains.

6.2.2 Oxygen Enhancement with Hydrogen Peroxide or ORC®

Oxygen supporting aerobic degradation of VC can also be delivered to impacted groundwater using chemicals such as Oxygen Release Compound (ORC) or hydrogen peroxide. ORC is a proprietary chemical developed and sold by Regenesis. ORC is a peroxide compound that slowly degrades in water, releasing oxygen. Hydrogen peroxide is a highly reactive, oxidizing compounds that rapidly breakdown in water, releasing oxygen. Chemical oxygenation technology differs from the other aerobic bioremediation technologies only in the means for delivery of oxygen to the groundwater. Chemical oxygenation requires storage of the chemical to be introduced to groundwater, a means to feed the chemical at the proper rate, and a means to distribute the chemical to the impacted groundwater.

The most widely used approach for oxygenation by ORC is to suspend a bag containing the ORC in a vertical well. The ORC slowly dissolves, delivering oxygen to the groundwater near the well by passive diffusion. The ORC must be replaced periodically to maintain a continuous source of oxygen. This would result in a limited radius of influence for each well, both laterally and vertically. The technology is not typically implemented in horizontal wells due to the need to periodically replace the ORC pouch and the limited vertical radius of influence that would be created by passive diffusion. Implementation of this technology for the SWFS Area would require a high density of vertical wells with placement of ORC at multiple depths in each well. Regular access would be required to each of the oxygenation wells to replenish the

ORC. No mechanical equipment other than the wells would be needed for this approach to oxygenation.

Chemical oxygenation using hydrogen peroxide requires the injection of the chemical into groundwater. This can be done by slowly feeding the chemical into vertical wells and relying on passive diffusion to deliver oxygen to the aquifer or by withdrawing groundwater, adding peroxide or ozone, and reinjecting the groundwater. The passive method would have similar advantages and disadvantages to other passive oxygenation methods.

Hydrogen peroxide is a strong oxidant and is classified as a hazardous, reactive chemical. Hydrogen peroxide is sold as a liquid; its use would require storage at the injection point(s) and periodic transport through the neighborhood to deliver fresh chemical for injection. It is corrosive and can react spontaneously with organic materials or reduced compounds. Hydrogen peroxide can spontaneously react when in concentrated form. This technology has limited application either within the HCIM or Outside Areas.

6.2.3 Co-Metabolic Treatment

Chlorinated solvents have been biologically degraded under aerobic conditions using in situ co-metabolic processes. Co-metabolic aerobic degradation can be accomplished by injecting a hydrocarbon substrate such as ethane along with oxygen. The co-metabolic process has been demonstrated through passive diffusion using the ISOC process or through groundwater recirculation systems using the Super-Ox technology. These technologies have been shown to promote the degradation of TCE, cis-1,2-DCE, and VC. Drawbacks of the technology include the potential for biological or chemical fouling of wells and equipment and the potentially explosive conditions created when combining oxygen and a flammable hydrocarbon substrate. This technology has not been implemented within fully developed urban areas.

6.2.4 Reductive Dechlorination, Biostimulation (anaerobic)

Reductive dechlorination involves injecting a carbohydrate electron donor (e.g., molasses, sodium lactate, or vegetable oil) into the affected groundwater to create reducing conditions and enhance naturally occurring reductive dechlorination processes. This is a proven technology with a substantial history of success in a variety of applications. The carbohydrate could be injected with wells, direct push probes, or groundwater recirculation systems. Groundwater recirculation systems could use vertical or horizontal wells. This could be implemented as either a reactive zone to treat a source area or as a biobarrier to intercept and treat groundwater as it moves downgradient.

This technology would likely address both TCE and VC. Natural bioattenuation of TCE is already occurring at the Site, which results in the accumulation of some DCE and VC. This also indicates that indigenous organisms can support reductive dechlorination of the chlorinated COCs. Injection of electron donor into the impacted groundwater would likely be needed to supply acceptable concentrations of electron donor to maintain favorable conditions for reductive dechlorination of VC. A large number of injection points would be required for injection over a large area. Recirculation systems using vertical wells would require numerous injection and extraction wells and large pumping volumes to address the large area of impacted groundwater. Horizontal wells could also be used to establish a recirculation system supporting reductive dechlorination. Recirculation systems would not likely encounter iron fouling, but could experience biological fouling. Permitting requirements could be significant for this technology to allow treatment and reinjection for the recirculation system. This technology could be applied alone or in conjunction with aerobic bioremediation to comprehensively address groundwater constituents that biodegrade under aerobic and anaerobic conditions.

6.2.5 Bioaugmentation

Bioaugmentation is an in situ remedial technology in which a biological seed, specifically adapted for degradation of the constituents of interest, is introduced to the impacted groundwater. Bioaugmentation could be conducted using anaerobic or aerobic biological seeds.

Under anaerobic conditions, the microorganism *dehalococcoides ethogenes* must be present for dechlorination of VC to ethene. For bioaugmentation technology, a microbial culture containing *dehalococcoides ethogenes* would be added to the impacted groundwater to promote reductive dechlorination of the VC. Injection wells are typically used for injecting the microorganisms. The culture added to the subsurface would then compete with indigenous organisms for nutrients and substrate. For many bioaugmentation applications, the added organisms do not compete successfully with indigenous organisms. Due to the ongoing natural attenuation within the SWFS Area, it is expected that indigenous organisms are present that effectively degrade Site COCs and that bioaugmentation would not enhance biodegradation.

Due to the use of oxygen and injection wells, aerobic bioaugmentation technology would encounter the same issues discussed above for iron fouling and biofouling. For either anaerobic or aerobic bioaugmentation technologies, permitting to allow injection would be required and would likely be complex due to introduction of a non-native biological product. The bacterial strain introduced by bioaugmentation processes is typically not fully adapted to the local environment; therefore, the bioaugmentation seed may require periodic or continual addition in order to maintain a viable population and effective bioremediation.

6.2.6 Natural Attenuation

Monitored natural attenuation is a proven technology that has been effective in reducing contaminant concentrations in groundwater when appropriate conditions are present. This process relies on the attenuation of groundwater constituents by natural processes including biodegradation, abiotic degradation, adsorption, and dilution. Due to the passive nature of this remedial technology, it can be readily implemented with a minimum of institutional issues such as permitting or arranging for access permissions, and also would have minimal potential for implementation problems such as fouling. Biodegradation of the chlorinated solvents present within the SWFS Area is currently observed and accounts for the presence of VC in the groundwater. The persistence of VC within the SWFS Area could be due to inhibition of the natural biodegradation process or due to the presence of downgradient source areas that release TCE to the groundwater, creating an additional influx of VC. Natural attenuation, including biodegradation, is currently occurring in the SWFS Area. The selection of a remedial strategy will include consideration for processes that have limited negative impact on the natural attenuation process. Natural attenuation may also provide a component of a comprehensive remedial alternative considered for this SWFS.

6.2.7 Phytoremediation

Phytoremediation is a set of processes that uses plants to destroy or remove contamination in groundwater. There are several ways plants can be used for the phytoremediation, including enhanced rhizosphere biodegradation, phyto-degradation, and phyto-volatilization. Enhanced rhizosphere biodegradation utilizes natural substances released by plant roots to supply nutrients to microorganisms, which enhances their ability to biodegrade organic contaminants. Phyto-degradation is the metabolism of contaminants within plant tissues and phyto-volatilization occurs as plants take up water containing organic contaminants and release the contaminants into the air through their leaves. The potential for application of phytoremediation in the SWFS Area is extremely limited by the depth of groundwater contamination and the current land use.

6.2.8 Air Sparging

Air sparging is an in situ technology in which air is injected through a contaminated aquifer. Injected air traverses horizontally and vertically in channels through the soil column, creating an underground stripper that removes contaminants by volatilization. This injected air helps to flush (bubble) the contaminants up into the unsaturated zone, where a vapor extraction system is usually implemented in conjunction with air sparging to remove the generated vapor phase contamination. Oxygen added to contaminated groundwater and vadose zone soils can also enhance aerobic biodegradation of contaminants below and above the water table.

Implementation of an air sparging system in the SWFS Area would require installation of numerous air sparging wells and vapor extraction systems to recover VOCs. VOCs that are not captured could potentially be harmful to residents and workers in buildings located above or nearby the air sparging system. The addition of oxygen to the water could have adverse effects on naturally anaerobic degradation process that has been documented to be occurring at the Site.

6.2.9 Chemical Oxidation

Chemical oxidation has been successfully used for in situ treatment of chlorinated solvents. Oxidants that have been used include potassium permanganate, hydrogen peroxide, ozone, and Fenton’s reagent. This technology is based on the injection of the chemical oxidant into the impacted groundwater. Injection of the chemicals can be accomplished using direct-push techniques, injection wells, or recirculation wells. This technology is typically considered only for treatment of highly impacted source areas; the technology is not well-suited for use in dilute groundwater plumes. High reactant chemical doses and low utilization efficiencies would be required for dilute plumes and result in high remediation costs.

Hydrogen peroxide, ferrous sulfate, and potassium permanganate are generally purchased and stored as a liquid, which must be metered into the groundwater. However, ferrous sulfate and potassium permanganate can be purchased as a solid and dissolved on site prior to injection into the groundwater. Ozone can be generated on site using specialized equipment. These chemical oxidants are all reactive, hazardous chemicals that require proper design and management to be used safely. For hydrogen peroxide and potassium permanganate, it would be necessary to periodically receive trucks delivering the oxidant to the injection location, which presents potential safety hazards. It is also likely that potential use of such hazardous and reactive chemicals would increase the complexity of negotiating access agreements, thus potentially delaying a remediation program incorporating this technology. While chemical oxidation may effectively degrade chlorinated solvents in groundwater, it would alter subsurface conditions necessary for natural biodegradation processes in all areas affected by the oxidant, essentially eliminating the biodegradation processes present in the impacted downgradient groundwater.

This technology would have more application to the HCIM Area than the Outside area; however, even within the HCIM Area, the depths of the chemical impacts, the complex geology and geochemistry (including the presence of metals in a highly reductive environment), the dispersed DNAPL, and the difficulties of delivery of the oxidant within interbedded soils limit the potential use of this technology. Chemical oxidation would only provide partial treatment of the HCIM Area. Due to the generally diluted nature of the Outside Area, chemical oxidation would not be cost-effective.

6.2.10 Thermal Treatment

Thermal treatment includes adding steam through injection wells or applying an electrical current into an aquifer to vaporize volatile and semi-volatile contaminants in groundwater. Vaporized components rise to the vadose zone, where they are removed by vacuum extraction and then treated. The process can be used to remove large portions of oily waste accumulations and to retard downward and lateral migration of organic contaminants. The process is applicable to shallow and deep contaminated areas, and readily available mobile equipment can be used. This technology would be difficult and costly to implement because of the large area and the current land use above the area requiring treatment.

6.2.11 In-Well Stripping

In-well air stripping is a process that has been proven in some applications for removal of VOCs from groundwater. Recirculation zones are created within the aquifer by injecting air into a specially designed vertical well with two or more screened sections. Compressed air is introduced into the well above the lower screen to simultaneously aerate the groundwater and strip volatile organics. The injected air reduces the density inside the well, causing groundwater to enter the deep screen and exit the well through the upper screen section. Volatile constituents present in the groundwater are transferred to the air, which flows up the well to a vapor collection system. Air vented from the well may require treatment by oxidation or adsorption systems to control emissions. The oxygenated groundwater created within the recirculation zone would also promote aerobic microbial activity to enhance biodegradation processes for constituents that degrade aerobically. For the SWFS Area, where chlorinated solvents were released that do not degrade aerobically, this technology may interfere with natural biodegradation processes. However, in-well air stripping would create an aerobic zone conducive to degradation of VC. Due to the potential for interfering with natural biological processes already active within the SWFS Area and the potential for fouling due to iron, this technology would not be effective.

6.2.12 Passive/Reactive Treatment Walls

Permeable reactive barriers (PRBs) using zero-valent iron to chemically reduce chlorinated solvents are proven to be effective for groundwater remediation. This technology is typically implemented as a reactive barrier to destroy COCs migrating from the source area with impacted groundwater. In order to make this technology cost-effective, a zero-valent iron PRB is typically implemented as a funnel and gate, in which a low-permeability barrier wall is placed within the flow path of the affected groundwater to direct flow to the zero-valent iron gate, where the reaction occurs. The zero-valent iron has been proven to reduce chlorinated solvents such as TCE. Zero-valent iron is less effective for destruction of VC. This approach would require significant, invasive construction to implement the funnel and gate, which is particularly problematic for use of this technology in the heavily developed urban environment in the SWFS Area vicinity. This technology is potentially applicable for implementation immediately downgradient of TCE source areas; however, given the extensive surface development, the presence of underground utilities, the presence of the barrier wall, and issues associated with gaining access for invasive construction and routine monitoring and maintenance, it would be very difficult to site and construct PRBs for optimal effectiveness.

6.2.13 Groundwater Extraction (Pump and Treat)

Migration of impacted groundwater could be controlled by implementing a hydraulic control with a groundwater extraction program, in which impacted groundwater is extracted to establish a hydraulic depression that prevents downgradient migration of groundwater. Hydraulic control can be established by withdrawing groundwater and discharging directly to surface water or by reinjecting the groundwater downgradient from the extraction wells, creating a zone of elevated water level. For either configuration, this technology requires placement of recovery wells (a line of closely spaced vertical wells or a long horizontal well) to intercept flow downgradient from source areas and extending across the area of impacted groundwater. For the direct discharge configuration, the extracted groundwater would be treated and either discharged to the King County POTW or discharged to the Duwamish Waterway via a National Pollutant Discharge Elimination System (NPDES) discharge permit. For the reinjection configuration, the extracted groundwater would be treated and reinjected using injection wells located in the natural downgradient direction from the extraction wells and permitted as injection wells. It is likely that the reinjection configuration would result in a higher pumping rate than the direct discharge configuration due to recycle from the injection wells back to the extraction wells. Groundwater extraction has been used effectively for source control and for controlling migration of impacted groundwater plumes.

Groundwater extraction would require pumping, treatment, and discharge of sufficient quantities of groundwater to provide effective and reliable containment. For a permeable aquifer, such as is present within the SWFS Area, it would likely be necessary to extract large volumes of groundwater if it were implemented as a downgradient migration barrier. For the SWFS Area, this technology is best suited for controlling migration of impacted groundwater in the vicinity of source areas. This technology is currently used as one component of the HCIM. If used for controlling migration from source areas, reinjection within the impacted groundwater may have adverse effects on migration of the impacted groundwater and on ongoing natural attenuation processes. Therefore, direct discharge would be the preferred approach for the impacted downgradient groundwater. It is expected that full treatment would be required to support direct discharge to the Duwamish Waterway under an NPDES permit. It would likely require substantial effort to obtain a discharge permit and extensive access negotiations would be required to obtain long term property access to build, operate, and maintain a treatment system and to obtain an easement to construct the discharge and outfall. Substantial property access would also be needed to provide for collection of the recovered groundwater if implemented as a downgradient barrier.

6.2.13.1 Air Stripping

Air stripping is an ex situ groundwater treatment technology used in pump and treat systems. In air stripping, VOCs in groundwater are removed by conveying large volumes of air counter-current to the groundwater flow. VOCs are volatilized into the air stream, thus reducing their concentration in the water and transferring their mass into the air stream. Generally, pH adjustment of the influent ground water feed stream or addition of proprietary water treatment chemicals are necessary to minimize the precipitation of minerals on the air stripper. Chemicals in the air stripper off-gas may be treated to meet specified permit requirements or discharged directly to the atmosphere, depending on mass limitations for atmospheric discharge. It is common to apply GAC to the off-gas for treatment prior to discharge.

Low-profile air strippers use a number of trays in a very small chamber to maximize air-water contact while minimizing space. Because of the significant vertical and horizontal space savings, these units are increasingly being used for groundwater treatment. These air strippers can be operated continuously or in a batch mode, where the air stripper is intermittently fed from a collection tank. Air stripping is currently being used within the HCIM Area to effectively remove VOCs from extracted groundwater prior to discharge to the POTW.

6.2.13.2 Adsorption

Liquid phase activated carbon adsorption is a full-scale technology in which groundwater is pumped through one or more vessels containing activated carbon to which dissolved organic contaminants adsorb. This technology is used for pump and treat systems. When the concentration of contaminants in the effluent from the bed exceeds a certain level, the carbon can be regenerated in place, removed and regenerated at an off-site facility, or removed and disposed. Carbon used for metals-contaminated groundwater probably cannot be regenerated and should be removed and properly disposed. Adsorption by activated carbon has a long history of use in treating drinking water as well as treating municipal, industrial, and hazardous wastes. This technology has been demonstrated to be effective at reducing VOCs in groundwater to very low concentrations. This technology has limited effectiveness for VOCs.

6.2.14 Barrier Wall

Physical containment requires construction of a low-permeability barrier wall to contain the impacted groundwater. Barrier walls providing physical containment are frequently used in association with pump and treat hydraulic containment. For this technology, placement of a low-permeability (e.g., soil/bentonite) barrier wall keyed into the lower confining unit to physically restrict the flow of groundwater would be required. Barrier walls have been constructed at some sites to totally enclose impacted groundwater, as a downgradient barrier, or as a funnel to support use of PRBs or biobarriers. This technology is presently used for the HCIM Area. For the impacted Outside Area groundwater, the depth of the lower confining unit is unknown, but is expected to be greater than 90 feet bgs. Due to this depth, construction of a barrier wall would require a large construction area with significant access requirements during the construction, which would likely span several months. Construction of barrier walls to the depth needed for the SWFS Area would require specialized, heavy construction and require extensive management to prevent loss of construction and excavated materials and to maintain ongoing commerce within the SWFS Area. Permitting requirements would be commensurate with any large construction project conducted in an urban area, requiring utility relocation, power outages, property acquisitions, and public entity easements.

A barrier wall within the HCIM Area has already been installed as an interim remedial measure. Low-flow groundwater extraction is being used in conjunction with the barrier wall to maintain an inward groundwater gradient. The cut-off wall and subsequent extraction system have been proven effective at controlling migration of contaminants from the HCIM Area.

6.3 VAPOR PATHWAY REMEDIATION TECHNOLOGIES

VOCs such as TCE and VC can migrate through the vadose zone from shallow groundwater and accumulate beneath building slabs and foundations. Given the shallow depth to groundwater (10 feet) and the sandy soil, groundwater VOCs can volatilize into the soil vapor spaces and migrate by diffusion. Differences in pressures between the shallow subsurface and building interiors can enhance migration of these volatile organics through building slabs and basement walls (including through cracks and joints), potentially causing occupants to inhale these compounds. These pressure differences are typically caused by bathroom fans, clothes dryers, and other appliances that evacuate air from building interiors. Cleanup levels protective of building occupants have been established for HCIM Area and Outside Area water table interval groundwater. Groundwater remediation technologies were discussed in Section 6.2 and screened on Tables 6-2 and 6-3. Until these groundwater cleanup levels are achieved, the vapor intrusion mitigation technologies used in the ongoing IPIM must be maintained to protect these occupants from unacceptable VOC exposures.

Several vapor mitigation technologies have been identified and are described in the following sections. With the exception of institutional controls, these technologies rely on physical methods to reduce the risk posed by the vapor pathway. The potentially applicable remediation technologies are described below and listed in Tables 6-5 and 6-6.

6.3.1 Soil Vapor Extraction

SVE is a well-documented technology for remediation of subsurface soil vapors. SVE has been proven to reduce volatile constituent levels in the subsurface by evacuation of soil gas. To address the vapor pathway associated with existing structures, SVE would typically consist of several vapor extraction wells installed adjacent to the existing structure. The wells would be plumbed to a vacuum source so that the wells would be evacuated of soil gas in a continuous manner. Depending on concentrations, this soil gas may be treated by oxidation or adsorption technologies or may be discharged directly to the atmosphere. This type of system would operate continuously until groundwater cleanup levels are achieved.

Compared to other vapor pathway remediation technologies, SVE is a fairly expensive and elaborate approach to address vapor intrusion into existing buildings. The installation of vapor extraction wells; piping; extraction blower; off-gas abatement device; and associated valves, hardware, and controls is a considerable investment to address this pathway. This technology would require easements or access agreements to install wells and construct buried piping. A continuous electrical source would be required to support the vacuum blower and possibly the off-gas abatement device. Frequent operations and maintenance is required to keep SVE systems operational. Compared to other more passive technologies, SVE is viewed as an extreme approach to mitigate this pathway.

6.3.2 Vapor Barrier

For new construction over an area susceptible to vapor intrusion by VOCs, a geomembrane barrier can be constructed beneath the new building slab, dramatically reducing the migration of VOCs into the building interior. This type of barrier can also serve as a moisture barrier for the structure. To improve effectiveness, this type of barrier can be installed in conjunction with active slab depressurization. Requirements for vapor barriers on new construction are frequently built into institutional controls for areas underlain by VOC groundwater plumes.

6.3.3 Active Slab Depressurization

Active slab depressurization technology can be applied to new structures during construction or can be retrofitted to existing structures. In general, the building foundation slab is drilled and a vent pipe is installed through the slab to the soil or rock base beneath. The vent pipe would be fitted with a small fan, which would impress a negative pressure on the subsurface, effectively venting VOCs that may accumulate under the slab. Vapors would be discharged above the roofline of the structure.

6.3.4 Foundation and Wall Sealing

This technology involves the application of caulk or other elastomeric sealing compounds along the joints and cracks in building slabs and subgrade walls. This would reduce the intrusion of volatile vapors into the structure. This technology is typically implemented in conjunction with active slab depressurization to increase the effectiveness of the vacuum fan.

6.3.5 Sub-membrane Depressurization

Sub-membrane depressurization typically involves the installation of a 3-6 mil polyethylene liner beneath the foundation of a raised foundation structure. The plastic liner would be sealed along all edges and a vent pipe fitted through the liner. The vent pipe would be fitted with a small fan, which would impress a negative pressure on the subsurface, effectively venting VOCs that may accumulate under the plastic liner. Vapors would be discharged above the roofline of the structure.

6.3.6 Building Pressurization

Building pressurization is a vapor intrusion mitigation technology that imparts a slight positive pressure on living spaces within a building, effectively preventing the flux of subsurface vapors into the structure. Typically, a small fan is installed and fan intake is ducted to the building exterior. The fan would draw low volumes of outside air into the structure and impart a slightly positive pressure on the building interior. In more elaborate installations, a heat exchanger may also be installed to condition the exterior air, reducing the burden on the structure heating or cooling system. This technology has been demonstrated effective for addressing vapor intrusion risks.

6.4 INSTITUTIONAL CONTROLS

Institutional controls are commonly used as a component of remedial alternatives to address residual soil and/or groundwater contamination. They also may be used to ensure that human health and the environment are protected during implementation of a remediation program that may require significant time to achieve remediation objectives. Institutional controls typically include administrative controls such as deed restrictions that prohibit actions that may result in exposure to soil or groundwater contaminants or signs to inform users of an area of potential hazards. A significant factor that may limit the effectiveness of institutional controls is the ability to enforce the control. For property owned by the responsibility party, enforceable controls can be established by including deed restrictions. For property that is not owned by the responsible party, institutional controls may not be enforceable.

Deed restrictions or property use limitations are institutional controls that involve the development of formal restrictions on how the property is managed and/or used in the future. Deed restrictions can be established for future site worker protection by preventing or limiting site excavation work or notifying future construction workers of the presence and location of affected site soil or groundwater. Restrictions can also preclude the future use or redevelopment of the site for certain uses such as residential, schools, day care centers, or hospitals. Restrictions can also establish requirements for new construction to address sealing or ventilation of concrete slabs, thereby reducing exposure to potentially harmful VOCs through the vapor intrusion pathway. Additional restrictions can be established to maintain remediation technologies put in place at a site. Requirements can also be established for site security, fencing, and signage to prevent unauthorized individuals from entering the site.

6.5 TECHNOLOGY SCREENING CRITERIA

The remediation technologies described in Sections 6.1, 6.2, and 6.4 were screened to identify those technologies best suited for potential use in developing remedial alternatives. The applicability of each technology was considered in light of the considerations presented in Section 5 of this SWFS and physical site characteristics. The criteria used for screening remediation technologies are as follows:

- **Technology Development Status** (bench, pilot, or full scale): the level of development for the technology. Technologies with full scale implementation would be favored over less developed technologies. Technologies successfully implemented in a variety of environmental and geologic settings would be favored over technologies with a more restricted application record.

- **Performance Record**: the record of successfully attaining the remediation objectives established for the technology in prior implementations. Technologies with a more successful performance record would be favored over technologies with fewer successes or more failures.

- **Contaminants Addressed**: the groundwater constituents the technology is capable of addressing. Only technologies demonstrated capable of addressing the specific constituents in the specific media of interest (soil or groundwater) will be retained for the SWFS.

- **Implementability Within the Constraints of the Site**: the expected capability of successfully implementing the technology within the SWFS Area in a reasonable time frame. Technologies requiring extensive permitting or access to numerous locations would not be favored over technologies requiring minimal access and simpler permitting. Technologies that require significant infrastructure (permanent wells, extensive piping runs, public and private easements, and access agreements) would require extensive administrative and logistical challenges and may ultimately be considered administratively unimplementable. Non-invasive technologies would be favored over highly invasive technologies for the Outside Area due to the extensive development in the area and the complications involved in gaining property access for conducting remediation. Technologies that support and build on the documented natural degradation of VOCs in both the HCIM and Outside Areas would be favored over those technologies that arrest or interrupt this natural degradation. Finally, technologies that are compatible with existing interim measures—specifically, the existing HCIM barrier wall—would be favored.

6.6 TECHNOLOGY SCREENING AND REVIEW OF RETAINED TECHNOLOGIES

The technologies discussed in Section 6.1, 6.2, and 6.4 were screened against the criteria described in Section 6.5 to identify technologies to be used in developing remedial alternatives for the soil, groundwater, and vapor pathways in the HCIM Area and the Outside Area. The results of the screening, including the rationale for retention or rejection, are summarized in Table 6-1 through 6-6. Technologies were either retained or rejected based upon their prior application history, ability to meet the remediation objectives, and an evaluation against the above screening criteria. Because this SWFS is intended to be a focused effort, this technology screening step is intended to produce a very short list of only the most applicable and promising technologies for further consideration. The remediation technologies retained for possible inclusion into remedial alternatives are discussed in the following subsections.

6.6.1 HCIM Area Soil Remediation Technologies

A broad range of technologies were evaluated to address HCIM Area soils. Physical, chemical, biological, and administrative remediation technologies were considered to address vadose zone soils impacted by VOCs, SVOCs, TPH, metals, and PCBs. Both in situ and ex situ technologies were evaluated. Ultimately, only two technologies were retained: (1) containment-cap/surface cover and (2) institutional controls. The basis for the rejection of the other candidate technologies is as follows:

- Ex situ technologies require excavation, which would require removal of a very competent microsilica cap that currently prevents exposure to contaminants and prevents surface water infiltration. Excavation of the vadose zone (from approximately 3 feet bgs (below cap) to approximately 8 to 10 feet bgs (groundwater table) would result in removal of only a portion of the impacted soil at the site. As previously stated, considerable soil contamination exists below the water table elevation in the HCIM Area. Excavation would also threaten the existing barrier wall, create significant logistical issues adjacent to the active railroad tracks, and would create substantial short-term risks to the community. At best, soil excavation would be a partial solution to the soil contamination problem. The surface cap/cover provides comparable human health risk protection. Removal of the impacted vadose zone soil would not significantly accelerate the cleanup of the impacted groundwater, given the current distribution of impacted groundwater to a depth of 90 feet bgs.

- In situ technologies, included biological and chemical treatment, were considered for soil treatment but were ultimately rejected. In situ biological treatment would likely address TPH but would have little effect on metals, PCBs, many key VOCs, and many SVOCs. Chemical treatment such as soil washing and stabilization is also expected to have limited effect on organic compounds in soil. If tailored to the site, these technologies would likely reduce concentrations of some COCs in HCIM Area soil, but it is unlikely that cleanup levels would be achieved. The marginal reduction in concentrations of soil COCs does not warrant the considerable area disruption and expense, especially given that the underlying groundwater is impacted and will be managed and contained over the long term.

- SVE was considered for reduction of VOCs in the vadose zone. This technology has already been implemented in the HCIM Area and was terminated after removal of approximately 19,000 pounds of VOCs. At that time, an analysis of the VOC removal rates indicated that the SVE system was achieving diminishing returns for the effort and expense expended.

Two soil remediation technologies were retained for supplementing the existing HCIM to use in the development of HCIM Area remedial alternatives:

- **Containment – Cap/Surface Cover**. Utilization of the current site cover system consisting of microsilica concrete and asphalt concrete is considered in the development of remedial alternatives.
- **Institutional Controls**. The development and implementation of institutional controls to limit future site use and development is considered in the development of remedial alternatives.

6.6.2 Outside Area Soil Remediation Technologies

The impacted soil in the Outside Area is diversely distributed in various areas both on and off the PSC properties, and is present on both public and private properties. Except for hot spots located near the Facility, soil COCs are primarily found near the ground surface beneath pavement and are generally distributed in a scattered fashion, making in situ technologies less effective for cleanup.

A broad range of technologies were considered to address Outside Area soils. Physical, chemical, biological, and administrative remediation technologies were considered to address vadose zone soils impacted by VOCs, SVOCs, TPH, metals, and PCBs. Both in situ and ex situ technologies were evaluated. Ultimately, only three technologies were retained: (1) disposal, (2) cap/surface cover, and (3) institutional controls. The basis for the rejection of the other candidate technologies is as follows:

- In situ technologies, including biological and chemical treatment, were considered for soil treatment but ultimately rejected. In situ treatment technologies would be impractical for the relatively small soil volumes that are scattered over a large area. In addition, implementation of in situ treatment technologies on land not owned by PSC would be administratively difficult.
- All ex situ technologies require excavation of the impacted soil COCs. The impacted soils that are located on the PSC properties are currently located under either a microsilica concrete or asphalt cap/cover. This would have to be broken and removed to access these soils for removal. The soils located off property on privately owned property would have to be excavated and brought to the PSC

properties for treatment. None of the ex situ remediation technologies are expected to treat the soil to below cleanup levels, so the soil would likely have to be disposed off site after treatment, potentially as a dangerous waste. Private property access would need to be negotiated with adjoining property owners. Excavation of certain areas may be prohibited without threatening adjacent structures. Worker exposure and public exposure to COC vapors and dust is increased by the soil excavation work.

Three technologies were retained for potential use in the development of remedial alternatives:

- **Off-Site Disposal (assumes excavation)**. For small shallow areas of impacted soil on private or public properties within the Outside Area, soil excavation and off-site disposal may be a practical economical approach in certain cases and will be carried forward into the alternatives analysis.

- **Cap/Surface Cover**. For PSC properties, the existing concrete and asphalt cap provides protection from exposure to soil COCs. Capping and restricting use of non-owned areas is also a potential option.

- **Institutional Controls**. For PSC properties, the development and implementation of institutional controls to limit future site use and development will be considered in the development of remedial alternatives. For other areas, administrative controls may be appropriate for adjacent land owners.

These technologies will be considered for development of remedial alternatives for the Outside Area. Additional characterization is presently being conducted to assess a hot spot located near the Facility. Depending on the results of this characterization, additional technologies, such as SVE, may be considered for potential remediation of the area as appropriate. All retained technologies may not be used in remedial alternatives.

6.6.3 HCIM Area Groundwater Remediation Technologies

A wide variety of groundwater treatment technologies were considered to address the groundwater COCs in the HCIM Area. Biological, physical, chemical, and administrative technologies were reviewed. The basis for the rejection of many of the technologies is as follows:

- Technologies that included the introduction of oxygen or air to stimulate aerobic biodegradation were rejected. Natural degradation of TCE in groundwater has been documented in the HCIM Area; this biodegradation would be arrested if oxygen were introduced into the groundwater.

- Cometabolic treatment was rejected due to health and safety concerns. Bioaugmentation was rejected because indigenous organisms are already degrading VOCs in HCIM Area groundwater.

- Chemical oxidation was rejected due to concerns that it could liberate unintended constituents (including metals). Also, the soil oxidant demand for an 80-foot saturated zone would be very large. In addition, the complex hydrostratigraphy below the PSC properties would make delivery of the oxidants to all COC-impacted areas impossible, resulting in only a partial cleanup and providing no substantial benefits, as discussed in Section 5.

- Thermal treatment (hot air, steam) was rejected because this technology would require heating soil/groundwater to a depth of 90 feet bgs to liberate VOCs and some SVOCs and TPH. The energy requirements and number of wells required to implement this would be excessive. This technology would likely not achieve cleanup levels for all COCs.

- Passive/reactive walls were rejected because a barrier wall already exists, and there is already almost no flow within the contained area.

Several technologies were retained for potential use in the development of remedial alternatives:

- **Reductive Dechlorination, Biostimulation (anaerobic)**. Anaerobic biodegradation has been documented in the HCIM Area groundwater. Biostimulation would enhance this natural phenomenon and may be successful in treating groundwater for vinyl chloride.

- **Monitored Natural Attenuation**. There is strong evidence of active natural attenuation within the affected groundwater. This is a natural process that would address TCE, cis-1,2-DCE, and VC without large-scale construction activities. This technology may be used as an element of a remedial alternative.

- **Groundwater Extraction (Pump and Treat).** This technology has been applied to numerous chlorinated solvent sites and is a proven technology; however, the restoration times associated with pump and treat for the HCIM Area will be extremely long. This technology would function primarily as hydraulic control approach and only secondarily as a mass removal approach.

- **Air Stripping**. If groundwater is pumped from the HCIM Area, air stripping has been proven effective for treatment of this aqueous waste stream.

- **Adsorption**. If groundwater is pumped from the HCIM Area, adsorption of VOCs onto GAC is a proven approach for aqueous waste stream treatment.

- **Barrier Wall**. The existing cement-bentonite barrier wall has been documented as effective in containing impacted soil and groundwater within the HCIM Area. This technology is retained for inclusion in the development of alternatives for the HCIM Area.

- **Institutional Controls**. A deed restriction or formal covenant could be established to prevent future use of site groundwater. This administrative technology will be retained for inclusion in the development of alternatives for the HCIM Area.

These retained technologies will be considered for developing HCIM Area remedial alternatives; all retained technologies may not be used.

6.6.4 Outside Area Groundwater Remediation Technologies

A wide variety of groundwater treatment technologies were considered to address the groundwater COCs in the Outside Area. Biological, physical, chemical, and administrative technologies were reviewed. Implementation of groundwater remedies in the Outside Area has many challenges, as discussed in Section 5. This area is fully developed and supports single-family residential dwellings as well as both commercial and industrial facilities. Remedial technology installations that include significant construction elements would require access agreements, easements, and designing around the existing above-ground and subsurface utility infrastructure that supports these neighborhoods. The basis for the rejection of many of the technologies is as follows:

- Technologies that included the introduction of oxygen or air to stimulate aerobic biodegradation were rejected. Natural degradation of TCE in groundwater has been documented in the Outside Area – this biodegradation would be arrested if oxygen were introduced into the groundwater. In addition, the addition of air or oxygen could increase the production of soil vapors and exacerbate the migration of vapors into indoor air spaces.

- Cometabolic aerobic treatment was rejected due to health and safety concerns, and bioaugmentation was rejected because indigenous organisms are already degrading VOCs in area groundwater.

- Chemical oxidation was rejected due to concerns that it could liberate unintended constituents (including metals). Also, the soil oxidant demand for the expansive

Outside Area saturated zone would be extremely high, and this approach would interfere with the natural anaerobic biodegradation that is already occurring.

- Thermal treatment (hot air, steam) was rejected as this technology would require heating soil/groundwater to a depth of 90 feet bgs across a very large area to liberate VOCs. The equipment, piping, and energy required to achieve this over more than 20 city blocks is enormous. This would require extensive piping runs on private property and in the public way, as well as a large number of injection and recovery wells. From an administrative standpoint, it is considered unimplementable, and has substantial risk that vapors would be created.

- Passive/reactive walls were rejected because actual permitting and construction of this technology over an approximately 1,400 linear foot area is logistically complex and likely not implementable. It would require acquisition of private property and public property easements. Utilities would be disrupted and may require some relocation to allow for wall construction. A funnel and gate barrier could disturb groundwater flow and raise groundwater elevations in unintended areas. Similar to passive/reactive walls, barrier walls were also considered administratively unfeasible.

- Groundwater extraction/hydraulic control was rejected due to the complexity of implementation. It would require long-term property access for the extraction and treatment system. Discharge permitting would also be problematic for this area.

The following technologies were retained for potential use in the development of Outside Area remedial alternatives:

- **Reductive Dechlorination, Biostimulation (anaerobic)**. This technology utilizes reductive chlorination and has been proven effective for biological degradation of chlorinated solvents at several sites. It would address TCE, cis-1,2-DCE, and, potentially, VC.

- **Monitored Natural Attenuation**. There is strong evidence of active natural attenuation within the affected groundwater. This is a natural process that would address TCE, cis-1,2-DCE, and VC without large scale construction activities. This technology may be used to as an element of a remedial alternative.

- **Institutional Controls**. It is likely that certain administrative controls would be included in a final remedy, such as maintenance of the existing IPIM. Because the Outside Area property is primarily owned by private land owners and the City, restrictions on the property title are not possible.

6.6.5 HCIM Area Inhalation Pathway Remediation Technologies

A number of vapor pathway treatment technologies were considered to address the intrusion of vapor into indoor air in present or future structures in the HCIM Area. The technologies generally involve active or passive ventilation systems applied to the subsurface or the structure to divert volatile vapors before they enter the indoor air space. This inhalation pathway monitoring and mitigation strategy is considered in this SWFS and may be chosen as part of the final remedial strategy for the HCIM Area.

SVE was evaluated as a potential vapor pathway mitigation measure. This remedial strategy was already conducted as an interim measure in the HCIM Area and was terminated, as the removal rates reached a point of diminishing returns. Therefore, this technology was rejected and is not considered further.

The following HCIM Area vapor pathway remediation technologies were retained for further consideration in the remedial alternatives analysis.

- **Vapor Barrier**. This technology is proven effective for new construction.
- **Active Slab Depressurization**. This technology imparts a negative pressure below the building slab and can be constructed on new or existing construction.
- **Foundation and Wall Sealing**. Sealing of subgrade walls (e.g. basements) and slabs reduces the intrusion of vapors. This is typically conducted in conjunction with other technologies.
- **Sub-membrane Depressurization**. This technology can be installed on existing structures where raised foundations exist.
- **Building Pressurization**. This technology is proven effective for new construction or existing construction and is demonstrated effective for mitigating the vapor pathway.
- **Institutional Controls**. These administrative controls may be put in place to ensure consideration of vapor pathway risks for any new construction within the footprint of the impacted groundwater plume.

6.6.6 Outside Area Inhalation Pathway Remediation Technologies

The vapor pathway remediation technologies that were considered to address the Outside Area are the same as those identified in the previous section for the HCIM Area. The Outside Area presents some unique challenges to manage the risk associated with the vapor pathway. This area is expansive, covering as much as 20 city blocks. Numerous single-family dwellings as well as commercial and industrial businesses are located in this area. VOC-impacted groundwater is located at approximately 10 feet bgs and is therefore in proximity to basements and home/building foundations.

The vapor pathway is currently mitigated within the Outside Area by the IPIM. This interim measure includes monitoring and specific mitigation measures to address vapor intrusion risks within the groundwater plume area. The actions that are currently being taken in the Outside Area are also included in this technology review and will be carried forward into the remedial alternatives analysis.

SVE was evaluated and rejected as a potential vapor pathway mitigation measure. SVE implementation across such an expansive area is considered administratively unimplementable. Property would need to be procured. Access agreements and easements would need to be obtained for wells, piping, utilities, and treatment equipment areas. Lower cost, more implementable, and more focused and appropriate technologies are available to mitigate the vapor pathway.

The technologies retained for further consideration in the remedial alternatives analysis are:

- Vapor Barrier
- Active Slab Depressurization
- Foundation and Wall Sealing
- Sub-membrane Depressurization
- Building Pressurization
- Institutional Controls

6.6.7 Remedial Alternatives Development

Remedial alternatives comprehensively addressing the project scope and objectives have been developed from these pools of potentially applicable remediation technologies. While the retained technologies present above are considered potential candidates for possible use in remediating soil, groundwater, and the vapor pathway for both the HCIM Area and the Outside Area, some technologies may not have been included in any of the remedial alternatives developed in this SWFS. The remedial alternatives addressed in the SWFS are described in Section 7.

TABLE 6-1

REMEDIATION TECHNOLOGY SCREENING FOR THE HCIM AREA SOIL
PSC Georgetown
Seattle, Washington

Technology Characteristics									
General Response Actions	**Remediation Technologies**	**Section**	**Technology Description**	**Technology Development Status**	**General Performance Record**	**Site Contaminants Addressed**	**Site-Specific Issues Affecting Technology or Implementation**	**Rationale for Retention or Rejection**	**Screening Result**
In Situ Biological Treatment	Bioventing	6.1.1	Oxygen is delivered to contaminated unsaturated soils by forced air movement (either extraction or injection of air) to increase oxygen concentrations and stimulate biodegradation.	Full-Scale	Performs well for non-halogenated organic compounds that biodegrade aerobically. Ineffective for halogenated organics, PCBs, and inorganics.	TPH, non-halogenated VOCs, SVOCs	In situ degradation of halogenated VOCs and SVOCs is only moderately effective.	Low effectiveness on high molecular weight organic COCs (SVOCs, PCBs) and ineffective for inorganics.	Reject
	Enhanced Bioremediation	6.1.2	The activity of naturally occurring microbes is stimulated by circulating water-based solutions through contaminated soils to enhance in situ biological degradation of organic contaminants. Nutrients, oxygen, or other amendments may be used to enhance bioremediation and contaminant desorption from subsurface materials.	Full-Scale	Has been shown to be moderately effective on halogenated VOCs and SVOCs and effective on TPH. Ineffective on inorganics and PCBs.	Halogenated VOCs, SVOCs, TPH	In situ degradation of halogenated VOCs is only moderately effective. Would require a system of numerous injection points to distribute bioremediation fluids to the subsurface across a large presently capped area.	Uncertain effectiveness on halogenated organics and SVOCs. Likely ineffective on inorganics and PCBs.	Reject
In Situ Physical/Chemical Treatment	Chemical Oxidation	6.1.3	Oxidation chemically converts hazardous contaminants to non-hazardous or less toxic compounds that are more stable, less mobile, and/or inert. The oxidizing agents most commonly used are ozone, hydrogen peroxide, or permanganate.	Full-Scale	Technology demonstrated to be effective under certain site conditions. Pilot test is required to evaluate feasibility and measure key design parameters.	Halogenated and non-halogenated VOCs and SVOCs	Handling of oxidant chemicals during remediation can be dangerous. Chemical oxidant demand of soil can consume large quantities of oxidant (pilot test required). Establishing effective oxidant delivery system for even vadose zone distribution difficult. Oxidants can mobilize metals. This technology would require numerous penetrations of the cap currently installed over the facility.	Worker safety concerns. High volumes of oxidant may be required to achieve cleanup levels for organics. Metals mobilization and reduced soil permeability are possible side effects. No reduction in mass of metals compounds. Will not achieve cleanup levels for all site COCs.	Reject
	Soil Flushing	6.1.4	Water, or water containing an additive to enhance contaminant solubility, is applied to the soil or injected into the ground water to raise the water table into the contaminated soil zone. Contaminants are leached into the groundwater, which is then extracted and treated.	Full-Scale	Poor performance record. Few sites have been successfully remediate using this technology.	Inorganics. Can also be effective on organics, depending on site conditions.	Requires recovery of water (hydraulic capture) and surfactant and separation facilities. Recovered water requires treatment and disposal and management of treatment residuals. Site would require different surfactants to treat all COCs. Large injection galleries or trenches would require the existing concrete cap to be removed.	Technology is not well proven. Requires extensive and complex fluids delivery system and recovered fluids treatment system. Would require removal of the concrete cap.	Reject
	Soil Vapor Extraction	6.1.5	Removes volatile constituents from the vadose zone. Using a blower, a vacuum is applied to wells screened in the vadose zone and the volatiles are entrained in the extracted air and removed with the soil vapor. Off gasses are generally treated to control emissions using thermal destruction or adsorption technologies.	Full-Scale	Proven reliable and effective technology	VOCs	SVE was conducted at the site for several years and approximately 19,000 pounds of solvents were removed. This activity was terminated when it was shown that continued operation would yield diminishing returns. This technology is not effective on the remaining COCs.	SVE was already conducted at the site as an interim measure, and additional SVE is not expected to remove significant additional VOCs from the vadose zone. SVE is only effective on VOCs.	Reject
	Solidification/ Stabilization	6.1.6	Contaminants are physically bound or enclosed within a stabilized mass (solidification), or chemical reactions are induced between the stabilizing agent and contaminants to reduce their mobility (stabilization).	Full-Scale	Mixed performance record. Stabilization reagents are effective but unproven in the long term. Effective and complete mixing can be difficult.	Inorganics	The volume increase due to stabilization reagents (bulk up) can be significant. Reagent delivery and effective mixing can be problematic for in situ applications. Presence of solidified material could effect future site development. Would require removal of the existing concrete cap/cover.	Poor effectiveness on organic COCs. Would require removal of the existing concrete cap/cover.	Reject

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REMEDIATION TECHNOLOGY SCREENING FOR THE HCIM AREA SOIL

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In Situ Thermal Treatment	Steam Injection	6.1.7	Steam is injected below the contaminated zone to heat up contaminated soil. The heating enhances the release of contaminants from the soil matrix. Some VOCs and SVOCs are stripped from contaminated zone and brought to the surface through soil vapor extraction.	Full-Scale	Performance of steam injection and stripping is highly variable and site specific. Requires a pilot test for demonstration.	VOCs, SVOCs, possibly PCBs	Effectiveness can be hindered by tight soils (silts and clays), highly variable permeability, high organic carbon, or high moisture content. Would require extensive network of steam distribution points to heat soil effectively. Would require installation numerous wells through the existing concrete cap/cover.	Ineffective on inorganics. Requires management of air emissions and treatment residuals. Numerous penetrations of the existing concrete cap/cover would be required.	Reject
Ex Situ Biological Treatment (assumes excavation)	Biopiles	6.1.8	Excavated soils are mixed with soil amendments and placed on a treatment area that includes leachate collection systems and some form of aeration. It is used to reduce concentrations of organic constituents in excavated soils through the use of biodegradation. Moisture, heat, nutrients, oxygen, and pH can be controlled to enhance biodegradation.	Full-Scale	Good for non-halogenated VOCs and TPH. Less effective on halogenated VOCs and poor effectiveness on PCBs.	Non-halogenated VOCs, TPH, some SVOCs	Would require extensive site excavation and soil management and removal of existing concrete cap/cover. Excavation could threaten integrity of the vadose zone portion of the containment wall. Extensive shoring and supporting systems would be required. Excavation along the eastern portion of the site could threaten current railroad operations and may be prohibited. Some impacted soils would likely remain in place due to the presence of existing structures/buildings. Treatability tests required to assess feasibility.	Unproven effectiveness on halogenated VOCs and PCBs. Ineffective on inorganics. Large excavation would disrupt existing site cover (cap). Increased worker and public exposure risk associated with excavation and treatment process.	Reject
Ex Situ Physical/Chemical Treatment (assumes excavation)	Soil Washing	6.1.9	Contaminants sorbed onto fine soil particles are separated from bulk soil in an aqueous-based system on the basis of particle size. The wash water may be augmented with a basic leaching agent, surfactant, pH adjustment, or chelating agent to help remove organics and heavy metals.	Full-Scale	Not widely commercially applied in the United States. Technology sometimes has difficulties treating complex mixtures of organics and inorganics.	VOCs, SVOCs, inorganics, TPH, PCBs	Would require extensive site excavation and soil management and removal of existing concrete cap/cover. Excavation could threaten integrity of the vadose zone portion of the containment wall. Extensive shoring and supporting systems would be required. Excavation along the eastern portion of the site could threaten current railroad operations and may be prohibited. Some impacted soils would likely remain in place due to the presence of existing structures/buildings. Worker and public exposure to impacted soils is significantly increased by this approach. Treatability tests required to assess feasibility. Produces wash water and soil residuals, which require further treatment and off-site disposal. Significant concentrations of humus (natural organics) or clay in soil can disrupt process.	Large excavation would disrupt existing site cap/cover. Containment wall could be compromised by excavation. Soil washing may not be effective for complex mixture of organics and inorganics. Increased worker and public exposure risk associated with excavation and treatment process.	Reject
Ex Situ Physical/Chemical Treatment (assumes excavation)	Solidification/ Stabilization	6.1.10	Contaminants are physically bound or enclosed within a stabilized mass (solidification), or chemical reactions are induced between the stabilizing agent and contaminants to reduce their mobility (stabilization).	Full-Scale	Generally effective for inorganics. Mature technology with documented performance record.	Inorganics, limited effectiveness with organics and PCBs	Would require excavation and soil management and removal of existing concrete cap/cover. Excavation could threaten integrity of the vadose zone portion of the containment wall. Extensive shoring and supporting systems would be required. Excavation along the eastern portion of the site could threaten current railroad operations and may be prohibited. Some impacted soils would likely remain in place due to the presence of existing structures/buildings. Treatability tests required to assess feasibility. Can result in significant volume increases (bulk up) that would likely result in off-site disposal of excess material. Because organic wastes would be encapsulated but not destroyed, long-term management of wastes would be required.	Large excavation would disrupt existing site cap/cover. Containment wall could be compromised by excavation. Volume increase (bulk up) results in off-site disposal of waste. Post treatment waste on site remains a long-term management issue. Not proven effective for organics. Increased worker and public exposure risk associated with excavation and treatment process.	Reject

TABLE 6-1

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Ex Situ Thermal Treatment (assumes excavation)	Thermal Desorption	6.1.11	Wastes are heated to volatilize water and organic contaminants. A carrier gas or vacuum system transports volatilized water and organics to the gas treatment system.	Full-Scale	Proven effective at low temperature for TPH and VOCs; at high temperature, effective for SVOCs, PAHs, and PCBs. Proven and commercial off-the-shelf technology offered by multiple vendors.	VOCs, SVOCs, TPH, PCBs, not effective on inorganics	Would require excavation and soil management and removal of existing concrete cap/cover. Excavation could threaten integrity of the vadose zone portion of the barrier wall. Extensive shoring and supporting systems would be required. Excavation along the eastern portion of the site could threaten current railroad operations and may be prohibited. Some impacted soils would likely remain in place due to the presence of existing structures/buildings. Worker and public exposure to impacted soils is significantly increased by this approach. Treatability tests required to assess feasibility. Requires large working area for setup of equipment. High soil moisture can increase costs due to extended soil drying. Emissions from thermal desorption must be captured and treated prior to discharge to the atmosphere.	Large excavation would disrupt existing site cap/cover and containment wall. High temperature desorption would address high molecular weight organics (SVOCs, PCBs) but would also potentially create emissions containing metals and dioxins/furans (related to PCB destruction). Will not achieve cleanup levels for all site COCs. Increased worker and public exposure risk associated with excavation.	Reject
Containment	Cap/Surface Cover	6.1.12	Surface caps constructed of asphalt concrete, portland cement concrete, or flexible membrane liners prevent direct exposure to soil contaminants and reduce infiltration of storm water into the subsurface, reducing the leaching of COCs to groundwater.	Full-Scale	Proven effective for preventing surface exposure to buried waste and for reducing infiltration of surface water through waste, limiting leaching of COCs to groundwater.	VOCs, SVOCs, TPH, PCBs, inorganics	Micro-silica concrete surface cap or asphalt concrete cap has been installed across the entire site. These low-permeability covers reduce infiltration and aid in the collection and capture of site storm water. Concrete caps provide excellent protection against direct exposure to COCs. These cover systems also prevent erosion and impacted sediment runoff from site.	Site surface is currently covered by micro-silica concrete or asphalt concrete cap. This cover system is performing well and meeting the objectives of preventing direct exposure to COCs and limiting surface water infiltration through impacted soils.	Retain
Disposal (assumes excavation)	Off-Site Disposal	6.1.13	Wastes exceeding site remedial goals are excavated and transported off site to an appropriate hazardous waste land disposal facility.	Full-Scale	Proven effective for all site COCs.	VOCs, SVOCs, TPH, PCBs, inorganics	Would require extensive site excavation and soil management and removal of existing concrete cap/cover. Excavation could threaten integrity of the vadose zone portion of the barrier wall. Extensive shoring and supporting systems would be required. Excavation along the eastern portion of the site could threaten current railroad operations and may be prohibited. Some impacted soils would likely remain in place due to the presence of existing structures/buildings.	Large excavation would disrupt existing site cap/cover, barrier wall, and activates at adjacent sites. Excavation is logistically complex and the potential for adverse worker exposure and public exposure to COCs is high. This technology simply transfers the waste from one location to another and does nothing to reduce mobility, toxicity, or volume of the COCs. Increased worker and public exposure risk associated with excavation.	Reject
Institutional Controls	Deed Restrictions and Property Use Limitations	6.1.14	Formal restrictions or covenants on future site development, land use, and site management can be implemented to prevent or mitigate exposure to COCs that remain in place in site soils.	Full-Scale	Proven effective for limiting exposure to COCs	All	Because it is likely that certain impacted soils will remain in place in the long term, limitations, engineering requirements, or restrictions on future site development, future worker exposure, and facility access will likely be required.	This technology will likely be a component of any remedial technologies selected for the site.	Retain

TABLE 6-2

REMEDIATION TECHNOLOGY SCREENING FOR THE OUTSIDE AREA SOIL

PSC Georgetown
Seattle, Washington

Technology Characteristics

General Response Actions	Remediation Technologies	Section	Technology Description	Technology Development Status	General Performance Record	Site Contaminants Addressed	Site-Specific Issues Affecting Technology or Implementation	Rationale for Retention or Rejection	Screening Result
In Situ Biological Treatment	Bioventing	6.1.1	Oxygen is delivered to contaminated unsaturated soils by forced air movement (either extraction or injection of air) to increase oxygen concentrations and stimulate biodegradation.	Full-Scale	Performs well for non-halogenated organic compounds that biodegrade aerobically. Ineffective for halogenated organics, PCBs, and inorganics.	TPH, non-halogenated VOCs, SVOCs	In situ degradation of halogenated VOCs is only moderately effective. Ineffective for PCBs and inorganics. Poor effectiveness for SVOCs. Requires easement or access agreements from numerous public and private entities. Does not address surfacial soil contamination.	Not practical or cost-effective to treat small volumes of soil distributed in various locations outside the HCIM, frequently on property not owned by PSC. Will not reduce all COCs concentrations to below cleanup levels. Access issues to construct the required infrastructure are logistically extremely complex.	Reject
	Enhanced Bioremediation	6.1.2	The activity of naturally occurring microbes is stimulated by circulating water-based solutions through contaminated soils to enhance in situ biological degradation of organic contaminants. Nutrients, oxygen, or other amendments may be used to enhance bioremediation and contaminant desorption from subsurface materials.	Full-Scale	Has been shown to be moderately effective on halogenated VOCs and SVOCs and effective on TPH. Ineffective on inorganics and PCBs.	Halogenated VOCs, SVOCs, TPH	In situ degradation of halogenated VOCs only moderately effective. Would require system of numerous injection points to distribute bioremediation fluids to the subsurface across a large area. Requires easement or access agreements from numerous public and private entities. Does not address surfacial soil contamination.	Not practical or cost-effective to treat small volumes of soil distributed in various locations outside the HCIM Area, frequently on property not owned by PSC. Will not reduce all COCs concentrations to below cleanup levels. Access issues to construct the required infrastructure are logistically extremely complex. Does not address surfacial soil contamination.	Reject
In Situ Physical/Chemical Treatment	Chemical Oxidation	6.1.3	Oxidation chemically converts hazardous contaminants to non-hazardous or less toxic compounds that are more stable, less mobile, and/or inert. The oxidizing agents most commonly used are ozone, hydrogen peroxide, or permanganate.	Full-Scale	Technology demonstrated to be effective under certain site conditions. Pilot test is required to evaluate feasibility and measure key design parameters.	Halogenated and non-halogenated VOCs and SVOCs	Handling of oxidant chemicals during remediation can be dangerous. Chemical oxidant demand of soil can consume large quantities of oxidant (pilot test required). Establishing an effective oxidant delivery system for even vadose zone distribution would be difficult. Ineffective for inorganics. Oxidants can mobilize metals. Requires easement or access agreements from numerous public and private entities. Does not address surfacial soil contamination.	Not practical or cost-effective to treat small volumes of soil distributed in various locations outside the HCIM Area, frequently on property not owned by PSC. Worker safety concerns. Oxidant volumes can be large if high soil oxidant demand. Metals mobilization and reduced soil permeability are possible side effects. Difficult to obtain access and easement rights. Does not address surfacial soil contamination.	Reject
	Soil Flushing	6.1.4	Water, or water containing an additive to enhance contaminant solubility, is applied to the soil or injected into the ground water to raise the water table into the contaminated soil zone. Contaminants are leached into the ground water, which is then extracted and treated.	Full-Scale	Poor performance record. Few sites have been successfully remediated using this technology.	Inorganics. Can also be effective on organics, depending on site conditions.	Requires recovery of water (hydraulic capture) and surfactant and separation facilities. Recovered water requires treatment and disposal and management of treatment residuals. Requires easement or access agreements from both public and private entities. Some untreated soil may remain in place due to existing structures. Does not address surfacial soil contamination.	Not practical or cost-effective to treat small volumes of soil distributed in various locations outside the HCIM Area, frequently on property not owned by PSC. Technology is not well proven. Access issues to construct the required infrastructure are logistically extremely complex.	Reject
	Soil Vapor Extraction	6.1.5	Removes volatile constituents from the vadose zone. Using a blower, a vacuum is applied to wells screened in the vadose zone and the volatiles are entrained in the extracted air and removed with the soil vapor. Off gasses are generally treated to control emissions using thermal destruction or adsorption technologies.	Full-Scale	Proven reliable and effective technology	VOCs	Implementation would require an expansive piping network or multiple SVE systems to address VOCs. Installation of vent wells and below grade piping would be difficult due to the large number underground utilities. Difficult to implement this technology to address surfacial soil contamination. Requires easement or access agreements from both public and private entities.	Not practical or cost-effective to treat small volumes of soil distributed in various locations outside the HCIM Area, frequently on property not owned by PSC. Difficult to implement SVE over a large area covered by businesses and residences. Technology would not effectively treat the entire volume of contaminated soil.	Reject

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REMEDIATION TECHNOLOGY SCREENING FOR THE OUTSIDE AREA SOIL

PSC Georgetown
Seattle, Washington

Technology Characteristics									
General Response Actions	**Remediation Technologies**	**Section**	**Technology Description**	**Technology Development Status**	**General Performance Record**	**Site Contaminants Addressed**	**Site-Specific Issues Affecting Technology or Implementation**	**Rationale for Retention or Rejection**	**Screening Result**
In Situ Physical/Chemical Treatment	Solidification/ Stabilization	6.1.6	Contaminants are physically bound or enclosed within a stabilized mass (solidification), or chemical reactions are induced between the stabilizing agent and contaminants to reduce their mobility (stabilization).	Full-Scale	Mixed performance record. Stabilization reagents are effective but unproven in the long term. Effective and complete mixing can be difficult.	Inorganics	The volume increase due to stabilization reagents (bulk up) can be significant. Reagent delivery and effective mixing can be problematic for in situ applications. Presence of solidified material could effect future site development. Some untreated soil may remain in place due to existing structures. Requires easement or access agreements from both public and private entities. Does not address surfacial soil contamination.	Not practical or cost-effective to treat small volumes of soil distributed in various locations outside the HCIM Area, frequently on property not owned by PSC. Poor effectiveness on organic COCs. Technology would not effectively treat the entire volume of contaminated soil. Access issues to construct the required infrastructure are logistically extremely complex.	Reject
In Situ Thermal Treatment	Steam Injection	6.1.7	Steam is injected below the contaminated zone to heat up contaminated soil. The heating enhances the release of contaminants from the soil matrix. Some VOCs and SVOCs are stripped from contaminated zone and brought to the surface through soil vapor extraction.	Full-Scale	Performance of steam injection and stripping is highly variable and site specific. Requires a pilot test for demonstration.	VOCs, SVOCs, possibly PCBs	Effectiveness can be hindered by tight soils (silts and clays), highly variable permeability, high organic carbon, or high moisture content. Would require extensive network of steam distribution points to heat soil effectively. surfacial contamination would not be addressed by this technology. Requires easement or access agreements from both public and private entities. Would be difficult to install due to the large number of underground utilities.	Not practical or cost-effective to treat small volumes of soil distributed in various locations outside the HCIM Area, frequently on property not owned by PSC. Ineffective on inorganics. Requires management of air emissions and treatment residuals. Access issues to construct the required infrastructure are logistically extremely complex.	Reject
Ex Situ Biological Treatment (assumes excavation)	Biopiles	6.1.8	Excavated soils are mixed with soil amendments and placed on a treatment area that includes leachate collection systems and some form of aeration. It is used to reduce concentrations of organic constituents in excavated soils through the use of biodegradation. Moisture, heat, nutrients, oxygen, and pH can be controlled to enhance biodegradation.	Full-Scale	Good for non-halogenated VOCs and fuel hydrocarbons. Less effective on halogenated VOCs and poor effectiveness on PCBs.	Non-halogenated VOCs, TPH, some SVOCs	Would require extensive excavation and soil management. Some impacted soils would likely remain in place due to the presence of existing structures/buildings. Treatability tests required to assess feasibility. Excavation would be difficult due to the large number of underground utilities. Requires easement or access agreements from both public and private entities.	Unproven effectiveness on halogenated VOCs, inorganics and PCBs. Volume of soil too small to be cost-effective. Access issues to construct the required infrastructure are logistically extremely complex. Increased worker and public exposure risk associated with excavation and treatment.	Reject
Ex Situ Physical/Chemical Treatment (assumes excavation)	Soil Washing	6.1.9	Contaminants sorbed onto fine soil particles are separated from bulk soil in an aqueous-based system on the basis of particle size. The wash water may be augmented with a basic leaching agent, surfactant, pH adjustment, or chelating agent to help remove organics and heavy metals.	Full-Scale	Not widely commercially applied in the United States. Technology sometimes has difficulties treating complex mixtures of organics and inorganics.	VOCs, SVOCs, inorganics, TPH, PCBs	Would require extensive excavation and soil management. Some impacted soils would likely remain in place due to the presence of existing structures/buildings. Treatability tests required to assess feasibility. Excavation would be difficult due to the large number of underground utilities. Requires easement or access agreements from both public and private entities.	Soil washing may not be effective for complex mixture of organics (PCBs) and inorganics. Increased worker and public exposure risk associated with excavation. Access issues to construct the required infrastructure are logistically extremely complex.	Reject
Ex Situ Physical/Chemical Treatment (assumes excavation)	Solidification/ Stabilization	6.1.10	Contaminants are physically bound or enclosed within a stabilized mass (solidification), or chemical reactions are induced between the stabilizing agent and contaminants to reduce their mobility (stabilization).	Full-Scale	Generally effective for inorganics. Mature technology with documented performance record.	Inorganics, limited effectiveness with organics and PCBs	Would require extensive excavation and soil management. Some impacted soils would likely remain in place due to the presence of existing structures/buildings. Treatability tests required to assess feasibility. Excavation would be difficult due to the large number of public and private entities requiring approval. Can result in significant volume increases (bulk up) that would likely result in off site disposal of excess material. Because organic wastes would be encapsulated but not destroyed, long-term management of wastes would be required.	Difficult to gain approval to excavate in off-site public and private land. Volume increase (bulk up) results in off site disposal of waste. Post-treatment waste on site remains a long-term management issue. Not proven effective for organics. Increased worker and public exposure risk associated with excavation.	Reject

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Technology Characteristics									
General Response Actions	**Remediation Technologies**	**Section**	**Technology Description**	**Technology Development Status**	**General Performance Record**	**Site Contaminants Addressed**	**Site-Specific Issues Affecting Technology or Implementation**	**Rationale for Retention or Rejection**	**Screening Result**
Ex Situ Thermal Treatment (assumes excavation)	Thermal Desorption	6.1.11	Wastes are heated to volatilize water and organic contaminants. A carrier gas or vacuum system transports volatilized water and organics to the gas treatment system.	Full-Scale	Proven effective at low temperature for petroleum fuels and VOCs; at high temperature, effective for SVOCs, PAHs, and PCBs. Proven and commercial off-the-shelf technology offered by multiple vendors.	VOCs, SVOCs, TPH, PCBs, not effective on inorganics	Would require extensive excavation and soil management. Some impacted soils would likely remain in place due to the presence of existing structures/buildings. Treatability tests required to assess feasibility. Excavation would be difficult due to the large number of public and private entities requiring approval. Requires large working area for setup of equipment. High soil moisture can increase costs due to extended soil drying. Emissions from thermal desorption must be captured and treated prior to discharge to the atmosphere.	High temperature desorption would address high molecular weight organics (SVOCs, PCBs) but would also potentially create emissions containing metals and dioxins/furans (related to PCB destruction). Not practical in treating small volumes of soil. Increased worker and public exposure risk associated with excavation.	Reject
Containment	Cap/Surface Cover	6.1.12	Surface caps constructed of asphalt concrete, portland cement concrete, or flexible membrane liners prevent direct exposure to soil contaminants and reduce infiltration of storm water into the subsurface, reducing the leaching of COCs to groundwater.	Full-Scale	Proven effective for preventing surface exposure to buried waste and for reducing infiltration of surface water through waste, limiting leaching of COCs to groundwater.	VOCs, SVOCs, TPH, PCBs, inorganics	Asphalt caps will reduce infiltration and aid in the collection and capture of site storm water. Concrete caps provide excellent protection against direct exposure to COCs. These cover systems also prevent erosion and impacted sediment runoff. Effective for contiguous areas in the Outside Area soil where COCs exceed cleanup levels and property is owned by PSC.	Site surface is currently covered by micro-silica concrete or asphalt concrete cap. This cover system is performing well and meeting the objectives of preventing direct exposure to COCs and limiting surface water infiltration through impacted soils.	Retain
Disposal (assumes excavation)	Off Site Disposal	6.1.13	Wastes exceeding site remedial goals are excavated and transported off site to an appropriate hazardous waste land disposal facility.	Full-Scale	Proven effective for all site COCs.	VOCs, SVOCs, TPH, PCBs, inorganics	Would require extensive excavation and soil management. Some impacted soils would likely remain in place due to the presence of existing structures/buildings. Excavation would be difficult due to the large number of public and private entities requiring approval.	This technology could potentially be used to remove surfacial soil contamination in Outside Area soil.	Retain
Institutional Controls	Deed Restrictions and Property Use Limitations	6.1.14	Formal restrictions or covenants on future site development, land use, and site management can be implemented to prevent or mitigate exposure to COCs that remain in place in site soils.	Full-Scale	Proven effective for limiting exposure to COCs	All	Because it is likely that certain impacted soils will remain in place in the long term, limitations or restrictions on future land development, maintenance of surface covers, and future worker exposure will likely be required.	This technology will likely be a component of any remedial technologies selected for the site. It is applicable to Outside Area soil where waste remains.	Retain

TABLE 6-3

REMEDIATION TECHNOLOGY SCREENING FOR HCIM AREA GROUNDWATER

PSC Georgetown
Seattle, Washington

				Technology Characteristics					
General Response Actions	Remediation Technologies	Section	Technology Description	Technology Development Status	General Performance Record	Site Contaminants Addressed	Site-Specific Issues Affecting Technology or Implementation	Rationale for Retention or Rejection	Screening Result
In Situ Biological Treatment	Enhanced Biodegradation with Biosparging	6.2.1	Air is injected into the saturated zone to increase oxygen levels and promote aerobic biological activity. Air is delivered using a compressor and vertical or horizontal injection wells.	Full-Scale	Performs well for organic compounds that biodegrade aerobically.	VC, TPH	Documented natural biological degradation of chlorinated VOCs (i.e., TCE) would be inhibited by the addition of oxygen. The technology could potentially exacerbate the vapor intrusion pathway by volatizing the VOCs in groundwater. The addition of oxygen could potentially stimulate growth of iron-reducing bacteria, which would cause fouling of injection points. Will not reduce all COC concentrations to below cleanup levels.	The technology will inhibit the documented naturally occurring biological degradation at the site. Aerobic conditions do not readily degrade TCE. Will not reduce all COC concentrations to below cleanup levels.	Reject
	Oxygen Enhancement with Hydrogen Peroxide or ORC	6.2.2	Oxygen is added to the saturated zone by adding chemicals such as hydrogen peroxide or ORC. The increased oxygen levels promote aerobic biological activity. Hydrogen peroxide or ORC solutions can be injected into the aquifer or introduced through slow release mechanisms placed in wells.	Full-Scale	Has been effectively used at TPH sites.	VC, TPH	Documented natural biological degradation of chlorinated VOCs (i.e., TCE) would be inhibited by the addition of oxygen. Injection of ORC or hydrogen peroxide would require numerous injection wells. Iron fouling due to the aerobic environment is a concern. Will not reduce all COC concentrations to below cleanup levels.	The technology will inhibit the documented naturally occurring biological degradation at the site. Aerobic conditions do not readily degrade TCE.	Reject
	Co-Metabolic Treatment	6.2.3	Chlorinated organic degradation by aerobic co-metabolization with indigenous organisms and alkane substrates such as ethane. Oxygen and the alkane substrate can be added through passive diffusion or through a groundwater circulation system.	Full-Scale	Has been effective for degradation of chlorinated solvents.	TCE, cis-1,2-DCE, VC, TPH	Documented natural biological degradation of chlorinated VOCs (i.e., TCE) would be inhibited by the addition of oxygen. Would require numerous wells for effective subsurface distribution or a large recirculating system. Iron precipitation and iron-reducing bacteria could foul system and limit the effective treatment area. The use of fuels (substrate) and oxygen present significant health and safety issues. Will not reduce all COC concentrations to below cleanup levels.	The technology will inhibit the natural occurring biological degradation at the site by creating aerobic conditions. Health and safety concerns.	Reject
	Reductive Dechlorination Biostimulation (Anaerobic)	6.2.4	A carbohydrate (e.g., molasses, sodium lactate) is injected into the affected groundwater to serve as an electron donor for indigenous organisms to enhance reductive dechlorination. A carbohydrate solution is distributed with injection wells, direct push probes, or groundwater recirculation systems.	Full-Scale	Proven effective under certain site conditions for degradation of chlorinated solvents.	TCE, cis-1,2-DCE, VC	Multiple injections of electron donor are typically required. Substantial monitoring is required to confirm effectiveness. This technology alone may not be capable of attaining the cleanup levels for VOCs.	May be effective at reducing site contaminant concentrations and could potentially accelerate the naturally occurring anaerobic degradation process.	Retain
	Bioaugmentation	6.2.5	Injection of specialty, non-indigenous microbes to enhance biodegradation. Microorganisms are commercially available for both aerobic and anaerobic degradation of chlorinated organics and petroleum hydrocarbons.	Full-Scale	Has been effective for biodegradation of chlorinated solvents. Requires application of specific microbial seed. May require repeated application.	TCE, cis-1,2-DCE, VC	Non-indigenous organisms may not compete successfully with indigenous organisms. TCE degradation is already occurring in the HCIM Area groundwater. This technology does not address metals.	TCE is already actively degrading in the HCIM Area groundwater. There does not appear to be a need for bioaugmentation to stimulate this documented process.	Reject
	Natural Attenuation	6.2.6	Intrinsic attenuation of groundwater constituents via the natural processes of biodegradation, aerobic degradation, adsorption, and dilution. This passive technology relies on natural conditions within impacted groundwater.	Full-Scale	Has been proven effective at sites with appropriate conditions.	VOCs, TPH, SVOCs	Natural biodegradation of TCE and cis-1,2-DCE is documented within the HCIM Area impacted groundwater, resulting in the generation of VC. Natural degradation of VC may be slow at the site.	Natural attenuation is a viable process and there is documented evidence that natural attenuation is active within the HCIM Area.	Retain

TABLE 6-3

REMEDIATION TECHNOLOGY SCREENING FOR HCIM AREA GROUNDWATER

PSC Georgetown
Seattle, Washington

				Technology Characteristics					
General Response Actions	**Remediation Technologies**	**Section**	**Technology Description**	**Technology Development Status**	**General Performance Record**	**Site Contaminants Addressed**	**Site-Specific Issues Affecting Technology or Implementation**	**Rationale for Retention or Rejection**	**Screening Result**
In Situ Physical/Chemical Treatment	Phytoremediation	6.2.7	Plants can supply nutrients to promote microbial growth that reduce contaminant concentrations in groundwater or plants can directly uptake contaminants in groundwater.	Full-Scale	Has been proven effective at sites with appropriate conditions.	VOCs, TPH, SVOCs	Implementation of this technology would require the removal of the concrete cap/cover currently installed on the site. The number of COCs and the extent of contamination at the site make it difficult to select the appropriate phytoremediation process.	Would require the removal of the concrete cap/cover. Would not effectively reduce all COCs concentration below cleanup levels.	Reject
In Situ Physical/Chemical Treatment	Air Sparging	6.2.8	Air is injected into the saturated zone to volatilize organic compounds. An air compressor is used to supply air to the saturated zone typically through air sparge wells.	Full-Scale	Has been effectively used at VOC-impacted sites.	VOCs, PHCs, SVOCs	Documented natural biological anaerobic degradation of chlorinated VOCs would be inhibited by the addition of oxygen. This technology would need to be used in conjunction with soil vapor extraction to capture volatilized contaminants.	The technology will inhibit the naturally occurring biological VOC degradation at the site. Would require an extensive SVE system with long-term operation and maintenance to capture all off-gas. This technology does not effectively address DNAPL.	Reject
In Situ Physical/Chemical Treatment	Chemical Oxidation	6.2.9	An oxidizing chemical (permanganate, hydrogen peroxide, Fentons Reagent) is added to the groundwater to chemically oxidize contaminants. Usually applied through injection wells or via direct push technology.	Full-Scale	Mixed performance record. Some applications have been very effective, while others have been unsuccessful in attaining cleanup objectives.	VOCs	Documented natural biological degradation of chlorinated VOCs would be inhibited by the addition of chemical oxidants. High iron concentrations at the site will exert a large oxidant demand, reducing efficiency of treatment. This technology does not effectively address DNAPL.	The technology will inhibit the natural occurring biological VOC degradation at the site. High iron concentrations exert oxidant demand. This technology does not address all site COCs. Does not address DNAPL.	Reject
	Thermal Treatment	6.2.10	Temperature in the saturated zone is increased by injecting steam or applying an electrical current. The increased temperature volatilizes organic compounds, which need to be removed using SVE.	Full-Scale	Mixed performance record. Some applications have been very effective, while others have been unsuccessful in attaining cleanup objectives.	VOCs, TPH, SVOCs	This technology would require numerous steam injection points and an off-gas treatment system to capture the volatilized contaminants. Iron fouling is likely. The energy requirement to treat (heat) deeper ground water is likely cost-prohibitive. This technology does not effectively address DNAPL.	Potential for iron fouling and the high energy requirements to heat deep groundwater provide the basis to reject this technology. Does not effectively address DNAPL.	Reject
	In-Well Stripping	6.2.11	Air is injected into a double-screened well, lifting the water in the well and forcing it out the upper screen. Simultaneously, additional water is drawn in the lower screen. Volatile compounds are transferred to the vapor phase and removed by vapor extraction.	Full-Scale	Mixed performance record. Some applications have been very effective, while others have been unsuccessful in attaining cleanup objectives.	VOCs, TPH	The documented natural biological degradation of chlorinated VOCs would be inhibited by the addition of oxygen (in well aeration). High iron levels at the site would likely cause iron precipitate and/or biological fouling of the air stripping wells. This technology would need to be used in conjunction with soil vapor extraction to capture volatilized contaminants.	Would inhibit the existing naturally occurring biological VOC degradation and may result in significant iron fouling. Does not address DNAPL. Would require an extensive SVE system with long-term operation and maintenance to capture all off-gas.	Reject
In Situ Physical/Chemical Treatment	Passive/Reactive Treatment Walls	6.2.12	Contaminant concentrations in groundwater are reduced as the groundwater flows through the permeable reactive barrier containing zero valent iron.	Full-Scale	Has been effectively used to reduce chlorinated VOC concentrations in groundwater.	VOCs	This technology would not be effective at treating HCIM Area contaminants because the HCIM barrier wall is already in place and there is negligible flow occurring within the containment. Would be difficult to build a passive/reactive barrier that was effective at reducing all COC below cleanup levels.	This technology is not compatible with the existing IRA barrier wall. Does not address DNAPL or complex mixture of COCs.	Reject

TABLE 6-3

REMEDIATION TECHNOLOGY SCREENING FOR HCIM AREA GROUNDWATER

PSC Georgetown
Seattle, Washington

				Technology Characteristics					
General Response Actions	**Remediation Technologies**	**Section**	**Technology Description**	**Technology Development Status**	**General Performance Record**	**Site Contaminants Addressed**	**Site-Specific Issues Affecting Technology or Implementation**	**Rationale for Retention or Rejection**	**Screening Result**
Ground Water Extraction/ Hydraulic Control	Ground Water Extraction (Pump and Treat)	6.2.13	Groundwater extraction wells are installed to remove contaminated groundwater, thereby reducing contaminant mass. Extracted water is then treated and discharged. May also be used for hydraulic control for contaminant migration reduction or prevention.	Full-Scale	Has been effectively used to remove contaminants. Is a long-duration technology.	VOCs, SVOCs, TPH, PCBs	This technology has been used successfully at the site as part of the HCIM barrier wall to maintain an inward hydraulic gradient within the HCIM Area. Extracted and treated water may not be accepted by King County POTW in the long-term, and storm sewer NPDES permitting could be complex and time-consuming.	Potentially effective long-term approach for containing source area (HCIM Area) groundwater COCs.	Retain
Ex Situ Physical/Chemical Treatment	Air Stripping	6.2.14	Extracted groundwater is passed downward against a stream of rising air. The countercurrent stream of air strips VOCs from the water. Contaminants in the air stream are then removed or treated by oxidation or adsorption technologies.	Full-Scale	Has been effectively used to remove VOCs from groundwater extracted from the HCIM Area as part of the HCIM.	VOCs	None, this technology is currently in use as part of the existing groundwater HCIM.	Has been effective in reducing VOC concentrations in extracted groundwater during operation of the HCIM.	Retain
Ex Situ Physical/Chemical Treatment	Adsorption	6.2.15	Extracted groundwater is passed through vessels containing granular-activated carbon. Organic compounds with an affinity for carbon are transferred from the aqueous or vapor phase to the solid phase by sorption to the carbon. Treated carbon products are available to address VOCs such as VC, that have a low affinity for conventional carbon.	Full-Scale	Has been effectively used to remove VOCs from both groundwater and vapor streams during the SVE and barrier wall HCIMs.	VOCs, SVOCs, TPH, PCBs	None, this technology is currently in use as part of the existing groundwater HCIM.	Has been effective at reducing VOC concentrations in air stripper off-gas during operation of the HCIM.	Retain
Physical Containment	Barrier Wall	6.2.16	Placement of a barrier wall that physically restricts flow of groundwater. The wall must be keyed into lower confining unit to be effective.	Full-Scale	Has been effectively used to contain contaminated groundwater.	VOCs, SVOCs, TPH, PCBs	None, barrier wall is in place as part of the existing HCIM.	Has been documented to be effective at containing site contaminants during operation of the HCIM.	Retain
Institutional Controls	Deed Restriction and Property Use Limitations	6.2.17	Formal restrictions or covenants governing future site development, land use, and site management can be implemented to prevent or mitigate exposure to groundwater COCs that remain in place on site.	Full-Scale	Has been used effectively to eliminate specific exposure pathways.	All	Because it likely that impacted groundwater will remain on site in the long term, limitations or restrictions on future site development, groundwater use, and deep excavations will be required to provide protection to future site workers or site occupants.	This technology will likely be a component of any remedial alternative selected for the site.	Retain

Notes:

1. VOCs - Volatile organic compounds
2. SVOC - Semi-volatile organic compounds
3. PCBs - Polychlorinated Biphenyls
4. VC- Vinyl chloride
5. TCE - Trichloroethene
6. cis-1,2-DCE - cis-1,2-Dichloroethene
7. ORC - Oxygen releasing compound

TABLE 6-4

REMEDIATION TECHNOLOGY SCREENING FOR OUTSIDE AREA GROUNDWATER

PSC Georgetown
Seattle, Washington

			Technology Characteristics						
General Response Actions	**Remediation Technologies**	**Section**	**Technology Description**	**Technology Development Status**	**General Performance Record**	**Site Contaminants Addressed**	**Site-Specific Issues Affecting Technology or Implementation**	**Rationale for Retention or Rejection**	**Screening Result**
In Situ Biological Treatment	Enhanced Biodegradation with Biosparging	6.2.1	Air is injected into the saturated zone at a concentration just adequate to promote and sustain aerobic biological activity. Air is delivered using a compressor and vertical or horizontal injection wells.	Full-Scale	Performs well for organic compounds that biodegrade aerobically.	VC, TPH	Documented natural anaerobic biological degradation of chlorinated VOCs (i.e., TCE) would be inhibited by the addition of oxygen. The addition of oxygen could potentially stimulate growth of iron-reducing bacteria, which would cause fouling of air injection points. The large area of VOC impacts in the Outside Area groundwater would require an extensive air delivery system. Logistically, site access, easements, and acquiring required property for the air injection system would be extremely complex in this off-site area. The technology could potentially exacerbate the vapor intrusion pathway by volatilizing the VOCs in groundwater.	The technology would inhibit the naturally occurring anaerobic biological degradation at the site. Furthermore, obtaining access, easements, and property required for system installation and monitoring is logistically complex and could be unimplementable.	Reject
	Oxygen Enhancement with Hydrogen Peroxide or ORC	6.2.2	Oxygen is added to the saturated zone by adding chemicals such as hydrogen peroxide or ORC. The increased oxygen levels promote aerobic biological activity. Hydrogen peroxide or ORC solutions can be injected into the aquifer or introduced through slow release mechanisms placed in wells.	Full-Scale	Has been effectively used at petroleum hydrocarbon sites.	VC, TPH	The documented natural biological degradation of chlorinated VOCs (i.e., TCE) would be inhibited by the addition of oxygen to the Outside Area groundwater. Injection of ORC or hydrogen peroxide would require numerous injection wells across a very large area. Access to the public lands and private properties to make the required injections and to conduct ongoing monitoring would be extremely complex. Iron and manganese fouling due to the introduction of oxygen could limit the ability to distribute the chemicals in the area of the impacted groundwater.	The technology will inhibit the documented naturally occurring biological degradation at the site. Aerobic conditions do not readily degrade TCE. Furthermore, iron fouling is a significant concern that could reduce treatment effectiveness. Finally, issues related to access for injections and monitoring could prevent or delay implementation.	Reject
	Co-Metabolic Treatment	6.2.3	Chlorinated organic degradation by aerobic co-metabolization with indigenous organisms and alkane substrates such as ethane. Oxygen and the alkane substrate can be added through passive diffusion or through a groundwater circulation system.	Full-Scale	Has been demonstrated effective for degradation of chlorinated solvents.	VC, TPH	Documented natural biological degradation of chlorinated VOCs (i.e., TCE) would be inhibited by the addition of oxygen. Would require numerous wells across a very large area for effective subsurface distribution of chemicals or the construction of a very large recirculating system. Iron precipitation and iron reducing bacteria could foul system and limit the effective treatment area. The use of fuels (substrate) and oxygen present significant health and safety issues for an urban mixed-use environment. Obtaining site access to private property, easements from public entities, and purchasing the required property make this technology logistically very complex.	The technology will inhibit the natural occurring biological degradation at the site by creating aerobic conditions. Health and safety concerns with using fuels and oxygen make application of this technology less favorable. Installation is logistically very complex.	Reject

TABLE 6-4

REMEDIATION TECHNOLOGY SCREENING FOR OUTSIDE AREA GROUNDWATER

PSC Georgetown
Seattle, Washington

Technology Characteristics									
General Response Actions	**Remediation Technologies**	**Section**	**Technology Description**	**Technology Development Status**	**General Performance Record**	**Site Contaminants Addressed**	**Site-Specific Issues Affecting Technology or Implementation**	**Rationale for Retention or Rejection**	**Screening Result**
In Situ Biological Treatment	Reductive Dechlorination Biostimulation (Anaerobic)	6.2.4	A carbohydrate (e.g., molasses, sodium lactate) is injected into the affected groundwater to serve as an electron donor for indigenous organisms to enhance reductive dechlorination. A carbohydrate solution is distributed with injection wells, direct push probes, or groundwater recirculation systems.	Full-Scale	Proven effective under certain site conditions for degradation of chlorinated solvents.	VOCs	Multiple injections of electron donor would typically be required and substantial monitoring would be required to confirm treatment effectiveness. This technology alone may not be capable of attaining the cleanup levels for VC. Logistically less complex than technologies that require permanent easements for installation of treatment equipment. Periodic injections would be made to maintain concentrations of the selected carbohydrate in Outside Area groundwater. The anaerobic biodegradation of VOCs is already documented and occurring at the site; this technology is complimentary to the observed natural degradation.	Should be effective at reducing site chlorinated VOC concentrations and is expected to accelerate the naturally occurring anaerobic degradation process. Less logistically complex than those alternatives that require significant constructed infrastructure for implementation.	Retain
	Bioaugmentation	6.2.5	Injection of specialty, non-indigenous microbes to enhance biodegradation. Microorganisms are commercially available for both aerobic and anaerobic degradation of chlorinated organics and petroleum hydrocarbons.	Full-Scale	Has been effective for biodegradation of chlorinated solvents. Requires application of specific microbial seed. May require repeated application.	VOCs	Non-indigenous organisms may not compete successfully with indigenous organisms. TCE degradation is already occurring and well documented in the Outside Area. Periodic injections of microbes and ongoing monitoring across the expansive Outside Area groundwater would require access to be obtained from both public entities and private parties.	TCE is already actively degrading in the Outside Area groundwater. There does not appear to be a need for bioaugmentation to stimulate this documented process.	Reject
	Natural Attenuation	6.2.6	Intrinsic attenuation of groundwater constituents via the natural processes of biodegradation, aerobic degradation, adsorption, and dilution. Passive technology relying on natural conditions within impacted groundwater.	Full-Scale	Has been proven effective at sites with appropriate conditions.	VOCs, TPH	Natural biodegradation of TCE and cis-1,2-DCE has been documented in the Outside Area groundwater, resulting in the generation of VC. VC appears to be naturally attenuating as groundwater flows southwest from the source area.	Natural attenuation is a viable process. There is documented evidence that natural attenuation is active and effective within the Outside Area groundwater.	Retain
In Situ Physical/Chemical Treatment	Air Sparging	6.2.8	Air is injected into the saturated zone to volatilize organic compounds. An air compressor is used to supply air to the saturated zone typically through air sparge wells.	Full-Scale	Has been effectively used at VOC-impacted sites.	VOCs, TPH	The documented natural biological anaerobic degradation of chlorinated VOCs would be inhibited by the addition of oxygen. This technology would need to be used in conjunction with soil vapor extraction to capture volatilized contaminants. Over the expansive area of the Outside Area groundwater, the network of wells and pipes required to effectively sparge the impacted groundwater would be extensive and logistically complex. Access to private property would be required as well as the establishment of public right-of-way easements. Exacerbation of vapor intrusion issues could also occur as a result of air sparging, if the vapor capture systems are not adequate.	The technology will inhibit the documented naturally occurring biological VOC degradation at the site. The technology is extremely logistically complex to implement in a mixed use urban environment. Sparged vapors could create indoor air vapor intrusion issues.	Reject

TABLE 6-4

REMEDIATION TECHNOLOGY SCREENING FOR OUTSIDE AREA GROUNDWATER

PSC Georgetown
Seattle, Washington

			Technology Characteristics						
General Response Actions	Remediation Technologies	Section	Technology Description	Technology Development Status	General Performance Record	Site Contaminants Addressed	Site-Specific Issues Affecting Technology or Implementation	Rationale for Retention or Rejection	Screening Result
In Situ Physical/Chemical Treatment	Chemical Oxidation	6.2.9	An oxidizing chemical (permanganate, hydrogen peroxide, Fentons Reagent) is added to the groundwater to chemically oxidize contaminants. Usually applied through injection wells or via direct push technology.	Full-Scale	Mixed performance record. Some applications have been very effective, while others have been unsuccessful in attaining cleanup objectives.	VOCs	Documented natural biological degradation of chlorinated VOCs would be inhibited by the addition of chemical oxidants. High iron concentrations at the site will exert a large oxidant demand, reducing efficiency of treatment. Injection of chemical oxidants over an expansive area at multiple depths would require very large volumes of oxidant. The soil oxidant demand exerted by this area would consume the majority of the oxidant, reducing treatment efficiencies. Development of private property access as well as public easements would be required to support injection and monitoring activities.	The technology will inhibit the natural occurring biological VOC degradation at the site. High iron concentrations exert oxidant demand, reducing treatment efficiency. Injection of oxidants over an expansive treatment area at multiple depths would require excessive volumes of oxidant to overcome soil oxidant demand due to naturally occurring soil organics. Access issues to conduct this work are significant.	Reject
	Thermal Treatment	6.2.10	Temperature in the saturated zone is increased by injecting steam or applying an electrical current. The increased temperature volatilizes organic compounds, which need to be removed using SVE.	Full-Scale	Mixed performance record. Some applications have been very effective, while others have been unsuccessful in attaining cleanup objectives.	VOCs, TPH	This technology would require numerous steam injection points and an off-gas treatment system to capture the volatilized contaminants. Access issues required to implement this strategy over the expansive Outside Area groundwater make this technology logistically unimplementable. Iron fouling is likely. The energy requirement to treat (heat) deeper groundwater across this large area would be enormous.	Access issues to construct the required infrastructure are logistically extremely complex. Potential for iron fouling is high. Energy requirements to heat deep groundwater across this large area provide the basis to reject this technology.	Reject
	In Well Stripping	6.2.11	Air is injected into a double-screened well, lifting the water in the well and forcing it out the upper screen. Simultaneously, additional water is drawn in the lower screen. Volatile compounds are transferred to the vapor phase and removed by vapor extraction.	Full-Scale	Mixed performance record. Some applications have been very effective, while others have been unsuccessful in attaining cleanup objectives.	VOCs, TPH	The documented natural biological degradation of chlorinated VOCs would be inhibited by the addition of oxygen (in well aeration). High iron levels at the site would likely cause iron precipitate and/or biological fouling of the air stripping wells. Also, the logistics of obtaining access from private parties and public entities for installation, maintenance, and monitoring of in-well-stripping wells would be very complex.	The inhibitory effects of air (oxygen) on the naturally occurring anaerobic biological VOC degradation and the strong potential for iron fouling. Access issues to construct the required infrastructure are logistically extremely complex.	Reject
	Passive/Reactive Treatment Walls	6.2.12	Contaminant concentrations in groundwater are reduced as the groundwater flows through the permeable reactive barrier containing zero valent iron. This technology is often implemented in a "funnel and gate" approach, utilizing low permeability barriers as the funnel and zero-valent iron as the permeable gate.	Full-Scale	Has been effectively used to reduce chlorinated VOC concentrations in groundwater	VOCs	Implementation of this technology across the Outside Area groundwater would be extremely logistically complex. Property would have to be acquired to install the low permeability walls and the passive/reactive barrier gate across the expansive width of the plume. If constructed across Fourth Avenue S., this would result in a wall of approximately 1,200 to 1,400 feet in length, all on public or private property. The disruption to public utilities, roadways, sidewalks, and traffic would be enormous. This may not be administratively implementable. Creation of this barrier system may also disturb groundwater flow patterns, raising groundwater elevations in some areas and potentially adversely affecting building foundations and utilities.	Extensive property acquisition requirements and potential issues caused by alterations to groundwater flow patterns make this technology very costly and difficult to implement.	Reject

TABLE 6-4

REMEDIATION TECHNOLOGY SCREENING FOR OUTSIDE AREA GROUNDWATER

PSC Georgetown
Seattle, Washington

Technology Characteristics									
General Response Actions	**Remediation Technologies**	**Section**	**Technology Description**	**Technology Development Status**	**General Performance Record**	**Site Contaminants Addressed**	**Site-Specific Issues Affecting Technology or Implementation**	**Rationale for Retention or Rejection**	**Screening Result**
Ground Water Extraction/ Hydraulic Control	Ground Water Extraction (Pump and Treat)	6.2.13	Groundwater extraction wells are installed to remove contaminated groundwater, thereby reducing contaminant mass. Requires installation of recovery wells, pumping of sufficient quantities of groundwater to provide containment, treatment, and discharge. May also be used for hydraulic control for contaminant migration reduction or prevention.	Full-Scale	Demonstrated effective in a variety of applications. Requires ongoing operation and maintenance. Not effective as a cleanup technology but only for plume control and management. Is a long-duration technology.	VOCs, TPH	Due to the width of the Outside Area groundwater plume (approximately 1,200 to 1,400 feet wide), this technology would be extremely complex to implement. Long-term property access would be needed to install, operate, and maintain the extraction and treatment components. It is likely that certain parcels would need to be acquired for the treatment operation. Reinjection would not be feasible. Large volumes of treated water would likely not be accepted by King County (POTW) and NPDES permitting would be complex and time-consuming.	Would be effective for long-term containment of groundwater plume only. Implementation of a multi-well extraction and treatment system is logistically complex and not administratively implementable. Property would need to be acquired and easements obtained. Disposal of extracted water would also pose a significant challenge.	Reject
Physical Containment	Barrier Wall	6.2.16	Placement of a low permeability barrier wall that physically restricts flow of groundwater. The wall is typically keyed into lower confining unit to be effective. Often this technology is applied in conjunction with groundwater extraction to provide full hydraulic containment.	Full-Scale	Has been effectively used to contain contaminated groundwater. A variety of construction methods and wall compositions are available for this technology.	VOCs, TPH	Due to the aerial extent of the impacted downgradient groundwater, the presence of multiple property owners (and mixed use residential/commercial/industrial), and numerous underground utilities, it is not feasible to totally enclose the Outside Area groundwater.	Barrier walls are administratively unfeasible, given the multiple property owners and interests within the Outside Area groundwater.	Reject
Institutional Controls	Deed Restriction and Property Use Limitations	6.2.17	Formal restrictions or covenants governing future groundwater wells or groundwater extraction can be implemented to prevent or mitigate exposure to groundwater COCs within the Outside Area groundwater.	Full-Scale	Has been used effectively to reduce exposure pathways.	VOCs, TPH	Because PSC does not own the majority of the land in the Outside Area, a deed restriction cannot be made without negotiation and potentially significant compensation to the respective property owners. However, restrictions on the issuance of new groundwater well permits can be developed in cooperation with the local permitting agency, preventing new supply wells from being constructed within the project boundaries.	This technology may be a component of any remedial alternative selected for the site.	Retain

TABLE 6-5

REMEDIATION TECHNOLOGY SCREENING FOR HCIM AREA VAPOR PATHWAYS

PSC Georgetown
Seattle, Washington

Technology Characteristics								
Remediation Technologies	**Section**	**Technology Description**	**Technology Development Status**	**General Performance Record**	**Site Contaminants Addressed**	**Site-Specific Issues Affecting Technology or Implementation**	**Rationale for Retention or Rejection**	**Screening Result**
Soil Vapor Extraction	6.3.1	Removes volatile constituents from the vadose zone. Using a blower, a vacuum is applied to wells screened in the vadose zone and the volatiles are entrained in the extracted air and removed with the soil vapor. Off gasses are generally treated to control emissions using thermal destruction or adsorption technologies. For vapor pathway, wells would be installed adjusted to buildings requiring abatement.	Full-Scale	Proven reliable and effective technology	VOCs, TPH	SVE was conducted at the site for several years, and approximately 19,000 pounds of solvents were removed. This activity was terminated when it was shown that continued operation would yield diminishing returns. Underground conveyance piping would be difficult to install due to concrete cap/cover that is in currently in place.	Difficult to install below grade piping with concrete cap/cover in place. Other technologies are equally effective and less costly and intrusive.	Reject
Vapor Barrier	6.3.2	Installation of a polyethylene barrier beneath a new building slab to reduce migration of VOCs into the buildings	Full-Scale	Proven reliable and effective technology	VOCs, TPH	This technology would be relatively easy to implement for newly constructed buildings.	Relatively easy to implement for newly constructed buildings and provides reduced risk for residential or worker inhalation of organic COCs.	Retain
Active Slab Depressurization	6.3.3	Building foundation slab is drilled and a vent pipe is installed through the slab to the soil or rock base beneath. The vent pipe is fitted with a small fan and VOCs are vented to the rooftop of the building.	Full-Scale	Proven reliable and effective technology	VOCs, TPH	This technology could be applied to both existing and new structures with slab-on-grade foundations. This technology would be relatively easy to implement.	Relatively easy to implement for new or existing buildings and provides reduced risk for residential or worker inhalation of organic COCs.	Retain
Foundation and Wall Sealing	6.3.4	Caulk or elastomeric sealing compounds are applied to cracks and joints in all slabs and subsurface walls to prevent the migration of VOCs into the building.	Full-Scale	Proven reliable and effective technology	VOCs, TPH	This technology could be applied to both existing and new structures with slab-on-grade foundations. This technology would be relatively easy to implement.	Relatively easy to implement for new or existing buildings and provides reduced risk for residential or worker inhalation of organic COCs.	Retain
Sub-membrane Depressurization	6.3.5	A 3-6 mil polyethylene liner is installed beneath the foundation of a raised foundation structure. The plastic liner is sealed along all edges and a vent pipe is fitted through the liner. The vent pipe is fitted with a small fan to vent vapors above the roofline of the structure.	Full-Scale	Proven reliable and effective technology	VOCs, TPH	This technology could be applied to both existing and new structures with sub-floors. This technology would be relatively easy to implement.	Relatively easy to implement for new or existing buildings and provides reduced risk for residential or worker inhalation of organic COCs.	Retain
Building Pressurization	6.3.6	A slight positive pressure is imparted on the living space of a structure to prevent intrusion from subsurface vapors. Typically a small fan draws small volumes of outside air into the building to provide the positive pressure.	Full-Scale	Proven reliable and effective technology	VOCs, TPH	This technology could be applied to both existing and new structures and is relatively easy to implement.	Relatively easy to implement for new or existing buildings and provides reduced risk for residential or worker inhalation of organic COCs.	Retain
Institutional Controls	6.3.7	Restrictions could be established preventing certain kinds of site development or new construction or requiring vapor mitigation measures be implemented. Also, notifications could be made on the property title, advising prospective purchasers of the potential risks posed by the vapor pathway.	Full-Scale	Proven reliable and effective technology	VOCs, TPH	Because it is likely that impacted groundwater will remain in place in the long term, limitations, engineering requirements, or restrictions on future site development will likely be required to prevent exposure through vapor pathways.	This technology will likely be a component of any remedial technologies selected for the site.	Retain

TABLE 6-6

REMEDIATION TECHNOLOGY SCREENING FOR OUTSIDE AREA VAPOR PATHWAYS

PSC Georgetown
Seattle, Washington

Technology Characteristics								
Remediation Technologies	**Section**	**Technology Description**	**Technology Development Status**	**General Performance Record**	**Site Contaminants Addressed**	**Site-Specific Issues Affecting Technology or Implementation**	**Rationale for Retention or Rejection**	**Screening Result**
Soil Vapor Extraction	6.3.1	Removes volatile constituents from the vadose zone. Using a blower, a vacuum is applied to wells screened in the vadose zone and the volatiles are entrained in the extracted air and removed with the soil vapor. Off gasses are generally treated to control emissions using thermal destruction or adsorption technologies. For vapor pathway, wells would be installed adjusted to buildings requiring abatement.	Full-Scale	Proven reliable and effective technology	VOCs, TPH	Would require numerous SVE systems to be effectively implemented on buildings and residential homes. Installation of vapor extraction wells would require easements or access agreements with numerous public and private entities. Underground conveyance piping would be difficult to install due to the large number of underground utilities.	Problems associated with implementation at numerous locations and acquiring the necessary easements and agreements for installation of extraction wells. Other technologies are equally effective and less costly and intrusive.	Reject
Vapor Barrier	6.3.2	Installation of a polyethylene barrier beneath a new building slab to reduce migration of VOCs into the buildings.	Full-Scale	Proven reliable and effective technology	VOCs, TPH	This technology would be relatively easy to implement for newly constructed buildings.	Relatively easy to implement for newly constructed buildings and provides reduced risk for residential or worker inhalation of organic COCs.	Retain
Active Slab Depressurization	6.3.3	Building foundation slab is drilled and a vent pipe is installed through the slab to the soil or rock base beneath. The vent pipe is fitted with a small fan, and VOCs are vented to the rooftop of the building.	Full-Scale	Proven reliable and effective technology	VOCs, TPH	This technology could be applied to both existing and new structures with slab-on-grade foundations. This technology would be relatively easy to implement.	Relatively easy to implement for new or existing buildings and provides reduced risk for residential or worker inhalation of organic COCs.	Retain
Foundation and Wall Sealing	6.3.4	Caulk or elastomeric sealing compounds are applied to cracks and joints in all slabs and subsurface walls to prevent the migration of VOCs into the building.	Full-Scale	Proven reliable and effective technology	VOCs, TPH	This technology could be applied to both existing and new structures with slab-on-grade foundations. This technology would be relatively easy to implement.	Relatively easy to implement for new or existing buildings and provides reduced risk for residential or worker inhalation of organic COCs.	Retain
Sub-membrane Depressurization	6.3.5	A 3-6 mil polyethylene liner is installed beneath the foundation of a raised foundation structure. The plastic liner is sealed along all edges and a vent pipe is fitted through the liner. The vent pipe is fitted with a small fan to vent vapors above the roofline of the structure.	Full-Scale	Proven reliable and effective technology	VOCs, TPH	This technology could be applied to both existing and new structures with sub-floors. This technology would be relatively easy to implement.	Relatively easy to implement for new or existing buildings and provides reduced risk for residential or worker inhalation of organic COCs.	Retain
Building Pressurization	6.3.6	A slight positive pressure is imparted on the living space of a structure to prevent intrusion from subsurface vapors. Typically a small fan draws small volumes of outside air into the building to provide the positive pressure.	Full-Scale	Proven reliable and effective technology	VOCs, TPH	This technology could be applied to both existing and new structures and is relatively easy to implement.	Relatively easy to implement for new or existing buildings and provides reduced risk for residential or worker inhalation of organic COCs.	Retain
Institutional Controls	6.3.7	Administrative controls could be established through cooperation with the municipality, whereby new construction within the Outside Area is required to address the vapor pathway as part of the design process.	Full-Scale	Proven reliable and effective technology	VOCs, TPH	Because it is likely that impacted groundwater will remain in place in the long term, limitations, engineering requirements, or restrictions on future site development will likely be required to prevent exposure through vapor pathways.	This technology will likely be a component of any remedial technologies selected for the site.	Retain

7.0 REMEDIAL ALTERNATIVE EVALUATION CRITERIA

Potentially applicable remedial alternatives were developed from the retained remediation technologies described in Section 6. These alternatives were designed to attain the remediation objectives presented in Section 5. Each of the remedial alternatives presented in this SWFS Report were evaluated relative to the criteria specified in the MTCA rules to select the preferred alternative. The evaluation criteria used for this SWFS must address requirements of the MTCA regulations and the RCRA Part B permit. The evaluation criteria for this SWFS include the following:

- protectiveness and risk reduction,
- permanence,
- cost,
- long-term effectiveness,
- management of short-term risks,
- technical and administrative implementability,
- public concern, and
- reasonable time frame to meet clean-up levels.

The remedial alternatives considered in this SWFS were designed to attain the cleanup objectives to the extent practicable. As described in Section 3, remediation levels included in this SWFS Report were established to ensure that COCs released from the Facility would attenuate to meet groundwater cleanup levels prior to discharge to surface water. These remediation levels incorporate natural attenuation processes occurring between the point where the remediation levels would be attained and the discharge to the Duwamish Waterway. As noted previously, these remediation levels address only COCs released from the Facility and do not address any non-PSC sources that may be present downgradient from the Facility.

The SWFS evaluation criteria are defined and discussed in the following subsections. These criteria are used to evaluate the remedial alternatives presented in Sections 8 and 9 of this report.

7.1 PROTECTIVENESS AND RISK REDUCTION

This criterion assesses the degree to which a remedial alternative protects human health and the environment and reduces potential risks to human or ecological receptors. Protectiveness and risk reduction evaluation addresses long-term effects rather than short-term effects, which are evaluated under a different criterion. Alternatives that attain remediation levels and/or cleanup levels are considered as protective under this criterion, and alternatives that meet remediation or cleanup levels in a shorter time are considered as providing a higher level of risk reduction. Alternatives that rely on engineering controls or institutional controls to provide protectiveness and risk reduction are generally ranked lower for this criterion than alternatives that do not rely on these controls.

Factors considered for evaluating this criterion include the following:

- potential risks to human health and the environment under present conditions. Pre-remediation and pre-interim action risks will be used as a baseline to assess the reduction in risks that would result from implementing the remedial alternative;
- present and future land use for the SWFS Area;
- present and potential for future use of any water resources either associated with or affected by the site constituents within the SWFS Area;
- potential effectiveness and reliability of institutional controls associated with the alternative;
- the availability of alternative water supplies, as appropriate;
- the capability of the alternative to limit and monitor migration of COCs;
- the toxicity of COCs; and
- the efficacy of any natural processes that may mitigate the impact of Facility COCs.

7.2 PERMANENCE

Permanence is the degree to which a remediation alternative attains cleanup objectives by permanently destroying COCs and the capability of the alternative to reduce the toxicity, mobility, or volume of affected media. Alternatives that actively degrade or destroy COCs would be ranked higher for this criterion than alternatives that utilize on-site or off-site containment. In accordance with MTCA requirements, the alternative providing the greatest degree of permanence is used as the baseline alternative against which other alternatives are compared.

Factors considered for evaluation of this criterion include the following:

- present and future land use above and adjacent to the project area;
- present and potential for future use of any water resources either associated with or that may be affected by site COCs within the SWFS Area;
- potential effectiveness and reliability of institutional controls associated with the alternative;
- the ability of the alternative to limit and monitor migration of COCs; and
- efficacy of any natural processes that may mitigate the impact of Facility COCs.

7.3 COST

Costs of remedial alternatives include implementation costs, operation and maintenance costs, monitoring costs, and reporting costs. Cost estimates were prepared for each remedial alternative considered in this SWFS. The costs include future costs for over a life of 30 years. Future costs are included in the total alternative cost using present worth analysis. Cost estimates will be prepared in accordance with EPA guidance for preparing FS cost estimates under CERCLA (EPA, 2000).

The costs for implementing a remedial alternative include engineering, permitting, public relations, construction, purchase of facilities and equipment, building demolition or utility relocation, transportation and disposal, building restoration, and site restoration costs. Implementation costs typically occur at the beginning of the implementation program but may also include costs that occur later in the remediation program, such as costs for replacement of key remedial system components. Details regarding cost estimates for each of the alternatives are presented in Appendix C.

Costs for operations, maintenance, monitoring, and reporting generally occur annually after construction has been completed. These costs include longer term, repeating expenses associated with multi-year remediation activities. Reporting costs are incurred to document monitoring and operations activities and provide regulatory information to Ecology. These ongoing costs usually include labor, power, utilities, analyses, subcontractors, and consumed materials. Future recurring costs for operations and maintenance, monitoring, and reporting are combined with initial implementation costs into a single NPV cost for each remedial alternative. The NPV calculations consider an annual discount rate (assumed to be 7 percent) that addresses the time value of money. The discount rate is typically described as the interest rate that could be obtained from a prudent investment. This NPV cost, including initial implementation costs and future recurring costs, is used to assess the cost criterion and compare the cost of the remedial alternatives. Details concerning operations, maintenance, monitoring, and reporting costs are included in Appendix C.

For this SWFS, a standard period of 30 years has been used for future recurring costs for all remedial alternatives evaluated, unless the estimated cleanup time frame is less than 30 years. This period has been based on the typical long-term groundwater monitoring period associated with closure of RCRA TSD facilities. In general practice, monitoring is conducted for several years after remediation has been completed to ensure that cleanup standards have been reliably attained. While the time required to achieve remediation objectives cannot be accurately predicted in the absence of site-specific monitoring or pilot testing data, preliminary estimates of the clean-up time for remedial alternatives will be made as appropriate and used to establish monitoring periods. For those alternatives where the time to meet remediation objectives is expected to be 30 years or longer, the standard monitoring period of 30 years will be used as a reasonable basis for the evaluation of remedial alternatives and comparison of remediation costs. Longer monitoring periods would have minimal impact on the NPV cost estimate because the larger discount would reduce their present value. Monitoring periods shorter than 30 years would have a more significant effect on the NPV cost than longer periods because the effect of the discount rate would be smaller.

7.4 LONG-TERM EFFECTIVENESS

For this criterion, the capability of a remedial alternative to reliably maintain its effectiveness over a long period of time is assessed. In addition, the production of residues is assessed; alternatives that do not generate hazardous substance residues would have a greater long-term effectiveness than alternatives that do produce such a residue. Permanent alternatives that result in destruction of COCs would provide better long-term effectiveness than alternatives relying on containment using engineering controls.

For evaluation of this criterion, both positive and negative long-term environmental consequences are assessed. Positive consequences of remedial alternatives other than those associated with reductions in exposure concentrations of COCs include enhancements to the environment that may result from remediation (such as improved habitat) or not causing a disturbance to the existing environment (such as not altering natural groundwater flow patterns). Negative long-term consequences include factors such as changes that may reduce environmental value (such as destroying habitat) or the introduction of new, persistent constituents to the environment as a result of remediation. The incremental benefit accrued for an alternative is compared to the negative consequences to assess disproportionality in long-term benefits and effectiveness.

Factors considered for evaluation of this criterion include the following:

- efficacy of any natural processes that may mitigate the long-term impact of COCs associated with the site;
- present and potential for future use of any water resources either associated with or that may be affected by the Facility COCs;
- potential effectiveness and reliability of institutional controls;
- the ability of the alternative to limit long-term migration of COCs; and
- present and future land use for the area above and adjacent to the project area, including any constraints land use may have on the alternative.

7.5 MANAGEMENT OF SHORT-TERM RISKS

Short-term risks associated with remedial alternatives include potential releases of material, water, particulates, or vapors containing COCs that could occur during implementation of the alternative. These types of losses could occur as a result of dust generation during excavation or handling of excavated materials, loss of affected soil or affected groundwater during treatment, or accidental releases during transport of affected media to a permanent disposal or treatment facility. Alternatives with minimal potential risks requiring management, such as MNA, would rank higher for this criterion than alternatives such as excavation and off-site disposal, which would have significant potential short-term risks.

7.6 TECHNICAL AND ADMINISTRATIVE IMPLEMENTABILITY

The technical and administrative implementability criterion assesses the capability to effectively implement a remedial alternative. Technical implementability assesses technical and physical factors such as the presence of existing buildings that may affect implementation of an alternative or the need to have very specialized equipment for implementation. Administrative implementability assesses factors such as permitting requirements or regulatory approvals needed for implementation. Administrative factors would most likely affect the implementation schedule, whereas technical factors could make an alternative ineffective. Simple, non-intrusive alternatives would rank high for technical implementability, while complex or highly intrusive alternatives would rank low. Alternatives with minimal permitting requirements and that are readily accepted by regulatory agencies would rank high for administrative implementability.

Factors considered for evaluation of this criterion include the following:

- the size and complexity of the remedial alternative;
- the degree to which the remedial alternative can be integrated with existing operations and activities within affected areas;
- regulatory requirements, including permitting;
- present and future land use for the area above and adjacent to the project area, including any specific constraints land use may have on the alternative;
- present and potential for future use of any water resources either associated with or that may be affected by the site; and
- potential effectiveness and reliability of institutional controls associated with the alternative.

7.7 PUBLIC CONCERN

For this criterion, the potential for creating concern among the general public, individuals at adjacent facilities, and the community if an alternative were to be implemented is assessed. Remedial alternatives likely to be readily accepted by the public would rank higher than alternatives that may create issues that must be addressed. Potential public concerns include factors such as increased truck traffic, adverse impacts for traffic, noise, dust, odors, release of vapors, use of hazardous materials, safety, and effects on property values. The heavy industrial, commercial, and residential land uses in an urban environment create significant potential for public concern related to site remediation.

7.8 REASONABLE RESTORATION TIME FRAME

The restoration time frame is the time required for an alternative to attain remediation objectives. In assessing this criterion, the practicability of attaining the shortest restoration time is assessed. Additional consideration is given to several factors, including existing risks to human health and the environment, site use, potential future site use, availability of alternative water supplies, and reliance on institutional controls. These factors are assessed as a whole and determine the urgency of achieving the remedial objectives for a specific site. Alternatives that achieve remediation objectives in a shorter time would rank higher for this criterion than alternatives requiring a longer time. The practicality and necessity of implementing an alternative within a shorter time and the potential effectiveness and reliability of any institutional controls associated with the alternative is assessed for this criterion.

8.0 DEVELOPMENT AND EVALUATION OF REMEDIAL ALTERNATIVES: HCIM AREA

The HCIM Area is entirely enclosed by a subsurface barrier wall. While most of the property within the HCIM Area is owned by PSC, the barrier wall extends onto two properties not owned by PSC. The HCIM Area encompasses the Facility and includes the source area where the primary releases of COCs occurred. The HCIM has isolated this source area from the impacted groundwater plume extending downgradient from the HCIM Area. The HCIM Area is currently inactive except for limited storage of equipment in the only remaining building in the HCIM Area (located on the former TASCO property). The area will eventually be redeveloped into industrial/commercial property consistent with land use in the immediate vicinity.

Historic releases within the HCIM Area include chlorinated solvents, petroleum hydrocarbons, and other waste materials. Characterization data show that soil and groundwater within the HCIM Area have been impacted by historic releases. Based on groundwater data, DNAPL is expected to be present within the HCIM Area. There is impacted groundwater above the silt unit, which serves as the lower confining layer for the upper aquifer. Groundwater below the silt unit has not been affected by site releases. The COCs within the HCIM Area include all COCs associated with the Facility (VOCs, SVOCs, PCBs, and metals), as discussed in Section 3. As noted in Section 5, the constituent concentrations and distribution, including the presence of DNAPL, precludes full restoration of the HCIM Area and attainment of the SPOC for both soil and groundwater. As discussed in Section 4, the COCs present within the barrier wall are persistent and represent potential risks via direct contact with soil, direct contact with groundwater, ingestion of either soil or groundwater, and inhalation of vapors released from impacted soil or groundwater. Remedial alternatives considered for the HCIM Area must address the nature and extent of impacted media in this area as well as the broad range of COCs and the potential exposure pathways. These alternatives must also be compatible with remedial actions that may be implemented in the Outside Area.

8.1 HCIM AREA REMEDIAL ALTERNATIVES

Remedial alternatives for the HCIM Area have been developed from the retained remediation technologies, as described in Section 6. Two remedial alternatives have been developed for detailed evaluation in this SWFS. These alternatives are designed to attain the remediation objectives described in Section 5 of this SWFS Report. The remedial alternatives represent a combination of one or more of the retained remediation technologies; not all retained technologies have been used in developing remedial alternatives.

The primary remediation objective for the HCIM Area is to prevent discharge of COCs from the HCIM Area to the Outside Area at concentrations that would exceed cleanup levels. A substantial interim measure implemented for the HCIM Area has proven effective in controlling the discharge of impacted groundwater from the Facility. This IM has been incorporated into the two remedial alternatives considered for the HCIM Area.

The remedial alternatives under consideration for the HCIM Area focus on the following:

- applying the existing low-permeability subsurface barrier to control groundwater flow and provide physical containment for impacted groundwater;
- improving and maintaining the current HCIM Area cap to provide physical containment, limit infiltration of storm water, control erosion and runoff of impacted soil, and to limit potential exposure to impacted surficial soil; and
- using institutional controls to address potential exposure pathways related to impacted soil and groundwater that will remain within the HCIM Area after the preferred remedial alternative is implemented.

These remedial alternatives focus only on containment of the Facility and near-Facility impacted groundwater because of the technical impracticability and disproportionate costs of attempting to attain a comprehensive cleanup of the HCIM Area. The impracticability and disproportionate costs of remediating the HCIM Area to attain the SPOC and for partial source removal was discussed in Section 5 of this SWFS Report. The remedial alternatives considered for the HCIM Area are described in the following subsections.

8.1.1 Alternative HA-1: Active Hydraulic Containment

Alternative HA-1 incorporates the existing HCIM with capping and institutional controls to provide a comprehensive remediation approach that addresses relevant COCs and potential exposure pathways. The existing HCIM, which consists of the subsurface barrier wall, groundwater recovery wells, and groundwater pretreatment system, has been fully incorporated into Alternative HA-1. This alternative provides active hydraulic control and containment by extracting groundwater from the area inside the barrier wall to maintain an inward hydraulic gradient. The components of Alternative HA-1 are shown on Figure 8-1.

The existing subsurface barrier wall would be maintained intact under this remedial alternative. The barrier wall completely encloses the HCIM Area and has been proven effective in limiting groundwater flow into the HCIM Area. Programs and systems for monitoring and inspecting the barrier wall to maintain its effectiveness have been established and proven effective. The existing barrier wall has a very low permeability (less than 10^{-8} cm/sec).

The existing groundwater recovery and pretreatment system, which is comprised of two extraction wells, an air stripper, and associated pumps and controls, has also been incorporated into this remedial alternative. Treated groundwater is discharged to a publicly owned treatment works (POTW) under a permit issued by King County. This system has also been proven effective in maintaining an inward hydraulic gradient during over a year of operation. The system has continuously and reliably maintained an inward hydraulic gradient and has met regulatory standards for treated groundwater quality and air emissions. Programs and systems have been established for operation, maintenance, inspection, and monitoring of the groundwater recovery and pretreatment system. Under this remedial alternative, an inward hydraulic gradient would be maintained across the barrier wall. As discussed in Appendix B, the expected loss of COCs through the wall would be negligible if the permeability of the barrier wall is in the high range (i.e., 1×10^{-7} cm/sec) because inward advective flow of groundwater would overwhelm outward diffusion. For low barrier wall permeability (i.e., 1×10^{-10} cm/sec) advective flow would be negligible and loss of COCs through the wall may occur by diffusion, and would represent the worst-case loss of Facility COCs under this alternative. The diffusion rate was estimated for chlorinated VOCs, which are of primary concern for potential risks. The estimated worst-case rate of diffusion through the barrier wall for this alternative is 0.0009 lb/day; details for these calculations are included in Appendix B. This diffusive flux of chlorinated VOCs through the barrier wall is considered negligible.

Alternative HA-1 would supplement the existing HCIM Area cap with new caps placed over areas that are not currently capped. Improvements to the cap covering the entire HCIM Area has been included in Alternative HA-1. Potential direct exposure pathways related to impacted soil present within the HCIM Area would be addressed by the cap, which would cover impacted soil within the HCIM Area (see Figure 8-1). This cap incorporates the existing microsilica concrete and asphalt caps that currently cover much of the HCIM Area and the areas of new cap. The new cap will consist of a minimum thickness of 3 inches of asphalt placed over the currently uncapped areas to provide a continuous, low-permeability cover. The cap would serve as a barrier to prevent direct contact with impacted soil, prevent erosion and runoff of impacted soil, and limit infiltration of surface water within the HCIM Area. The cap would reduce the amount of water that must be pumped from the HCIM Area to maintain an inward hydraulic gradient by limiting infiltration of surface water. The new cap would be designed consistent with any planned development. The cap would be regularly inspected and maintained to ensure it effectively provides an engineered barrier and limits infiltration.

A key component of this remedial alternative would be controlling the inhalation pathway by limiting vapor intrusion for existing buildings and any future construction that would occur within the HCIM Area. The following vapor intrusion technologies may be incorporated into existing or future buildings within the HCIM Area:

- Vapor Barrier
- Active Slab Depressurization
- Foundation and Wall Sealing
- Sub-membrane Depressurization
- Building Pressurization

As discussed in more detail below, institutional controls would be established to require appropriate vapor intrusion provisions in buildings.

Groundwater monitoring is a key component of the remedial alternatives for the Site. Remedial alternatives proposed for the HCIM Area would be implemented simultaneously with remedial alternatives for the Outside Area. Because groundwater quality monitoring is included in the alternatives considered for the Outside Area, groundwater quality monitoring has not been included in Alternative HA-1. For the HCIM Area, groundwater monitoring will be limited to water level monitoring inside and outside the barrier wall, as is currently being conducted for the HCIM. The locations for water level monitoring wells included in Alternative HA-1 are shown on Figure 8-1. For estimating monitoring costs, it has been assumed that the wells would be monitored quarterly for 3 years, followed by annual sampling for 27 years, for a total monitoring period of 30 years.

The final component of Alternative HA-1 is a set of institutional controls that would ensure the alternative is fully protective of human health. The institutional controls included in this alternative are as follows:

- Prohibit use of groundwater beneath the HCIM Area for any purpose;

- Require use of appropriate personal protective equipment and compliance with the Hazardous Waste Operations (HAZWOPER) requirements specified in 29 CFR 1910.120 for all subsurface work conducted within the HCIM Area;

- Require appropriate characterization and management for any groundwater or soil removed from the HCIM Area. Recovered soil or groundwater must be managed in accordance with the requirements of the Washington Dangerous Waste Rules (WAC 173-303);

- Require installation and operation of appropriate engineering controls to limit the entry and accumulation of soil gas within any building present or constructed over any portion of the HCIM Area;

- Require inspection and maintenance of the cap covering impacted portions of the HCIM Area. Any site construction or development would also be required to maintain the continuity and effectiveness of the cap; and

- Require operation, maintenance, inspection, and monitoring of the existing HCIM components (barrier wall recovery wells, groundwater extraction and pretreatment system, instruments and controls, and monitoring wells) in accordance with the existing operation, monitoring, and maintenance plan.

These institutional controls will be enforceable conditions incorporated into the deed for the properties either partially or totally contained within the HCIM Area.

8.1.2 Alternative HA-2: Passive Hydraulic Containment

Remedial Alternative HA-2 provides passive hydraulic containment of impacted soil and groundwater within the HCIM Area using the existing subsurface barrier wall. This alternative incorporates all components of Alternative HA-1 except for the groundwater recovery and pretreatment system. The cap included in Alternative HA-2 would cover the entire HCIM Area and be designed to maximize runoff and minimize infiltration. The components for Alternative HA-2 are shown in Figure 8-1.

This remedial alternative would rely solely on the barrier wall to provide hydraulic control and containment for impacted soil and groundwater within the HCIM Area. The existing groundwater recovery and pretreatment system would not be used under this alternative, thereby significantly decreasing operation and maintenance requirements. The low-permeability barrier wall would effectively limit the influx and efflux of groundwater. Due to the very low permeability of the barrier wall, minimal flow would occur through the wall. The groundwater flow through the wall would result in only marginally higher VOC migration than the amount of VOCs transmitted through the wall by diffusion, which occurs even with active groundwater recovery inside the barrier wall. The conservatively estimated loss of chlorinated VOCs (including PCE, TCE, DCE, and VC) through the barrier wall for this alternative is about 0.0026 lb/day (see Appendix B for details). This nominal loss of constituents through the barrier wall under this alternative would affect remediation conducted in the Outside Area, as discussed in Sections 9 and 10.

The cap for Alternative HA-2 would be the same as described above for Alternative HA-1. This cap, which includes new capping to supplement the existing cap so that the entire HCIM Area is properly covered, would limit infiltration of surface water into the contained area and serve as a barrier to prevent runoff of impacted soil and limit direct contact with impacted media. The cap incorporates the existing microsilica concrete and asphalt cap with additional asphalt capping, as shown in Figure 8-1.

The groundwater monitoring program for Alternative HA-2 would be the same as discussed above for Alternative HA-1. Water levels would be monitored inside and outside the barrier wall to allow the groundwater gradient across the wall to be monitored, but the gradient would not be controlled as it would be for Alternative HA-1. The groundwater monitoring program included in this alternative would be the same as for Alternative HA-1 and would include quarterly water level monitoring for 3 years followed by annual monitoring for 27 years. As noted for Alternative HA-1, groundwater quality monitoring would be incorporated into the remedial alternative for the Outside Area.

The institutional controls included in Alternative HA-1 would also be included in Alternative HA-2 with the exception that the operation and maintenance of the groundwater pump and treat system would not be included. These controls would ensure that the alternative would be protective of human health and the environment.

8.2 EVALUATION OF HCIM AREA REMEDIAL ALTERNATIVES

The objectives for the two remedial alternatives considered for the HCIM Area are to contain impacted soil within the HCIM Area, prevent direct contact with site COCs, limit constituent migration from the HCIM Area to acceptable levels, be compatible with future redevelopment of the PSC properties, and be fully compatible with the remedial approach selected for the Outside Area. Both alternatives would attain these objectives.

This section compares and evaluates the remedial alternatives based on the MTCA criteria of protectiveness and risk reduction, permanence, cost, long-term effectiveness, management of short-term risks, technical and administrative implementability, public concerns, and restoration time frame, as discussed in Section 7. In the subsections below, the two alternatives are evaluated relative to each other. For each criterion, the alternatives are ranked either High or Low. A High rating means that the alternative is expected to perform better than the other alternative with respect to the criterion being evaluated. A Low rating indicates that the alternative is expected to perform more poorly than the other alternative. A Low rating does not mean that the alternative would not adequately meet the criterion; it only means that the other alternative would be more effective in meeting that specific criterion.

Both remedial alternatives attain the remediation objectives outlined in Section 5.3. Direct contact with affected soil is addressed by placement of a cap over affected soil and implementing institutional controls limiting subsurface work and requiring appropriate health and safety measures. The cap also minimizes potential dust generation in addition to preventing runoff of affected soils. Institutional controls have been included in both alternatives to require vapor intrusion barriers for any buildings constructed within the HCIM Area that will be occupied on a regular basis. The barrier wall provides protection of human and ecological receptors by providing a physical containment barrier that significantly reduces the release of groundwater constituents from the HCIM Area. Any constituents that may pass through the barrier wall would be addressed by the remedial alternatives for the Outside Area. Therefore, the remedial alternatives considered for the HCIM Area would comprehensively attain the remediation objectives established in this SWFS.

In the following subsections, each of the remedial alternatives is compared to the evaluation criteria described in Section 7. These comparisons summarize the primary factors that address each criterion. The evaluation has been summarized for all evaluation criteria in Table 8-1.

8.2.1 Protectiveness and Risk Reduction Evaluation

In general terms, the protectiveness and risk reduction criterion assesses the degree to which remedial alternatives protect human health and the environment and provide a reduction in risks posed by the contamination. Both alternatives are expected to significantly reduce risks and be protective of human health and the environment. However, the alternatives differ in overall protectiveness and risk reduction. Both alternatives would rely on essentially the same institutional controls to prevent direct exposure to impacted soil and groundwater and would therefore be equally protective in this respect.

The relative ranking of the two alternatives for this criterion is shown on Table 8-1. Alternative HA-1, which relies on active pumping to maintain an inward hydraulic gradient, was ranked higher than Alternative HA-2, which is a passive remedial system, although both alternatives are almost equally protective. Alternative HA-1 was ranked higher because it would actively maintain an inward hydraulic gradient, which would slightly reduce the discharge of groundwater COCs through the barrier wall. Alternative HA-1 would also remove COCs from the HCIM Area. Since groundwater recovery requires pretreatment and pretreatment is most effectively done using an air stripper, Alternative HA-1 would result in the release of some constituents to the atmosphere. The higher rating was assigned to Alternative HA-1 due to the active hydraulic control and because some site COCs would be recovered and ultimately destroyed.

8.2.2 Permanence

The permanence criterion, as defined in Section 7, assesses the degree to which the remedial alternative would reduce the toxicity and mobility of affected media through permanent destruction of hazardous substances. Neither of the remedial alternatives considered for the HCIM Area would provide significant permanent destruction of site COCs; however, alternative HA-1 would provide a slightly greater degree of destruction than Alternative HA-2 (Table 8-1).

Alternative HA-1, which includes groundwater recovery and pretreatment, was ranked High for this criterion because it includes limited recovery and destruction of groundwater COCs. Groundwater recovered under Alternative HA-1 would be pretreated using an air stripper. The pretreatment groundwater would be discharged to a POTW for biological treatment, where the COCs would either be biologically degraded or stripped to the atmosphere. Volatile COCs stripped from the groundwater would be either adsorbed or destroyed by the permanganate/ activated carbon adsorber. Adsorbed VOCs would be destroyed. Additional destruction of site COCs would occur due to ongoing in situ biodegradation, which is active in situ within the HCIM Area. The in situ biodegradation would be essentially the same for both remedial alternatives. Given the slight difference in permanence, Alternative HA-2 was ranked lower than Alternative HA-1.

8.2.3 Costs

Net Present Value (NPV) cost estimates were prepared for the two HCIM Area remedial alternatives, as presented in Table 8-2 and described in Appendix C. The NPV costs combine initial costs for implementation of an alternative with recurring costs for future for operation, maintenance, and monitoring. NPV cost estimates allow the alternatives to be compared on an equal basis. Implementation costs include estimates for obtaining access to conduct the remediation; for engineering and planning; for purchasing equipment, materials, and chemicals; for permitting; and for construction. Recurring costs include estimates for operation and maintenance labor, materials and chemicals used in remediation, periodic replacement of remediation equipment, long-term property access, power and waste disposal, water quality monitoring, and project management. The NPV costs are based on 30-year implementation and operation periods for both alternatives.

The NPV costs for Alternative HA-2 would be lower than for Alternative HA-1, resulting in a high ranking for Alternative HA-2. Alternative HA-1 includes substantial costs for operation and maintenance of the groundwater recovery and pretreatment system.

8.2.4 Long-Term Effectiveness

Long-term effectiveness includes the degree of certainty and reliability of the alternative to maintain its effectiveness over the long term. This criterion also considers whether treatment residue remains from the alternative that will require management. The benefits realized by an alternative are compared to the negative consequences associated with the alternative in assessing long-term effectiveness. Both alternatives would incorporate the same institutional controls; therefore, the institutional controls for each alternative would have essentially the same effectiveness and reliability.

As shown in Table 8-1, Alternative HA-2 was ranked higher for long-term effectiveness. Alternative HA-1 was assigned a lower relative ranking because it includes a groundwater recovery and pretreatment system that would require continuous operation and maintenance to maintain the full effectiveness of the remedial alternative. The groundwater recovery and pretreatment system includes mechanical, electrical, and electronic components that can fail and require periodic replacement. Additionally, the equipment requires an external power source to maintain the equipment operational. Alternative HA-2 is an entirely passive remedial alternative that would not require power or active operation. However, Alternative HA-2 would require periodic inspection and may need occasionally maintenance. Alternative HA-2 is expected to maintain full long-term effectiveness with minimal need for maintenance or repair.

8.2.5 Management of Short-Term Risks

Short-term risk refers to the risk to human health and the environment during implementation of an alternative. Neither of the alternatives considered for the HCIM Area would create significant short-term risks because most of the construction for implementation has been completed. However, Alternative HA-1 includes active withdrawal of impacted groundwater. Since this alternative contains groundwater in above-grade piping, there would be some potential short-term exposure if piping or equipment failed. Therefore, Alternative HA-1 has a slightly greater short-term risk than Alternative HA-2. For this reason, Alternative HA-2 was ranked High and Alternative HA-1 was ranked Low for management of short-term risks.

8.2.6 Technical and Administrative Implementability

This criterion assesses both technical and administrative issues related to construction and operation of the remedial alternatives. Factors considered in assessing the alternatives against this criterion include administrative/regulatory requirements, impact on existing land uses, the means for implementing and enforcing institutional controls, and requirements for extensive construction or ongoing operation and maintenance.

As shown in Table 8-1, Alternative HA-2 was ranked higher than Alternative HA-1 for technical and administrative implementability. Both alternatives can be readily implemented for the HCIM Area. Alternative HA-1 would require ongoing, long-term operation and maintenance, which would require substantial administrative resources. The discharge permit required for Alternative HA-1 would also require periodic renewal, thus increasing requirements for regulatory review and input.

8.2.7 Public Concerns

Potential community concerns with implementation of each remedial alternative are assessed for this criterion, including general concerns of the public and specific concerns of neighboring landowners. It is expected that the primary public concerns associated with the HCIM Area alternatives would be from neighboring landowners because the site and neighboring sites are used for industrial purposes. The primary public concerns are expected to be related to VOC releases to ambient air, odors, and noise.

For this criterion, a High rating indicates the lowest expected public concern (greatest acceptance) and a Low rating indicates the greatest expected public concern (least acceptance). Alternative HA-2 was ranked High for this criterion. This alternative differs from Alternative HA-1 in that it does not include active operation and would not recover impacted groundwater from the subsurface. Public concerns may arise concerning the overall protectiveness or level of cleanup achieved by a remedial alternative and from potential adverse short-term impacts created by alternative implementation. Due to the diversity of public opinion, it is likely that both types of concerns may arise simultaneously from different members of the community. The groundwater recovery system included in Alternative HA-1 has the potential to release VOCs to the air, discharge directly to the public sewer, and create odors. Additionally, the blower associated with the air stripper would make some noise when in operation. Alternative HA-1 also provides a slightly greater level of cleanup than Alternative HA-2, which is a passive alternative that would have minimal potential for causing a public nuisance. Due to the expected diversity of public concerns that could favor either alternative, both alternatives were rated Low for this criterion.

8.2.8 Reasonable Restoration Time Frame

Restoration time frame assesses the urgency of achieving remediation objectives and the practicability of attaining a shorter restoration time frame, with consideration given to a number of factors such as site risks, site use and potential use, availability of alternative water supply, effectiveness and reliability of institutional controls, and toxicity of hazardous substances at the site.

As noted previously in Section 5, restoration of the HCIM Area is technically impracticable. The presence of DNAPL precludes site restoration and attainment of the SPOC for both soil and groundwater. Both alternatives being considered for the HCIM Area are based on long-term containment of impacted soil and groundwater. Neither alternative will restore the site or attain cleanup levels in the HCIM Area within a reasonable timeframe; therefore, neither alternative was assigned a ranking for this criterion.

8.3 SELECTION OF HCIM AREA PREFERRED REMEDIAL ALTERNATIVE

Selection of a preferred alternative under MTCA requires that a preference be given to alternatives that use permanent solutions to the maximum extent practicable, provide for a reasonable restoration time frame, and consider public concerns. According to MTCA (WAC 173-340-200), a permanent solution or permanent cleanup action means an action in which cleanup standards can be met without further action being required at the site involved, other than the approved disposal of any residue from the treatment of hazardous substances.

The MTCA rules also specify that a baseline alternative be defined as the remedial alternative that permanently destroys site COCs to the maximum extent practicable and achieves the shortest restoration time frame. The baseline alternative is to be used as a basis for comparing other remedial alternatives and selecting the preferred alternative. For the HCIM Area, only two remedial alternatives have been established as potentially applicable to the site; of the two, Alternative HA-1 would have a slightly higher level of permanence than Alternative HA-2. However, neither alternative is expected to be capable of restoring the site to pre-release conditions. As outlined in Section 5, the HCIM Area meets the MTCA exemption for a permanent remedy because of the disproportionate costs of attempting to implement a permanent solution. In addition, it has been determined that it is technically impractical to clean up the HCIM Area to cleanup levels. For these reasons, a baseline alternative is not defined for this SWFS. The two alternatives are compared to each other to select the preferred alternative for the HCIM Area.

8.3.1 Comparison of HCIM Area Alternatives

The two remedial alternatives developed for the HCIM Area are similar. The primary difference between the two alternatives is that Alternative HA-1 provides a physical barrier and active control of the groundwater gradient to contain impacted groundwater, while Alternative HA-2 provides passive containment using only a physical barrier and cap.

Both alternatives rely on control/containment of near-facility impacted soil and groundwater to achieve remediation objectives for the HCIM Area. Alternative HA-1 would provide limited removal of Facility-related COCs through groundwater recovery and pretreatment. However, groundwater recovery does not provide substantial removal of COCs. As noted by site characterization and monitoring data, many of the organic constituents present within the HCIM Area are actively biodegrading. The two alternatives would provide an equivalent level of biodegradation for organic constituents. The diffusion combined with advection rate of COCs through the barrier wall is expected to be slightly greater for Alternative HA-2 than it would be for Alternative HA-1 due to the inward hydraulic gradient maintained by active groundwater under Alternative HA-1. Both alternatives are compatible with future redevelopment and use of the industrial site, although Alternative HA-2 would be slightly preferred because it would not require long-term access for operation and maintenance of the groundwater recovery and pretreatment system. The two alternatives rely equally on institutional controls for attaining remediation objectives.

As shown in Table 8-1, Alternative HA-1 was ranked higher than Alternative HA-2 for only two out of the seven rated criteria. Alternative HA-1 was ranked higher in protectiveness and permanence because of the limited additional removal of site COCs provided by groundwater recovery and pretreatment. Alternative HA-2 was ranked higher for four of the seven rated criteria. The passive containment provided by Alternative HA-2, coupled with the extensive cap, is expected to provide better performance with respect to long-term effectiveness, management of short-term risks, implementability, and cost. The alternatives were considered equal for potential public concerns, largely due to the expected diversity of public opinion that could favor either alternative. The primary concern regarding Alternative HA-2 is the potential flux of site COCs through the barrier wall that would occur during passive containment. The estimated COC flux through the barrier wall for Alternative HA-2 is a conservative calculation based on theoretical calculations and assumed conditions, and is not based on measured results.

8.3.2 Preferred HCIM Area Remedial Alternative

Based on the comparison presented above, the preferred remedial alternative for the HCIM Area is Alternative HA-2, which provides passive containment. This remediation approach is readily implementable; most of the containment and monitoring components are currently in place. A few areas are not presently capped and, therefore, an asphalt capping would be required to limit infiltration and provide for complete protection from direct contact with COCs. Due to the passive nature of this alternative, long-term operation and maintenance would include routine inspection and maintenance of the barrier wall and cap. For this reason, the preferred alternative would not rely heavily on routine operator attention to attain its full capability and would be highly reliable. The primary potential for failure of the physical components of the preferred alternative would be catastrophic seismic events in the area or construction disturbance of the cap or barrier wall. Failure of the cap or barrier wall by either of these scenarios can be corrected by repairing the damaged areas using proven, readily available technologies.

The preferred remedial alternative for the HCIM Area would fully attain remediation objectives:

- The preferred alternative would prevent direct contact with soils and inhalation of dust within the HCIM Area by providing a cap over affected soils and by implementing institutional controls that would require appropriate health and safety precautions for future subsurface construction;
- The preferred alternative would reduce risks due to inhalation of vapors by incorporating institutional controls requiring vapor intrusion provisions for future buildings that may be occupied; and

- The preferred alternative would protect human and ecological receptors in the Duwamish Waterway by effectively containing affected groundwater and limiting the further release of COCs.

In addition, the preferred alternative provides the following:

- A readily implementable remediation approach that can be fully constructed and implemented with minimal delays for engineering, permitting, and construction;
- Long-term physical containment of near-facility impacted soil and groundwater through engineered barriers constructed of durable, natural materials;
- An isolated environment established in the contained area to promote and maintain active biological degradation of organic site constituents;
- A monitoring well network that will allow ongoing monitoring and assessment of the effectiveness of the remedial measures;
- A reliable, low-maintenance remediation approach using proven, robust technologies; and
- An approach that would create minimal short-term risks and [have minimal?] potential for causing public concern about exposure to site constituents during construction.

The preferred alternative (HA-2) for the HCIM Area is fully compatible with the existing HCIM system, is compatible with the remedial alternatives being considered for Outside Area, and is fully compliant with MTCA and Dangerous Waste regulations. However, as noted previously, the estimated COC flux through the barrier wall is based on theoretical calculations and assumed conditions. The flux through the wall can not be accurately measured. For this reason, PSC is committed to maintaining the active pumping and an inward gradient until the flux through the wall can be more confidently determined. Alternative HA-2 would be implemented in a phased manner, as described in Section 10, to ensure that it is effective and protective of human health and the environment. Active pumping, as included in Alternative HA-1, would be maintained to minimize the loss of COCs through the barrier wall during initial implementation of the preferred alternative. Groundwater monitoring outside the barrier wall would be maintained and if the results of monitoring indicate that concentrations are declining as predicted by the groundwater modeling and mass flux calculations, then PSC will make a request to Ecology to turn off the pump and treatment system.

The preferred remedial alternative for the HCIM Area would comply with all ARARs and the requirements of the Permit and achieve the environmental indicator standards for controlling potential exposure to both soil and groundwater for affected media located at and near the Facility. The preferred alternative would comply with MTCA, the Dangerous Waste Regulations (WAC 173-303), and the RCRA regulations. This alternative would provide effective containment for affected soil and groundwater in accordance with the MTCA regulations. Only minor amounts of dangerous wastes would be generated from implementation of the alternative, primarily resulting from installation of monitoring wells and well sampling.

The preferred HCIM Area alternative would effectively contain and control near-Facility affected soils and groundwater; institutional controls included in the alternative address the inhalation pathway for soil and groundwater and potential direct exposure pathways. Therefore, the preferred alternative for the HCIM Area would control potential exposures related to affected soil, groundwater, and soil gas, achieving the environmental indicator goals for the Facility. Affected media located outside the HCIM Area are addressed by the Outside Area alternatives, as discussed in Section 9.

TABLE 8-1

EVALUATION OF HCIM AREA REMEDIAL ALTERNATIVES
PSC Georgetown
Seattle, Washington

Standards/Criteria	Alternative HA-1: Active Hydraulic Containment	Alternative HA-2: Passive Hydraulic Containment
Protectiveness and Risk Reduction Evaluation	H	L
Permanence	H	L
Cost	L	H
Long-Term Effectiveness	L	H
Management of Short-Term Risks	L	H
Technical and Administrative Implementability	L	H
Public Concerns	L	L
Restoration Time Frame	NA	NA

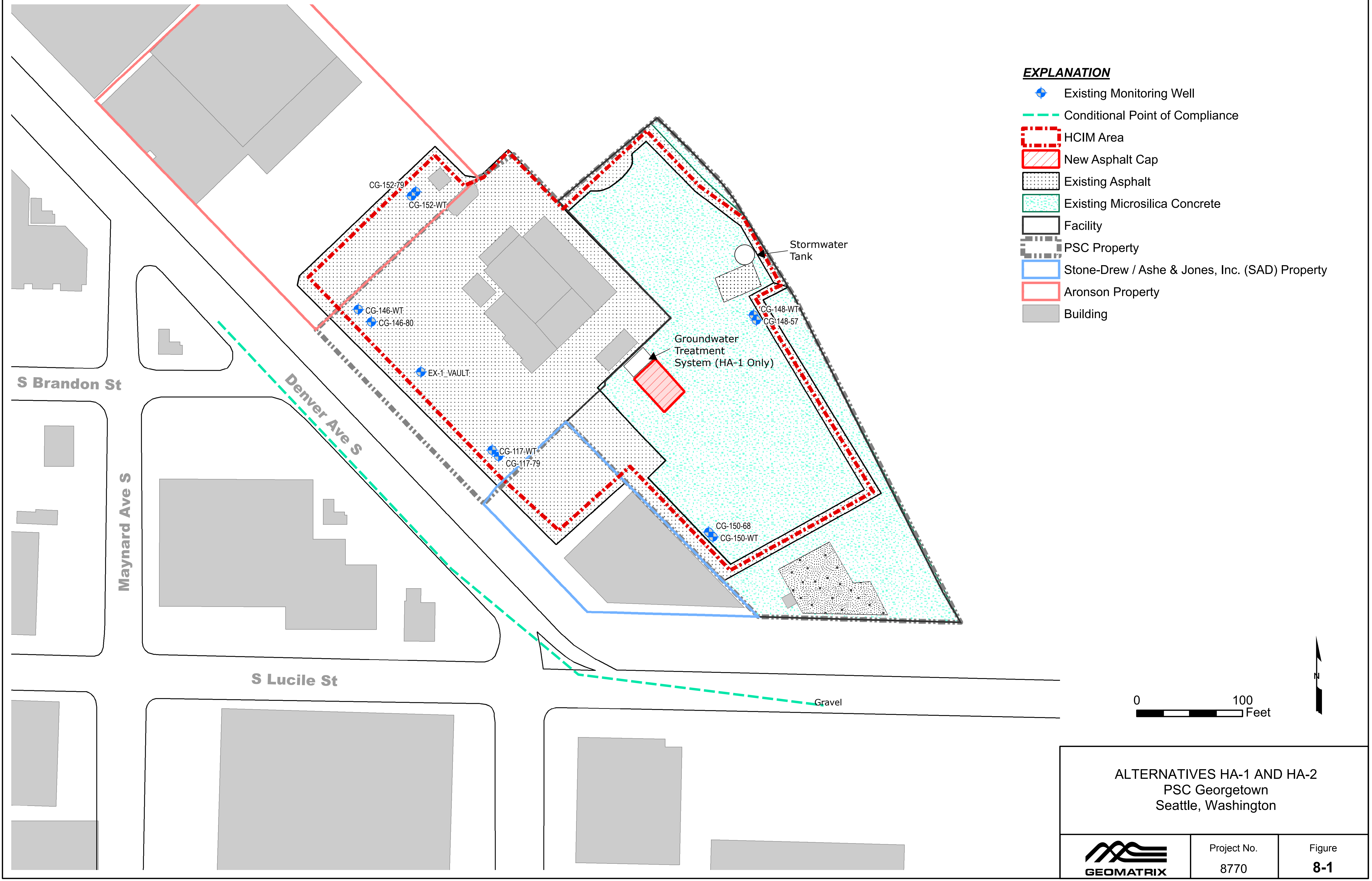
Notes:

1. The two alternatives are evaluated relative to each other. A low rating does not mean that the alternative does not meet remediation objectives.
2. Comparison Ratings:
   H = Higher relative ranking
   L = Lower relative ranking
   NA = Not Applicable

TABLE 8-2

ESTIMATED COSTS FOR HCIM AREA ALTERNATIVES
PSC Georgetown
Seattle, Washington

Alternative	Initial Cost	Net Present Value Cost
HA-1	$36,900	$3,030,400
HA-2	$36,900	$1,149,200



ALTERNATIVES HA-1 AND HA-2
PSC Georgetown
Seattle, Washington

GEOMATRIX

Project No.	Figure
8770	8-1

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9.0 DEVELOPMENT AND EVALUATION OF REMEDIAL ALTERNATIVES: OUTSIDE AREA

Remedial alternatives for the Outside Area must comprehensively address the affected media, COCs specific to the affected media, and potential exposure pathways for this area. Affected media include groundwater, soil, and soil gas. Groundwater exposure pathways to be addressed by remedial alternatives for the Outside Area include direct contact, ingestion (direct and incidental), and volatilization to soil gas or directly to indoor air. Potential exposure pathways for impacted soil include direct contact, incidental ingestion, and volatilization to soil gas. The exposure pathway of potential importance for impacted soil gas is migration of the soil gas to indoor air.

Currently, the extent of impacted groundwater to be addressed by the Outside Area remedial alternatives is defined by the extent of the indicator COCs identified in Section 4 (TCE, VC, and 1,4-dioxane). These indicator COCs are present in the Outside Area within the water table, shallow, and intermediate groundwater sample intervals. In the intermediate groundwater sample interval, VC is the major contaminant along a 400 foot section just downgradient of the barrier wall, along Denver Avenue South. Concentrations for VC in this area are as high as 1,000 µg/L. VC and TCE are found in the shallow groundwater interval over about 120 linear feet along the intersection of Denver Ave South and South Lucille Street, where concentrations for TCE range from 0.4 to 1.7 µg/L and concentrations for VC range from 3.4 to 15 µg/L. In the water table groundwater interval, many chlorinated COCs are present in addition to the indicator COCs just downgradient of the barrier wall, from the northwest corner of the barrier wall to the intersection of South Lucille Street and Airport Way South. These include 1,1,1 TCA, 1,1 DCA, 1,1 DCE, PCE, TCE, and VC. Concentrations for these constituents range from just above cleanup levels to 100 µg/L, depending on the location along this 800-foot corridor. In addition to these chlorinated VOCs, metals, SVOCs, and BTEX were detected in groundwater. As discussed in Section 4, these constituents are of lesser significance to the SWFS, which is focused on the indicator parameters defined in Section 4. The remaining indicator COC, 1,4-dioxane, is of importance due to its high solubility and mobility and due to its persistence in the environment. While 1,4-dioxane would not be addressed by most commonly used remediation technologies, monitoring data indicate that it is readily attenuated prior to reaching the Duwamish Waterway.

For the indicator COCs (TCE, VC, and 1,4-dioxane) in groundwater, there are only two potential exposure pathways: (1) groundwater discharge to surface water with exposure to ecological receptors or ingestion of fish by human receptors, and (2) vapor migration to buildings (the inhalation pathway). The inhalation pathway currently is being addressed by the IPIMs.

Impacted soil within the Outside Area is limited to the area near the Facility. Soil constituents identified in Outside Area soils include VOCs, SVOCs, and metals. Of the COCs identified in Outside Area soils, metals were the most widespread and were found in locations upgradient, cross gradient, and downgradient from the Facility; this distribution suggests that the metals contamination may be an area background issue. Impacted soil has been identified in only five off-property sampling locations, including one located in Airport Way South, well upgradient from the Facility. SVOCs were detected in soil on PSC properties and in two off-property locations, including the upgradient sampling location. VOCs were identified in only one off-property sample collected in the street to the southwest of the PSC properties. In general, impacted soil is shallow. All locations where impacted soil was identified are currently capped by pavement or roadways. Due to the limited extent of impacted soils within the Outside Area and the limited potential for exposure to soil constituents, impacted soil in the Outside Area will not be considered significant for this SWFS.

The Outside Area covers the portion of the Site located outside of the HCIM Area, extending from the area immediately downgradient from the barrier wall to Fourth Avenue South. This area is zoned General Industrial 2 (as discussed in Section 1), which includes industrial, commercial, and residential properties. The Outside Area was separated from the contamination source areas when the HCIM barrier wall was completed in January of 2004. The construction of this barrier wall not only separated the source area from groundwater within the Outside Area, it also substantially changed groundwater flow patterns; it is likely that the area immediately downgradient from the barrier wall is still adapting to the changes made by the wall. Due to the size of the enclosed area (approximately 2 acres of surface with a barrier wall about 300 feet wide [parallel to the groundwater flow], 600 feet long, and tied into the uppermost confining unit), the groundwater flow pattern immediately downgradient from the barrier wall will likely be adjusting in the shallow aquifer for several years and for much longer in the intermediate aquifer. Groundwater flow in the “shadow” of the barrier wall will be much slower than flow rates outside the shadow of the wall, which are estimated to be 25 feet per year in the intermediate groundwater interval and 190 feet per year in the water table and shallow intervals.

Although the barrier wall around the HCIM Area isolates the ongoing source for COCs in the Outside Area, there is a potential for flux of COCs through the barrier wall at very low concentrations. Therefore, the Outside Area remedial alternatives must address a continuous source of low concentration COCs from the HCIM Area. This is consistent with mass flux calculations through the wall described in Section 8. This potential low concentration release through the barrier wall must be addressed when evaluating remedial alternatives for the Outside Area and when assessing attainment of clean up levels.

As noted in Sections 4 and 5, substantial data have been collected documenting that natural attenuation, including very active biodegradation, is occurring within the Outside Area. Appendix A describes the approach to calculating the observed biodegradation rates. Attenuation has been documented for both chlorinated and non-chlorinated VOCs. Due to the history of the Facility and the fairly high groundwater flow velocity (approximately 200 feet per year in the water table and shallow intervals), it is assumed that the impacted Outside Area groundwater plume beyond the “shadow” recently created by the barrier wall is under steady-state conditions, reflecting convective transport by groundwater migration, retardation by the saturated zone matrix, and degradation by natural processes. It has also been confirmed that off-site, non-PSC releases have occurred at locations outside the scope of the FS in the area west of Fourth Avenue South. It is expected that the same conditions contributing to natural attenuation of the impacted groundwater within the Outside Area will cause natural attenuation of releases from the downgradient sources. The remediation strategies developed for the Outside Area should incorporate these natural attenuation processes to the extent practicable and should also be designed so that they do not interfere with natural attenuation for the downgradient source areas.

Fate and transport modeling was done to assess natural degradation and groundwater flow processes that are active in the Outside Area. Modeling was done using BIOCHLOR, a screening level model that incorporates biodegradation and retardation with advective transport of groundwater constituents. This model has been accepted by EPA for preliminary assessment of the fate and transport of chlorinated VOCs in groundwater. The current, measured groundwater gradients were used for this for modeling. Aquifer parameters (hydraulic conductivity and porosity) were taken from the RI Report. Default parameters specified by Ecology in the MTCA regulations were used for the soil organic carbon fraction and the partitioning coefficients. Degradation rates used for modeling intrinsic biodegradation were estimated using methodology previously accepted by Ecology. Degradation rates used for modeling enhanced bioremediation were taken from published literature for similar sites. Initial concentrations used for these model runs were the measured maximum concentrations in the areas located immediately downgradient from the barrier wall. Details concerning the modeling are presented in Appendix B. The results from the modeling were used in designing and evaluating the Outside Area remedial alternatives, as discussed below.

9.1 OUTSIDE AREA REMEDIAL ALTERNATIVES

Outside Area remedial alternatives presented in this SWFS have been developed from the remediation technologies described in Section 6 that were retained after the screening process. These alternatives have been designed to attain the remediation objectives described in Section 5 of this SWFS Report. The CPOC for ultimate attainment of cleanup levels is oriented southeast, along the western side of Denver Avenue South, through the intersection with South Lucile Street, and eastward along the south side of South Lucile Street (see Figure 9-1). The long-term remediation goal for the Outside Area remedial alternatives will be to attain groundwater cleanup levels at this CPOC. During remediation of the Outside Area, monitoring would be conducted at the CPOC to assess attainment of remediation levels and cleanup levels. The remediation levels were established as described in Section 3.3. These remediation levels allow for natural attenuation between the CPOC and the Duwamish Waterway. Groundwater monitoring data that have been collected in the vicinity of this CPOC indicate that remediation levels are currently being attained. Therefore, within the Outside Area, the groundwater affected by releases of COCs from the facility, is not adversely affecting downgradient surface water quality.

Although the historic releases from the Facility are not adversely affecting the Duwamish Waterway, current groundwater monitoring data indicate that cleanup levels protective of the vapor pathway are being exceeded in the water table interval within the Outside Area. For this reason, the ongoing IPIM, which has been found to be effective in controlling this exposure pathway, will be an integral part of any remedial alternative considered for the Outside Area.

The remedial alternatives developed for the Outside Area combine one or more of the retained remediation technologies with the IPIM; not all retained technologies were used in developing remedial alternatives. Two remedial alternatives for the Outside Area have been developed for detailed evaluation. The first alternative (Alternative OA-1) relies on MNA, a system of monitoring wells, the IPIM, and institutional controls. The second alternative (Alternative OA-2) enhances biological activity in the most contaminated portions of the Outside Area by addition of an electron donor. This option incorporates most of the elements of Alternative OA-1, but has the benefit of accelerating attainment of cleanup levels by removing the highest source areas outside the HCIM.

Remedial objectives specific to the Outside Area include the following:

- Attain remediation levels at the CPOC within a reasonable time;
- Ultimately and within a reasonable time, reduce constituent concentrations to achieve groundwater cleanup levels at the CPOC;
- Do not adversely affect existing land use within the Outside Area;
- Do not create nuisance conditions or conditions adverse to treating downgradient source areas; and
- Be compatible with the existing interim measures (both the HCIM and the IPIMs).

Preliminary, conceptual designs have been prepared for the Outside Area remedial alternatives to complete this SWFS. In order to complete the conceptual designs, assumptions have been made as needed based on professional judgment and the limited data available from the RI Report and subsequent investigations. The conceptual designs for the Outside Area remedial alternatives are described in the following subsections. Estimated costs for the alternatives are presented in Appendix C.

9.1.1 Alternative OA-1: Monitored Natural Attenuation

Alternative OA-1 relies primarily on natural attenuation, which has been proven effective for degradation of TCE and its daughter products within the Outside Area groundwater plume. Available groundwater monitoring data indicate that groundwater COCs originating at or near the Facility currently attenuate to achieve groundwater cleanup levels prior to potential exposure to human or ecological receptors. Due to the age of the release, it is likely that the conditions currently observed within most of the Outside Area represent steady-state conditions. Completion of the HCIM, which occurred in early 2004, has isolated the former source area from the Outside Area, thereby substantially reducing the release of COCs to the Outside Area. Due to this containment of the source of COCs, it is expected that the mass of COCs within the Outside Area will continuously decline as the result of ongoing natural attenuation processes. Recent groundwater monitoring data (Second Quarter of 2005) have shown a dramatic decrease in VOC concentrations immediately downgradient of the barrier wall in most wells. Additionally, recent groundwater monitoring data indicate that natural attenuation in the area immediately downgradient from the barrier wall is currently attaining the remediation levels defined in Section 3 of this SWFS Report.

MNA is a proven technology that has been effective in reducing chlorinated solvent concentrations in groundwater when appropriate conditions are present. This process relies on the attenuation of groundwater constituents by natural processes, including biodegradation, abiotic degradation, adsorption, and dilution. Due to the passive nature of this remediation technology, it can be readily implemented with a minimum of institutional issues such as permitting or arranging for access permissions, and also would have minimal potential for implementation problems such as fouling. Biodegradation of chlorinated solvents and non-chlorinated organics present in the Site is active; biodegradation of the chlorinated solvents accounts for the presence of the cis-1,2-DCE and the VC observed in Outside Area groundwater. Natural attenuation also accounts for the limited extent of groundwater affected by non-chlorinated organics; most of these organics are fully degraded upgradient of Denver Avenue South, based on observed groundwater monitoring data and preliminary fate and transport modeling. Available data also indicate that 1,4-dioxane attenuates to attain cleanup levels prior to discharge to the Duwamish Waterway. Based on available site characterization data, MNA achieves the remediation objectives and addresses the primary exposure pathways for groundwater within the Outside Area. The existing IPIM addresses the remaining exposure pathway for this area.

Alternative OA-1 is a permanent remedial alternative that would gradually decrease the mass of COCs present in the Outside Area. Biodegradation would permanently destroy both chlorinated and non-chlorinated VOCs and most SVOCs. As part of the fate and transport evaluation completed for this SWFS, the VOC mass flux though the barrier wall was estimated (Appendix B). It was conservatively estimated that approximately 0.03 lb/day of total site COCs could flow through the barrier wall, assuming that the preferred remedial alternative identified in Section 8 has been implemented.

Fate and transport modeling has been completed for the Alternative OA-1, and the modeling results are detailed in Appendix B. This modeling was performed using a range of biodegradation rates for the chlorinated VOCs. Using the biodegradation rates that were calculated using a mass flux approach (outlined in Appendix A) and calibrating the model to the actual monitoring data, the fate and transport modeling indicates that the cleanup levels would be met at and downgradient from Fourth Avenue South under existing conditions; therefore, under this alternative releases from the Facility would not affect the downgradient sources located west of Fourth Avenue South. As the COC mass within the Outside Area decreases, it is expected that the affected groundwater plume within the Outside Area would contract, ultimately attaining groundwater cleanup levels at the CPOC. Based on the conservative modeling evaluation, it is estimated that MNA would attain groundwater cleanup levels at the CPOC (along Denver Avenue South) within 50 to 60 years. The fate and transport modeling also indicates that COCs from the Facility would not reach the Duwamish Waterway even if the HCIM were not in place; however, this assumes that no other sources of halogenated VOCs are present downgradient of the Facility. The modeling was used to define remediation levels that would need to be attained at the CPOC. These remediation levels are currently being met for the indicator COCs, and modeling indicates that these remediation levels will be met in the future.

Since remediation levels are currently attained at the CPOC and are projected to continue to be attained upstream of Fourth Avenue South, and with the IPIMs adequately addressing the inhalation pathway, no adverse risks to human health and the environment are expected under Alternative OA-1. The existing IPIMs would be maintained as part of this remedial alternative to ensure that the inhalation pathway is adequately addressed until such time as the groundwater cleanup levels for that pathway are ultimately met throughout the SWFS Area. After it has been confirmed that groundwater concentrations within the water table interval have decreased below cleanup levels based on the inhalation pathway, the IPIMs would be discontinued. Based on the fate and transport modeling, the IPIMs would need to be operated for as long as 60 years.

Recent groundwater data from the second quarter of 2005 indicate that VOCs concentrations in the monitoring wells, immediately downgradient of the barrier wall, have been reduced sharply since the barrier wall was installed. Several of the wells have seen an order of magnitude drop in VOC concentrations over the last year. These data support the MNA evaluations performed to date and the fate and transport modeling projections of cleanup timeframes. Further monitoring is required to confirm this modeling.

A monitoring well network is an integral part of MNA. For Alternative OA-1, a monitoring well network would be placed within the Outside Area, as shown on Figure 9-1. Monitoring would be conducted in the CPOC located along the west side of Denver Avenue South and the south side of Lucile Street South (Figure 9-1) and in monitoring wells located within the area downgradient from Denver Avenue South/South Lucile Street and upgradient from Fourth Avenue South (Figure 9-2). As outlined above, the proposed remediation levels are currently being met at the CPOC. The CPOC wells would be monitored to ensure these remediation levels continue to be attained. Following sufficient degradation of COCs within the Outside Area, the CPOC wells would be monitored to confirm attainment of cleanup levels. Wells downgradient from the CPOC would be monitored to assess groundwater quality between the CPOC and Fourth Avenue until cleanup levels would be attained at the CPOC. It was assumed that there would be three sets of nested monitoring wells (three wells per nest for a total of nine wells) comprising the monitoring network along the CPOC. A total of 27 wells would be regularly monitored for this alternative. For cost estimating purposes, it has been assumed that quarterly monitoring of 11 wells located near the barrier wall would be done 3 years, as required under the existing monitoring program, followed by annual monitoring for 27 years. The remaining 16 wells were assumed to be monitored annually for 30 years. Groundwater samples would be analyzed for VOCs, 1,4-dioxane, and MNA parameters (alkalinity, ethane, and ethene).

Institutional controls are normally a key component of most remedies to ensure that human health and the environment are adequately protected. For off-site groundwater plumes, institutional controls are not readily implementable and enforceable. In the case of Alternative OA-1 for the period prior to attainment of cleanup levels at the CPOC, some form of institutional or administrative controls would be required. These would include the following:

- Limit withdrawal and use of groundwater within and downgradient from the project area. Currently the City of Seattle has a bylaw preventing the withdrawal of groundwater for use as a drinking water source, and this will serve as the administrative control for groundwater use;

- Where groundwater levels exceed cleanup levels for direct exposure, appropriate personal protective equipment and exposure monitoring for subsurface work conducted in and downgradient from the project area will be required. This type of control is not readily implemented and will need to be addressed through community awareness and notifications to the City of Seattle; and

- Maintain the IPIMs until monitoring data indicate groundwater is below cleanup levels based on the inhalation pathways. The maintenance of IPIMs will be a requirement of the permit and, therefore, will not be considered an institutional control. In addition, the City will be notified that new buildings in the area where groundwater concentrations exceed the inhalation pathway cleanup levels should be constructed with appropriate vapor barriers.

9.1.2 Alternative OA- 2: Enhanced Anaerobic Bioremediation

Alternative OA-2 includes enhanced anaerobic bioremediation to address the high levels of COCs present in hot spots immediately downgradient of the HCIM Area. This alternative would require that the IPIMs be maintained until cleanup levels are met at the CPOC. As noted previously, the HCIM has essentially eliminated the source area for Outside Area groundwater.

The treatment of these hot spots would effectively shrink the groundwater plume present in the Outside Area and reduce the restoration time frame relative to Alternative OA-1. For this alternative, enhanced anaerobic bioremediation would be conducted to accelerate the ongoing biodegradation of TCE, cis-1,2-DCE, VC, and other chlorinated hydrocarbons that are currently located outside the barrier wall. All other components described above for Alternative OA-1 would be incorporated into this alternative. Groundwater downgradient from the bioremediation areas would be monitored to confirm the effectiveness of the enhanced bioremediation process and to confirm attainment of remediation levels and cleanup levels at the same CPOC described for Alternative OA-1. Electron donor and, if appropriate, nutrients, would be injected across the flowpath in the hot spots with the highest COC concentrations, which are generally located just outside the HCIM Area. The electron donor and nutrients would enhance microbial degradation of chlorinated solvents. For Alternative OA-2, it is expected that the enhanced bioremediation approach would accelerate attainment of cleanup levels at the CPOC.

Proven, readily available electron donor materials used to promote reductive dechlorination include molasses, sodium lactate, and emulsified vegetable oil. The specific electron donor that would be used for the Outside Area would be determined through pilot testing conducted during preparation of the corrective action plan. For the purpose of cost estimating for this SWFS, it was assumed that sodium lactate would be used as electron donor in the water table and shallow groundwater intervals. In the intermediate interval, the groundwater flow is relatively slow (estimated to be about 25 ft/yr); therefore, a slow-releasing electron donor would be preferred for the intermediate groundwater interval. Costs for enhanced bioremediation in the intermediate groundwater interval were based on injection of emulsified vegetable oil. It was assumed that multiple electron donor injections would be required for the water table and shallow groundwater intervals; therefore, it was assumed the electron donor would be added to these intervals using recirculation wells. For the intermediate interval, it was assumed that a single injection would be adequate; therefore, direct push methods would be used for injecting the electron donor. Across all three groundwater intervals, the electron donor would create anaerobic conditions that would promote reductive dechlorination of the chlorinated VOCs.

Based on this approach, the conceptual design for Alternative OA-2 includes the installation of a line of bioremediation injection and extraction wells completed in the water table and shallow groundwater intervals. As noted earlier, groundwater flow in the shadow of the barrier wall may be limited. In order to ensure that the substrate spreads uniformly throughout the subsurface in a reasonable time frame, a recirculating injection system was designed. The well spacing and layout (Figure 9-3) was designed to provide electron donors to the most contaminated areas (i.e., hot spots) outside the barrier wall and allow injection to be done in a stepwise manner across the hot spots. Electron injection would be accomplished by withdrawing groundwater from a central well, mixing electron donor with the extracted groundwater, and injecting the groundwater into two adjacent wells. Injection would continue until electron donor is detected in the extracted groundwater. The well spacing was estimated so that electron donor could be injected into one recirculation cell (three wells) in one day. The full cross section of the hot spots would be treated in a stepwise manner. For areas where affected groundwater is limited to the water table interval, a single recirculation set would include three wells and two injection wells spaced 30 feet apart with an extraction well in the center, with all wells completed in the water table interval. If contamination is present in both the shallow and water table groundwater intervals, the same approach would be used but each injection or extraction well would be replaced by nested wells completed in both groundwater intervals, for a total of six wells. The water table interval has the most extensive spread of COCs. Wells will be screened from 10 to 20 feet bgs for 800 feet just downgradient of the HCIM barrier. There are high levels of some COCs in the intermediate groundwater interval for about 120 feet at the intersection of South Lucile Street and Denver Ave South. Thus, there are nested wells with screens at 10 to 20 feet bgs for the water table and at 30 to 40 feet bgs for treatment of the intermediate groundwater interval. The total number of wells included for electron donor injection to the water table and shallow groundwater intervals includes 35 injection and 31 extraction wells.

The conceptual design for bioremediation of the intermediate groundwater interval is shown on Figure 9-3. Due to the lower hydraulic conductivity of the intermediate groundwater interval, it was assumed that electron donor would be introduced using direct-push methods. The estimated spacing for the push probes is 10 feet with 40 push probe locations total. At each push probe location, it was assumed that emulsified vegetable oil would be injected at multiple depths to cover the affected depth of groundwater in the intermediate interval. The intermediate aquifer has COCs at depths from 60 to 100 feet bgs. There could be up to four vegetable oil injection points for each push probe location.

In the water table and shallow groundwater sample intervals, it was assumed that repeat injections would be conducted periodically to maintain a high level of biological activity and effectively reductive dechlorination of the chlorinated VOCs and breakdown products. For estimating costs, it was assumed that two injections would be performed each year over a

2-year period, for a total of four injection events. For the intermediate groundwater interval, a longer-lasting, one-time injection of vegetable oil was assumed to estimate costs.

Pilot testing for Alternative OA-2 would be needed to confirm the effectiveness of this technology and to collect site-specific design data. Costs for pilot testing have been included in the implementation cost estimate. Pilot testing would likely be done using a set of nested wells in an area with the highest concentration of COCs. Monitoring wells may also be needed to perform pilot testing.

The effectiveness of Alternative OA-2 would be confirmed using a monitoring well network identical to that described above for Alternative OA-1. Monitoring wells would be placed along the CPOC downgradient from injection wells to monitor the effectiveness of the enhanced bioremediation and monitor attainment of the remediation level. The approximate locations of the monitoring wells for this alternative are shown on Figure 9-2. The monitoring frequency and analytical parameters for this alternative would be the same as described above for Alternative OA-1.

The enhanced bioremediation option was also evaluated by fate and transport modeling (Appendix B) The results of that modeling indicate that the cleanup levels at the CPOC may be met faster than for Alternative OA-1 (within about 30 years) if this alternative is implemented. It is estimated that the enhanced bioremediation under this alternative would decrease the time for meeting the inhalation pathway cleanup objectives between the CPOC and Fourth Avenue South from 50 to 60 years under Alternative OA-1 to about 30 years. It should be noted that at this time, the modeling performed for the enhanced anaerobic bioremediation is based on estimated enhancement of VOC degradation using literature rate constants. Actual improvement in the strong natural anaerobic conditions is difficult to predict until pilot testing has been performed. Estimated remediation times using the available data and literature values are very uncertain, and should only be considered as qualitative indicators of actual remediation times and for comparison purposes. For estimating costs, the groundwater monitoring program was considered to continue for 5 years beyond the estimated restoration time, with a maximum monitoring period of 30 years.

Administrative controls would be incorporated into the alternative to ensure that human health and the environment are adequately protected by Alternative OA-2. These administrative controls for this alternative would be the same as described above for Alternative OA-1.

9.2 EVALUATION OF OUTSIDE AREA REMEDIAL ALTERNATIVES

The primary objective for the remedial alternatives described in Section 9.1 is to reduce constituent concentrations sufficiently to meet remediation levels. The remediation levels currently are being met at the proposed CPOC located along Denver Avenue South, as described above and the remediation levels will continue to be attained.

This section compares and evaluates the remedial alternatives based on the MTCA criteria of protectiveness and risk reduction, permanence, cost, long-term effectiveness, management of short-term risks, technical and administrative implementability, public concerns, and restoration time frame, as defined and discussed in Section 7 of this SWFS Report. In the subsections below, the two alternatives are evaluated relative to each other. A High rating means that the alternative is expected to perform better with respect to the criterion being evaluated than the other alternative. A Low rating indicates that the alternative is expected to perform less effectively than the other alternative. A Low rating does not mean that the alternative would not adequately meet the criterion; it only means that other alternative would be more effective in meeting the specific criterion. The two alternatives considered in this SWFS are as follows:

- Alternative OA-1: Monitored Natural Attenuation
- Alternative OA-2: Enhanced Anaerobic Bioremediation

The two remedial alternatives for the Outside Area will both attain the remedial objectives outlined in Section 5.3. Affected soils in the Outside Area that are located outside PSC properties are likely a local background issue and are not addressed by this SWFS, as previously noted. Affected soils located on PSC properties would be capped to prevent direct contact and generation of dust. Additionally, the cap would limit runoff of affected soil. Both alternatives incorporate the ongoing IPIMs in the Outside Area to intercept vapor intrusion and limit potential exposures via the inhalation pathway. Groundwater monitoring data indicate that remediation levels are already attained at the CPOC for the two remedial alternatives; therefore, human and ecological receptors using surface water are not exposed to unacceptable risks related to the Facility. Therefore, the remedial alternatives considered for the Outside Area comprehensively attain the remedial objectives established in this SWFS.

The comparisons for the two alternatives presented below summarize the primary factors addressing each criterion. The evaluation has been summarized for all evaluation criteria in Table 9-1.

9.2.1 Protectiveness and Risk Reduction Evaluation

In general terms, the protectiveness and risk reduction criterion assesses the degree to which a remedial alternative protects human health and the environment and provides a reduction in risks posed by the contamination. The two alternatives considered for the Outside Area are equal for protectiveness and risk reduction because both rely on biodegradation of Facility constituents to achieve remediation levels and, ultimately, cleanup levels and both incorporate the IPIM to address the vapor pathway. Each of the two alternatives would be adequately protective of human health and the environment. Since Facility target COCs in groundwater already meet remediation levels, both alternatives would be fully protective of the Duwamish Waterway. Ultimately both alternatives will attain cleanup levels at the CPOC, which would enable shutdown of the IPIM. Both alternatives rely on the same institutional controls to prevent direct exposure to affected groundwater and would be, therefore, equally protective in this respect.

Each of the alternatives has been ranked for attainment of this criterion (see Table 9-1). Both Alternative OA-1 (MNA) and Alternative OA-2 (enhanced bioremediation) were rated High for this criterion. The two alternatives are not substantively different for protectiveness and risk reduction.

9.2.2 Permanence

The permanence criterion, as defined in Section 7, assesses the degree to which the remedial alternative would reduce the toxicity and mobility of affected media through permanent destruction of hazardous substances. Both remedial alternatives considered for this SWFS would provide permanent destruction for most of the Facility COCs. Chlorinated VOCs, which are the primary concern for the Outside Area, would be effectively destroyed by both alternatives. Available monitoring data indicate that all other organic Facility COCs and metals are attenuated to the point that cleanup levels would be attained prior to discharge of the groundwater to the Duwamish Waterway. Both alternatives provide equivalent, permanent destruction for the most significant COCs present in the Outside Area, and provide equivalent attenuation for those COCs that are not permanently destroyed. Since Alternatives OA-1 and OA-2 would both be essentially equivalent for permanence and be very effective in destroying key COCs, both of these alternatives were rated High for this criterion.

9.2.3 Costs

Net Present Value (NPV) cost estimates were prepared for both alternatives, as presented in Table 9-2 and described in Appendix C. The NPV costs combine initial costs for implementation of an alternative with recurring costs for future for operation, maintenance, and monitoring. NPV cost estimates allow the alternatives to be compared on an equal basis. Implementation costs include costs for obtaining access to conduct the remediation; costs for engineering and planning; costs for equipment, materials, and chemicals; costs for permitting; and costs for construction. Recurring costs include costs for operation and maintenance labor, costs for materials and chemicals used in remediation, costs for periodic replacement of remediation equipment, costs for long-term property access, utility and power costs, waste disposal costs, groundwater monitoring costs, and project management and reporting costs. The NPV costs are based on a 30-year period for both alternatives, based on the estimated restoration and monitoring times for the two alternatives (see Section 9.1). Groundwater monitoring was assumed to occur quarterly for the first 3 years, followed by semiannual sampling until the end of the estimated restoration time. Costs for maintaining the IPIM intact until groundwater concentrations in the water table interval attain cleanup levels protective of the inhalation pathway were also included in both alternatives.

The alternatives were ranked for cost based on the estimated NPV cost. Alternative OA-2 was ranked Low for cost because it has a higher NPV cost than Alternative OA-1.

9.2.4 Long-Term Effectiveness

Long-term effectiveness includes the degree of certainty and reliability for the alternative to maintain its effectiveness over the long term and whether treatment residue remains from the alternative that will require management. The benefits realized by an alternative are compared to the negative consequences associated with the alternative in assessing long-term effectiveness. Both Outside Area alternatives would incorporate the IPIM and the same institutional controls, and both utilize the same mechanism to remediate the Outside Area. Neither alternative would create residuals that require off-site management. Therefore, both alternatives were ranked equal for this criterion. Since both alternatives would be permanent for the key constituents, both are expected to be protective of the Duwamish Waterway throughout the remediation period, and both would be effective in protecting human health, the two alternatives were both rated High for long-term effectiveness.

9.2.5 Management of Short-Term Risks

Short-term risks refer to the potential risks to human health and the environment that may occur during implementation of an alternative. Neither alternative considered for the Outside Area in this SWFS would create significant short-term risks. However, the alternatives are not equal for this criterion. Alternative OA-2, which relies on enhanced, in situ, anaerobic bioremediation, would create limited short-term risks. Addition of electron donor to the subsurface would require recovery and reinjection of affected groundwater. Although this operation can and would be designed to be conducted safely, there would be limited risk for equipment failure that could result in short-term risk. Additionally, there is a possibility that anaerobic biodegradation of the electron donor could create methane in the subsurface, potentially causing localized fire hazards. Short-term risks would also be greater for Alternative OA-2 because it would require installation of a large number of wells and push probes, increasing the potential for construction accidents. For these reasons, Alternative OA-2 was ranked Low for this criterion and Alternative OA-1 was ranked High.

9.2.6 Technical and Administrative Implementability

This criterion assesses both technical and administrative issues related to construction and operation of the remedial alternatives. Factors considered in assessing the alternatives against this criterion include administrative/regulatory requirements, impact on existing land uses, the means for implementing and enforcing institutional controls, and access for construction operations. Since both alternatives incorporate the existing IPIM, the alternatives are equal for implementing remedial action for the inhalation pathway. Due to the heavy urban development of the Site, significant implementability issues are associated with both remedial alternatives, but these issues are greater for Alternative OA-2 than for Alternative OA-1. The large number of wells push probes required for injection of electron donor would require appropriate access and permits, particularly for those wells that would be installed in or along public roads. Additionally, it would be necessary to obtain injection permits to allow reinjection of groundwater dosed with electron donor. Both alternatives would have minimal impact on existing land uses because they both rely on in situ remediation methods that require minimal surface facilities. Pilot testing would likely be necessary for effective implementation of enhanced bioremediation (Alternative OA-2), which would require a separate mobilization and phase of field work. Alternative OA-1 would only require access for installation of new monitoring wells and for periodic monitoring. Due to the increased complexity for implementation of Alternative OA-2, it was ranked Low for this criterion.

9.2.7 Public Concerns

Potential community concerns with implementation of remedial alternatives are assessed for this criterion, including concerns the general public may have and specific concerns of neighboring landowners. It is expected that the potential public concerns associated with the Outside Area alternatives would be from neighboring landowners because of the heavy urban development of the area and the possible need to gain access to private properties for installation and operation for Alternative OA-2. The potential public concerns are expected to be related to potential VOC releases to ambient air, odors, and noise during implementation of the alternative. Additional public concerns are likely to be related to traffic alterations during any construction or other work conducted in public roads.

For this criterion, a High rating indicates the lowest expected public concern (greatest acceptance) and a Low rating indicates the greatest expected public concern (least acceptance). Alternative OA-1 (MNA) was ranked High for this criterion and Alternative OA-2 was ranked Low. Alternative OA-1 was ranked higher because it is a generally passive remediation approach; most of the activity that may invoke public concern would be during groundwater monitoring, which is already being done in the area. Alternative OA-2 would require significant field work to install new wells, thereby increasing the potential for public concern due to noise, odors, and impacts on traffic. Electron donor injection events associated with Alternative OA-2 (projected to occur twice annually for 2 years) may also raise public concern due to the potential for noise and odors. Traffic may also be disrupted during injection events due to the necessity of placing some bioremediation wells in the public roadway.

Public concern could also be raised for Alternative OA-1 due to the public perception that MNA is not an “aggressive” form of cleanup; however, this perception can be readily overcome with a good public communication plan.

9.2.8 Reasonable Restoration Time Frame

Restoration time frame assesses the urgency of achieving remediation objectives and the practicability of attaining remediation objectives in a shorter time frame, with consideration given to a number of factors, including site risks, site use and potential use, availability of alternative water supply, effectiveness and reliability of institutional controls, and toxicity of hazardous substances at the site. The two Outside Area alternatives are not substantially different for this criterion. The community including and surrounding the Outside Area is served by the Seattle Public Utilities, which supplies all drinking and process water used in the area. As noted in the RI Report, groundwater beneath the entire SWFS Area is not a water supply aquifer. Significant risks associated with the Outside Area have been addressed by the IPIMs; characterization data show that COCs related to the Facility attenuate to below cleanup levels prior to reaching the Duwamish Waterway. The remediation levels defined in Section 3 of this report are currently being met at the CPOC and are predicted to be met in the long term. Therefore, since risks are currently being managed at acceptable levels, there is no high urgency to shorten the restoration time for the Outside Area.

As presented in Table 9-1, Alternative OA-2 was rated High for this criterion and Alternative OA-1 was rated Low. Enhanced bioremediation, which is included in Alternative OA-2, will result in a shorter restoration time frame. The increased rate of destruction from Alternative OA-2 based on modeling should allow shutdown of the IPIM program at an earlier date. Similarly, the increased rate of degradation under Alternative OA-2 should attain cleanup levels at the CPOC sooner. As noted in Section 9.1, it is estimated that Alternative OA-1 would reduce the Outside Area hot spots to cleanup levels within 50 to 60 years, while Alternative OA-2 would attain cleanup levels in the hot spots within about 30 years. However, the estimated time to meet cleanup levels for Alternative OA-2 is based on modeling and actual results are expected to vary. The estimate for OA-2 potentially only reduces the estimated time for Alternative OA-1 by a factor of approximately 2 or less, which is likely within the range of uncertainty in these estimates.

9.3 SELECTION OF PREFERRED OUTSIDE AREA REMEDIAL ALTERNATIVE

Selection of a preferred alternative under MTCA requires that a preference be given to alternatives that use permanent solutions to the maximum extent practicable, provide for a reasonable restoration time frame, and consider public concerns. According to MTCA (WAC 173-340-200), a permanent solution or permanent cleanup action means an action in which cleanup standards can be met without further action being required at the site involved, other than the approved disposal of any residue from the treatment of hazardous substances. Both remedial alternatives considered for the Outside Area are permanent for most of the organic COCs because they would result in destruction of the COCs via biodegradation.

The MTCA rules also specify that a baseline alternative be defined as that remedial alternative that permanently destroys site COCs to the maximum extent practicable and achieves the shortest restoration time frame. The baseline alternative is to be used as a basis for comparing other remedial alternatives and selecting the preferred alternative. For the Outside Area, only two remedial alternatives have been established as potentially applicable to the Site. Although both alternatives permanently destroy most COCs, Alternative OA-2 would have a higher level of permanence than Alternative OA-1 because it would achieve a shorter restoration time. Therefore, Alternative OA-2 would be considered the baseline alternative for this SWFS. However, since there are only two alternatives considered potentially feasible for the Outside Area, the two alternatives will be compared to each other to select the preferred remedial alternative.

9.3.1 Comparison of Outside Area Alternatives

The two remedial alternatives considered for implementation in the Outside Area would utilize the same indigenous organisms to provide biodegradation for organic COCs. They would also use the natural attenuation for recalcitrant COCs, the same monitoring network, incorporate the same IPIMs to address the inhalation pathway, and utilize the same institutional controls. The primary difference between the two alternatives is that Alternative OA-2 would enhance the subsurface environment to promote biological activity and theoretically provide more rapid biodegradation of chlorinated VOCs.

The comparison of the two alternatives relative to the FS evaluation criteria is summarized on Table 9-1. Alternative OA-1 was ranked High for seven of the eight criteria, while Alternative OA-2 (the baseline alternative) was ranked High for four of the eight criteria. Alternative OA-2 was ranked higher than Alternative OA-1 only for restoration time because of the more rapid degradation rate that would be achieved by Alternative OA-2. Alternative OA-1 was ranked higher than Alternative OA-2 for cost, implementability, and potential for public concerns. The two alternatives were ranked equal for protectiveness and risk reduction, permanence, and long-term effectiveness. Since Alternative OA-1 would be less invasive than Alternative OA-2, it would create fewer short-term risks and would be simpler to implement. The permitting, drilling, and substrate injection associated with Alternative OA-2 would not be required for Alternative OA-1. The potential for creating nuisance conditions associated with Alternative OA-2 (including potential for noise, odors, and affecting traffic) would not occur with Alternative OA-1. The passive bioremediation that would be provided by MNA under Alternative OA-1 rates better for the evaluation criteria than the more active bioremediation that would occur under Alternative OA-2. In addition, the recent groundwater data from the monitoring program confirm that MNA appears to be degrading COCs near the barrier wall faster than the modeling has predicted.

9.3.2 Preferred Outside Area Remedial Alternative

The preferred remedial alternative for the Outside Area is Alternative OA-1. This alternative would provide permanent destruction of most site COCs, including the halogenated VOCs that are most significant for potential risks to human health and the environment. The existing IPIMs would be maintained to address the inhalation pathway until MNA reduces COC concentration levels to cleanup levels. Constituents released from the Facility that are not readily degraded by natural processes have been shown to attenuate to cleanup levels prior to discharge of the groundwater to the Duwamish Waterway. This remedial alternative is readily implementable, with minimal permitting and construction requirements. The IPIMs, which are an important element of this alternative, have already been implemented and are currently being operated and maintained. Construction and operation activities in the Outside Area are complex due to the dense urban development that includes industrial, commercial, and residential properties. Much of the monitoring well network needed to implement Alternative OA-1 is already in place; additional drilling would be limited. A well-established groundwater monitoring program is already in place for the Outside Area that would be continued under Alternative OA-1. This alternative would not interfere with anticipated remedial measures that may be implemented in the identified source areas downgradient from the Outside Area. Although enhanced bioremediation would likely reduce the time frame to meet cleanup levels in the SWFS Area, based on the preliminary estimates presented in this SWFS the shortened remediation time frame is not sufficient to clearly favor Alternative OA-2 as the preferred remedy, particularly in consideration of the other criteria.

The preferred remedial alternative for the Outside Area fully attains remediation objectives:

- The preferred alternative prevents direct contact with soils and inhalation of dust in areas affected by the Facility by providing a cap and implementation of institutional or administrative controls that would require appropriate health and safety precautions for future subsurface construction;

- The preferred alternative reduces risks due to inhalation of vapors by maintaining the existing IPIM until cleanup levels would be attained; and

- The preferred alternative protects potential human and ecological receptors due to releases from the Facility since remediation levels are being attained at the CPOC and IPIMs are addressing the inhalation pathway.

In addition, the preferred alternative provides the following:

- A readily implementable remediation approach that could be fully constructed and implemented in with minimal delays for permitting and construction. This is especially important due to the complex, densely developed urban environment present throughout the Outside Area;

- A proven and active approach that would result in permanent destruction of the most significant groundwater COCs and most other organic COCs;

- A comprehensive groundwater monitoring network that would confirm the effectiveness of the alternative and also identify any problems prior to creating actual risks to human health and the environment;

- A comprehensive IPIM system to address the inhalation pathway until cleanup levels are achieved;

- A reliable, low-maintenance remediation approach using proven, robust technologies; and
- An approach creating minimal short-term risks and minimal potential for causing public concern for exposure to site constituents during construction.

The preferred alternative for the Outside Area is fully compatible with the preferred alternative for the HCIM Area, incorporates the IPIMs, and is fully compliant with MTCA regulations.

The preferred remedial alternative for the Outside Area would comply with all ARARs and the requirements of the Permit and achieve the environmental indicator standards for controlling potential exposure to both soil and groundwater for media affected by Facility releases within the Outside Area. The preferred alternative would comply with MTCA, the Dangerous Waste Regulations (WAC 173-303), and the RCRA regulations. Cleanup levels and remediation levels established in accordance with the MTCA regulations will be achieved. The alternative would also provide permanent destruction for key Facility constituents. No dangerous wastes would be produced other than minor quantities of drilling and sampling wastes. The preferred alternative would address all potential exposure pathways, including migration to surface water, direct exposure to soil, and inhalation of vapors migrating into buildings through capping, natural attenuation, and the IPIMs. Therefore, the preferred alternative for the Outside Area would achieve the environmental indicator goals. In conjunction with the preferred alternative for the HCIM Area, this alternative would comprehensively address historic releases related to the Facility.

TABLE 9-1

EVALUATION OF OUTSIDE AREA REMEDIAL ALTERNATIVES
PSC Georgetown
Seattle, Washington

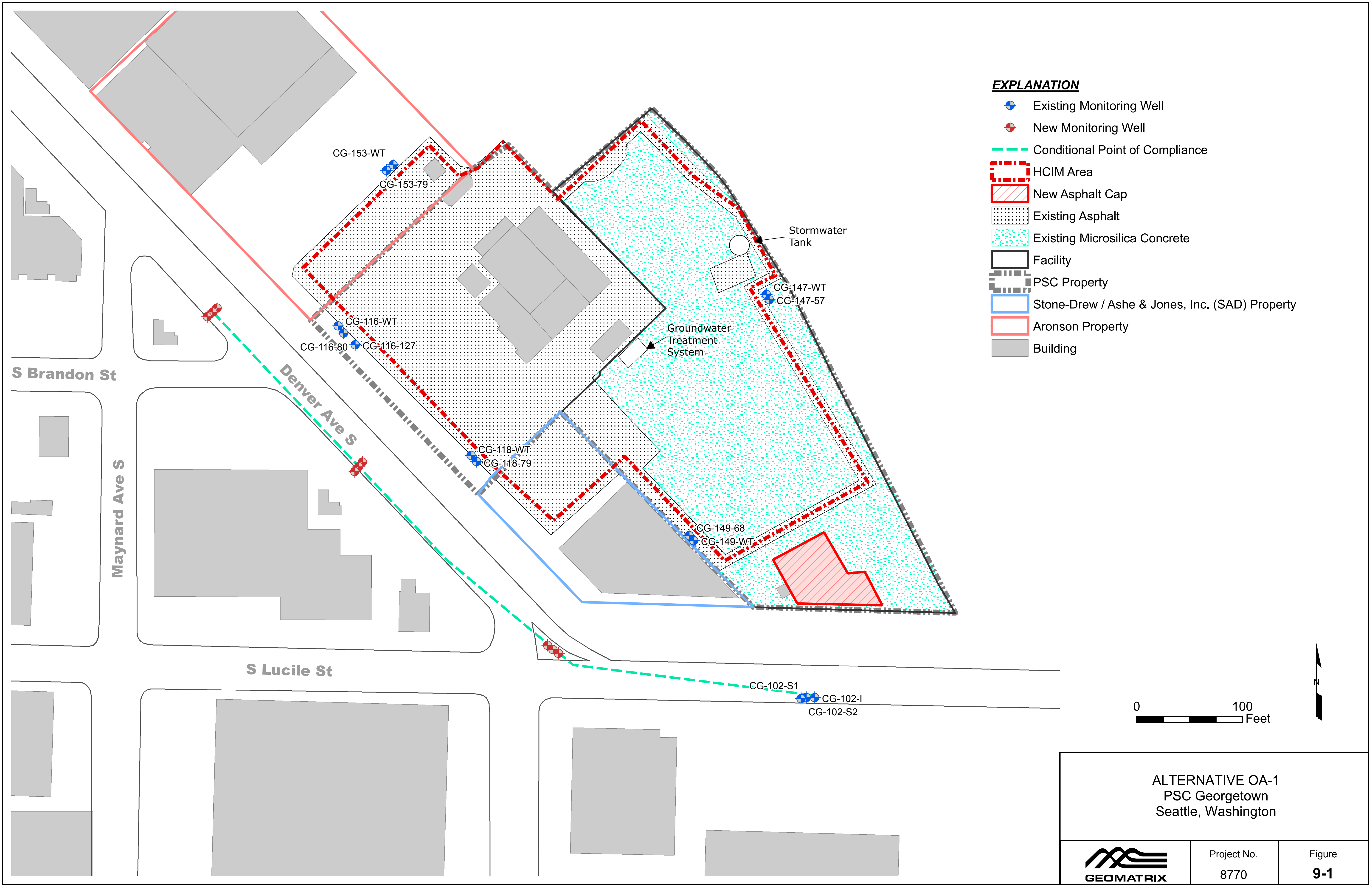
Standards/Criteria	Alternative OA-1: Monitored Natural Attenuation	Alternative OA-2: Enhanced Anaerobic Bioremediation
Protectiveness and Risk Reduction Evaluation	H	H
Permanence	H	H
Cost	H	L
Long-Term Effectiveness	H	H
Management of Short-Term Risks	H	L
Technical and Administrative Implementability	H	L
Public Concerns	H	L
Restoration Time Frame	L	H

Notes:
1. The two alternatives are evaluated relative to each other. A low rating does not mean that the alternative does not meet remediation objectives.
2. Comparison Ratings:
    H = Higher relative ranking
    L = Lower relative ranking
    NA = Not Applicable

TABLE 9-2

ESTIMATED COSTS FOR OUTSIDE AREA ALTERNATIVES
PSC Georgetown
Seattle, Washington

Alternative	Initial Cost	Net Present Value Cost
OA-1	$106,100	$2,212,700
OA-2	$857,900	$3,319,500



ALTERNATIVE OA-1
PSC Georgetown
Seattle, Washington

GEOMATRIX

Project No.	Figure
8770	9-1

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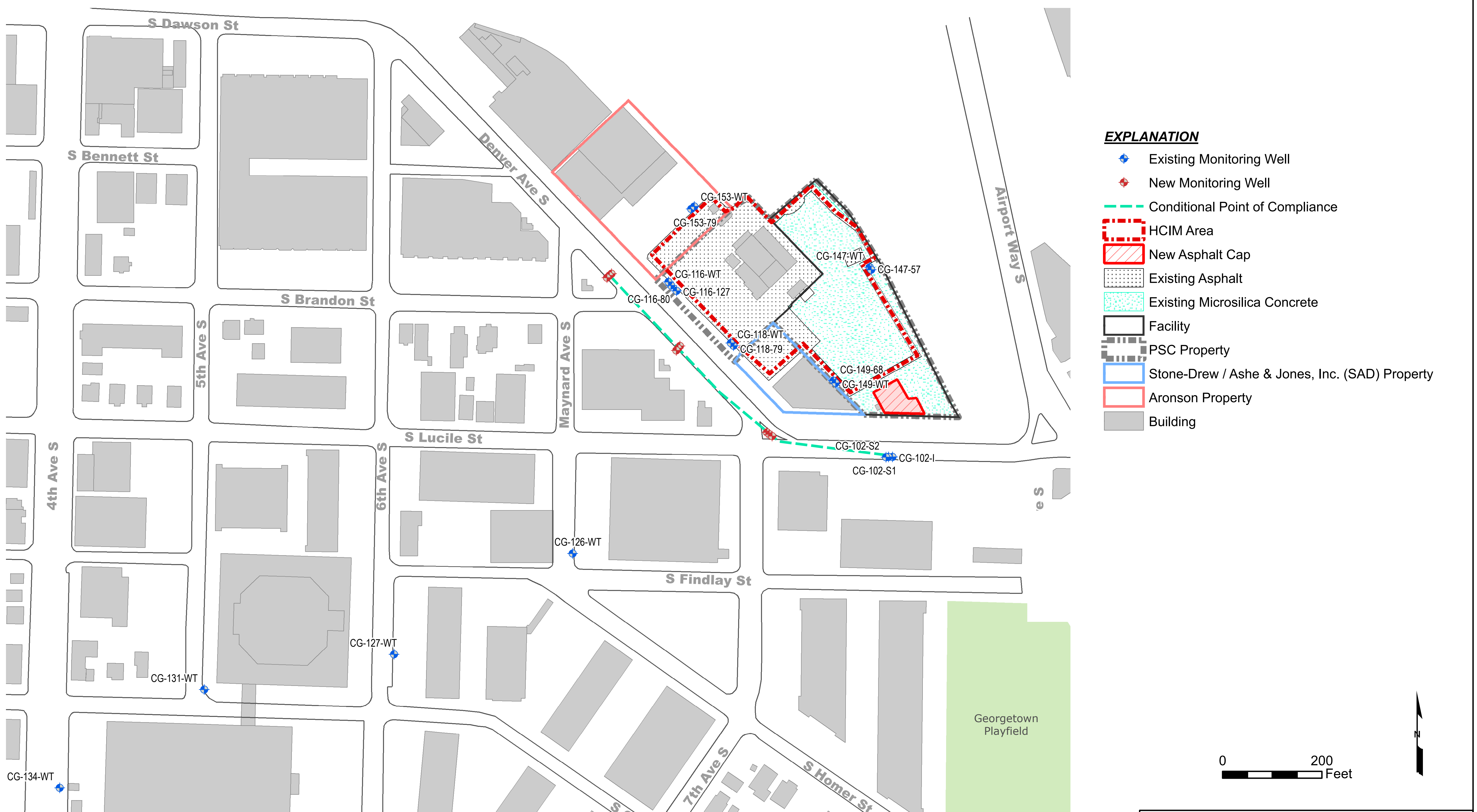

EXTENDED MONITORING WELL NETWORK
PSC Georgetown
Seattle, Washington

GEOMATRIX	Project No. 8770	Figure 9-2

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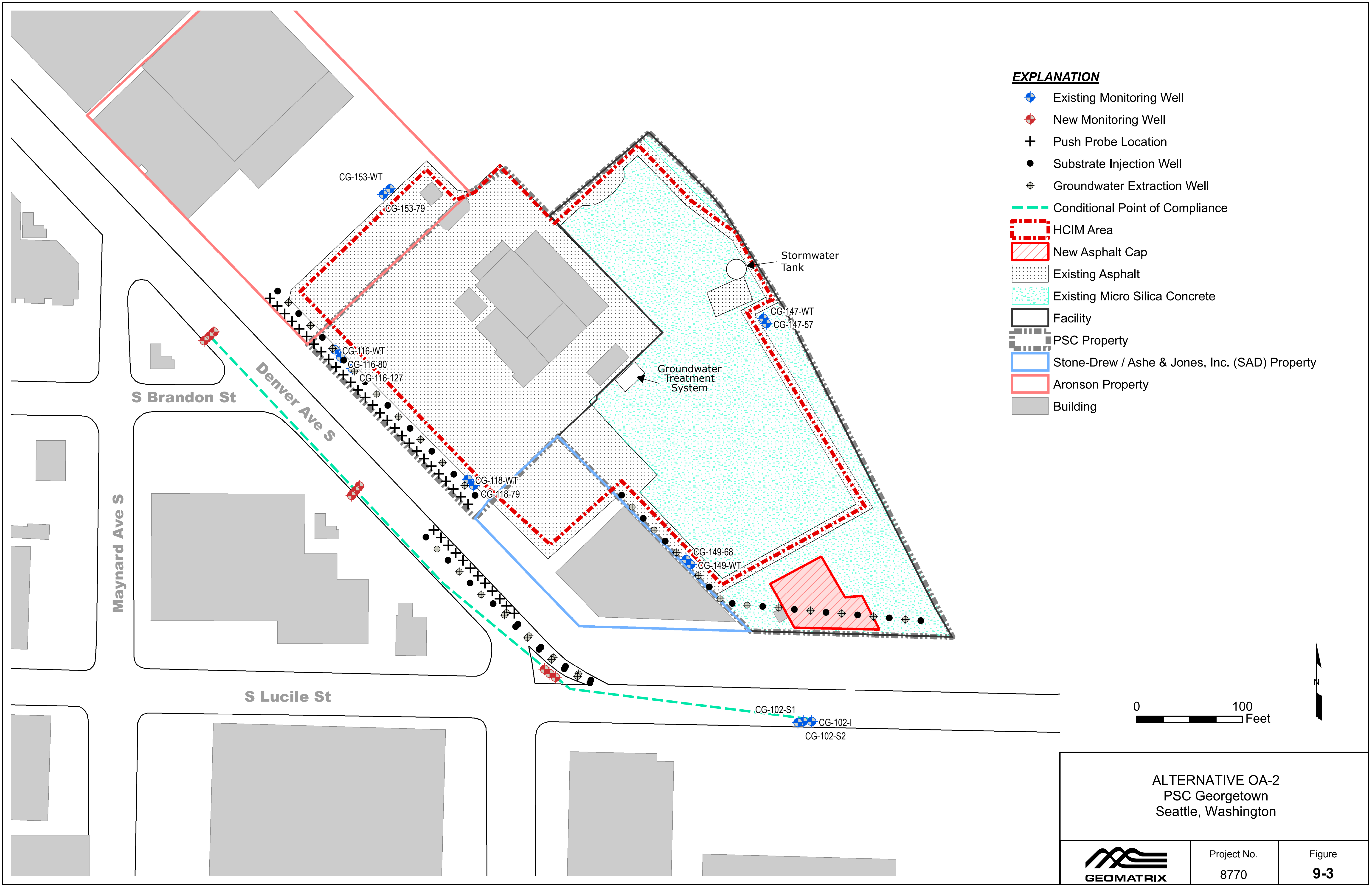

ALTERNATIVE OA-2
PSC Georgetown
Seattle, Washington

GEOMATRIX

Project No.
8770

Figure
9-3

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10.0 SITE WIDE REMEDIATION

The overall objective of this SWFS is to identify the preferred approach for remediation of releases from the Facility. As noted previously, the HCIM effectively separated the areas affected by historic releases by providing highly effective hydraulic control and containment around near-facility affected media. For this reason, the SWFS was separated into two parts; separate, “mini-feasibility studies” were done for the HCIM Area and the Outside Area. The FS conducted for the HCIM Area addressed the releases and affected media located inside the HCIM barrier wall, which encompasses portions of property owned by three different parties. The FS conducted for the Outside Area, which encompasses hundreds of different property owners, addressed media affected by migration of COCs originally released within the Facility. Primary releases occurred only within the HCIM Area, which served as a secondary source for the Outside Area prior to construction of the barrier wall. Implementation of the HCIM removed the source of COCs for the Outside Area. The preferred remedial alternatives selected in this SWFS Report for each of these two SWFS areas must be combined to develop a comprehensive, Site Wide remediation approach that addresses all affected media and potential exposure pathways associated with the Facility.

The approach for combining the two preferred remedial alternatives into a comprehensive remediation approach addressing Site Wide issues is presented below in Section 10.1. The general approach anticipated to implement the comprehensive remediation approach is described in Section 10.2.

10.1 PREFERRED REMEDIATION APPROACH

The preferred remedial alternatives selected in this SWFS for the HCIM Area and the Outside Area will be implemented together to comprehensively remediate releases from the Facility. The preferred remedial alternative for the HCIM Area includes the following:

- A totally enclosing, low-permeability subsurface barrier wall surrounding the Facility and near-facility affected groundwater;
- A low-permeability cap (or equivalent cover such as buildings) completely covering the entire area enclosed by the barrier wall;
- A monitoring well network to assess groundwater levels inside and outside the barrier wall; and
- Institutional controls to restrict groundwater recovery within the enclosed area, restrict and regulate subsurface work conducted within the enclosed area, require

vapor barriers as part of building construction, and to require maintenance of the barrier wall and cap.

The preferred remedial alternative for the Outside Area includes the following:

- MNA for permanent biodegradation of organic constituents present in groundwater;
- A comprehensive monitoring well network to assess groundwater quality in the hot spots, along the CPOC, and in areas downgradient from the CPOC;
- The existing IPIMs that address the inhalation pathway within the Outside Area; and
- Administrative controls and public communication to restrict groundwater recovery within the Outside Area, and to notify the public of hazards of subsurface work conducted below the water table within areas warranted based on groundwater concentrations.

The preferred Site Wide remediation approach, consisting of Alternative HA-2 and OA-1, is shown in Figure 10-1. The estimated cost for the preferred Site Wide remediation approach is summarized in Table 10-1. The remediation approaches for the two areas complement each other and combine to fully address affected media, COCs, and potential exposure pathways related for the Facility. The barrier wall and cap for the HCIM Area would effectively contain primary source areas for soil and groundwater, thereby minimizing the potential for exposures via direct contact and via groundwater migration/direct contact. The barrier wall and cap for the HCIM Area are low maintenance and constructed of natural materials with a very long effective life. Ultimately the Facility will be redeveloped and the existing cap could be incorporated into the development or replaced with a covering that performs the same function such as a building, parking structure or parking lot.

The active natural attenuation that occurs within the Outside Area is predicted to attain cleanup levels at a CPOC located along the western side of Denver Avenue South and on the south side of South Lucile Street within 50 to 60 years, assuming no other source areas are present within the Site. Conservative fate and transport modeling has also predicted that the remediation levels already being met at the CPOC and the natural attenuation process would control any Facility-related COCs in groundwater from migrating to the Duwamish Waterway at concentrations exceeding cleanup levels protective of surface water. The IPIMs that have been implemented in the Outside Area adequately address the inhalation pathway, thus ensuring that the SWFS Area preferred remediation approach will be protective of human health until cleanup levels are attained at the CPOC.

Modeling conducted for the preferred remedial alternatives indicates that the limited flux of COCs that would occur through the barrier wall would degrade under natural conditions to attain cleanup levels prior to reaching the CPOC. The IPIMs would be maintained until it has been confirmed that cleanup levels protective of the inhalation pathway have been attained in the water table groundwater interval at all the IPIM locations. Finally, the groundwater monitoring network for the combined remedial alternatives is sufficiently robust to identify any deviations from the predicted model and with sufficient time to address any problems. The comprehensive groundwater monitoring program included in the SWFS Area preferred remediation approach would be conducted for 5 years beyond initial attainment of cleanup levels at the CPOC, a period of time sufficient to confirm that remediation has been completed. The final remediation approach proposed for the SWFS Area in this SWFS Report (Figure 10-1) provides a comprehensive solution to historic releases and meets regulatory requirements under RCRA and MTCA.

The preferred remediation approach for the SWFS Area would be compatible with potential remedial actions that are likely to be implemented in the co-mingled plume area located downgradient from Fourth Avenue South. The fate and transport evaluation conducted for this SWFS indicates that constituents released from the Facility will attenuate to achieve cleanup levels based on protection of surface water prior to the point where groundwater discharges to surface water. Most of the attenuation has been shown to occur upgradient of Fourth Avenue South. The Facility containment provided by Alternative HA-2 has detached the plume from the source area; monitoring data collected since completion of the HCIM have already shown substantial decreases in COC concentrations downgradient from the Facility.

Conservative modeling and calculations done for this SWFS, predict that the remediation approach for the SWFS Area will achieve cleanup levels at the proposed CPOC, located just across Denver Avenue South from the Facility.

10.2 IMPLEMENTATION

A preliminary plan has been developed for implementation of the preferred remediation approach for the Facility. An incremental approach would be taken to implement the preferred remediation alternatives for the HCIM and Outside Areas. This incremental implementation approach has been developed to minimize potential risks to human health and the environment and to confirm that the assumptions and predictions made during this SWFS and the conceptual design of the remedial alternatives are accurate. The existing HCIM would be maintained active and in good working order prior to full implementation of the preferred remediation approach outlined in Section 10.1. As previously noted, the IPIMs would be maintained active until cleanup levels are attained within the Outside Area. The preliminary implementation plan outlined here would be developed more fully as part of the Corrective Action Plan that will be prepared after Ecology approval of the final SWFS Report. The institutional and administrative controls included in the preferred alternatives would be implemented upon approval of the Corrective Action Plan by Ecology.

The following approach is proposed for implementation of the preferred Site Wide remediation approach:

1. Maintain the HCIM and the IPIMs as currently operated.
2. Develop and implement institutional controls as described above for Alternatives HA-2 and OA-1.
3. Install appropriate caps within the PSC properties to cover affected soil.
4. Evaluate need to install additional monitoring wells along the CPOC identified for the preferred remedial alternative.
5. Commence groundwater monitoring as described in Section 8 for Alternative HA-2 and in Section 9 for Alternative OA-1.
6. After one to two years of groundwater monitoring, assess observed degradation rates for groundwater COCs within the Outside Area.
7. If the observed degradation rates confirm the MNA evaluation in this SWFS, perform a trial shutdown of the groundwater recovery system. If degradation rates do not confirm the MNA evaluation, maintain operation of the groundwater recovery system and continue to evaluate MNA and degradation rates.
8. Evaluate degradation rates for one to two years after trial shut down of the groundwater recovery system to assess the effects of shutdown on MNA outside the barrier wall.
9. If the observed degradation rates are consistent with the evaluation performed in this SWFS, continue the trial shutdown program and prepare a request to Ecology for permanent shutdown of the groundwater recovery system. If the observed degradation rates are not sufficient to attain remediation objectives, resume operation of the groundwater recovery system.
10. After Ecology approval of permanent shutdown of the groundwater extraction system, the system would be decommissioned.

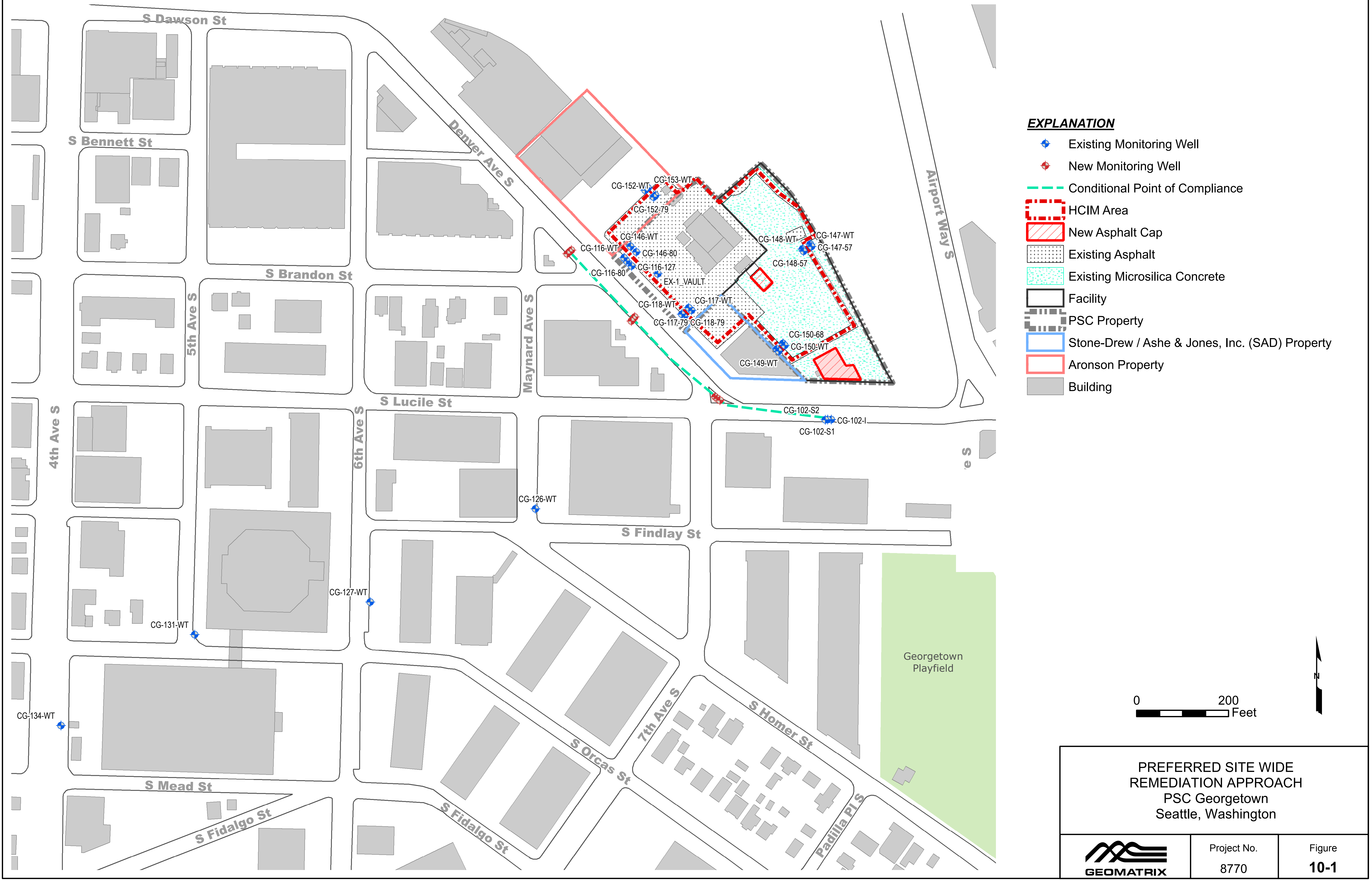
Under the proposed implementation approach, active groundwater recovery and treatment would be maintained until actual monitoring data support the evaluation presented in this SWFS. During a trial shutdown period, additional monitoring data would be collected to confirm that shutdown of the groundwater recovery system would not adversely affect natural attenuation within the Outside Area. Only after several years of collecting monitoring data would a formal request be issued to Ecology to approve permanent shutdown of the groundwater recovery system. After receipt of Ecology approval, the groundwater recovery system would be permanently decommissioned.

TABLE 10-1

ESTIMATED COSTS FOR PREFERRED SITE WIDE REMEDIATION APPROACH

PSC Georgetown
Seattle, Washington

Preferred Alternative	Initial Cost	Net Present Value Cost
HA-2	$36,900	$1,149,200
OA-1	$106,100	$2,212,700
Total Cost	**$143,000**	**$3,361,900**



PREFERRED SITE WIDE
REMEDIATION APPROACH
PSC Georgetown
Seattle, Washington

GEOMATRIX

Project No.	Figure
8770	**10-1**

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11.0 REFERENCES

Air Force Center for Environmental Excellence (AFCEE). 2004. *Principles and practices of enhanced anaerobic bioremediation of chlorinated solvents.* August.

Analytical Resources, Inc. 2005. August 25, 2005 Price List.

Burlington Environmental Inc. (BEI). 1993. SVE Interim Measures Design and Implementation Work Plan.

Chemfate. 2005. Vinyl Chloride KOC. Available at http://www.syrres.com/esc/free_demos.htm, accessed on August 15, 2005.

City of Seattle. 2002. GIS maps: Seattle's Commercial Zones and Seattle's Industrial Zones. Available at http://www2.seattle.gov/dpb/gis/arco,s/viewer.asp, Seattle Department of Planning and Development.

Dalton, Olmsted, & Fuglevand. 2005. Report on Solvent Sources Downgradient of PSC Georgetown Facility, Seattle, Washington. March.

Kennedy/Jenks. 2005. Limited Site Investigation Summary Report, Argo Yard, Seattle, Washington. April 22.

Philip Services Corporation (PSC). 1998. Interim Measures Completion Report for the Soil Vapor Extraction System, Philip Georgetown Facility, Seattle, Washington. May 13.

PSC. 2001. Draft Human Health and Environmental Risk Assessment.

PSC. 2003. Final Comprehensive Remedial Investigation Report, PSC Georgetown Facility, Seattle, Washington.

PSC. 2004a. Addendum II to the Final Comprehensive Remedial Investigation Report, PSC Georgetown Facility. August 20.

PSC. 2004b. Addendum II to the Final Comprehensive Remedial Investigation Report, PSC Georgetown Facility. September 24.

PSC. 2004c. Addendum I to the Final Comprehensive Remedial Investigation Report, PSC Georgetown Facility. October 19.

PSC. 2004d. Addendum IV to the Final Comprehensive Remedial Investigation Report, PSC Georgetown Facility. October 29.

PSC. 2004e. Quarterly Report, January – March 2004. First Quarter, Philip Services Corporation, Georgetown Facility, Seattle, Washington. May 17.

PSC. 2005. Revised Georgetown Off-Site Soil Investigation Sampling and Analysis Plan. July.

Pioneer Technologies Corporation (PTC). 2003. Final Human Health and Ecological Risk Assessment. November.

United States Environmental Protection Agency (EPA). 1993. *Guidance for Evaluation the Technical Impracticability of Ground-Water Restoration.* Publication 9234.2-25. Office of Solid Waste and Emergency Response. September.

EPA. 2000. *A Guide to Developing and Documenting Cost Estimates During the Feasibility Study*.

Wiedemeier, T. H., C. J. Newell, H. S. Rifai, and J. T. Wilson. 1999. *Natural Attenuation of Fuels and Chlorinated Solvents in the Subsurface*. John Wiley and Sons, Inc., New York, New York.

PERSONAL COMMUNICATIONS

Cascade Drilling, Inc. Telephone conversation between Brian of Cascade Drilling and Patrick Hsieh of Geomatrix. August 22, 2005.

APPENDIX A
ESTIMATION OF CHLORINATED VOC BIODEGRADATION RATES

PSC Georgetown
Seattle, Washington

1.0 INTRODUCTION

This appendix describes the estimation of chlorinated volatile organic compound (VOC) biodegradation rates at the Philip Services Corporation (PSC) former dangerous waste treatment and storage facility (Facility). The determination of biodegradation rates is necessary to complete groundwater fate and transport modeling, performed in support of evaluating potential remedial alternatives in the Site Wide Feasibility Study (SWFS), as described in Appendix B.

The following sections describe:

- Hydrogeologic conditions near the Facility, including estimates of groundwater velocities.
- Contaminant fate and transport, including contaminant concentration distribution, a conceptual model of contaminant transport, and mass balance calculations between two cross sections near the Facility.
- Methods and results of estimating biodegradation rates by calibration of a contaminant transport model (BIOCHLOR) to average concentrations at the two cross sections.

2.0 HYDROGEOLOGIC CONDITIONS

This section summarizes hydrogeologic conditions based on boring logs, water level measurements, and hydraulic conductivity tests presented in the RI Report (PSC, 2003) and boring logs of monitoring wells installed as part of the barrier wall performance mentoring network (Geomatrix, 2004). The investigations reported in the RI identified five hydrogeologic units that occur with increasing depths. These hydrogeologic units are described below:

- The shallow sand unit (including fill) consists of poorly graded, fine to medium sand with fine gravel and varies from approximately 20 to 65 feet in thickness. The upper portions of the unit may be composed of fill including material dredged from the Duwamish River. The shallow sand unit grades into the intermediate sand and silt unit. An average hydraulic conductivity of 3.2 x 10^{-2} centimeter per second (cm/sec) for the shallow sand unit based on grain size, slug test, and pumping test data was presented in the RI Report.

- The intermediate sand and silt unit consists of discontinuous interbedded silty sand and sandy silt lenses with shell fragments. The unit ranges in thickness from 13 to 68 feet. Near the Facility, the shallow sand unit is quite distinct from the intermediate sand and silt unit. Downgradient from the Facility the intermediate sand and silt unit becomes much sandier, with fewer silt layers, suggesting that by East Marginal Way South, the shallow sand and the intermediate sand and silt units may be acting as a single hydrogeologic unit. An average hydraulic conductivity of 5.1×10^{-3} cm/sec for the intermediate sand and silt unit based on grain size, slug test, and pumping test data was presented in the RI Report. The lower hydraulic conductivity as compared to the overlying shallow sand unit is consistent with the finer-grained nature of the intermediate unit in the vicinity of the Facility.

- The silt unit, which represents the aquitard separating the shallower aquifers from the deep sand and silt unit, consists predominately of silt and very fine sand ranging in thickness from 11 to 50 feet. Clam shells and shell fragments are commonly present. Some borings encountered worm burrows, mud cracks, and occasional fine laminations. Laboratory tests indicated a vertical hydraulic conductivity of 1×10^{-7} cm/sec to 5×10^{-6} cm/sec.

- The deep sand and silt unit consists of sandy silt, fine sand and interbedded, lenses of silty sand. The top of the unit lies at depths of between approximately 84 and 128 feet. The RI presents a hydraulic conductivity estimate of 3×10^{-3} cm/sec for the deep sand and silt unit based on grain size, slug test, and pumping test data.

- The bedrock consists of consolidated sedimentary sandstone and siltstone. Beneath the Facility, bedrock was encountered at a depth of approximately 56 feet bgs. The depth to bedrock likely increases to a maximum depth of about 330 to 660 feet near the Duwamish Waterway.

For the purposes of this evaluation, only the upper sand unit and the intermediate sand and silt unit were considered in developing the groundwater flow conceptual model and estimating contaminant mass and biodegradation rates. These hydrogeologic units encompass the water table, shallow, and intermediate sample intervals from the RI Report, which were defined to evaluate water quality data based on depth below ground surface, rather than hydrogeologic units. The water table and shallow sample intervals generally correspond to samples from the upper sand unit, and the Intermediate sample interval generally corresponds to samples from the intermediate sand and silt unit.

Based on contoured water level data from the upper sand unit and the intermediate sand and silt unit, groundwater flow directions near the Facility are generally to the west and southwest, with a hydraulic gradient of approximately 0.0017. Assuming an effective porosity of 0.30, estimated horizontal groundwater velocities for the upper sand and the intermediate units are approximately 190 and 30 feet per year (ft/yr), respectively. Vertical hydraulic gradients measured between these units are generally flat to slightly upward and range from 0 to 0.004, with the stronger upward gradients in the vicinity of the Facility. Given that these vertical hydraulic gradients are similar to the horizontal hydraulic gradients, and that vertical hydraulic conductivity is likely at least an order-of-magnitude lower than the measured horizontal hydraulic conductivities, it is assumed for the purposes of this evaluation that vertical groundwater flow between the shallow sand and intermediate sand and silt units is negligible. In reality, there is likely some upward component of flow near the Facility.

The constituents of concern (COCs) identified for the Facility are limited to the shallow sand unit and the intermediate sand and silt unit. The intermediate silt unit (aquitard) is effectively limiting migration of COCs to the deep sand and silt unit. Based on the RI, the primary COCs that need to be addressed in the SWFS are volatile organic compounds (VOCs), primarily trichloroethylene (TCE) and to a lesser extent perchloroethene (PCE) and the daughter compounds of these VOCs such as vinyl chloride (VC).

Hydrogeologic cross sections depicting these units and the associated COCs, were developed at the locations shown on Figure A-1 using lithologic data from soil borings and monitoring well installations. Hydrogeologic cross-sections are presented on Figures A-2a through A-2d and A-3a through A-3d. The cross sections were oriented approximately perpendicular to groundwater flow. Cross section A-A' spans the Facility through the source area now contained by the barrier wall. Cross section B-B' is located approximately 800 feet downgradient from the Facility and immediately upgradient from where other suspected sources of chlorinated VOCs are thought to exist.

As shown on the hydrogeologic cross sections, the water table is encountered in the shallow sand unit at an elevation of approximately 10 feet (NAVD 88). In cross section A-A' the base of the shallow sand unit and the top of the intermediate sand and silt unit occurs at elevations of approximately -47 to -31 feet. In cross section B-B', the top of the intermediate sand and silt unit occurs at elevations of approximately -25 to -15 feet.

3.0 CONTAMINANT FATE AND TRANSPORT

The primary fate and transport issue for chlorinated VOCs is natural attenuation in groundwater through biodegradation. The generally anaerobic conditions observed in the shallow sand unit and the intermediate sand and silt unit are conducive to biodegradation of the chlorinated VOCs by reductive dechlorination (PSC, 2003). Under anaerobic conditions, chlorinated ethenes biodegrade as follows:

- PCE → TCE → cis-1,2-dichloroethene (cis-1,2-DCE) → VC → ethene → ethane

VC can also degrade under aerobic conditions by direct aerobic oxidation to carbon dioxide. The more highly chlorinated VOCs generally degrade more readily under anaerobic conditions, while the lesser chlorinated VOCs such as VC generally degrade more quickly under aerobic conditions. Biodegradation appears to be limiting the downgradient migration of PCE and TCE and their breakdown products, cis-1,2-DCE and VC.

The remainder of this section presents an overview of chlorinated VOC distribution between the Facility and Sixth Avenue South, based on groundwater reconnaissance samples from the RI collected between 2000 and 2001 and groundwater monitoring well data collected in May 2002. These data sets were selected as they provide the most complete data sets of the chlorinated VOC distribution prior to installation of the barrier wall. Using the contaminant distribution and the understanding of hydrogeologic conditions, a contaminant transport conceptual site model is developed, and contaminant mass at each cross section is estimated.

3.1 CONTAMINANT DISTRIBUTION

PCE, TCE, cis-1,2-DCE, and VC data were posted on the hydrogeologic cross sections and isoconcentration contours were developed, as shown on Figures A-2a through A-2d and A-3a through A-3d.

VC and cis-1,2-DCE concentrations and distributions are similar in cross section A-A', with relatively broad distribution of concentrations greater than 1 μg/L in the shallow sand unit. Higher concentration areas, represented by the 1,000 μg/L contours on these sections, are also similar in location and extent. The highest cis-1,2-DCE and VC concentrations occur near the north end of cross section A-A', spanning the interface between the shallow sand unit and the intermediate sand and silt unit. TCE and PCE concentrations are generally much lower and less wide-spread in the shallow sand unit than cis-1,2-DCE and VC concentrations. The highest TCE concentrations (up to 82,900 μg/L) occur at the interface between the shallow sand unit and the intermediate sand and silt unit, in the same general locations as the highest cis-1,2-DCE and VC concentrations. Detectable concentrations of PCE are generally limited to the upper 10 feet of the shallow sand unit, with two relatively low concentration detections at the interface between the shallow sand unit and the intermediate sand and silt unit.

The chlorinated VOC concentrations and distributions observed in cross section A-A' are significantly different than those of downgradient cross section B-B'. Chlorinated VOCs were not detected in the intermediate sand and silt unit in the downgradient cross section. The highest VOC concentrations are limited to the upper 30 feet of the shallow sand unit in cross section B-B'. The very high concentrations detected at the interface between the upper sand unit and the intermediate sand and silt unit in cross section A-A' do not appear to have migrated to the downgradient cross section B-B'.

VC and cis-1,2-DCE concentrations continue to be co-located at downgradient cross section B-B', with TCE and PCE showing a different distribution. PCE is virtually absent at cross section B-B'. Maximum concentrations of PCE, cis-1,2-DCE, and VC decrease in the downgradient direction between the cross sections, reflecting the effects of biodegradation and dispersion. TCE concentrations remain relatively unchanged. The low initial concentrations of TCE are likely biodegrading, but are being replenished due to biodegradation of PCE to TCE.

3.2 CONTAMINANT TRANSPORT CONCEPTUAL MODEL

Based on the understanding of local hydrogeologic conditions and contaminant distribution, the following contaminant transport conceptual model was developed:

- Prior to construction of the barrier wall, groundwater flowed to the west and southwest through chlorinated VOC source areas at the Facility. Dissolved phase PCE, TCE, cis-1,2-DCE, and VC migrated downgradient from the Facility to the west and southwest. Given an initial release date of sometime in the1970s, it is assumed that the plume had achieved steady state conditions at the locations of the two cross sections at the time the data presented in the RI were collected. It is also assumed that dissolved phase chlorinated VOC concentrations exiting the Facility with groundwater flow have not changed over time.

- No known sources of chlorinated VOCs other than at the Facility are present at or upgradient of cross section B-B'. Changes in chlorinated VOC concentrations between the Facility and Sixth Avenue South occur only due to biodegradation and hydrodynamic dispersion.

- Groundwater flow rates in the shallow sand unit are approximately an order-of-magnitude higher than groundwater flow rates in the intermediate sand and silt unit. Contaminant distributions shown on cross section B-B' downgradient of the Facility show that VOCs are essentially limited to the shallow sand unit, indicating that contaminants in the intermediate sand and silt unit have not significantly migrated beyond the Facility.

- Groundwater with high chlorinated VOC concentrations at the base of the shallow sand unit in cross section A-A' is either immobile, or more likely migrates slowly so that the VOCs at this depth fully attenuate prior to reaching downgradient cross section B-B'. Regardless, the VOCs do not contribute to concentrations detected in the shallow sand unit at downgradient cross sections B-B'.
- Horizontal groundwater flow rates in the vicinity of the Facility are much greater than vertical flow rates. As such, horizontal flow within each hydrogeologic unit can be assumed and flow and contaminant transport between the shallow sand unit and intermediate sand and silt unit can, for the purposes of this analysis, be ignored.
- Groundwater flow rates at and between each cross section are uniform, with a seepage velocity within the shallow sand unit of approximately 190 ft/yr.

This conceptual model forms the basis for estimating contaminant mass presented in the following section and interpreting the results.

3.3 CONTAMINANT MASS

Mass balance and mass flux approaches can be used to indicate whether biodegradation is occurring and to estimate biodegradation rates (e.g., King, et al., 1999; Devlin, et al., 2002). One advantage of a mass-based approach is that the effects of dilution or dispersion, which can complicate interpretation of concentration data, do not change the total mass. For this evaluation, a mass balance (based on mass flux) was calculated at the two cross sections, allowing for a direct comparison of changes in plume composition over a given travel distance.

Contaminant concentration data between the cross sections are affected by transformation due to biodegradation and dispersion. Due to the effects of dispersion, the decline in contaminant concentrations between the cross sections does not necessarily indicate that biodegradation is reducing contaminant mass. Similarly, because biodegradation successively transforms PCE to TCE to cis-1,2-DCE to VC, which ultimately degrades to ethene, stable or increasing TCE, cis-1,2-DCE and VC concentrations between cross sections can occur even if VOCs are undergoing significant biodegradation. To provide a better understanding of potential biodegradation and to remove the effects of dispersion, total mass of PCE, TCE, cis-1,2-DCE, and VC, both in milligrams and moles, were calculated at each cross section. The contaminant transport model calibrated to estimate biodegradation rates, as discussed in Section 4, requires contaminant concentrations. Average concentrations of PCE, TCE, cis-1,2-DCE, and VC were also calculated for use in the model.

Contaminant mass and average concentration for each constituent at each cross section was calculated using the following procedure:

- The areas between successive contour intervals (e.g., between the 1 and 10 µg/L contours, 10 and 100 µg/L contours, etc.) were calculated using ArcView GIS software. These areas were converted to aquifer volumes using an arbitrary aquifer thickness perpendicular to the cross section of 1 foot.

- The aquifer volumes were converted to groundwater volumes by multiplying by a porosity of 0.3.

- The mass in milligrams between each contour interval was calculated by multiplying the water volume by the average concentration within that contour interval. The average concentration was calculated as the linear average between contour intervals (e.g., 5.5 µg/L was used between the 1 and 10 µg/L contours). For areas not falling between two contour intervals, the average concentration was calculated by taking the linear average between the contoured concentration and the maximum concentration within that interval. For example, the highest concentration enclosed by the 10 µg/L PCE contour interval on Figure A-2a is 15.7 µg/L. The average concentration inside this contour was calculated as the average of 10 and 15.7 µg/L, or 12.85 µg/L. The total mass for each constituent was then calculated by summing the masses between each contour interval.

- The mass in moles for each constituent was calculated by dividing the total mass in each cross section by the molecular weight.

- The average concentration of each constituent was calculated by dividing the total mass in milligrams by the volume of water bounded by the 1 µg/L contour. The volume of water was calculated using the same assumptions of a 1 foot aquifer thickness and porosity of 0.30 described above.

Mass calculations were limited to the shallow sand unit. Based on the conceptual model, all mass within the shallow sand unit stays within this unit as it migrates downgradient, such that changes in mass between cross sections are only due to the effects of biodegradation. Two sets of mass calculations were performed for cross section A-A', one including the high concentrations area at the base of the shallow sand unit and one excluding this area. Results are summarized in Tables A-1 and A-2.

In cross section A-A', when the high concentration area at the base of the upper sand unit is included, the total chlorinated VOC mass is approximately 14.7 moles, of which approximately 66 percent is VC, 31 percent is cis-1,2-DCE, 3 percent is TCE, and less than 1 percent is PCE. When the high concentration area at the base of the upper sand unit is excluded, the total chlorinated VOC mass is approximately 10.1 moles, of which approximately 63 percent is VC, 37 percent is cis-1,2-DCE, and less than 1 percent is PCE and TCE. In cross section B-B', the total chlorinated VOC mass is approximately 0.6 moles, of which approximately 89 percent is VC, 10 percent is cis-1,2-DCE, 1 percent is TCE, and less than 1 percent is PCE.

Excluding the high concentration area at the base of the upper sand unit at cross section A-A', there is approximately a 94 percent reduction in total moles of chlorinated VOCs between cross sections A-A' and B-B'. Total moles of PCE decrease from 0.0027 to 0.0001, total moles of TCE decrease from 0.0084 to 0.0073, total moles of cis-1,2-DCE decrease from 3.7 to 0.06, and total moles of VC decrease from 6.4 to 0.5.

The molar mass estimates track changes in total plume mass and, therefore, are not affected by dispersion. The decreases in both total moles of chlorinated VOCs and moles of each individual constituent provide strong, compelling evidence that biodegradation is reducing contaminant concentrations between the Facility and Sixth Avenue South.

The areas bounded by the 1 μg/L contour for each constituent (except PCE) are relatively unchanged between cross section A-A' and B-B' (Tables A-1 and A-2), with the contoured downgradient areas within about 10 to 15 percent of the contoured upgradient areas. The cross sectional area of the PCE plume is reduced by approximately 80 percent downgradient of the Facility, likely due to reduction of the low initial PCE concentrations to below the laboratory detection limits. The relatively unchanged plume dimensions at the two cross sections indicate that transverse dispersion is not significantly affecting the plume between the Facility and Sixth Avenue South, such that changes in average concentration (as shown on Table A-2) between these locations are primarily due to biodegradation.

4.0 ESTIMATION OF BIODEGRADATION RATES

Biodegradation rates were estimated by calibration of a BIOCHLOR model using the average contaminant concentrations at cross sections A-A' and B-B'. BIOCHLOR will also be used for the fate and transport modeling in the SWFS (see Appendix B). The BIOCHLOR (ver. 2.2) software was developed on behalf of the U.S. Air Force Center for Environmental Excellence by Groundwater Services, Inc. to assess natural attenuation of chlorinated solvents in groundwater. BIOCHLOR simulates the degradation of chlorinated solvent compounds in groundwater systems. BIOCHLOR is a Microsoft Excel programmed spreadsheet that simulates 1-D advection, 3-D dispersion, linear adsorption, and biotransformation via reductive dechlorination for chlorinated solvents.

4.1 DEGRADATION RATE ESTIMATE METHODS

Biodegradation rates were estimated by calibration of a BIOCHLOR model for the area between cross sections A-A' and B-B', using average concentrations at these locations. Values for most model input parameters were selected based on comments received from Ecology on previous modeling presented in the Draft RI Report and the physical dimensions of the area being modeled. These model input parameters and sources of the values are summarized in Table A-3.

Source area width and depth were selected as the plume width and depth measured at cross section A-A'. Source concentrations were selected as the average concentrations at cross section A-A', calculated by dividing the total mass for each constituent by the total groundwater volume within the 1 µg/L contour as determined in the contaminant mass estimates. The high concentration area at the base of the shallow sand unit was not included in this calculation, thereby reducing the source area concentrations used in the model. This has the conservative effect of producing lower biodegradation rates (longer half lives) from model calibration. The target model output concentrations for calibration were based on the average concentrations at cross section B-B'.

Biodegradation rates were estimated by calibrating the model output to the average concentrations at cross section B-B'. The PCE biodegradation rate was estimated by varying the PCE half life until the model predicted concentration equaled the average concentration at cross section B-B'. Then, keeping the PCE half life constant, the TCE biodegradation rate was estimated by varying the TCE half life until the predicted average concentration equaled the average concentration at cross section B-B'.

4.2 ESTIMATED DEGRADATION RATES

Table A-4 presents the calibration targets, calibrated biodegradations rates, and model output. Calibrated half lives for PCE, TCE, cis-1,2-DCE, and VC of 1.2, 3.0, 0.65 and 0.82 years, respectively, produced the best fit to average concentrations at cross section B-B'. These half lives are within the range of commonly cited literature values for biodegradation of chlorinated VOCs shown on Table A-5 (e.g., Wiedemeier et al., 1999). The TCE and cis-1,2-DCE biodegradation rates are also generally similar to the rates estimated in the RI and used in modeling for the Downgradient FS (Geomatrix, 2005), while the estimated VC biodegradation rate is considerably faster than what was used in the Downgradient FS.

5.0 SENSITIVITY ANALYSIS

A limited sensitivity analysis was performed to evaluate the sensitivity of model output (contaminant concentration predictions at cross section B-B') to model inputs. The sensitivity analysis was limited to transverse dispersivity and biodegradation half lives.

Transverse dispersivity (α_y) was set to zero in calibrating the model, based on the observation that the cross sectional area of the plume had not significantly increased between the Facility and Sixth Avenue South. In reality, horizontal dispersion perpendicular to the direction of flow is likely resulting in some reduction in contaminant concentrations. To evaluate the effects of including transverse dispersion, the calibrated model was run with a transverse dispersivity set equal to 0.1 times the longitudinal dispersivity (α_x). As shown on Table A-5, the modeled concentrations with transverse dispersivity included are virtually identical to the calibrated concentrations with no transverse dispersivity. This is due to the large width of the plume in the source area (650 feet) relative to the modeled flow path length (800 feet) and transverse dispersivity used (2.3 feet).

Model sensitivity to three sets of alternate biodegradation half lives was also evaluated. The first set of half lives used is from fate and transport modeling for areas downgradient of the Facility that was previously performed for the Downgradient FS (Geomatrix, 2005). These biodegradation rates were selected based on comments received from the Washington State Department of Ecology (Ecology) on previous modeling presented in the Draft RI Report. The other two sets of half lives are literature values representing the high and low range of estimated biodegradation rates selected from Tables 6.6 and 6.7 of Wiedemeier et al. (1999). Biodegradation rates that were evaluated and resulting modeled concentrations are shown on Table A-5.

Using the biodegradation rates from the Downgradient FS slightly underestimates the average TCE concentrations, and overestimates the average cis-1,2-DCE and VC concentrations by factors of about 5 and 12 times, respectively. Using the low degradation rates from the literature overestimates the average concentrations, especially PCE, cis-1,2-DCE, and VC. Similarly, the high degradation rates underestimate the average measured concentrations.

Based on these results, the calibrated biodegradation rates, when used with the advection and adsorption parameters in Table A-3, most accurately simulate natural attenuation of chlorinated VOCs downgradient of the Facility. Additionally, model results, at least over the area for which the calibrated model was developed, are not sensitive to inclusion of transverse dispersivity.

6.0 SUMMARY

Total mass in milligrams and moles, plume areas perpendicular to flow, and average concentrations were estimated at two cross sections located near the Facility. Mass balance results indicate that biodegradation of chlorinated VOCs is occurring between the Facility and Sixth Avenue South, with approximately 94 percent of the total moles of PCE, TCE, cis-1,2-DCE, and VC attenuated between these locations. The relatively unchanged plume dimensions between these locations indicate that dispersion is not significantly affecting the plume, and that changes in average concentration are primarily due to biodegradation.

Biodegradation rates were estimated by calibrating a contaminant transport model using the average concentrations at the cross sections. Estimated biodegradation rates are within the range of commonly cited literature values. Predicted concentrations from the calibrated model were compared to predicted concentrations using a range of biodegradation rates, including rates previously used in the Downgradient FS. The biodegradation rates from the calibrated model provided the best fit to the concentration data, while the alternate biodegradation rates significantly overestimated or underestimated average measured concentrations.

7.0 REFERENCES

Devlin, F.J., M. McMaster, J.F. Baker, 2002, Hydrogeologic Assessment of In Situ Natural Attenuation in a Controlled Field Experiment, Water Resources Research, Vol. 38, No. 1.

Geomatrix Consultants, Inc., 2004, Monitoring Well Boring Logs Submission, Prepared for: Philip Services Corporation, Georgetown, Seattle, Washington, April 19.

Geomatrix Consultants, Inc., 2005, Downgradient Groundwater Feasibility Study Report, Georgetown Facility, Seattle, Washington, May.

King, Mark W.G., James F. Barker, John F. Devlin, Barbara J. Butler, 1999, Migration and Natural Fate of a Coal Tar Creosote Plume, 2. Mass Balance and Biodegradation Indicators, Journal of Contaminant Hydrology, Vol. 39, 281-307.

Philip Services Corporation, 2003, Final Comprehensive Remedial Investigation Report, PSC Georgetown Facility, Seattle, Washington.

Wiedemeier, T.H., C.J. Newell, H.S. Rifai and J.T. Wilson, 1999, Natural Attenuation of Fuels and Chlorinated Solvents in the Subsurface: John Wiley and Sons, Inc., New York, New York.

TABLE A-1

SUMMARY OF PLUME CHARACTERISTICS, INCLUDING HIGH CONCENTRATION AREA IN CROSS SECTION A-A'

PSC Georgetown
Seattle, Washington

Cross Sectional Area	Cross Section	
Plume area at Section (ft^2)	A-A'	B-B'
PCE	3,425	690
TCE	9,500	9,500
DCE	24,000	21,000
VC	24,000	20,000

Mass	Cross Section	
Total Mass at Section (in mg)	A-A'	B-B'
PCE	480	9
TCE	52,000	960
DCE	440,000	6,100
VC	610,000	34,000
Change in Mass (in mg)		
PCE	-470	
TCE	-51,000	
DCE	-430,000	
VC	-580,000	

Moles	Cross Section	
Total Moles at Section	A-A'	B-B'
PCE	0.0029	0.0001
TCE	0.4	0.0073
DCE	4.5	0.06
VC	9.8	0.54
Total	14.7	0.6
Change in Moles		
PCE	-0.0028	
TCE	-0.3884	
DCE	-4.48	
VC	-9.22	
Total	-14.0851	

Concentration	Cross Section	
Average Concentration (µg/L)	A-A'	B-B'
PCE	6.6	0.6
TCE	256	4.8
DCE	888	14
VC	1,182	81
Change in Concentration (µg/L)		
PCE	-6.0	
TCE	-252	
DCE	-874	
VC	-1,101	

1. Mass and mole totals are for a 1-foot thick volume of aquifer along each section. Negative values indicate a decrease in mass or concentration.

TABLE A-2

SUMMARY OF PLUME CHARACTERISTICS, NOT INCLUDING HIGH CONCENTRATION AREA IN CROSS SECTION A-A'

PSC Georgetown
Seattle, Washington

Cross Sectional Area	Cross Section	
Plume area at Section (ft^2)	A-A'	B-B'
PCE	3,300	690
TCE	8,200	9,500
DCE	22,000	21,000
VC	22,000	20,000

Mass	Cross Section	
Total Mass at Section (in mg)	A-A'	B-B'
PCE	440	9
TCE	1,100	960
DCE	360,000	6,100
VC	400,000	34,000
Change in Mass (in mg)		
PCE	-430	
TCE	-140	
DCE	-350,000	
VC	-370,000	

Moles	Cross Section	
Total Moles at Section	A-A'	B-B'
PCE	0.0027	0.0001
TCE	0.0084	0.0073
DCE	3.7	0.06
VC	6.4	0.5
Total	10.1	0.6
Change in Moles		
PCE	-0.0026	
TCE	-0.0011	
DCE	-3.65	
VC	-5.86	
Total	-9.5119	

Concentration	Cross Section	
Average Concentration (µg/L)	A-A'	B-B'
PCE	6.4	0.6
TCE	6.1	4.8
DCE	774	14
VC	856	81
Change in Concentration (µg/L)		
PCE	-5.8	
TCE	-1.3	
DCE	-760	
VC	-776	

1. Mass and mole totals are for a 1-foot-thick volume of aquifer along each section. Negative values indicate a decrease in mass or concentration.

TABLE A-3

BIOCHLOR INPUT PARAMETERS FOR MODEL CALIBRATION
PSC Georgetown
Seattle, Washington

Parameter	Value	Units	Source
Advection			
Hydraulic Conductivity	0.032	cm/s	Geometric mean of shallow sand unit hydraulic conductivity values
Hydraulic Gradient	0.0017	ft/ft	Site-wide average from the Draft RI report
Effective Porosity	0.3	unitless	Ecology default value
Seepage Velocity	187.6	ft/yr	Calculated
Dispersion			
α_x	22.6	Feet	Calculated using modified Xu and Ekstein equation
α_y	0	Feet	No transverse dispersion, minimal change in plume area observed between cross sections
α_z	0	Feet	No vertical dispersion into intermediate unit assumed
Adsorption			
Soil Bulk Density	1.51	kg/L	Ecology default value
Fraction Organic Carbon	0.001	unitless	Ecology default value
PCE Partition Coefficient	265	L/kg	Ecology default value
TCE Partition Coefficient	94	L/kg	Ecology default value
DCE Partition Coefficient	35.5	L/kg	Ecology default value
VC Partition Coefficient	18.6	L/kg	Ecology default value
Model Dimensions			
Model Length	800	Feet	Distance between cross section A-A' and B-B'
Model Width	1500	Feet	Sufficiently wide to define downgradient plume
Source Area Width	650	Feet	Plume width at cross section A-A'
Source Area Depth	50	Feet	Average plume thickness at cross section A-A'
Simulation Time	30	Years	Sufficient time to reach steady state conditions
Source Data			
PCE Concentration	6.4	µg/L	Average concentration at cross section A-A'
TCE Concentration	6.1	µg/L	Average concentration at cross section A-A'
DCE Concentration	774	µg/L	Average concentration at cross section A-A'
VC Concentration	856	µg/L	Average concentration at cross section A-A'
Source Type	Continuous, single planar		Constant source assumed

TABLE A-4

BIOCHLOR CALIBRATION TARGETS AND RESULTS

PSC Georgetown
Seattle, Washington

Parameter	Value	Units	Source
Calibration Targets			
PCE Concentration	0.6	µg/L	Average concentration at cross section B-B'
TCE Concentration	4.8	µg/L	Average concentration at cross section B-B'
DCE Concentration	14	µg/L	Average concentration at cross section B-B'
VC Concentration	81	µg/L	Average concentration at cross section B-B'
Biodegradation - 1st Order Decay Half Life			
PCE to DCE	1.2	Years	Model calibration
TCE to DCE	3.0	Years	Model calibration
DCE to VC	0.65	Years	Model calibration
VC to Ethene	0.82	Years	Model calibration
Calibrated Output			
PCE Concentration	0.6	µg/L	Model output
TCE Concentration	4.8	µg/L	Model output
DCE Concentration	14	µg/L	Model output
VC Concentration	81	µg/L	Model output

TABLE A-5

COMPARISON OF ALTERNATE DEGRADATION RATES

PSC Georgetown
Seattle, Washington

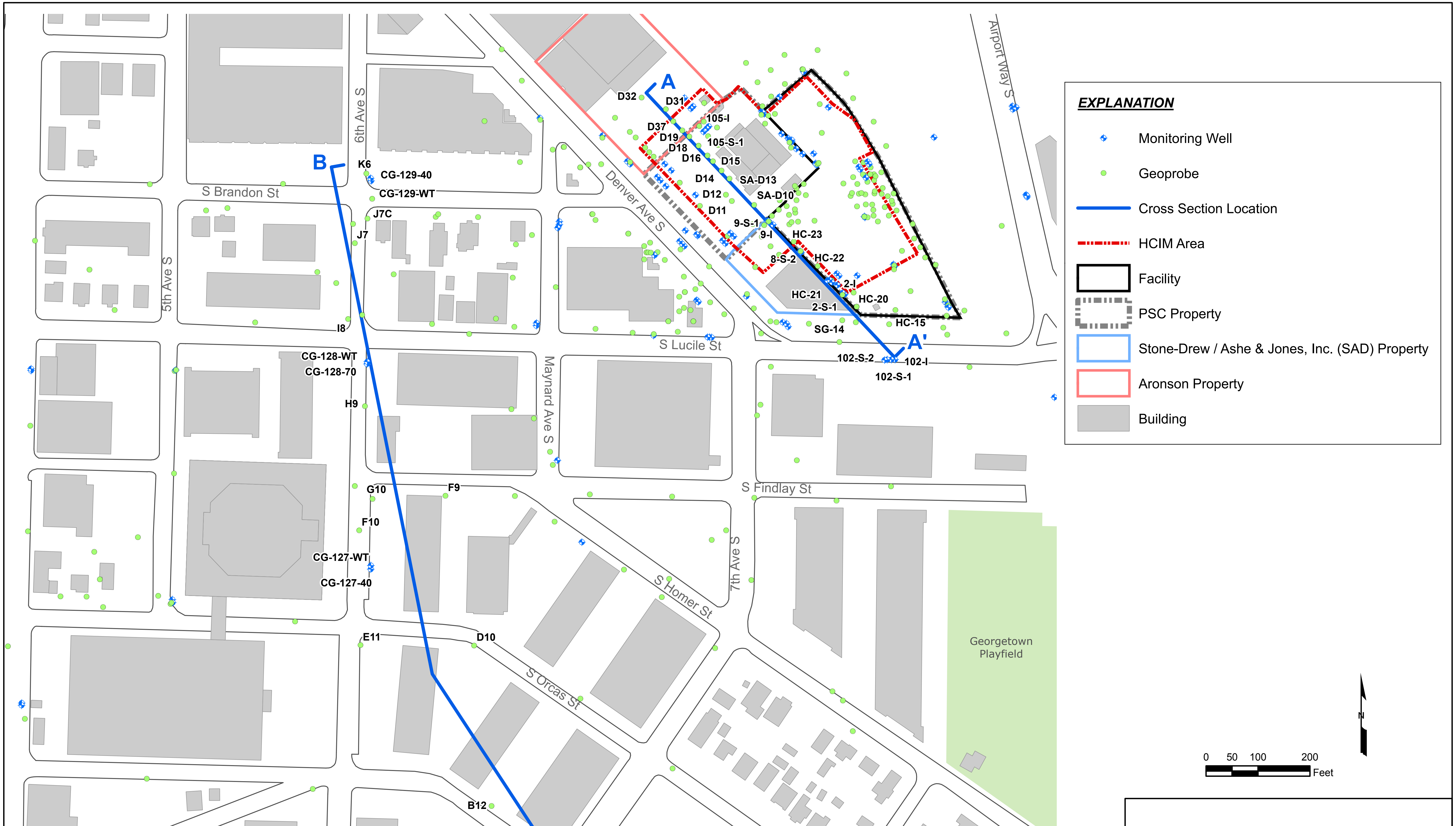
Biodegradation Half Lives in Years

	Calibrated Rates	Calibrated Rates with Transverse Dispersion	Downgradient FS Rates (1)	Literature Values - Low Rates (2)	Literature Values - High Rates (2)
PCE to TCE	1.2	1.2	1.2	10	0.58
TCE to DCE	3.0	3.0	2.14	14	0.76
DCE to VC	0.65	0.65	1.12	5.0	0.22
VC to Ethene	0.82	0.82	8.21	5.8	0.26

Modeled Concentration at Cross Section B-B' in μg/L

	Calibrated Rates	Calibrated Rates with Transverse Dispersion	Downgradient FS Rates (1)	Literature Values - Low Rates (2)	Literature Values - High Rates (2)	Average Measured Concentrations
PCE	0.6	0.6	0.6	4.8	0.1	0.6
TCE	4.8	4.7	3.5	6.1	0.6	4.8
DCE	14	14	67	433	0.2	14
VC	81	81	957	682	0.6	81

1. Half lives are from the Downgradient FS (Geomatrix, 2005). PCE half life was not used in the Downgradient FS. The calibrated PCE half life developed in this appendix is used instead.
2. Literature values are from Tables 6.6 and 6.7 of Wiedemeier, et al., 1999.



CROSS SECTION LOCATIONS
PSC Georgetown
Seattle, Washington

GEOMATRIX

Project No.	Figure
8770	A-1

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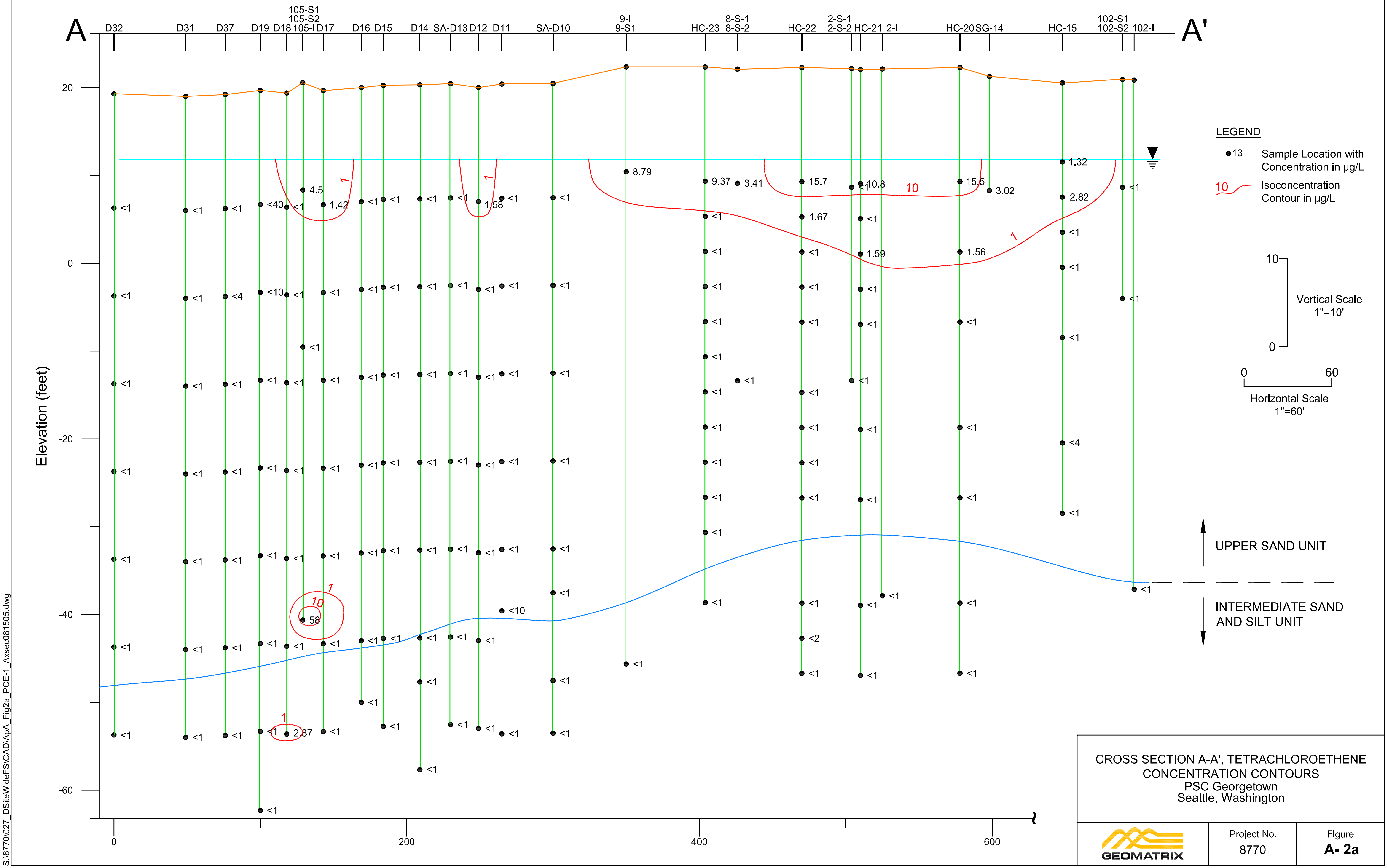

CROSS SECTION A-A', TETRACHLOROETHENE
CONCENTRATION CONTOURS
PSC Georgetown
Seattle, Washington

GEOMATRIX

Project No.	Figure
8770	A- 2a

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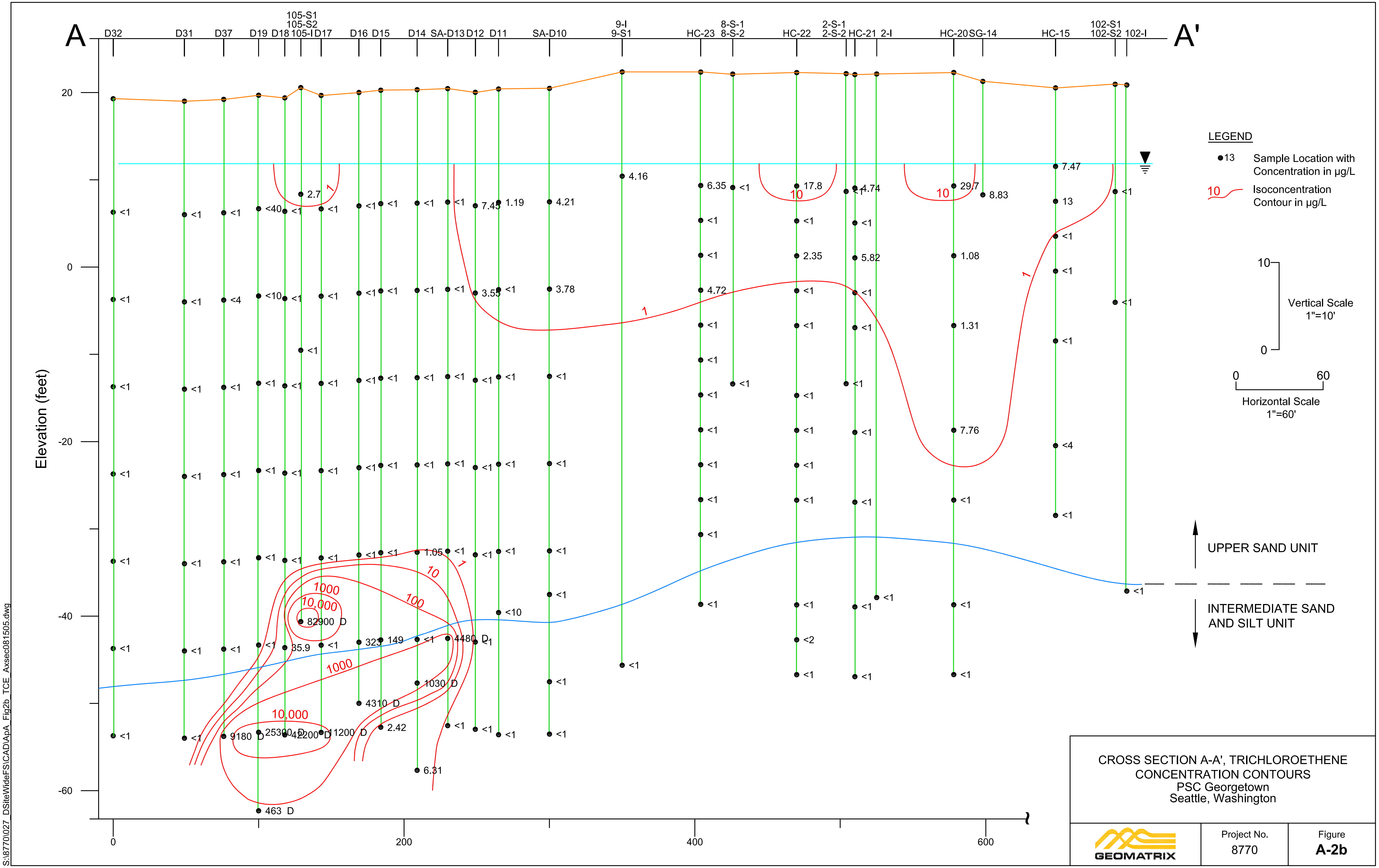

CROSS SECTION A-A', TRICHLOROETHENE CONCENTRATION CONTOURS
PSC Georgetown
Seattle, Washington

GEOMATRIX

Project No.
8770

Figure
A-2b

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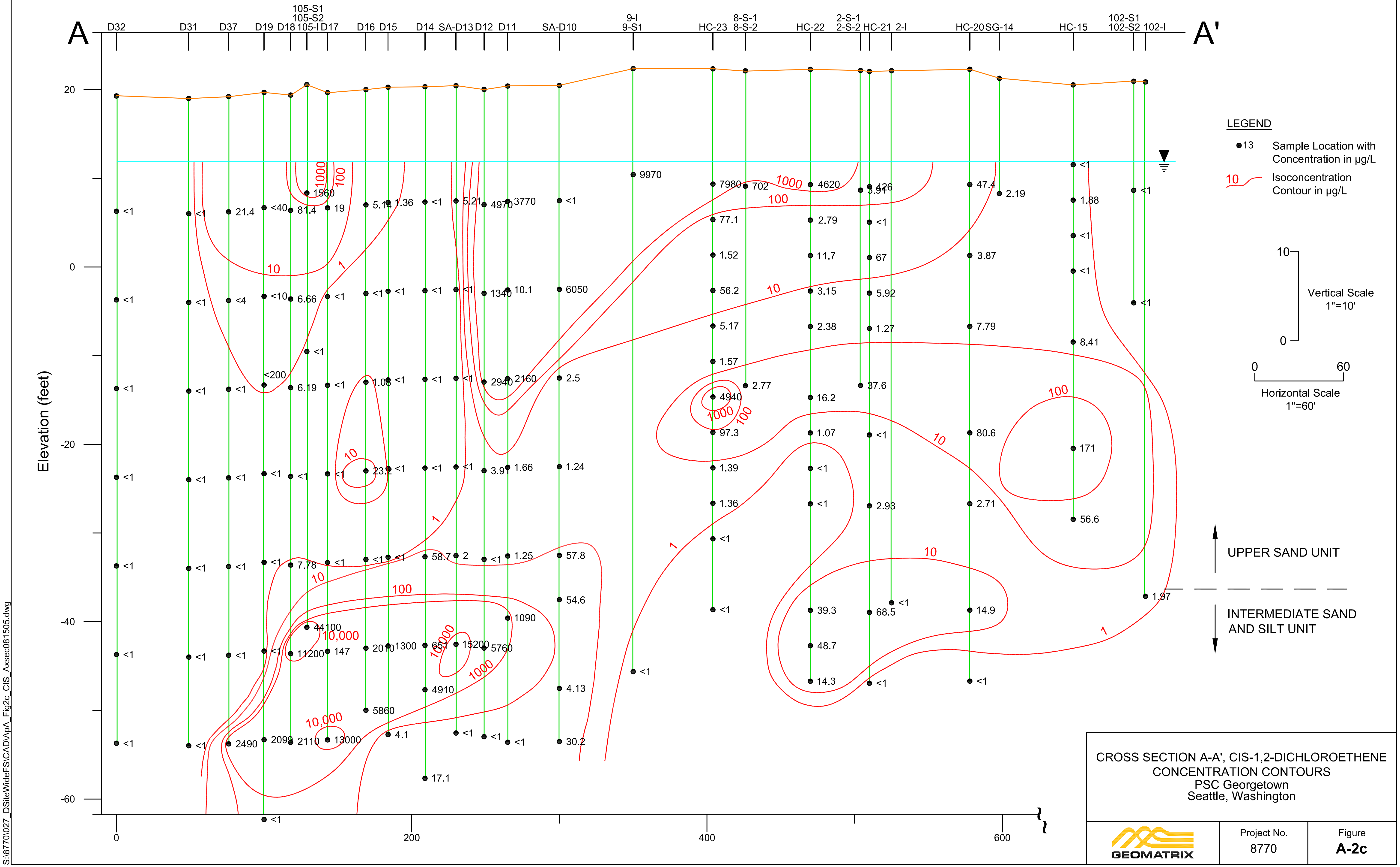

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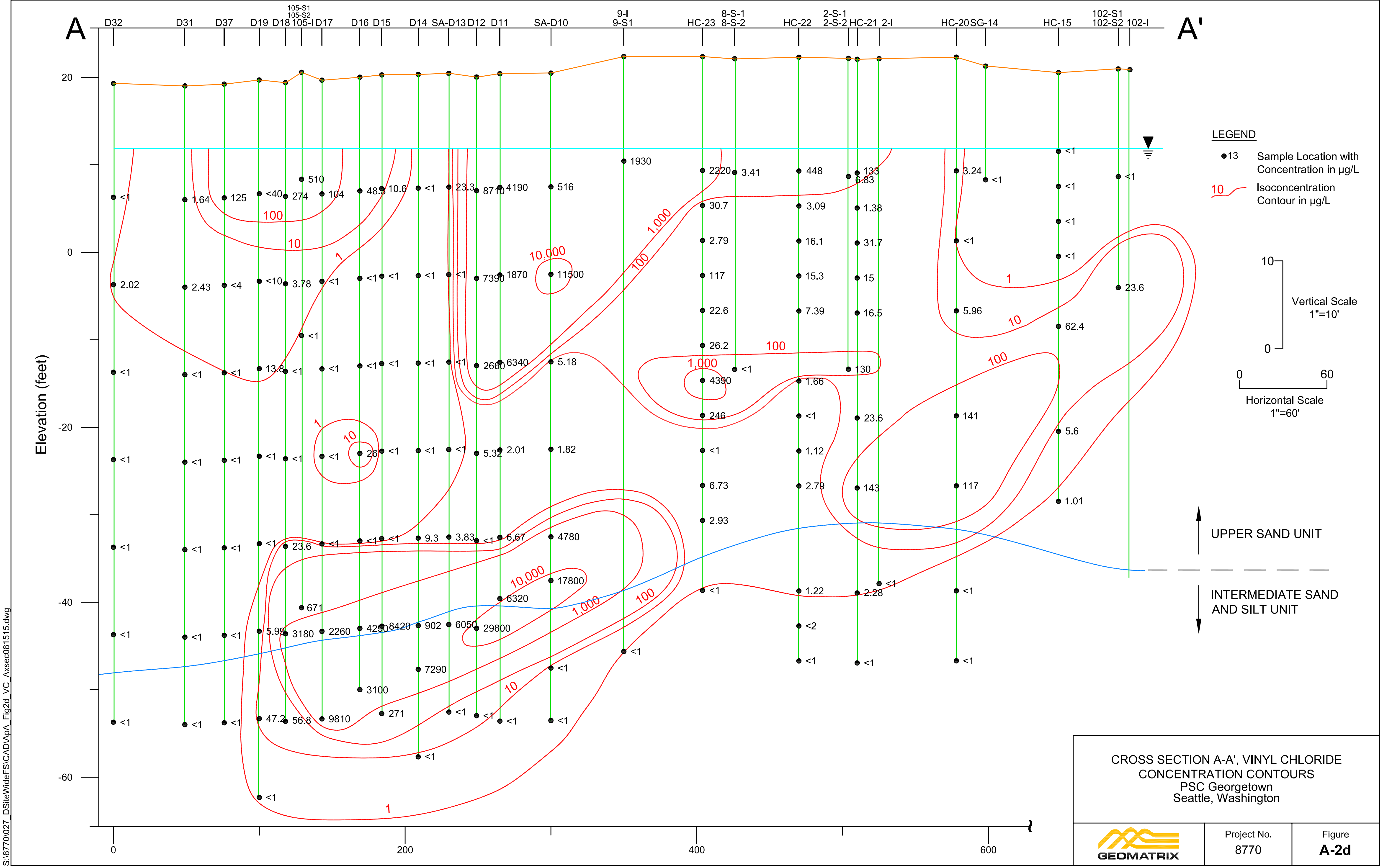
CROSS SECTION A-A', CIS-1,2-DICHLOROETHENE
CONCENTRATION CONTOURS
PSC Georgetown
Seattle, Washington

GEOMATRIX

Project No.	Figure
8770	A-2c



CROSS SECTION A-A', VINYL CHLORIDE CONCENTRATION CONTOURS
PSC Georgetown
Seattle, Washington

GEOMATRIX

Project No.	Figure
8770	A-2d

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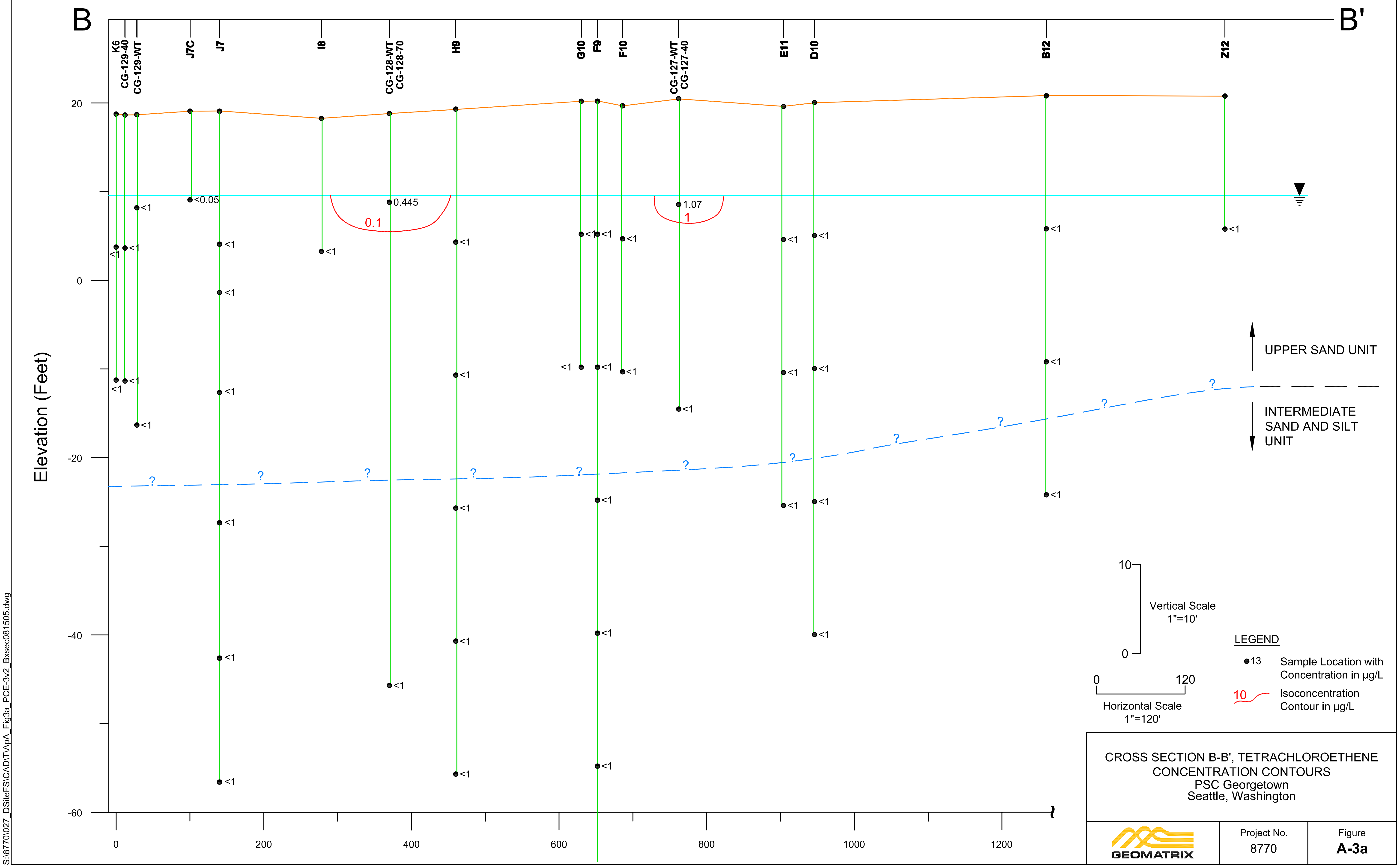

CROSS SECTION B-B', TETRACHLOROETHENE CONCENTRATION CONTOURS
PSC Georgetown
Seattle, Washington

GEOMATRIX

Project No.
8770

Figure
A-3a

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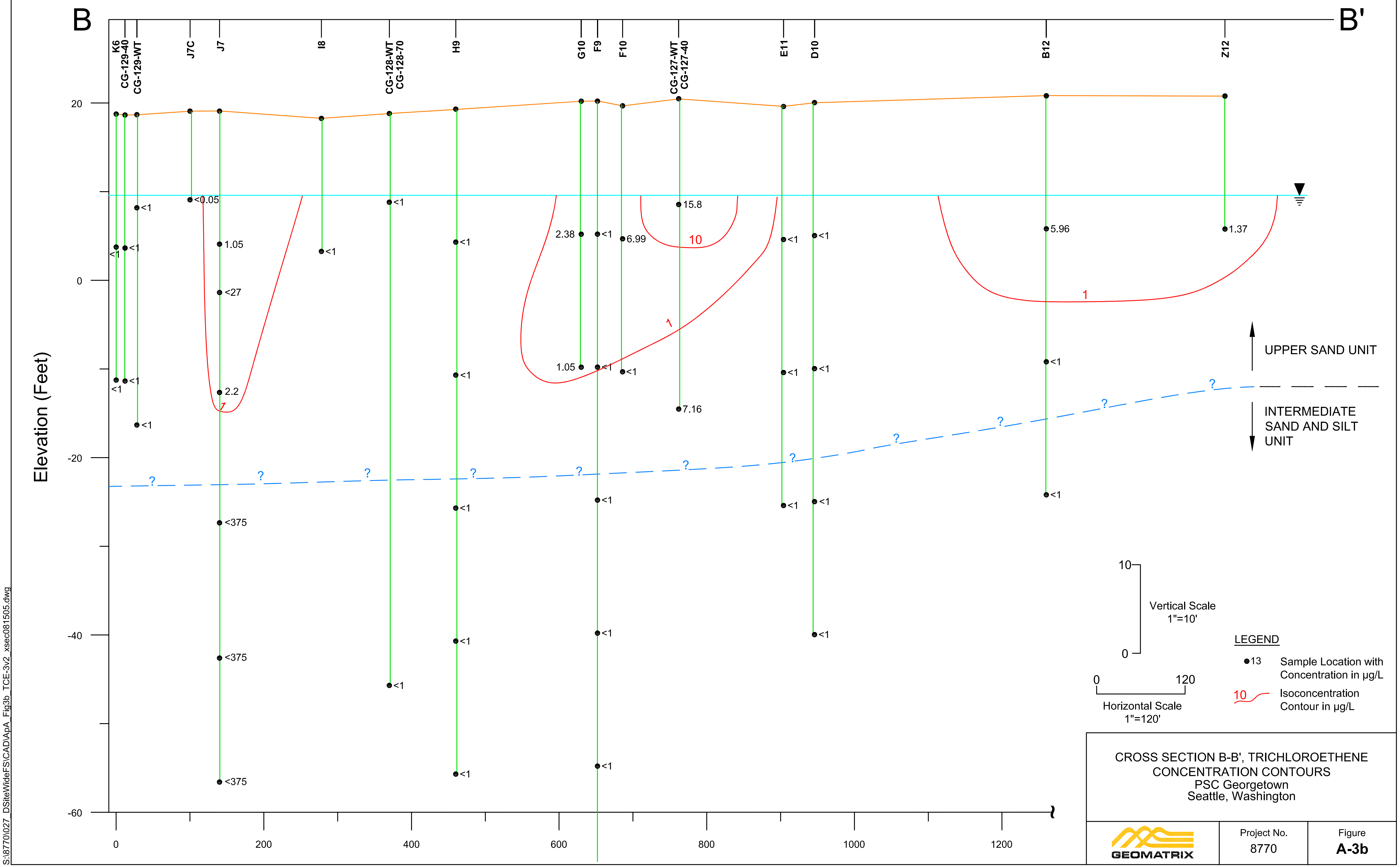

CROSS SECTION B-B', TRICHLOROETHENE
CONCENTRATION CONTOURS
PSC Georgetown
Seattle, Washington

GEOMATRIX

Project No.	Figure
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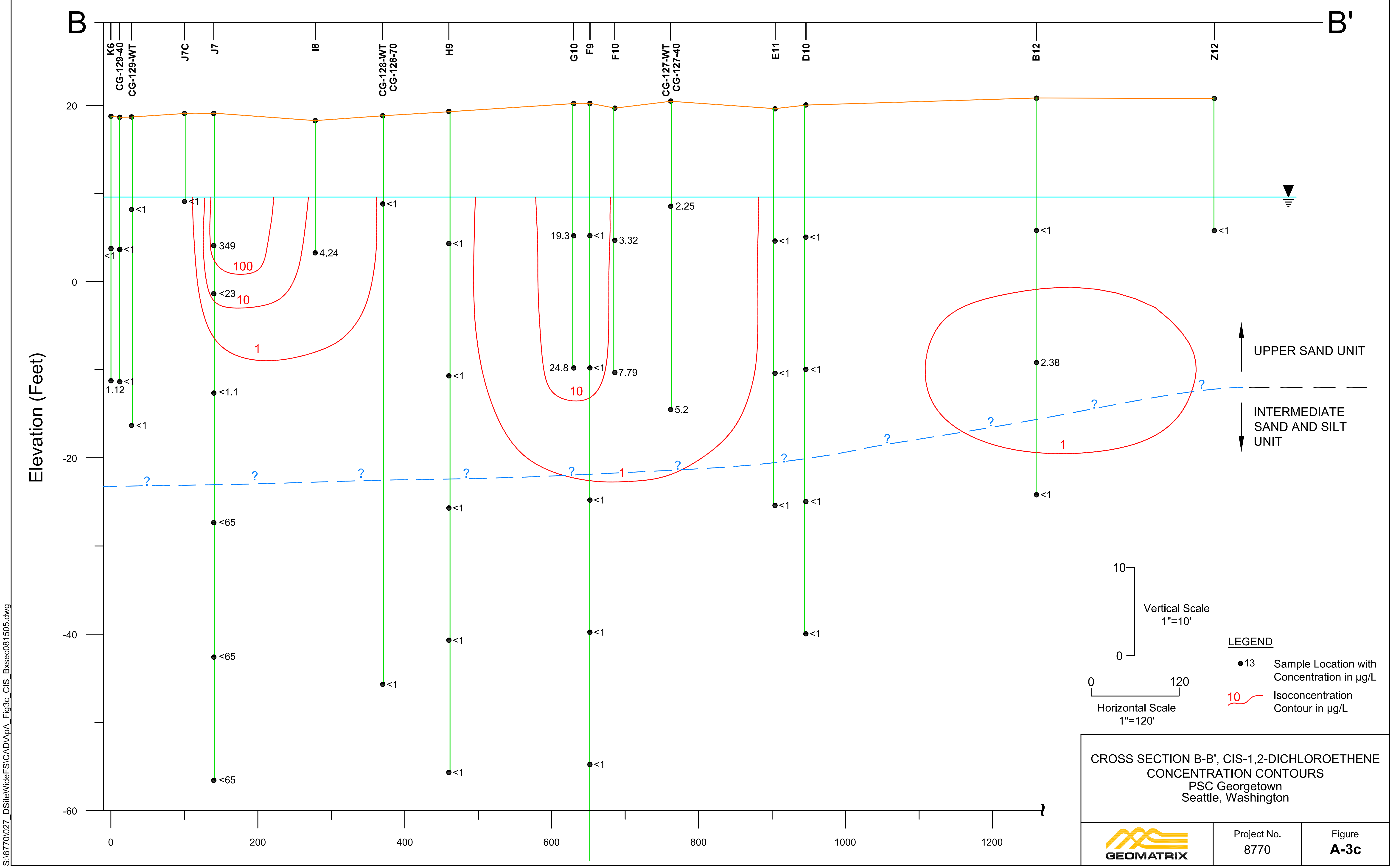

CROSS SECTION B-B', CIS-1,2-DICHLOROETHENE
CONCENTRATION CONTOURS
PSC Georgetown
Seattle, Washington

GEOMATRIX

Project No.
8770

Figure
A-3c

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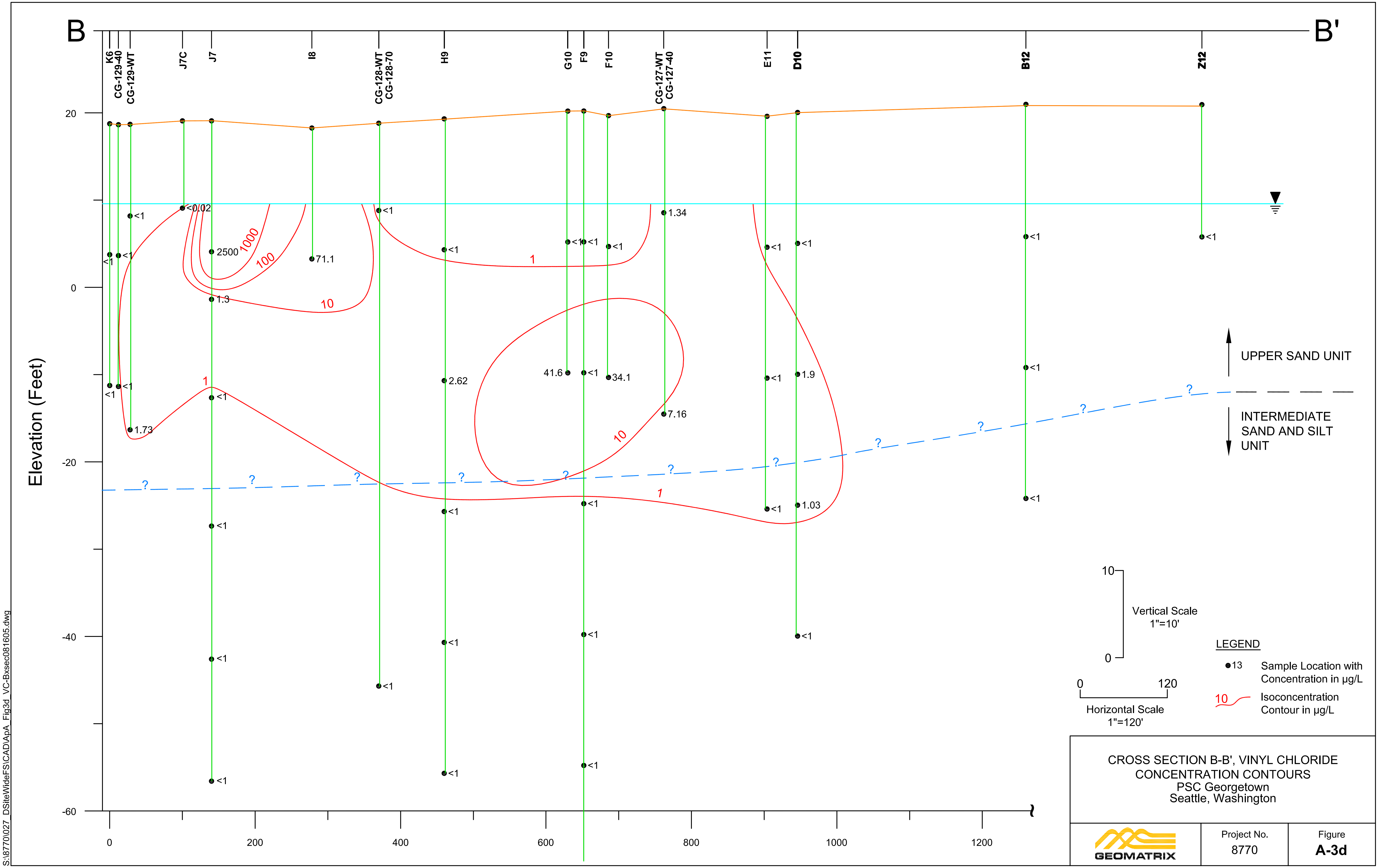

CROSS SECTION B-B', VINYL CHLORIDE CONCENTRATION CONTOURS
PSC Georgetown
Seattle, Washington

Project No.
8770

Figure
A-3d

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APPENDIX B
GROUNDWATER FATE AND TRANSPORT MODELING
PSC Georgetown
Seattle, Washington

1.0 INTRODUCTION

This appendix describes groundwater fate and transport modeling performed to support development and evaluation of remedial alternatives in the Site Wide Feasibility Study (SWFS) for the Philip Services Corporation (PSC) former dangerous waste treatment and storage facility (Facility). Historical releases to the subsurface at the Facility have resulted in a dissolved-phase plume extending downgradient from the Facility. The plume consists primarily of the chlorinated volatile organic compounds (VOCs) cis-1,2-dichloroethene (cis-1,2-DCE) and vinyl chloride (VC), with lower concentrations of perchloroethene (PCE), trichloroethene (TCE). A dissolved 1,4-dioxane plume also extends from the Facility to approximately Second Avenue South at concentrations above cleanup levels.

A hydraulic control interim measure (HCIM) containment barrier was implemented in 2004. The HCIM included installation of a subsurface barrier wall with a pump-and-treat system to maintain an inward hydraulic gradient to contain and effectively isolate affected soil and groundwater contaminant source areas on and near the Facility. Contaminant concentrations in the dissolved-phase plume outside of and downgradient from the HCIM barrier are expected to decline over time, due to flushing with upgradient water and biodegradation of VOCs. Fate and transport modeling of alternatives for the area contained by the HCIM and the downgradient area outside the HCIM are described below.

Fate and transport modeling is focused on two remediation areas defined in the SWFS: (1) the area enclosed by the HCIM barrier wall (the HCIM Area) and (2) the area outside the barrier wall (the Outside Area). Different processes control fate and transport in each of these areas, and modeling was developed to address issues specific to each area, as follows:

- **HCIM Area.** Modeling was performed to estimate potential chlorinated VOC flux through the HCIM barrier wall for active (pumping) and passive (non-pumping) hydraulic containment alternatives. Estimated chlorinated VOC flux values were then used to estimate resulting contaminant concentrations outside the HCIM barrier wall for each alternative.

- **Outside Area.** Fate and transport modeling was performed using BIOCHLOR to evaluate the effectiveness of natural attenuation processes in reducing chlorinated VOC concentrations to below cleanup levels downgradient of a proposed conditional point of compliance (CPOC) along Denver Avenue South. Additional modeling was performed to estimate the remediation time for chlorinated VOC concentrations to meet cleanup levels between the barrier wall and the CPOC and the area between the CPOC and Fourth Avenue South. Remediation time estimates were performed under existing natural attenuation conditions and with enhanced biodegradation in the area immediately outside the barrier wall.

The following sections present modeling for the HCIM Area, modeling for the Outside Area, a summary of the results, and cited references.

2.0 HCIM AREA

Two alternatives were evaluated for the HCIM Area. Alternative HA-1 would continue with the existing pump and treat system to maintain an inward hydraulic gradient. Alternative HA-2 would discontinue the pump and treat system, allowing an outward hydraulic gradient to develop along the downgradient portions of the wall (i.e., the Denver Avenue side of the wall). Potential contaminant fluxes across the wall and associated contaminant concentrations outside the wall are estimated for each of these alternatives.

The major mechanisms for contaminant migration through the wall are diffusion and advection with mechanical dispersion. In advection with dispersion, contaminants move with flowing groundwater (advection). Mechanical dispersion is caused by areas of higher and lower than average groundwater velocity within individual pores and in the porous medium as a whole, resulting in a diffuse or spread-out contaminant front rather than a sharp front. Diffusion describes the movement of contaminants from areas of higher concentrations to lower concentration in response to a concentration gradient, independent of groundwater movement.

2.1 ALTERNATIVE HA-1 - ACTIVE HYDRAULIC CONTAINMENT

Under Alternative HA-1, outward diffusive flux through the wall is partially or entirely offset by inward advective/dispersive flux resulting from the inward hydraulic gradient maintained by the pump and treat system. The contaminant concentration at any point in the wall can be calculated by (Devlin and Parker, 1996):

$$C = C_o \exp\left(\frac{vL}{\alpha v - D_{eff}}\right);$$

where:

- C is the contaminant concentration at distance x from the inner face of the wall;
- C_o is the contaminant concentration at the inside face of the wall;
- v is the groundwater velocity through the wall in cm/sec;
- L is the thickness of the wall;
- α is the longitudinal dispersivity in cm; and
- D_{eff} is the effective diffusivity of the contaminant through the barrier wall in units of cm^2/sec, and is equal to the diffusivity in water (D_w) times the tortuosity (τ) of the flow path through the wall;

This equation is valid for $0 < \alpha v < D_{eff}$ (Devlin and Parker, 1995). For $\alpha v < 0$ advection and diffusion are operating in the same direction, and groundwater flow would be directed outward through the wall. For $\alpha v \geq D_{eff}$ advection completely offsets diffusion and no outward contaminant flux through the wall occurs. As the velocity approaches zero, αv becomes much less than D_{eff} and diffusion outward through the wall is the dominant process.

The above equation was applied to estimate contaminant concentrations at the outer edge of the barrier wall (i.e., at $x = L$). Values of D_w for PCE, TCE, cis-1,2-DCE, and VC were taken from the United States Environmental Protection Agency's (USEPA) Soil Screening Guidance (USEPA, 1996). Tortuosity of the Impermix® barrier wall material has been estimated using a sodium chloride tracer at between 0.02 and 0.08 (Gilbert Tallard, 2005, personal communication). The average value of 0.05 was used for this estimate. The barrier wall as constructed is approximately 0.5 feet (15 centimeters) thick. Cross section A-A' in Appendix A generally corresponds to the source area contained by the barrier wall. Average contaminant concentrations for the water table, shallow, and intermediate aquifer zones calculated along this cross section were used to represent average concentrations currently inside the wall. These chemical parameters are summarized on Table B-1.

Groundwater velocity through the wall depends on the hydraulic gradient across the wall, wall hydraulic conductivity, and wall porosity. Under current pumping conditions a hydraulic head difference across the wall of approximately 1 foot is maintained, which with a wall thickness of 0.5 feet gives a gradient of 2 ft/ft. Laboratory measured hydraulic conductivity values for the Impermix® barrier wall material range 8×10^{-9} to 3×10^{-10} cm/sec (Geomatrix, 2004). Final hydraulic conductivity of the wall in the field may differ from the laboratory measurements, and calculations were performed using values ranging from 10^{-10} to 10^{-7} cm/sec. Porosity of the wall material is unknown, but was assumed to be 0.5 for this analysis. These hydraulic parameters and estimated groundwater velocities are summarized on Table B-1.

Calculated contaminant concentrations at the outer edge of the barrier wall for a range of wall hydraulic conductivities are shown on Table B-1. For a relatively high hydraulic conductivity (10^{-7} cm/sec), advection dominates and diffusion is not expected to result in mass flux across the wall. At a lower hydraulic conductivity (e.g., 10^{-10} cm/sec), inward groundwater velocity approaches zero and diffusion dominates, such that the concentration at the outer edge of the wall approaches the concentration inside the wall. It is important to note that these calculations are at the outer face of the wall in the wall material, and that concentrations in the aquifer material outside the wall would be much lower due to mixing and dilution with ambient groundwater flowing outside the wall.

Potential total contaminant flux out of the wall will range from a low of zero for the case where inward advection dominates to a high equal to the outward diffusive flux when inward groundwater velocity nears zero. The outward diffusive contaminant flux (J_d) in units of $\mu g/cm^2$-sec is described by the following equation:

$$J_d = \frac{D_{eff}}{L} \times \left(C_o - C\right)/1000\,;$$

where 1000 is a conversion factor between cm^3 and liters. Table B-2 presents estimated contaminant flux through the wall. These flux values represent the maximum estimated flux through the wall under Alternative HA-1.

Loading across the wall is calculated as the flux multiplied by the saturated surface area of the wall (1,500 feet long by 75 feet deep, or 120,000 square feet). Loading of PCE, TCE, cis-1,2-DCE, and VC is shown on Table B-2. Total loading of these constituents is estimated as 0.0009 pounds per day (lb/day).

The average concentration in $\mu g/cm^3$ outside the wall was calculated by dividing the average contaminant flux through the wall by the average groundwater flow rate per unit area (q), or Darcy flux. The Darcy flux of 5.4×10^{-5} cm/sec was calculated as the product of the average hydraulic gradient (0.0017) and hydraulic conductivity (0.032 cm/sec) from the Remedial

Investigation (RI) Report. Multiplying by 1000 cm^3/L converts the result to units of µg/L. Results of these calculations are shown in the final column of Table B-2. Estimated concentrations of PCE (0.003 µg/L), TCE (0.14 µg/L), cis-1,2-DCE (0.61 µg/L), and VC (0.09 µg/L) are below applicable surface water and indoor air based cleanup levels. These concentrations represent the maximum contaminant concentrations expected in the aquifer outside the wall due to contaminant flux through the wall under Alternative HA-1.

2.2 ALTERNATIVE HA-2 - PASSIVE HYDRAULIC CONTAINMENT

Alternative HA-2 includes discontinuing the pump-and-treat system and relying on the barrier wall to control migration of contaminants from the Facility. To evaluate the effectiveness of this alternative, contaminant flux through the barrier wall in the absence of pumping was estimated.

Under this alternative a hydraulic gradient across the contained area would be established in response to existing regional groundwater flow. The hydraulic gradient across the downgradient (Denver Avenue side) of the wall would result in groundwater flow and contaminant flux outward across the wall. Under long term, steady state conditions the outward flux is described by the following equation:

$$J = C_o \times q_w ;$$

where q_w is the Darcy flux through the wall, equal to the hydraulic gradient across the wall times the wall hydraulic conductivity.

Hydraulic gradient across the downgradient face of the wall was calculated based on the wall thickness and the head difference across the wall. Total head difference between the upgradient and downgradient ends of the HCIM was estimated at 0.56 feet, based on the regional hydraulic gradient of 0.0017 times the distance across the site of 330 feet. Because the hydraulic conductivity of the aquifer inside the wall is several orders of magnitude higher than the hydraulic conductivity of the wall material, almost all of the head losses will occur across the upgradient and downgradient segments of the wall. Hydraulic gradients and head losses in the interior of the HCIM would be negligible. Given this assumption, there would be about a 0.28 foot head difference across the wall between the aquifer upgradient of the HCIM and the interior, and a 0.28 foot head difference across the wall between the interior and the aquifer downgradient of the HCIM. Under non-pumping conditions, the hydraulic gradient across the 0.5 foot thick wall would be 0.56.

As discussed under Alternative HA-2, hydraulic conductivity values for the Impermix® barrier wall material range 8 x 10^{-9} to 3 x 10^{-10} cm/sec. As a conservative estimate of long term flux out of the wall under non-pumping conditions, a hydraulic conductivity for the wall material of 10^{-7} cm/sec was assumed. Table B-3 presents the estimated contaminant fluxes and loading across the wall using average contaminant concentrations from inside the HCIM. Total loading of PCE, TCE, cis-1,2-DCE, and VC is estimated at 0.0026 lb/day.

The average concentration outside the wall in μg/L was calculated by dividing the average contaminant flux through the wall by the average Darcy flux outside the wall. Results of these calculations are shown in the final column of Table B-3. Estimated concentrations of PCE (0.007 μg/L), TCE (0.26 μg/L), cis-1,2-DCE (0.92 μg/L), and VC (1.2 μg/L) are below applicable surface water and indoor air based cleanup levels. These concentrations represent the maximum long term steady state contaminant concentrations expected in the aquifer outside the wall due to contaminant flux through the wall under Alternative HA-2. These concentrations are below applicable surface water and indoor air based cleanup levels.

3.0 OUTSIDE AREA

Two alternatives were evaluated for the Outside Area. Alternative OA-1 relies on existing natural attenuation processes, including biodegradation and dispersion, to reduce contaminant concentrations in the residual source area outside the HCIM wall and downgradient of the Facility. Alternative OA-2 would include injecting a substrate, such as lactate, to enhance the existing anaerobic biodegradation processes of chlorinated VOCs in the residual source area, more rapidly reducing source area concentrations.

Modeling was performed to:

- Estimate chlorinated VOC concentrations downgradient of the Facility under natural attenuation conditions expected prior to construction of the HCIM barrier wall. These estimates were performed to assess whether the model gives a reasonable approximation of existing conditions.
- Evaluate the effectiveness of the existing natural attenuation processes (Alternative OA-1) in reducing chlorinated VOC concentrations in groundwater downgradient of the Facility to below applicable cleanup levels.
- Determine remediation levels for groundwater at Denver Avenue South under natural attenuation conditions that are protective of the Duwamish Waterway.

- Additional modeling was performed to estimate the time frame required for contaminant concentrations at the point of compliance and from the CPOC to Fourth Avenue South to decline to below cleanup levels for Alternatives OA-1 and OA-2.

The following sections discuss natural attenuation modeling and estimates of the remediation time.

3.1 NATURAL ATTENUATION MODELING

Data from the RI and calculations presented in Appendix A of this report indicate the chlorinated VOCs downgradient of the Facility are actively degrading under existing anaerobic conditions, resulting in a reduction in total plume mass and concentration between the Facility and Fourth Avenue South. Modeling was conducted to evaluate the effectiveness of these natural attenuation processes in reducing chlorinated VOC concentrations in groundwater to below applicable cleanup levels.

3.1.1 Model Selection

Natural attenuation modeling of chlorinated VOCs was performed using BIOCHLOR (ver. 2.2) software. This model was developed on behalf of the U.S. Air Force Center for Environmental Excellence by Groundwater Services, Inc. to assess natural attenuation of solutes in groundwater. This model has been accepted by the U.S. Environmental Protection Agency (EPA), and is available for downloading from the EPA CLU-IN web site.

BIOCHLOR simulates the natural attenuation of commonly found chlorinated solvents. BIOCHLOR is a Microsoft Excel programmed spreadsheet that simulates one dimensional advection, three dimensional dispersion, linear adsorption, and biotransformation via reductive dechlorination for chlorinated solvents.

3.1.2 BIOCHLOR Model Input Parameters

BIOCHLOR model input parameters and sources for the values selected are summarized in Table B-4.

General Model Parameters

Model input parameters such as hydraulic conductivity, hydraulic gradient, porosity, soil bulk density, soil total organic carbon content, and chemical partitioning coefficients are the same as were used to develop the calibrated model and estimate biodegradation rates in Appendix A. Model dimensions were based on the plume dimensions at the Facility and the location downgradient for which VOCs concentrations were being modeled. Model predicted concentrations were determined for two locations. The first location is Fourth Avenue South, west of which other potential sources of chlorinated VOCs have been identified and are being investigated by other parties. The second location is the Duwamish River, where groundwater ultimately discharges to potential surface water receptors. Longitudinal (α_x) dispersivity was calculated based on the flow path length, resulting in different values depending on the location for which VOC concentrations were being modeled (i.e., either Fourth Avenue South or the Duwamish). Transverse (α_y) dispersivity was set equal to 0.1 times α_x.

Initial Concentrations

Two sets of initial concentrations were used, depending on whether pre- or post-HCIM construction conditions were being simulated. For pre-HCIM construction conditions, initial concentrations were the average concentrations for the water table and shallow aquifer intervals calculated in Appendix A. Construction of the HCIM isolated these higher concentration source areas. A “hot-spot” area in the water table and shallow aquifer intervals with concentrations of chlorinated VOCs above cleanup levels has been identified outside the wall between the HCIM wall and Denver Avenue South. Wells with concentrations above cleanup levels include 103-S-1, 103-S-2, 104-S-1, CG-118-WT, CG-119-40, and CG-149-WT (Figure B-1). Wells completed in the intermediate zone outside the wall also exhibit VC concentrations above cleanup levels. As discussed in Appendix A, contaminants in the intermediate zone appear to be fully attenuating a short distance downgradient from the source area, and are not contributing to concentrations observed in the water table and shallow zones. As such, the intermediate zone was not included in estimating source area concentrations or natural attenuation modeling of the water table and shallow zones.

Initial concentrations outside the barrier wall were selected as the average of the most recent PCE, TCE, cis-1,2-DCE, and VC concentrations from each of the hot spot wells, as shown on Table B-5. Locations for the hot spot wells are shown on Figure B-1. Constituents not detected above the detection limit were included in the average at half the associated detection limit. Note that the highest concentrations of PCE, TCE, and cis-1,2-DCE occurred at well 103-S-1, which has not been sampled since May 2004, approximately 6 months after completion of the barrier wall. Concentrations in this well may currently be lower, due to biodegradation and flushing with water from upgradient of the site.

Source Type

The source type was modeled as “continuous,” meaning that the concentrations immediately outside the barrier wall are constant and do not decrease over time. In reality, these concentrations are expected to decline over time since the source area is contained within the HCIM wall and no longer provides significant contaminant mass to replace mass outside the wall lost due to biodegradation and flushing with water from upgradient of the site.

Table B-6 presents PCE, TCE, cis-1,2-DCE, and VC concentrations at the hot spot outside the wall location measured immediately prior to wall construction (3rd Quarter 2003), immediately after wall construction (1st Quarter 2004), and in the first or second quarter of 2005. Locations for the hot spot wells are shown on Figure B-1. Only one sample has been collected at well 103-S-1 over this time and it is not included in this table. Since construction of the wall, total concentrations of chlorinated VOCs at four of the hot spot wells (103-S-1, 103-S-2, 104-S-1, CG-119-40, and CG-149-WT) have decreased by 35 to 90 percent, while total concentrations have increased at CG-118-WT. VC and cis-1,2-DCE concentrations have declined significantly in shallow aquifer interval wells 103-S-2 and CG-119-40, and TCE concentrations have declined at 103-S-2. VC and cis-1,2-DCE concentrations also appear to have declined at 104-S1, although the reductions are less clear. Wells CG-118-WT and CG-149-WT, located adjacent to the wall, show reductions in PCE concentrations, with stable or slightly increasing TCE concentrations. CG-118-WT shows slight increases in VC and cis-1,2-DCE. CG-149-WT shows a significant decrease in cis-1,2-DCE and increase in VC. This pattern of a general reduction in contaminant concentrations, with some increases in concentrations of degradation daughter products (e.g., VC) is consistent with flushing and biodegradation of the hot spot area.

Although contaminant concentrations are clearly declining outside the wall, the five quarters of post-construction trend data are not sufficient to predict future reductions in concentrations. As such, the continuous source area concentration was used as a conservative assumption for evaluating worst-case long-term concentrations downgradient of the Facility.

Biodegradation Rates

A range of potential biodegradation rates for natural attenuation without enhancement were applied in evaluating the effectiveness of natural attenuation. These biodegradation rates, presented in Table B-7, include:

- Rates estimated from the mass balance and model calibration approach in Appendix A (referred to subsequently as the Appendix A Rates);
- Rates from fate and transport modeling for areas downgradient of the Facility that was previously performed for the Downgradient FS (Geomatrix, 2005). These biodegradation rates were selected based on comments received from the Washington State Department of Ecology (Ecology) on previous modeling

presented in the Draft RI report. These rates are referred to as the Downgradient FS Rates.

- Two sets of biodegradation rates representing the high and low range of estimated biodegradation rates selected from Tables 6.6 and 6.7 of Wiedemeier et al. (1999). These rates are referred to as the Wiedermeier Rates.

Model runs for the no-wall condition and the existing HCIM condition were performed using each of these biodegradation rates. Model runs to determine remediation levels at Denver Avenue South were performed using only the rates estimated from the mass balance approach, which provided the best prediction of current conditions downgradient of the Facility.

3.1.3 Model Runs

Three sets of natural attenuation model runs were performed. The model runs included:

- **Pre-HCIM conditions.** The model was run using average contaminant concentrations inside the wall and the range of biodegradation rates. The purpose of these runs was to evaluate the potential downgradient impacts associated with the facility prior to installation of the HCIM.

- **Post-HCIM conditions.** The model was run using average contaminant concentrations in the hot spot area outside the wall and the range of biodegradation rates. The purpose of these runs was to evaluate the potential future downgradient impacts associated with the hot spot area. Given the conservative assumption about the continuous source area concentrations, results from this model should be considered as worst case.

- **Remediation Levels.** The model was run using the Appendix A Rates. TCE and VC concentrations outside the wall were adjusted until model predicted concentrations at the Duwamish River met surface water based cleanup levels. The resulting source area concentrations were selected as the remediation levels. A remediation level for 1,4-dioxane was determined following the same procedure. Biodegradation of 1,4-dioxane was assumed to be negligible, and was modeled using an extremely slow (99 year) half life.

3.1.4 Natural Attenuation Modeling Results

Pre-HCIM Conditions

BIOCHLOR model predicted contaminant concentrations under natural attenuation conditions for the pre-HCIM scenario are presented in Table B-8. Concentrations predicted at Fourth Avenue South using the Appendix A Rates are generally consistent with the range of concentrations historically detected in that area. Although some locations in the vicinity of Fourth Avenue South (e.g., CG-131-WT) may have higher measured concentrations of TCE and cis-1,2-DCE than the model predicts, other locations have lower measured concentrations. Discrepancies in the TCE concentrations are due in large part to measured downgradient concentrations that are higher than source area concentrations in the water table and shallow zones inside the wall. Model predicted and measured concentrations of VC near Fourth Avenue South show very close agreement using the calibrated biodegradation rates. Model predicted concentrations at the Duwamish Waterway using the Appendix A Rates are below surface water based cleanup levels for all constituents.

Using the Downgradient FS rates, predicted PCE and TCE concentrations are similar to those predicted using the calibrated biodegradation rates. Predicted cis-1,2-DCE concentrations are slightly higher, but still in the range of measured concentrations at Fourth Avenue South. Predicted VC concentrations at Fourth Avenue South are approximately 40 times higher than any observed concentrations in the area, indicating that these biodegradation rates do not accurately represent actual natural attenuation conditions.

Using the conservative (slower degradation) end of the range of Wiedermeier Rates, predicted TCE concentrations are higher than for the calibrated or Downgradient FS rates, but still within the general range of measured concentrations at Fourth Avenue South. Predicted PCE, cis-1,2-DCE, and VC concentrations are much higher than measured concentrations at Fourth Avenue South. Using the higher end (faster degradation) of the range of Wiedermeier rates, predicted concentrations at Fourth Avenue South are well below measured concentrations in the area. Neither of the sets of literature value biodegradation rates provides a reasonable match to measured concentrations downgradient of the site.

Based on these results, the biodegradation rates from the calibrated model in Appendix A provide the best prediction of actual natural attenuation and resulting contaminant concentrations downgradient from the Facility. Results using these biodegradation rates should be relied on to predict contaminant concentrations for the post-HCIM conditions and to establish remediation levels at Denver Avenue South. Additionally, it appears that concentrations in the source area prior to installation of the HCIM would not result in groundwater concentrations at the Duwamish River that exceed surface water cleanup levels.

Post-HCIM Conditions

BIOCHLOR model predicted contaminant concentrations under natural attenuation conditions for the post-HCIM scenario are presented in Table B-9. It is worth noting that these predictions are based on a continuous source area with no reduction in concentration over time. Source area concentrations are expected to continue to decrease over time, resulting in a corresponding decrease in downgradient concentrations. These model results should be interpreted as potential worst-case peak concentrations resulting from current hot spot concentrations outside the wall.

Model predictions using the Appendix A Rates result in PCE, cis-1,2-DCE, and VC attenuating to below cleanup levels before reaching Fourth Avenue South. TCE concentrations are predicted to exceed the indoor air and surface water based cleanup levels at Fourth Avenue South. All constituent concentrations are predicted to be below cleanup levels at the Duwamish River. As discussed in the pre-HCIM conditions model results, these biodegradation rates provide the best prediction of actual natural attenuation and resulting contaminant concentrations downgradient from the Facility. Post-HCIM model predictions using these biodegradation rates are considered the best estimate of future peak concentrations resulting from the hot spot area.

Remediation Levels

The BIOCHLOR model was also used to establish remediation levels for the CPOC on the east side of Denver Avenue South protective of surface water at the Duwamish River. Using the Appendix A Rates for TCE and VC, source area concentrations were varied until predicted concentrations at the Duwamish River met surface water cleanup levels. A similar procedure was followed for 1,4-dioxane, using a conservatively slow biodegradation half life of 99 years. Based on this approach, the following remediation levels were established:

- TCE – 40 μg/L
- Vinyl chloride – 1,000 μg/L
- 1,4-dioxane – 100 μg/L

These remediation levels apply to all the remedial alternatives considered in this SWFS.

3.2 REMEDIATION TIME ESTIMATE

Estimates of the time frame required before concentrations outside the wall are below applicable cleanup levels were made by modeling the reduction in concentrations in the hot spot area via biodegradation. The potential effects of flushing or dilution with upgradient water were not considered. Models were developed to address the hot spot area between the wall and Denver Avenue South and the downgradient area between Denver Avenue South and Fourth

Avenue South. Biodegradation was assumed to follow a first order sequential decay model. For a given constituent, the dissolved phase concentration is described by:

$$C_t = C_{t-1} \times \exp\left(\frac{-0.693 \times \Delta t}{t_{1/2}}\right) + R$$

where:

- C_t is the contaminant concentration at time t;
- C_{t-1} is the contaminant concentration at the previous time step;
- Δt is the time step in years;
- $t_{1/2}$ is the half life in years; and
- R is the source reaction term accounting for increased concentration due to degradation of a parent compound (e.g., PCE to TCE) during the same time step.

The general procedure for the hot spot area was to estimate the total mass (sorbed phase and dissolved phase) of each chlorinated VOC within a unit volume of aquifer, based on the initial dissolved phase concentration of each constituent and assuming linear, equilibrium partitioning. The above equation was applied to each constituent using the dissolved phase concentration. At the end of each time step the total change in dissolved phase concentration was used to calculate the change of mass within the unit volume of aquifer. The change in mass was subtracted from the total mass, and the new total mass was then redistributed between the sorbed and dissolved phase within the unit volume using the partitioning coefficient. Biodegradation of the dissolved phase component for the next time step was then calculated. This procedure was repeated until dissolved phase concentrations of all constituents were below cleanup levels.

As groundwater migrates downgradient from the hot spot area, biodegradation will continue to reduce VOC concentrations. Neglecting the effects of dispersion, changes in concentrations in a unit of water as it moves downgradient are described by the same first order sequential decay equation. At the end of each time step, the concentration in the hot spot area was used as input to a decay model for the downgradient area, which was calculated following the same procedure as the hot spot area model.

Input parameters for these models are presented in Table B-10. Initial dissolved phase concentrations were selected as the highest post-HCIM construction concentrations of PCE, TCE, cis-1,2-DCE, and VC detected in the water table and shallow intervals between the wall and Denver Avenue South. Partitioning coefficients were calculated using the octanol-carbon partitioning coefficients (K_{oc}) from Table B-4 with an assumed fraction organic carbon (foc) of 1 percent. This foc value is conservatively high, resulting in relatively high partitioning coefficients. Using these foc and partitioning coefficient values with the measured groundwater concentrations in the hot spot area results in a conservatively high estimate of sorbed mass that acts as a reservoir to replace dissolved phase constituents as they are biodegraded. The net result of this assumption will be a conservatively high estimate for the remediation time. A soil density of 85 pounds/ft^3 and a porosity of 0.4 were also assumed, based on average values measured at the Facility (URS, 2003; PSC, 2003).

For Alternative OA-1, biodegradation rates in the hot spot and downgradient area were assumed to remain unchanged from current conditions. Biodegradation rates estimated from calibration of the BIOCHLOR model in Appendix A were used for this alternative. For Alternative OA-2, biodegradation rates in the hot spot area will be enhanced through addition of a substrate, such as lactate. For this alternative, literature values representing the average of estimated biodegradation rates for field-scale studies (Table 6.7 of Wiedemeier et al., 1999) were used for the hot spot area and calibrated rates from Appendix A were used for the area downgradient of Denver Avenue South.

Model results, using a 0.5 day time step, are presented in Table B-11. Time to meet cleanup levels in the hot spot area is estimated at up to 56 years for Alternative OA-1, and up to 23 years for Alternative OA-2. Because the hot spot area and downgradient area biodegradation rates are the same in Alternative OA-1, the time to meet cleanup levels in the downgradient area is the same as in the hot spot area for this alternative. The time to meet cleanup levels in the downgradient area is up to 28 years for Alternative OA-2. In Alternative OA-2, existing biodegradation rates downgradient of the CPOC at Denver Avenue South are slower than the biodegradation rates expected in the hot spot area that would be subject to enhanced anaerobic bioremediation. Chlorinated VOCs migrating downgradient with groundwater would degrade more slowly than chlorinated VOCs in the hot spot area, resulting in a longer remediation time in the downgradient area than in the hot spot area for Alternative OA-2.

These results are preliminary estimates of remediation time, based on conservative assumptions about hot spot area concentrations and, for Alternative OA-2, using literature values for biodegradation rates. As such, the estimated values for the remediation time are highly uncertain, especially for Alternative OA-2. These results should be considered as general indicators of the effectiveness of the alternatives relative to each other. The preliminary estimates indicate the remediation time for Alternative OA-1 is roughly twice the remediation time for Alternative OA-2. Although a shorter remediation time is expected for Alternative OA-2, the difference in estimated remediation times for these alternatives is not substantial relative to the uncertainties in the data used for these estimates.

As discussed in Section 3 and shown on Table B-6, total chlorinated VOC concentrations in 4 of the 5 hot spot area wells outside the barrier wall have declined by 35 to 90 percent in the first year since the HCIM was completed. Concentration reductions of this magnitude correspond to half lives on the order of 0.4 to 1.1 years, which are similar to the range of half lives for existing biodegradation conditions used in the remediation time modeling, lending qualitative support to the validity of the model predictions. Groundwater quality data collected from the hot spot area wells in the future can be used to develop biodegradation rates specific to the hot spot area, and provide more refined estimates of the likely remediation time.

4.0 SUMMARY

Fate and transport modeling was performed for the HCIM Area and the Outside Area. Modeling for the HCIM Area was focused on potential contaminant flux through the barrier wall and the resultant contaminant concentrations outside the wall under pumping and non-pumping conditions. Modeling for the Outside Area was focused on two issues: (1) evaluating the effectiveness of natural attenuation in meeting cleanup levels downgradient of the CPOC, including determining remediation levels applicable at the CPOC and (2) estimating the remediation time. Results of the modeling are summarized as follows:

- Dispersion modeling results for the HCIM Area indicate that expected contaminant flux through the wall under both pumping and non-pumping conditions would result in contaminant concentrations outside the wall that are below applicable surface water and indoor air based cleanup levels. Predicted concentrations are also much less than current concentrations outside the wall, such that the incremental increase in concentration would not significantly alter the estimated downgradient contaminant concentrations modeled with BIOCHLOR or the estimated remediation time for the uncontained area.

- Evaluation of BIOCHLOR modeling results using a range of biodegradation rates indicates that the rates calculated through model calibration in Appendix A provide the best fit to historical contaminant concentrations downgradient of the Facility, particularly VC. Using these rates, model results indicate that chlorinated VOCs associated with releases from the Facility prior to installation of the HCIM are likely attenuating to below cleanup levels before reaching the Duwamish River, although they do likely result in TCE and VC concentrations above surface water and indoor air based cleanup levels at Fourth Avenue South.

- Model results for post-HCIM-construction conditions using the calibrated Appendix A Rates indicate that chlorinated VOC concentrations will continue to attenuate to below cleanup levels before reaching the Duwamish River. These results also indicate that maximum VC concentrations will attenuate to below cleanup levels before reaching Fourth Avenue South.

- Remediation levels for the CPOC on the east side of Denver Avenue South protective of surface water at the Duwamish River were established for TCE (40 μg/L), VC (1,000 μg/L), and 1,4-dioxane (100 μg/L).

- Estimates of remediation time indicate that without enhancement of hot spot area biodegradation rates, it will take on the order of 50 to 60 years to meet cleanup levels between the HCIM wall and Fourth Avenue South. With enhanced hot spot area biodegradation, the estimated remediation time is on the order of 30 years.

5.0 REFERENCES

Devlin, J.F. and B.L. Parker, 1996, Optimum Hydraulic Conductivity to Limit Contaminant Flux Through Cutoff Walls, Groundwater, Vol. 34, No. 4.

Gilbert Tallard, 2005, personal communication.

Geomatrix, 2004, Hydraulic Control Interim Measures Implementation Report, Philip Services Corporation, Georgetown Facility, Seattle, Washington, June.

Philip Services Corporation, 2003, Final Comprehensive Remedial Investigation Report, PSC Georgetown Facility, Seattle, Washington.

Philip Services Corporation, 2005a, Quarterly Report, October-December, 2004, Philip Services Corporation's Georgetown Facility, Seattle, Washington, February 16.

Philip Services Corporation, 2005b, Quarterly Progress Report, January-March, 2005, Philip Services Corporation's Georgetown Facility, Seattle, Washington, May 18.

URS, 2003, Hydraulic Control Interim Measures Construction Work Plan, Volume II, Appendix C, Philip Services Corporation's Georgetown Facility, Seattle, Washington, prepared by URS and Geomatrix Consultants, April 9.

USEPA, 1996, Soil Screening Guidance: User's Guide, EPA Document Number: EPA540/R-96/018, July.

USEPA, 1996, BIOSCREEN, Natural Attenuation Decision Support System, User's Manual Version 1.3, EPA Document Number: EPA600/R-96/087, August.

Wiedemeier, T.H., C.J. Newell, H.S. Rifai and J.T. Wilson, 1999, Natural Attenuation of Fuels and Chlorinated Solvents in the Subsurface: John Wiley and Sons, Inc., New York, New York.

TABLE B-1

ALTERNATIVE HA-1
ESTIMATED CONTAMINANT FLUX THROUGH THE BARRIER WALL

PSC Georgetown
Seattle, Washington

Chemical Parameters

Constituent	Diffusivity in Water (cm^2/sec)	Effective Diffusivity (cm^2/sec)	Average Concentration Inside Wall (µg/L)
PCE	8.2E-06	4.1E-07	6.6
TCE	9.1E-06	4.6E-07	256
DCE	1.1E-05	5.7E-07	888
VC	1.2E-06	6.2E-08	1,182

Hydraulic Parameters

Wall Hydraulic Conductivity (cm/s)	Hydraulic Head Difference Across Wall (feet)	Wall Thickness (feet)	Dispersivity (cm)	Hydraulic Gradient Across Wall (ft/ft)	Wall Porosity (unitless)	Inward Groundwater Velocity Across Wall (cm/sec)
1.0E-07	1.0	0.5	1.5	2.0	0.5	4.0E-07
1.0E-08	1.0	0.5	1.5	2.0	0.5	4.0E-08
1.0E-09	1.0	0.5	1.5	2.0	0.5	4.0E-09
1.0E-10	1.0	0.5	1.5	2.0	0.5	4.0E-10

Calculated Contaminant Concentrations at exterior edge of wall in µg/L

	Wall Hydraulic Conductivity (cm/s)			
Constituent	1.0E-07	1.0E-08	1.0E-09	1.0E-10
PCE	NA	1.1	5.6	6.5
TCE	NA	55	224	253
DCE	NA	265	796	879
VC	NA	0	393	1069

NA - not applicable, $\alpha v > D_{eff}$ indicating no flux out of wall.

TABLE B-2

ALTERNATIVE HA-1
ESTIMATED MAXIMUM CONTAMINANT FLUX THROUGH THE BARRIER WALL

PSC Georgetown
Seattle, Washington

Constituent	Diffusivity in Water (cm^2/sec)	Effective Diffusivity (cm^2/sec)	Average Concentration Inside Wall (µg/L)	Wall Thickness (cm)	Contaminant Flux Through Wall (µg/cm^2/sec)	Loading Across Wall (lb/day)	Average Darcy Flux Outside Wall (cm/sec)	Average Concentration Outside Wall (µg/L)
PCE	8.2E-06	4.1E-07	6.6	15	1.8E-10	0.000004	5.4E-05	0.003
TCE	9.1E-06	4.6E-07	256	15	7.7E-09	0.00015	5.4E-05	0.14
DCE	1.1E-05	5.7E-07	888	15	3.3E-08	0.00065	5.4E-05	0.61
VC	1.2E-06	6.2E-08	1,182	15	4.8E-09	0.00009	5.4E-05	0.09

TABLE B-3

ALTERNATIVE HA-2
ESTIMATED CONTAMINANT FLUX THROUGH THE BARRIER WALL

PSC Georgetown
Seattle, Washington

Constituent	Wall Hydraulic Conductivity (cm/s)	Hydraulic Head Difference Across Wall (feet)	Wall Thickness (feet)	Hydraulic Gradient Across Wall (ft/ft)	Darcy Flux Across Wall (cm/sec)	Average Concentration Inside Wall (μg/L)	Contaminant Flux Through Wall (μg/cm^2/sec)	Loading Across Wall (lb/day)	Average Darcy Flux Outside Wall (cm/sec)	Contaminant Concentration Outside Wall (μg/L)
PCE	1.0E-07	0.28	0.5	0.56	5.6E-08	6.6	3.7E-10	0.000007	5.4E-05	0.007
TCE	1.0E-07	0.28	0.5	0.56	5.6E-08	256	1.4E-08	0.00029	5.4E-05	0.26
DCE	1.0E-07	0.28	0.5	0.56	5.6E-08	888	5.0E-08	0.00099	5.4E-05	0.92
VC	1.0E-07	0.28	0.5	0.56	5.6E-08	1,182	6.6E-08	0.0013	5.4E-05	1.2

TABLE B-4

BIOCHLOR INPUT PARAMETERS

PSC Georgetown
Seattle, Washington

Parameter	Value	Units	Source
Advection			
Hydraulic Conductivity	0.032	cm/s	Geometric mean of shallow sand unit hydraulic conductivity values
Hydraulic Gradient	0.0017	ft/ft	Site-wide average from the Draft RI report
Effective Porosity	0.3	unitless	Ecology default value
Seepage Velocity	187.6	ft/yr	Calculated
Dispersion			
α_x	28.6/39.8	Feet	Based on flow path length, calculated using modified Xu and Ekstein equation
α_y	2.8/3.9	Feet	No transverse dispersion, minimal change in plume area between Facility and 4th Avenue South
α_z	0	Feet	No vertical dispersion into intermediate unit assumed
Adsorption			
Soil Bulk Density	1.51	kg/L	Ecology default value
Fraction Organic Carbon	0.001	unitless	Ecology default value
PCE Partition Coefficient	265	L/kg	Ecology default value
TCE Partition Coefficient	94	L/kg	Ecology default value
DCE Partition Coefficient	35.5	L/kg	Ecology default value
VC Partition Coefficient	18.6	L/kg	Ecology default value
Model Dimensions			
Model Length	1400/3360	Feet	Distances from barrier wall to 4th Aveneue South and Duwamish River
Model Width	1500	Feet	Sufficiently wide to define downgradient plume
Source Area Width	400/650	Feet	Plume width at Facility, outside/inside wall
Source Area Depth	50	Feet	Average plume thickness at Facility
Simulation Time	30	Years	Sufficient time to reach steady state conditions
Source Data			
PCE Concentration	variable	μg/L	Average concentration inside or outside wall, depending on modeled scenario
TCE Concentration	variable	μg/L	Average concentration inside or outside wall, depending on modeled scenario
DCE Concentration	variable	μg/L	Average concentration inside or outside wall, depending on modeled scenario
VC Concentration	variable	μg/L	Average concentration inside or outside wall, depending on modeled scenario
Source Type	Continuous, single planar		Constant source assumed

TABLE B-5

HOT SPOT AREA CONCENTRATIONS OUTSIDE THE HCIM WALL

PSC Georgetown
Seattle, Washington

Location	Sample Date	PCE	TCE	DCE	VC
103-S-1	05-May-04	15.5	17.2	13.8	3.07
103-S-2	14-Feb-05	<0.05	1.72	5.37	9.95
104-S-1	10-Feb-05	<1	<1	1.35	3.01
CG-118-WT	16-May-05	2.1	1.2	7.4	4.9
CG-119-40	17-May-05	<0.13	0.37	2.2	3.8
CG-149-WT	17-May-05	0.92	7.3	29	36
Average		**3.2**	**4.7**	**9.9**	**10.1**

TABLE B-6

HOT SPOT AREA CONCENTRATIONS OUTSIDE THE HCIM WALL CHANGE OVER TIME

PSC Georgetown
Seattle, Washington

		Pre-HCIM	Post-HCIM	
		3Q03	1Q04	1Q05/2Q05
Water Table	**104-S-1**			
	PCE	0.65	0.36	<1
	TCE	0.45	0.568	<1
	cis-1,2-DCE	2.94	3.31	1.35
	VC	3.86	6.68	3.01
	CG-118-WT			
	PCE	---	3.26	2.1
	TCE	---	1.21	1.2
	cis-1,2-DCE	---	2.94	7.4
	VC	---	2.31	4.9
	CG-149-WT			
	PCE	---	3.53	0.92
	TCE	---	5.07	7.3
	cis-1,2-DCE	---	160	29
	VC	---	8.16	36
Shallow	**103-S-2**			
	PCE	0.05	<0.05	<0.05
	TCE	3.01	2.08	1.72
	cis-1,2-DCE	13.1	8.46	5.37
	VC	30.9	21.2	9.95
	CG-119-40			
	PCE	<0.05	<0.05	<0.13
	TCE	0.27	0.407	0.37
	cis-1,2-DCE	6.84	5.29	2.2
	VC	62.4	35.2	3.8

TABLE B-7

NATURAL ATTENUATION BIODEGRADATION RATES

PSC Georgetown
Seattle, Washington

Constituent	Biodegradation Half Lives in Years			
	Appendix A Calibrated Rates	Downgradient FS Rates	Wiedemeier Rates - Slow Rates	Wiedemeier Rates - Fast Rates
PCE	1.20	1.20	10.0	0.58
TCE	3.0	2.14	13.6	0.76
DCE	0.65	1.12	5.0	0.22
VC	0.82	8.21	5.8	0.26

TABLE B-8

PRE-HCIM MODEL RESULTS

PSC Georgetown
Seattle, Washington

Modeled Concentrations at 4th Avenue South

Constituent	Surface Water Based Cleanup Levels (µg/L)	Indoor Air Based Cleanup Levels (µg/L)	Source Area Concentration (µg/L)	Modeled Concentration in µg/L			
				Appendix A Calibrated Rates	Downgradient FS Rates	Wiedemeier Rates - Slow Rates	Wiedemeier Rates - Fast Rates
PCE	0.2	5	6.4	0.12	0.12	3.8	0.0027
TCE	0.8	0.4	6.1	2.6	1.5	5.8	0.054
DCE	165	73	774	1.2	12	282	0.0164
VC	2	1.28	856	9.7	764	547	0.019

Modeled Concentrations at the Duwamish River

Constituent	Surface Water Based Cleanup Levels (µg/L)	Indoor Air Based Cleanup Levels (µg/L)	Source Area Concentration (µg/L)	Modeled Concentration in µg/L			
				Appendix A Calibrated Rates	Downgradient FS Rates	Wiedemeier Rates - Slow Rates	Wiedemeier Rates - Fast Rates
PCE	0.2	5	6.4	0.0004	0.0006	1.8	0
TCE	0.8	0.4	6.1	0.22	0.072	4.4	0
DCE	165	73	774	0.044	0.092	67	0
VC	2	1.28	856	0.054	311	218	0

TABLE B-9

ALTERNATIVE OA-1
MODEL RESULTS
PSC Georgetown
Seattle, Washington

Modeled Concentrations at 4th Avenue South

Constituent	Surface Water Based Cleanup Levels (µg/L)	Indoor Air Based Cleanup Levels (µg/L)	Source Area Concentration (µg/L)	Modeled Concentration in µg/L			
				Appendix A Calibrated Rates	Downgradient FS Rates	Wiedemeier Rates - Slow Rates	Wiedemeier Rates - Fast Rates
PCE	0.2	5	4.82	0.06	0.06	1.9	0.0013
TCE	0.8	0.4	3.84	1.57	0.9	3.9	0.030
DCE	165	73	9.05	0.32	0.70	4.2	0.0091
VC	2	1.28	9.80	0.42	10.9	6.7	0.010

Modeled Concentrations at the Duwamish River

Constituent	Surface Water Based Cleanup Levels (µg/L)	Indoor Air Based Cleanup Levels (µg/L)	Source Area Concentration (µg/L)	Modeled Concentration in µg/L			
				Appendix A Calibrated Rates	Downgradient FS Rates	Wiedemeier Rates - Slow Rates	Wiedemeier Rates - Fast Rates
PCE	0.2	5	4.82	0.0002	0.0002	0.73	0
TCE	0.8	0.4	3.84	0.13	0.035	2.3	0
DCE	165	73	9.05	0.027	0.027	1.4	0
VC	2	1.28	9.80	0.030	4.0	2.6	0

TABLE B-10

REMEDIATION TIME MODEL INPUT PARAMETERS

PSC Georgetown
Seattle, Washington

Parameter	Value	Units	Source
Soil Parameters			
Dry Density	85	lb/ft^3	Average value measured at site
Porosity	0.4	---	Average value measured at site
Initial Concentrations			
PCE	15.5	mg/L	Highest post-HCIM concentration
TCE	17.2	mg/L	Highest post-HCIM concentration
CIS	117.00	mg/L	Highest post-HCIM concentration
VC	36.00	mg/L	Highest post-HCIM concentration
Partitioning Coefficients			
PCE	2.65	L/kg	Ecology default value times Foc of 0.01
TCE	0.9	L/kg	Ecology default value times Foc of 0.01
DCE	0.36	L/kg	Ecology default value times Foc of 0.01
VC	0.19	L/kg	Ecology default value times Foc of 0.01
1st Order Decay Half Life - Natural Attenuation Rates			
PCE to DCE	1.2	Years	Calibrated Rates (Appendix A)
TCE to DCE	3.0	Years	Calibrated Rates (Appendix A)
DCE to VC	0.65	Years	Calibrated Rates (Appendix A)
VC to Ethene	0.82	Years	Calibrated Rates (Appendix A)
1st Order Decay Half Life - Enhanced Rates			
PCE to DCE	0.66	Years	Table 6.7 of Wiedemeier et al. (1999)
TCE to DCE	0.76	Years	Table 6.7 of Wiedemeier et al. (1999)
DCE to VC	0.65	Years	Table 6.7 of Wiedemeier et al. (1999)
VC to Ethene	0.24	Years	Table 6.7 of Wiedemeier et al. (1999)

TABLE B-11

REMEDIATION TIME MODEL RESULTS

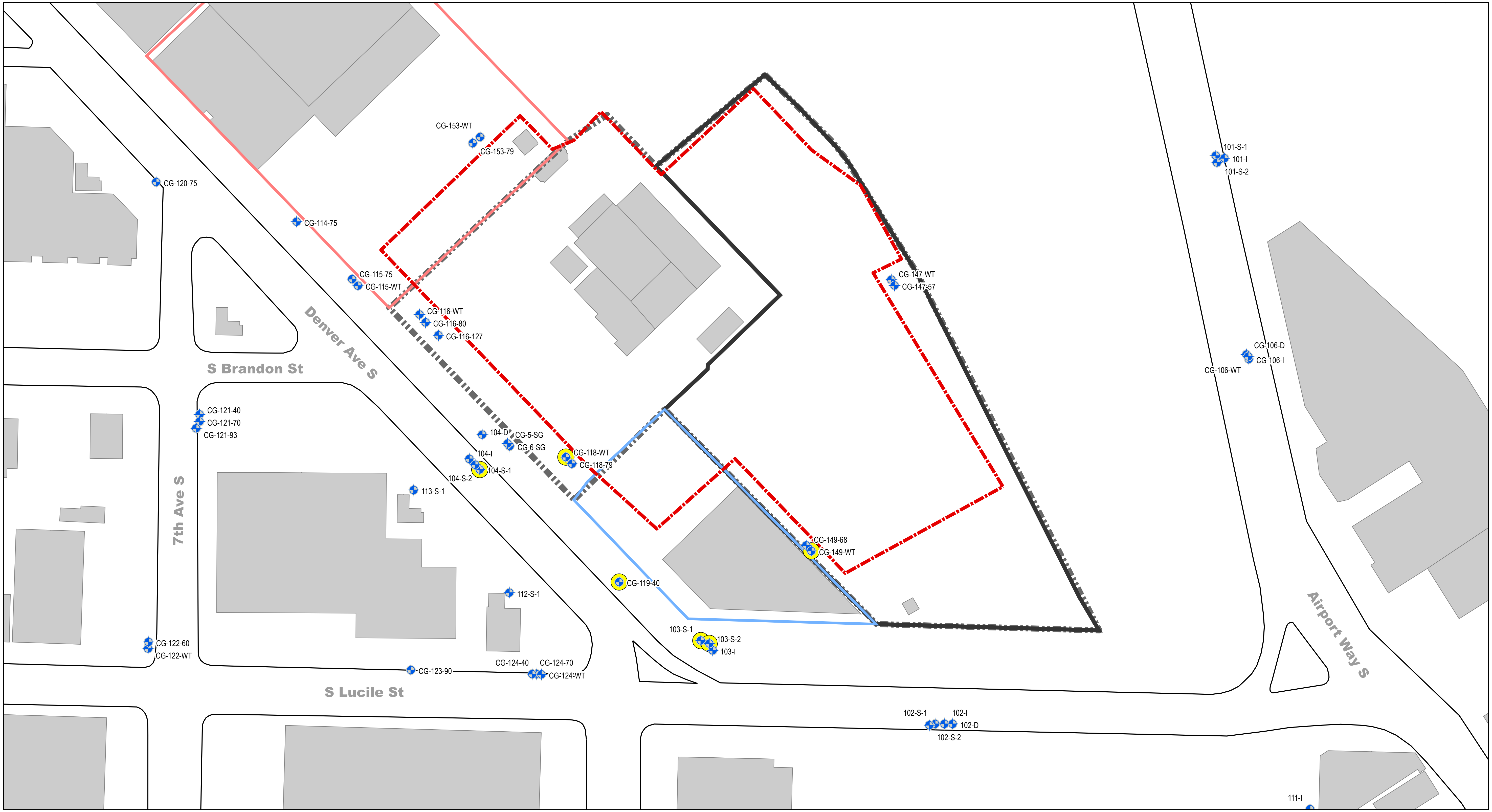
PSC Georgetown
Seattle, Washington

Time to Meet Cleanup Levels between the HCIM Wall and Denver Avenue South

	Cleanup Level (µg/L)	Alternative OA-1 Time (Years)	Alternative OA-2 Time (Years)
PCE	0.2	42	23
TCE	0.4	56	21
DCE	73	0.6	0.7
VC	1.3	28	7

Time to Meet Cleanup Levels Between Denver Avenue South and 4th Aveneue South

	Cleanup Level (µg/L)	Alternative OA-1 Time (Years)	Alternative OA-2 Time (Years)
PCE	0.2	42	28
TCE	0.4	56	26
DCE	73	0.6	0.7
VC	1.3	28	12



EXPLANATION

- ⊕ Existing Outside Area Monitoring Well
- ● Water Table or Shallow Zone Hot Spot
- HCIM Area
- ▭ Facility
- PSC Property
- ▭ Stone-Drew / Ashe & Jones, Inc (SAD) Property
- ▭ Aronson Property
- ▨ Building

0 40
Feet

N

OUTSIDE AREA HOT SPOT
MONITORING WELL LOCATIONS
PSC Georgetown
Seattle, Washington

GEOMATRIX

Project No.	Figure
8770	**B-1**

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APPENDIX C
REMEDIAL ALTERNATIVE COST ESTIMATES

Site Wide Feasibility Study
PSC Georgetown
Seattle, Washington

The cost estimates for the remedial alternatives were developed based on the conceptual designs for the alternatives described in Sections 8 and 9 of this Site Wide Feasibility Study (SWFS) Report. In general, these cost estimates were prepared in accordance with the methods described in the *A Guide to Developing and Documenting Cost Estimates During the Feasibility Study* (EPA, 2000). Details regarding preparation of these costs estimates are described below.

Cost estimates were prepared for the each of the remedial alternatives described in Sections 8 and 9 of the SWFS report. Rounding was applied to the total costs only. Net Present Value (NPV) costs were prepared for each alternative, which combine the initial implementation costs as well as the recurring costs for operation, maintenance, monitoring, and future equipment replacement. The initial implementation costs include design, construction, permitting, and the first dose of treatment substrate costs incurred during the initial implementation of the alternative. Recurring costs include costs that would occur regularly over the life of the remediation due to operation, maintenance, monitoring, property access, purchasing materials, and replacing equipment that may become worn out. The initial implementation and NPV costs are summarized for each of the alternatives on Table C-1. Detailed estimates for each of the alternatives are presented in Table C-2. Recurring cost estimates are summarized in Table C-3 for each of the alternatives. The initial implementation costs and recurring costs are combined to calculate the NPV cost in Table C-4. All costs presented in these tables are in 2005 dollars.

The quantities shown in the cost tables were estimated based on the assumed scope of the remedial alternatives and preliminary conceptual designs, as described in Sections 8 and 9. Reasonable assumptions based on professional judgment were made as appropriate to prepare the quantity estimates. The cost estimates based on these quantities are, therefore, preliminary estimates suitable for use in this SWFS for comparing the alternatives. These cost estimates are not suitable for final design or for budgeting.

The unit prices for most of the line items presented in the cost estimate tables were taken from *RSMeans, Building Construction Cost Data, 2005; RSMeans, Environmental Remediation Cost Data-Unit Price, 2005*; vendor quotes; or based on actual experience and engineering judgment. The following general assumptions were made and may appear as footnotes to the cost estimate tables:

- Production rates and prices would be based on standard 40-hour work week; no overtime or shift differential was included.
- The personal protective equipment would be Level D, unless otherwise noted.
- Any waste generated would be non-hazardous solid waste, except as otherwise noted.
- Any surface asphalt and concrete removed as part of remediation were assumed to be uncontaminated and were assumed to be recycled.
- No unique or specialty equipment or approaches were considered unless otherwise noted.
- Costs for potable water have not been estimated and have not been included in the remediation cost estimates.
- No security guards would be required.
- Work would be performed without interruptions or multiple mobilizations and setups unless noted otherwise.
- The estimates are accurate to +50 percent and -30 percent.
- No prevailing wage or union standby labor costs have been included.
- Costs for legal fees associated with gaining access for remedial construction have not been included.

The initial implementation cost estimate (Table C-2) presents the consultant cost separately as a percentage of the remediation construction. The specific line items have been divided into investigation, design, permitting, project management, and construction management as appropriate. The assigned percentages were obtained from EPA guidance (EPA, 2000) and from professional experience.

The estimated recurring costs have also been generalized for simplicity. The unit prices used for recurring cost estimates include the cost of the consultant and contractor costs, as appropriate. A separate line item for annual project management has been added at a fixed unit price of $30,000 per year for each of the remedial alternatives. The duration of remediation and monitoring were assumed to be 30 years.

The NPV table (Table C-4) presents the calculated present value based on a discount (interest) rate of 7 percent. The annual costs from the recurring cost tables were used to calculate the NPV costs. Both the initial and recurring cost estimates include a contingency to address uncertainties and to reflect the preliminary nature of these cost estimates.

REFERENCES

R. S. Means. 2005. *Environmental Cost Data*-2005. 11th Edition.

R. S. Means. 2005. *Building Construction Cost Data*. 18th Edition.

United States Environmental Protection Agency (EPA). 2000. *A Guide to Developing and Documenting Cost Estimates During the Feasibility Study*.

TABLE C-1

COST SUMMARY

PSC Georgetown
Seattle, Washington

Alternative	Initial Cost	Net Present
HCIM Area Remedial Alternatives		
HA-1: Active Hydraulic Containment	$36,900	$3,030,400
HA-2: Passive Hydraulic Containment	$36,900	$1,149,200
Outside Area Remedial Alternatives		
OA-1: Monitored Natural Attenuation	$106,100	$2,212,700
OA-2: Enhanced Anaerobic Bioremediation	$857,900	$3,319,500
Preferred Site Wide Approach		
HA-2 and OA-1	$143,000	$3,361,900

TABLE C-2

INITIAL IMPLEMENTATION COSTS
HA-1: Active Hydraulic Containment
PSC Georgetown
Seattle, Washington

Item	Unit	Unit Cost	Quantity	Cost
1 **Health and Safety**				
Health and Safety Officer	day	$600	1	$600
Equipment	day	$95	5	$475
PPE	person-day	$7.50	20	$150
2 **Surveying**				
Surveying	day	$1,500	1	$1,500
3 **Cap Construction**				
Mobilization/Demobilization	Lump Sum	$5,000	1	$5,000
Materials and Equipment	SF	$0.83	1,500	$1,245
Labor (4 laborers)	per hour	$180	40	$7,200
Subtotal				$16,170
Contingency	50%			$8,085
Total Remediation Construction Cost				$24,255
Professional Technical Services				
Permitting	%	7%	$24,255	$1,698
Engineering Design Costs	%	20%	$24,255	$4,851
Construction Management	%	15%	$24,255	$3,638
Project Management	%	10%	$24,255	$2,426
Subtotal, Professional Services				$12,613
TOTAL INITIAL IMPLEMENTATION COST				**$36,900**

Notes:
1. 2005 Dollars.
2. Costs are +50% -30%.
3. 40 hour work week.
4. Level D PPE.
5. Assume all paving 3" asphalt

TABLE C-2

INITIAL IMPLEMENTATION COSTS
HA-2: Passive Hydraulic Containment

PSC Georgetown
Seattle, Washington

Item	Unit	Unit Cost	Quantity	Cost
1 **Health and Safety**				
Health and Safety Officer	day	$600	1	$600
Equipment	day	$95	5	$475
PPE	person-day	$7.50	20	$150
2 **Surveying**				
Surveying	day	$1,500	1	$1,500
3 **Cap Construction**				
Mobilization/Demobilization	Lump Sum	$5,000	1	$5,000
Materials and Equipment	SF	$0.83	1,500	$1,245
Labor (4 laborers)	per hour	$180	40	$7,200
Subtotal				**$16,170**
Contingency	50%			$8,085
Total Remediation Construction Cost				**$24,255**
Professional Technical Services				
Permitting	%	7%	$24,255	$1,698
Engineering Design Costs	%	20%	$24,255	$4,851
Construction Management	%	15%	$24,255	$3,638
Project Management	%	10%	$24,255	$2,426
Subtotal, Professional Services				**$12,613**
TOTAL INITIAL REMEDIATION COST				**$36,900**

Notes:
1. 2005 Dollars.
2. Costs are +50% -30%.
3. 40 hour work week.
4. Level D PPE.
5. Assume all paving 3" asphalt

TABLE C-2

INITIAL IMPLEMENTATION COSTS
OA-1: Monitored Natural Attenuation
PSC Georgetown
Seattle, Washington

Item	Unit	Unit Cost	Quantity	Cost
1 **Health and Safety**				
Health and Safety Officer	day	$600	2	$1,200
Equipment	day	$95	15	$1,425
PPE	person-day	$7.50	45	$338
2 **Site Preparation**				
Public Access	lump sum	$3,500	1	$3,500
Utility Location	day	$600	1	$600
Temporary Facilities	week	$750	1	$750
3 **Surveying**				
Surveying	day	$1,500	1	$1,500
4 **Monitoring Wells**				
Mobilization/Demobilization	lump sum	$1,000	1	$1,000
Concrete Coring	per well	$75	9	$675
Monitoring Well Installation (2" PVC)	linear foot	$55	390	$21,450
Monitoring Well Development	per well	$300	1	$300
Base Price Per Well	each	$200	1	$200
Waste Disposal	drum	$150	39	$5,850
5 **Cap Construction**				
Mobilization/Demobilization	Lump Sum	$5,000	1	$5,000
Materials and Equipment	SF	$0.83	4,900	$4,067
Labor (4 laborers)	per hour	$180	40	$7,200
6 **Traffic Control**				
Barricade (Barrels with flashers)	each weekly	$20	20	$400
Labor (2 flaggers)	per hour	$70	40	$2,800
Subtotal				**$58,255**
Contingency	30%			$17,476
Total Remediation Construction Cost				**$75,731**
Professional Technical Services				
Permitting	%	7%	$75,731	$5,301
Engineering Design Costs	%	15%	$75,731	$11,360
Construction Management	%	10%	$75,731	$7,573
Project Management	%	8%	$75,731	$6,058
Subtotal, Professional Services				**$30,292**
TOTAL INITIAL REMEDIATION COST				**$106,100**

Notes:

1. 2005 Dollars.
2. Costs are +50% -30%.
3. 40 hour work week.
4. Level D PPE.
5. Assume all paving 3" asphalt

TABLE C-2

INITIAL IMPLEMENTATION COSTS
OA-2: Enhanced Anaerobic Bioremediation
PSC Georgetown
Seattle, Washington

Item	Unit	Unit Cost	Quantity	Cost
1 **Health and Safety**				
Health and Safety Officer	day	$600	10	$6,000
Equipment	day	$95	60	$5,700
PPE	person-day	$7.50	300	$2,250
2 **Site Preparation**				
Public Access	lump sum	$3,500	1	$3,500
Utility Location	day	$600	2	$1,200
Temporary Facilities	month	$3,000	1	$3,000
Temporary Storage Area	lump sum	$3,000	1	$3,000
3 **Surveying**				
Surveying	day	$1,500	2	$3,000
4 **Monitoring Wells**				
Mobilization/Demobilization	lump sum	$1,000	1	$1,000
Concrete Coring	per well	$75	9	$675
Monitoring Well Installation (2" PVC)	linear foot	$55	390	$21,450
Monitoring Well Development	per well	$300	1	$300
Base Price Per Well	each	$200	1	$200
Waste Disposal	drum	$150	39	$5,850
5 **Enhanced Bioremediation**				
Pilot Test	lump sum	$90,000	1	$90,000
Recirculation Well Installation				
Mobilization/Demobilization	per well	$500	66	$33,000
Concrete Coring	per well	$75	66	$4,950
Injection/Extraction Wells (4" PVC)	linear foot	$61	1,480	$90,280
Base Price Per Well	each	$300	66	$19,800
Waste Disposal	drum	$150	148	$22,200
Direct Push Injections				
Mobilization/Demobilization	lump sum	$1,100	1	$1,100
Concrete Coring	per well	$75	40	$3,000
Injection Wells Direct Push	per day	$2,500	20	$50,000
Tax	per hole	$50	40	$2,000
Waste Disposal	drum	$150	2	$300
Chemical	per pound	$3	1,800	$5,400
Recirculation Well Substrate Injection				
Mobilization/Demobilization	per set of 3	$250	30	$7,500
Substrate Mixing/Injection Trailer	lump sum	$25,000	1	$25,000
Waste Disposal	drum	$150	6	$900
Chemical	per pound	$3	11,000	$33,000
Testing Equipement	lump sum	$3,000	1	$3,000
Application (labor)	per set of 3	$750	30	$22,500
Vehicle Rental	day	$75	30	$2,250
6 **Cap Construction**				
Mobilization/Demobilization	Lump Sum	$5,000	1	$5,000
Materials and Equipment	SF	$0.83	4,900	$4,067
Labor (4 laborers)	per hour	$180	40	$7,200
7 **Traffic Control**				
Barricade (Barrels with flashers)	Each weekly	$20	50	$1,000
Labor (2 flaggers)	per hour	$70	80	$5,600
Subtotal				**$496,172**
Contingency	30%			$148,852
Total Remediation Construction Cost				**$645,024**
Professional Technical Services				
Permitting	%	7%	$645,024	$45,152
Engineering Design Costs	%	12%	$645,024	$77,403
Construction Management	%	8%	$645,024	$51,602
Project Management	%	6%	$645,024	$38,701
Subtotal, Professional Services				**$212,858**
TOTAL INITIAL REMEDIATION COST				**$857,900**

Notes:
1. 2005 Dollars.
2. Costs are +50% -30%.
3. 40 hour work week.
4. Level D PPE.
5. Assume all paving 3" asphalt.

TABLE C-3

RECURRING COSTS
PSC Georgetown
Seattle, Washington

	ITEM	Unit	Unit Cost	HA-1 Active Hydraulic Containment				HA-2 Passive Hydraulic Containment				OA-1 Monitored Natural Attenuation				OA-2 Enhanced Anaerobic Bioremediation			
				Annual Quantity	Annual Cost	Lifetime Quantity	Lifetime Cost	Annual Quantity	Annual Cost	Lifetime Quantity	Lifetime Cost	Annual Quantity	Annual Cost	Lifetime Quantity	Lifetime Cost	Annual Quantity	Annual Cost	Lifetime Quantity	Lifetime Cost
1	**INSPECTION**																		
	Site Inspection	each	$500	1	$500	30	$15,000	1	$500	30	$15,000	1	$500	30	$15,000	1	$500	30	$15,000
Subtotal					**$500**		**$15,000**		**$500**		**$15,000**		**$500**		**$15,000**		**$500**		**$15,000**
2	**ANNUAL COSTS INCLUDING O&M**																		
	Annual operation labor	day	$600	52	$31,200	1560	$936,000	52	$31,200	156	$93,600	0	$0	0	$0	0	$0	0	$0
	Electricity	monthly	$400	12	$4,800	360	$144,000	12	$4,800	36	$14,400	0	$0	0	$0	0	$0	0	$0
	Waste Water Discharge		$12,000	1	$12,000	30	$360,000	1	$12,000	3	$36,000								
	Misc. Maintenance	lump sum	$70,000	1	$70,000	30	$2,100,000	1	$70,000	3	$210,000	0	$0	0	$0	0	$0	0	$0
	Treatment system cleaning	lump sum	$28,800	1	$28,800	30	$864,000	1	$28,800	3	$86,400	0	$0	0	$0	0	$0	0	$0
	Well Maintenance	per well	$5,000	1	$5,000	30	$150,000	1	$5,000	30	$150,000	3	$15,000	90	$450,000	3	$15,000	90	$450,000
Subtotal					**$151,800**		**$4,554,000**		**$151,800**		**$590,400**		**$15,000**		**$450,000**		**$15,000**		**$450,000**
3	**SEMI-ANNUAL DOSING (Years 1 & 2)**																		
	Anaerobic Bioremediation																		
	Water Table and Shallow																		
	Chemical	per pound	$3	0	$0	0	$0	0	$0	0	$0	0	$0	0	$0	22,000	$66,000	33,000	$99,000
	Well Development/Biofouling Treatment		$300	0	$0											10	$3,000	15	$4,500
	Application (labor and equipment)	per well	$700	0	$0	0	$0	0	$0	0	$0	0	$0	0	$0	60	$42,000	90	$63,000
Subtotal					**$0**		**$0**		**$0**		**$0**		**$0**		**$0**		**$111,000**		**$166,500**
5	**FIVE YEAR REPLACEMENT COSTS**																		
	Controls & Instruments	each	$500	NA	NA	6	$3,000	NA	NA	0	$0	NA	NA	0	$0	NA	NA	0	$0
	Cap Maintenance	per year	$2,000	NA	NA	6	$12,000	NA	NA	6	$12,000	NA	NA	6	$12,000	NA	NA	6	$12,000
	Discharge Permit		$10,000	NA	NA	6	$60,000	NA	NA	0	$0	NA	NA	0	$0	NA	NA	0	$0
Subtotal					NA		**$75,000**		NA		**$12,000**		NA		**$12,000**		NA		**$12,000**
6	**TEN YEAR REPLACEMENT COSTS**																		
	Monitoring Well Installation (2" PVC)	linear foot	$55	NA	NA	390	$21,450	NA	NA	390	$21,450	NA	NA	390	$21,450	NA	NA	390	$21,450
	MonitoringWell Development	per well	$300	NA	NA	3	$900	NA	NA	3	$900	NA	NA	3	$900	NA	NA	3	$900
	Base Price Per Well	each	$200	NA	NA	3	$600	NA	NA	3	$600	NA	NA	3	$600	NA	NA	3	$600
	Waste Disposal	drum	$50	NA	NA	39	$1,950	NA	NA	39	$1,950	NA	NA	39	$1,950	NA	NA	39	$1,950
Subtotal					NA		**$24,900**		NA		**$24,900**		NA		**$24,900**		NA		**$24,900**
7	**QUARTERLY GW MONITORING (Years 1-3)**																		
	Sampling	per day	$1,200	0	$0	0	$0	0	$0	0	$0	12	$14,400	36	$43,200	12	$14,400	36	$43,200
	Analysis - VOCs, Ethenes	each well	$285	0	$0	0	$0	0	$0	0	$0	44	$12,540	132	$37,620	44	$12,540	132	$37,620
	Analysis - Alkalinity, 1,4-Dioxane	each well	$195	0	$0	0	$0	0	$0	0	$0	44	$8,580	132	$25,740	44	$8,580	132	$25,740
	Reporting	per round	$5,000	0	$0	0	$0	0	$0	0	$0	4	$20,000	12	$60,000	4	$20,000	12	$60,000
Subtotal					**$0**		**$0**		**$0**		**$0**		**$55,520**		**$166,560**		**$55,520**		**$166,560**
8	**ANNUAL GW MONITORING (Years 1-3)**																		
	Sampling	per day	$1,200	0	$0	0	$0	0	$0	0	$0	4	$4,800	12	$14,400	4	$4,800	12	$14,400
	Analysis - VOCs, Ethenes	each well	$285	0	$0	0	$0	0	$0	0	$0	16	$4,560	48	$13,680	16	$4,560	48	$13,680
	Analysis - Alkalinity, 1,4-Dioxane	each well	$195	0	$0	0	$0	0	$0	0	$0	16	$3,120	48	$9,360	16	$3,120	48	$9,360
	Reporting	per round	$10,000	0	$0	0	$0	0	$0	0	$0	1	$10,000	3	$30,000	1	$10,000	3	$30,000
Subtotal					**$0**		**$0**		**$0**		**$0**		**$22,480**		**$67,440**		**$22,480**		**$67,440**
8	**ANNUAL GW MONITORING (Years 4+)**																		
	Sampling	per day	$1,200	0	$0	0	$0	0	$0	0	$0	7	$8,400	210	$252,000	7	$8,400	210	$252,000
	Analysis - VOCs, Ethenes	each well	$285	0	$0	0	$0	0	$0	0	$0	27	$7,700	810	$230,850	27	$7,700	810	$230,850
	Analysis - Alkalinity, 1,4-Dioxane	each well	$195	0	$0	0	$0	0	$0	0	$0	27	$5,270	810	$157,950	27	$5,270	810	$157,950
	Reporting	per round	$10,000	0	$0	0	$0	0	$0	0	$0	1	$10,000	30	$300,000	1	$10,000	30	$300,000
Subtotal					**$0**		**$0**		**$0**		**$0**		**$31,370**		**$940,800**		**$31,370**		**$940,800**
9	**IPIM**																		
	Investigation	lump sum	$ 100,000	0	$0	0	$0	0	$0	0	$0	1	$100,000	6	$600,000	1	$100,000	6	$600,000
	Maintenance	lump sum	$ 5,000	0	$0	0	$0	0	$0	0	$0	1	$5,000	30	$150,000	1	$5,000	30	$150,000
Subtotal					**$0**		**$0**		**$0**		**$0**		**$105,000**		**$750,000**		**$105,000**		**$750,000**
10	**PROJECT MANAGEMENT**																		
	Project Management	year	$30,000	1	$30,000	30	$900,000	1	$30,000	30	$900,000	1	$30,000	30	$900,000	1	$30,000	30	$900,000
Subtotal					**$30,000**		**$900,000**		**$30,000**		**$900,000**		**$30,000**		**$900,000**		**$30,000**		**$900,000**

Notes:
1. All costs in 2005 Dollars.
2. Costs are +50% -30%.
3. Assumed 40 hour work week.
4. No taxes have been included.
5. Annual costs are assumed to occur for up to 30 years following remedial construction.
6. Contingency included in individual annual cost items in the NPV table.

TABLE C-4

NET PRESENT VALUE

PSC Georgetown
Seattle, Washington

	HA-1 Active Hydraulic Containment						HA-2 Passive Hydraulic Containment					
Year	Initial & Replacement Costs	Annual O&M, Inspection, IPIM	Project Management	Groundwater Monitoring	Yearly Total	NPV	Initial & Replacement Costs	Annual O&M, Inspection, IPIM	Project Management	Groundwater Monitoring	Yearly Total	NPV
1	$36,900	$152,300	$30,000	$0	$284,960	$266,318	$36,900	$152,300	$30,000	$0	$284,960	$266,318
2		$152,300	$30,000	$0	$236,990	$206,996		$152,300	$30,000	$0	$236,990	$206,996
3		$152,300	$30,000	$0	$236,990	$193,454		$152,300	$30,000	$0	$236,990	$193,454
4		$152,300	$30,000	$0	$236,990	$180,799	$15,683	$5,500	$30,000	$0	$66,537	$50,761
5	$12,500	$152,300	$30,000	$0	$253,240	$180,557	$2,000	$5,500	$30,000	$0	$48,750	$34,758
6		$152,300	$30,000	$0	$236,990	$157,916		$5,500	$30,000	$0	$46,150	$30,752
7		$152,300	$30,000	$0	$236,990	$147,585		$5,500	$30,000	$0	$46,150	$28,740
8		$152,300	$30,000	$0	$236,990	$137,930		$5,500	$30,000	$0	$46,150	$26,860
9		$152,300	$30,000	$0	$236,990	$128,907		$5,500	$30,000	$0	$46,150	$25,103
10	$20,800	$152,300	$30,000	$0	$264,030	$134,219	$10,300	$5,500	$30,000	$0	$59,540	$30,267
11		$152,300	$30,000	$0	$236,990	$112,592		$5,500	$30,000	$0	$46,150	$21,926
12		$152,300	$30,000	$0	$236,990	$105,226		$5,500	$30,000	$0	$46,150	$20,491
13		$152,300	$30,000	$0	$236,990	$98,342		$5,500	$30,000	$0	$46,150	$19,151
14		$152,300	$30,000	$0	$236,990	$91,909		$5,500	$30,000	$0	$46,150	$17,898
15	$12,500	$152,300	$30,000	$0	$253,240	$91,786	$2,000	$5,500	$30,000	$0	$48,750	$17,669
16		$152,300	$30,000	$0	$236,990	$80,277		$5,500	$30,000	$0	$46,150	$15,633
17		$152,300	$30,000	$0	$236,990	$75,025		$5,500	$30,000	$0	$46,150	$14,610
18		$152,300	$30,000	$0	$236,990	$70,117		$5,500	$30,000	$0	$46,150	$13,654
19		$152,300	$30,000	$0	$236,990	$65,530		$5,500	$30,000	$0	$46,150	$12,761
20	$20,800	$152,300	$30,000	$0	$264,030	$68,230	$10,300	$5,500	$30,000	$0	$59,540	$15,386
21		$152,300	$30,000	$0	$236,990	$57,236		$5,500	$30,000	$0	$46,150	$11,146
22		$152,300	$30,000	$0	$236,990	$53,492		$5,500	$30,000	$0	$46,150	$10,417
23		$152,300	$30,000	$0	$236,990	$49,992		$5,500	$30,000	$0	$46,150	$9,735
24		$152,300	$30,000	$0	$236,990	$46,722		$5,500	$30,000	$0	$46,150	$9,098
25	$12,500	$152,300	$30,000	$0	$253,240	$46,659	$2,000	$5,500	$30,000	$0	$48,750	$8,982
26		$152,300	$30,000	$0	$236,990	$40,809		$5,500	$30,000	$0	$46,150	$7,947
27		$152,300	$30,000	$0	$236,990	$38,139		$5,500	$30,000	$0	$46,150	$7,427
28		$152,300	$30,000	$0	$236,990	$35,644		$5,500	$30,000	$0	$46,150	$6,941
29		$152,300	$30,000	$0	$236,990	$33,312		$5,500	$30,000	$0	$46,150	$6,487
30	$20,800	$152,300	$30,000	$0	$264,030	$34,685	$10,300	$5,500	$30,000	$0	$59,540	$7,822
	$136,800	$4,569,000	$900,000	$0	**$7,287,500**	**$3,030,400**	$89,500	$605,400	$900,000	$0	**$2,073,300**	**$1,149,200**

TABLE C-4

NET PRESENT VALUE

PSC Georgetown
Seattle, Washington

	OA-1 Monitored Natural Attenuation							OA-2 Enhanced Anaerobic Bioremediation						
Year	**Initial & Replacement Costs**	**Annual Injection**	**Annual O&M, Inspection, IPIM**	**Project Management**	**Groundwater Monitoring**	**Yearly Total**	**NPV**	**Initial & Replacement Costs**	**Annual Injection**	**Annual O&M, Inspection, IPIM**	**Project Management**	**Groundwater Monitoring**	**Yearly Total**	**NPV**
1	$106,100	$0	$115,500	$30,000	$78,000	$428,480	$400,449	$857,900	$55,500	$115,500	$30,000	$78,000	$1,477,970	$1,381,280
2		$0	$115,500	$30,000	$78,000	$290,550	$253,778		$111,000	$115,500	$30,000	$78,000	$434,850	$379,815
3		$0	$115,500	$30,000	$78,000	$290,550	$237,175		$0	$115,500	$30,000	$78,000	$290,550	$237,175
4		$0	$115,500	$30,000	$31,370	$229,931	$175,413		$0	$115,500	$30,000	$31,370	$229,931	$175,413
5	$2,000	$0	$115,500	$30,000	$31,370	$232,531	$165,791	$2,000	$0	$115,500	$30,000	$31,370	$232,531	$165,791
6		$0	$115,500	$30,000	$31,370	$229,931	$153,213		$0	$115,500	$30,000	$31,370	$229,931	$153,213
7		$0	$20,500	$30,000	$31,370	$106,431	$66,280		$0	$20,500	$30,000	$31,370	$106,431	$66,280
8		$0	$20,500	$30,000	$31,370	$106,431	$61,944		$0	$20,500	$30,000	$31,370	$106,431	$61,944
9		$0	$20,500	$30,000	$31,370	$106,431	$57,891		$0	$20,500	$30,000	$31,370	$106,431	$57,891
10	$10,300	$0	$20,500	$30,000	$31,370	$119,821	$60,911	$10,300	$0	$20,500	$30,000	$31,370	$119,821	$60,911
11		$0	$20,500	$30,000	$31,370	$106,431	$50,565		$0	$20,500	$30,000	$31,370	$106,431	$50,565
12		$0	$20,500	$30,000	$31,370	$106,431	$47,257		$0	$20,500	$30,000	$31,370	$106,431	$47,257
13		$0	$20,500	$30,000	$31,370	$106,431	$44,165		$0	$20,500	$30,000	$31,370	$106,431	$44,165
14		$0	$20,500	$30,000	$31,370	$106,431	$41,276		$0	$20,500	$30,000	$31,370	$106,431	$41,276
15	$2,000	$0	$20,500	$30,000	$31,370	$109,031	$39,518	$2,000	$0	$20,500	$30,000	$31,370	$109,031	$39,518
16		$0	$20,500	$30,000	$31,370	$106,431	$36,052		$0	$20,500	$30,000	$31,370	$106,431	$36,052
17		$0	$20,500	$30,000	$31,370	$106,431	$33,693		$0	$20,500	$30,000	$31,370	$106,431	$33,693
18		$0	$20,500	$30,000	$31,370	$106,431	$31,489		$0	$20,500	$30,000	$31,370	$106,431	$31,489
19		$0	$20,500	$30,000	$31,370	$106,431	$29,429		$0	$20,500	$30,000	$31,370	$106,431	$29,429
20	$10,300	$0	$20,500	$30,000	$31,370	$119,821	$30,964	$10,300	$0	$20,500	$30,000	$31,370	$119,821	$30,964
21		$0	$20,500	$30,000	$31,370	$106,431	$25,704		$0	$20,500	$30,000	$31,370	$106,431	$25,704
22		$0	$20,500	$30,000	$31,370	$106,431	$24,023		$0	$20,500	$30,000	$31,370	$106,431	$24,023
23		$0	$20,500	$30,000	$31,370	$106,431	$22,451		$0	$20,500	$30,000	$31,370	$106,431	$22,451
24		$0	$20,500	$30,000	$31,370	$106,431	$20,983		$0	$20,500	$30,000	$31,370	$106,431	$20,983
25	$2,000	$0	$20,500	$30,000	$31,370	$109,031	$20,089	$2,000	$0	$20,500	$30,000	$31,370	$109,031	$20,089
26		$0	$20,500	$30,000	$31,370	$106,431	$18,327		$0	$20,500	$30,000	$31,370	$106,431	$18,327
27		$0	$20,500	$30,000	$31,370	$106,431	$17,128		$0	$20,500	$30,000	$31,370	$106,431	$17,128
28		$0	$20,500	$30,000	$31,370	$106,431	$16,007		$0	$20,500	$30,000	$31,370	$106,431	$16,007
29		$0	$20,500	$30,000	$31,370	$106,431	$14,960		$0	$20,500	$30,000	$31,370	$106,431	$14,960
30	$10,300	$0	$20,500	$30,000	$31,370	$119,821	$15,741	$10,300	$0	$20,500	$30,000	$31,370	$119,821	$15,741
	$143,000	$0	$1,185,000	$900,000	$1,081,000	**$4,301,700**	**$2,212,700**	$894,800	$166,500	$1,185,000	$900,000	$1,081,000	**$5,495,500**	**$3,319,500**

Notes:
1. Discount rate of 7%.