Revised Technical Memorandum No. 4: Technology Identification and Screening

Site Wide Feasibility Study

PSC Georgetown Facility

Seattle, Washington

Prepared for:

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

January 2007

Project No. 8770

Geomatrix

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1.0 PURPOSE AND SCOPE

This Technical Memorandum has been prepared to document work completed to date for the revised Site Wide Feasibility Study (SWFS) for the Philip Services Corporation (PSC) Georgetown facility.[1] This SWFS is intended to meet corrective action provisions of the PSC Georgetown facility RCRA Part B Permit and the requirements of the MTCA. The Permit, as issued under the authority of the Washington Department of Ecology (Ecology), covers the regulated areas of the former PSC facility operations. PSC closed these areas (and all dangerous waste operations within these areas) in August 2003 under a closure plan approved by Ecology. At that time, all dangerous waste operations at the facility ceased.

During 2003 and 2004, PSC implemented the hydraulic control interim measure (HCIM). The HCIM required construction of (1) a subsurface barrier wall keyed into the aquitard underlying the Site and (2) a pump-and-treat system designed to maintain an inward gradient to contain contaminated groundwater beneath the facility and adjacent properties. Implementation of the HCIM required PSC to purchase the TASCO property and adjoining railroad spur, and to acquire easements on two other properties adjacent to the facility (the Stone-Drew/ Ashe &

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[1] Throughout this memorandum, the term "facility" is used to refer to the former Resource Conservation and Recovery Act (RCRA) dangerous waste operations located at 734 South Lucile Street, owned and operated by PSC. The term "corrective action facility" may also include certain properties adjacent to the former dangerous waste facility property that were acquired by PSC following closure of the dangerous waste operations in August 2003 (e.g., adjacent property to the northwest formerly owned by The Amalgamated Sugar Company [TASCO] that was impacted by historical releases from the PSC facility). The facility RCRA Part B permit (Permit) requires PSC to perform corrective action beyond the boundaries of the permitted facility to address such releases. The Washington Model Toxics Control Act (MTCA) regulations, Washington Administrative Code [WAC] Chapter 173-340 , also require PSC to perform cleanup actions to address releases from the facility at "any site or area where a hazardous substance has been deposited, stored, disposed of, or placed, or otherwise come to be located" (*see* WAC 173-340-200). For purposes of this Technical Memorandum, the term "Site" includes both the facility and other areas (e.g., TASCO) that have been affected by releases that occurred at the facility.

Jones [SAD] property and the Aronson property). The HCIM has proven effective in providing hydraulic control of contaminated groundwater in these areas of the Site.

The Permit requires that the SWFS address all areas affected by releases from the facility. The area addressed by the SWFS (i.e., the SWFS Area) includes the properties currently owned by PSC (the facility and the adjacent TASCO property), portions of properties adjacent to the PSC properties (Union Pacific Rail Road [UPRR], Aronson, and SAD properties), and the contiguous areas affected by releases from the facility extending downgradient (west) to Fourth Avenue South. The area affected by facility releases has been defined in the RI Report and subsequent Addenda. After the RI Report was completed, additional releases to soil and groundwater from non-PSC sources were identified downgradient from the facility, near Fourth Avenue South. The specific chemicals released in these downgradient areas include many of the facility constituents of concern (COCs). These downgradient releases have resulted in an area of comingled 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. Remedial action for the area downgradient from Fourth Avenue South will be addressed separately.

In response to comments received from Ecology on the initial draft SWFS report, PSC and Ecology have agreed to use a collaborative, phased process in preparing the revised draft SWFS report to ensure consensus among PSC, Ecology, and other interested parties on key issues that affect the SWFS. During this process, PSC will develop the five separate Technical Memoranda addressing the topics listed below to satisfy Permit and MTCA requirements for the complete SWFS:

1. Cleanup Levels, Constituents of Concern, Point of Compliance, Fate and Transport Modeling, and Corrective Action Schedule
2. Remediation Areas
3. Inhalation Pathway Interim Measure
4. Technology Identification and Screening
5. Remedial Alternatives Development and Evaluation

PSC will prepare and submit each technical memorandum in draft form to Ecology. Following Ecology review and comment, PSC will revise the draft memoranda as appropriate for final approval by Ecology. It was agreed that work on Technical Memorandum No. 4 (this memorandum) would begin after Ecology's final approval of both Technical Memoranda Nos. 2 and 3. Technical Memorandum No. 5 will be prepared after final approval of Technical Memorandum No. 4. PSC will prepare the complete revised draft SWFS following Ecology's approval of Technical Memorandum No. 5 by combining the five memoranda listed above.[2]

This memorandum identifies and evaluates remediation technologies that could potentially be implemented to address soil and groundwater impacts within the SWFS Area. Based on this initial screening, remedial alternatives are identified for further consideration and evaluation in the SWFS. Additionally, this memorandum presents the remediation objectives of the SWFS and describes current groundwater trends, both within the HCIM Area and the Outside Area.

To avoid creating acronyms in the continuing text of this memorandum, a list of acronyms and shortened names for terms not otherwise defined in the text is presented below:

API	Asian Pacific Islander
ARAR	Applicable state and federal laws
BTEX	benzene, toluene, ethylbenzene, and xylenes
bgs	below ground surface
C1	Commercial 1 zone
cis-1,2-DCE	cis-1,2-dichloroethene
cm/sec	centimeters per second
CPOC	conditional point of compliance
COC	constituent of concern
COI	constituent of interest
COPC	constituent of potential concern
DNAPL	dense nonaqueous phase liquid
EPA	U.S. Environmental Protection Agency

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[2] These memoranda have been designed so that individual sections may be incorporated directly into the revised draft FSWP. It is anticipated that the text from the individual memoranda will appear in the report in a sequence different from the sequence of the memoranda as submitted to Ecology.

EPC	exposure point concentration
EZVI	Emulsified zero-valent iron
FS	feasibility study
GAC	granular activated carbon
gpm	gallons per minute
HCIM Area	area within the hydraulic control interim measure barrier wall
HRC	hydrogen-releasing compound
HSRA-1	HCIM Area Soil Remediation Area 1
HSRA-2	HCIM Area Soil Remediation Area 2
HWMU	hazardous waste management unit
ICOC	indicator constituent of concern
IG1	General Industrial 1 zone
IG2	General Industrial 2 zone
IPIM	inhalation pathway interim measure
LNAPL	light nonaqueous phase liquid
µg/kg	micrograms per kilogram
µg/L	micrograms per liter
mV	millivolts
mg	milligram
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
MDL	method detection limit
NAPL	nonaqueous phase liquid
NPDES	National Pollutant Discharge Elimination System
NPV	net present value
O&M	operation and maintenance
ORC	Oxygen Release Compound™
OSIRA-1	Outside Area Shallow/Intermediate Remediation Area 1
OSIRA-2	Outside Area Shallow/Intermediate Remediation Area 2

OSIRA-3	Outside Area Shallow/Intermediate Remediation Area 3
OSRA-1	Outside Soil Remediation Area 1
OSRA-2	Outside Soil Remediation Area 2
OSRA-3	Outside Soil Remediation Area 3
Outside Area	the SWFS Area outside the boundaries of the HCIM Area
OWTRA-1	Outside Area Water Table Remediation Area 1
OWTRA-2	Outside Area Water Table Remediation Area 2
OWTRA-3	Outside Area Water Table Remediation Area 3
PAH	polycyclic aromatic hydrocarbon
PCB	polychlorinated biphenyl
PCE	tetrachloroethene (perchloroethylene)
POTW	publicly owned treatment works
PRB	permeable reactive barrier
PQL	practical quantitation limit
redox	reduction/oxidation
RI	remedial investigation
RL	remediation level
SAD	Stone-Drew/Ashe & Jones
scfm	standard cubic feet per minute
SEAR	surfactant-enhanced aquifer remediation
SVOC	semivolatile organic compound
SWFS	Site Wide Feasibility Study
SWFS Area	area within the scope of the SWFS
SWMU	solid waste management unit
SPOC	standard point of compliance
SVE	soil vapor extraction
TASCO	The Amalgamated Sugar Company [
TCE	trichloroethene
TPH	total petroleum hydrocarbon

TSD	treatment storage disposal
UPRR	Union Pacific Railroad Company
UST	underground storage tank
VC	vinyl chloride
VIAM	vapor intrusion assessment and mitigation
VOC	volatile organic compound
WAC	Washington Administrative Code

2.0 REMEDIATION AREAS

This section of Technical Memorandum 4 summarizes the various remediation areas being addressed by the SWFS and presents a summary of COCs for each area. The SWFS Area has been separated into two general areas for the purposes of the SWFS: (1) the area enclosed by the HCIM barrier wall (HCIM Area) and (2) the portion of the SWFS Area outside the barrier wall (Outside Area). The technical justification for the individual remediation areas addressed in this memorandum was presented in the SWFS Technical Memorandum No. 2. The RI data, which were the primary source used to develop remediation areas, are at this point in time largely outdated. Therefore, this section also presents a discussion of current conditions based on the most recent groundwater monitoring results and the trends over time shown by the monitoring.

2.1 HCIM REMEDIATION AREAS

The HCIM Area is defined as the area contained by the barrier wall and includes portions of the facility, the TASCO property, the Aronson Property, and the SAD property. The perimeter of the HCIM Area is totally enclosed by a low-permeability barrier wall. The bottom of the HCIM Area consists of an aquitard with a permeability estimated on the order of 10^{-6} to 10^{-5} cm/sec. The former primary source areas associated with the facility at which historical releases are thought to have primarily occurred are located on the facility within the HCIM Area. Therefore, the highest observed constituent concentrations in both soil and groundwater are contained by the barrier wall. Remediation areas for soil and groundwater within the HCIM Areas were defined in SWFS Technical Memorandum No. 2.

2.1.1 Soil Remediation Areas

The RI results presented in Appendix 9A of the RI report and summarized in SWFS Technical Memorandum No 2 indicate that concentrations of COCs in all five COC classes (VOCs, SVOCs, PCBs, inorganics, and TPH) in soil exceed cleanup levels on the facility. However, these soil constituents have not been observed on the adjacent properties, including TASCO (now owned by PSC), SAD, or Aronson, and the concentrations of the COCs detected in shallow groundwater on the adjacent properties are not indicative of ongoing source areas present in soil. The nature and distribution of soil constituents in the HCIM Area provide a general basis for selection of soil remediation areas; specifically, the portions of the facility inside the HCIM Area will be considered a single remediation area for soil and the TASCO, SAD, and Aronson properties will be considered a second remediation area. The HCIM Area soils present on TASCO, SAD, and Aronson properties are not anticipated to be significantly impacted, except in the areas immediately adjacent to portions of the facility that were previously actively used for site operations. Figure 2-1 shows the two soil remediation areas defined for the HCIM Area. The remediation area incorporating the facility is referred to as HCIM Area Soil Remediation Area 1 (HSRA-1); the TASCO, SAD, and Aronson properties within the HCIM Area are referred to as HCIM Area Soil Remediation Area 2 (HSRA-2).

2.1.2 Groundwater Remediation Areas

Groundwater within the HCIM Area has been impacted with the same COCs that are found in soil. The impacts to groundwater for constituents other than PCBs are known to be present throughout the entire HCIM Area, including all saturated zones above the aquitard on the facility and the TASCO, Aronson, and SAD properties. Groundwater impacted by PCBs appears to be limited to the North Field, West Field, and the central portion of the facility. With the exception of PCBs, the different COC classes generally co-exist in groundwater distributed over most of the HCIM Area. Therefore, the nature and distribution of groundwater constituents do not provide a basis for defining groundwater remediation areas, though the exposure pathways associated with different intervals will vary.

Site investigation data indicate that DNAPL is likely present within two portions of the HCIM Area. The areas considered most likely to be impacted by DNAPL, based on groundwater constituent concentrations exceeding 1% of the TCE solubility, include the North Field area, portions of the TASCO property, and the area northeast of the SAD property. DNAPL is likely present in the silt layers of the interbedded sand and silt aquifer down to the Silt Aquitard. The anticipated distribution of DNAPL within the HCIM Area does not appear to warrant the creation of separate groundwater remediation areas to address it. The identified areas can be effectively addresses as "hot spots" within affected groundwater. Therefore, a single HCIM Groundwater Remediation Area has been created, as shown on Figure 2-2.

Groundwater recovery and natural biodegradation reactions are expected to change the nature and distribution of groundwater COCs within the HCIM Area. Groundwater monitoring data show that reductive dechlorination reactions are active within the HCIM Area. These reactions are expected to reduce groundwater concentrations of the chlorinated solvents. The monitoring data show that groundwater concentrations for the less toxic non-chlorinated VOCs are generally constant within the HCIM Area, which is expected due to the reducing conditions that are present.

Access to the HCIM Area is reasonably available. Most of the property within the HCIM Area is owned by PSC and is not actively used. The two small areas extending onto the Aronson and SAD properties are covered by an easement. Land use over the Aronson and SAD areas is for parking and/or equipment storage, which would not significantly affect access needed for remediation. In the event that PSC sells or leases the facility or the TASCO property in the future, an access agreement would be included in the sale or lease agreement to ensure that remediation and monitoring activities can and will be performed to address affected groundwater. Therefore, access and land use considerations would not substantially affect remedial action for the HCIM Area, and do not provide a basis for defining groundwater remediation areas inside the HCIM Area.

2.2 HCIM AREA CURRENT CONDITIONS

Recently collected groundwater monitoring data for facility wells indicate that the containment system has maintained conditions conducive to active biodegradation. Data collected in Spring 2006 show a generally decreasing trend for TCE in some monitoring wells. Data from the same wells show an increasing trend for VC and cis-1,2-DCE, both of which are biodegradation products of TCE. These data indicate that reductive dechlorination is active in the HCIM Area; it is expected that concentrations of VC and cis-1,2-DCE will decrease in the future as the mass of TCE decreases and degradation of VC and cis-1,2-DCE progresses to ethane and CO2. Figures displaying concentration trends through Spring 2006 at several wells within the HCIM Area are included in Appendix A.

2.3 OUTSIDE AREA REMEDIATION AREAS

The Outside Area is a densely developed urban area that includes private and public landowners. Land uses are varied and include residences and both commercial and industrial businesses. Many active subsurface utilities are also present in this area. The Outside Area incorporates affected portions of the properties neighboring the facility, including the UPRR property (to the east of the PSC facility), the SAD property (to the southwest of the PSC facility), and the Aronson property (to the north of the PSC property). The Outside Area also includes areas extending west of Denver Avenue South. Remediation areas have been defined for soil and groundwater within the Outside Area.

2.3.1 Soil Remediation Areas

Site investigations have identified limited portions of the Outside Area where soil has been impacted at concentrations exceeding final SWFS cleanup levels. Most of the soil within the

Outside Area has not been affected by facility releases. The impacted soil areas are either on or adjacent to the facility. Data presented in the Off-site Soil Characterization Report (Geomatrix, 2006) and the RI report indicate that there are three general outside areas that have been impacted by COCs at concentrations exceeding final SWFS cleanup levels. These three areas have been defined as soil remediation areas for the Outside Area.

The first soil remediation area is located on UPRR property adjacent to the facility property boundary. This area is described in detail in the Off-site Soil Characterization Report (Geomatrix, 2006). The area along the facility property line with UPRR that appears to have been impacted by facility releases has been designated as a soil remediation area. For the SWFS, it will be designated as Outside Soil Remediation Area 1 (OSRA-1). Soil within OSRA-1 has been affected by several organic COCs, including VOCs (both chlorinated and non-chlorinated), SVOCs, TPH, paint thinner, metals, and PCBs. This area is used as a rail yard, and is adjacent to active rail lines. Remedial actions in OSRA-1 must be protective of rail lines, require property negotiations, and require detailed planning to minimize adverse impacts to UPRR operations. OSRA-1 is shown on Figure 2-1.

The second soil remediation area is located on facility property, southeast of the HCIM barrier wall. This area has been impacted by VOCs, metals, and PCBs. This area has been designated as Outside Soil Remediation Area 2 (OSRA-2) and is shown on Figure 2-1. Although located on PSC property, this area extends onto the utility easement along South Lucile Street. The utility easement may represent a constraint for some remediation technologies for this area.

The third Outside Soil Remediation Area is located on facility property and extends onto the SAD property. This includes soils between the barrier wall and the SAD building, soils beneath the SAD building, and soils extending to South Lucile Street and Denver Avenue South. Soils on the PSC portion of this area are impacted by VOCs, SVOCs, TPH, metals, and PCBs, although it is not known whether or not these COCs extend much below the SAD building. This soil remediation area has been designated as Outside Soil Remediation Area 3 (OSRA-3), as shown on Figure 2-1. This soil remediation area is constrained by the SAD building, the HCIM barrier wall, and utility easements along both South Lucile Street and Denver Avenue South. These two structures and easements will affect access to implement select soil remediation technologies in this area.

2.3.2 Groundwater Remediation Areas

Groundwater within much of the Outside Area has been affected by COCs at concentrations exceeding final SWFS cleanup levels. Substantial evidence has also been collected that almost all organic COCs are actively degrading and/or attenuating within the saturated zone. In general, groundwater COCs are highest in the area near the facility and decrease in concentration as groundwater moves downgradient, toward the Duwamish Waterway. Given the nature and extent of groundwater COCs within the Outside Area, it is appropriate to identify groundwater remediation areas. Based on the considerations identified above, four groundwater remediation areas have been defined for the Outside Area, as discussed below.

2.3.2.1 SAD Property Area

Based on the highest observed Outside Area COC concentrations in groundwater, the areas located between the barrier wall and the SAD building and extending west and south, beneath the SAD property, have been defined as groundwater remediation areas for the water table and shallow/intermediate depth intervals. These groundwater remediation areas have been designated as Outside Area Water Table Remediation Area 1 (OWTRA-1) and Outside Area Shallow/Intermediate Remediation Area 1 (OSIRA-1), as shown on Figures 2-3 and 2-4, respectively. These remediation areas are co-located within the area extending from the barrier wall west to Denver Avenue South and south to South Lucile Street. These remediation areas are co-located with soil remediation area OSRA-3. Groundwater within OWTRA-1 and OSIRA-1 has multiple groundwater COCs, including VOCs (both chlorinated and non-chlorinated), SVOCs, TPH, PCBs, and metals. Groundwater within OWTRA-1 has generally higher COC concentrations than groundwater within OSIRA-1. PSC can readily access the portion of these remediation areas on PSC property located on the upgradient portion of this area. Remediation will be constrained by the SAD structures, the barrier wall, SAD site activities, and the utility easements along South Lucile Street and Denver Avenue South. Due to the proximity of this remediation to the SAD building and the likelihood that groundwater remediation would extend beneath their property, it is expected that SAD would need to approve remediation plans for both of these remediation areas prior to implementing remediation.

2.3.2.2 South Denver Avenue Area

Groundwater beneath the area located downgradient of the HCIM barrier wall and extending to the area near South Denver Avenue has been impacted by relatively high concentrations of VOCs and SVOCs, although this area is less impacted than the area near and beneath the SAD property. This area has been impacted by VOCs (chlorinated and non-chlorinated), SVOCs, TPH, and metals in the water table, shallow, and intermediate depth intervals. Remediation areas have been defined separately for the water table and the shallow/intermediate depth intervals. The water table remediation area has been designated as Outside Area Water Table Remediation Area 2 (OWTRA-2) and the shallow/intermediate remediation area has been designated as Outside Area Shallow/Intermediate Remediation Area 2 (OSIRA-2), as shown on Figures 2-3 and 2-4, respectively. Both remediation areas encompass properties owned by PSC, Aronson, SAD, the City of Seattle, and several property owners along the west side of Denver Avenue South. Remediation in these areas would be constrained by access issues due to the multiple property owners, current land use at these properties, and the presence of utilities beneath and along Denver Avenue South.

2.3.2.3 Remaining Outside Area

The remaining portion of the Outside Area groundwater extends from the area near Denver Avenue South downgradient to the westernmost extent of the SWFS Area, along Fourth Avenue South. This area is a heavily developed urban area with numerous and diverse property owners and several public roads. Due to the heavy urban development, number of property owners, and extensive network of underground utilities in this area, potential access issues related to select remediation technologies could be extremely complex. It should be noted that in the time since the facility source area has been contained by the HCIM, groundwater monitoring data within the Outside Area have shown a decreasing trend for most COCs, especially near the former facility. Remediation areas have been defined separately for the water table depth interval and the shallow/intermediate depth intervals based on different COCs and different cleanup levels.

The water table remediation area has been designated as Outside Area Water Table Remediation Area 3 (OWTRA-3). This area is shown in Figure 2-3 and covers the area extending from OWTRA-2 to Fourth Avenue South. The COCs present in this area include VOCs (primarily chlorinated), SVOCs, TPH, and metals. 1,4-Dioxane has not been detected in this remediation area at concentrations exceeding cleanup levels.

The shallow/intermediate remediation area has been designated as Outside Area Shallow/Intermediate Remediation Area 3 (OSIRA-3), as shown on Figure 2-4. COCs present in this remediation area include VOCs, SVOCs, TPH, and metals. This remediation area includes the 1,4-dioxane plume that has been identified within the SWFS Area. Remediation of 1,4-dioxane requires different considerations than the other constituents.

Several wells located in this portion of OWTRA-3 and OSIRA-3 had EPCs for chlorinated VOCs exceeding final SWFS cleanup levels based on protection of surface water. In order to assess the potential for these wells to impact the Duwamish Waterway, modeling was conducted using BIOCHLOR to estimate the concentration of chlorinated solvents remaining in groundwater at the point it discharges to the Duwamish. The modeling parameters used for assessing cleanup levels (Technical Memorandum No. 1) were used for this modeling; only the source concentration (the EPC) and the distance to the Duwamish were changed. Model runs were conducted for each well with the EPC for chlorinated solvents exceeding the final SWFS cleanup level.

The results for these model runs are presented in Table 2-1. The predicted concentrations of all constituents at the Duwamish for all wells other than for TCE in Well CG-131-WT were below final SWFS cleanup levels based on protection of surface water. For Well CG-131-WT, the predicted TCE concentration at the Duwamish is less than two times the cleanup level. The TCE EPC used for modeling from this well is 50.9 µg/L; monitoring data collected during semiannual sampling during 2005 and 2006 show a decreasing trend in TCE concentration for monitoring well CG-131-WT, with 26 µg/L TCE detected during the first quarter of 2006 (PSC, 2006). Given the decreasing trend observed in this well and the conservative modeling approach used to assess the potential impact from the downgradient wells, it is unlikely that the concentrations observed in CG-131-WT are contributing to risks in the Duwamish Waterway. It should also be noted that several downgradient water table wells also have constituents that exceed final SWFS cleanup levels based on the inhalation pathway; the VIAM presently manages risks associated with the water table constituents.

2.3.2.4 Deep Aquifer

A separate remediation area has been designated for the deep aquifer. This remediation area is designated as the Deep Aquifer Remediation Area. This remediation area extends from beneath the facility property to Fourth Avenue South, downgradient of the facility. Five wells have been completed within the deep aquifer; one of these wells is located on the facility, one is just upgradient, two are located near Denver Avenue South, and one is located near South Lucile Street. The four off-site wells are very near the facility; therefore, these wells provide limited information regarding the nature and extent of constituents in the deep aquifer. The aquitard underlying the facility has only been identified in these five wells; no downgradient wells have identified the aquitard; the extent of the aquitard is not defined by these wells and other borings conducted for the RI.

Even though the aquitard has not been observed in borings conducted downgradient of the facility, it is expected that the aquitard is continuous from the facility to the Duwamish Waterway. Soil borings located at the Boeing Development Center, near River Mile 4.5, confirm that the aquitard is present adjacent to the Duwamish at an elevation of -50 to -30 feet MSL. Borings at the former Rhone-Poulenc facility (River Mile 4.1) indicate that the aquitard is present next to the Duwamish at an elevation of -55 to -45 ft MSL. Data from these two sites suggest that the depth to the aquitard increases towards the north. The discharge area downgradient of the facility is in the vicinity of River Mile 1.5, about 2.5 river miles downstream from the former Rhone-Poulenc site. These data indicate that the it is likely that the aquitard identified beneath the facility extends to the Duwamish, separating the water table, shallow, and intermediate depth intervals from the deep aquifer. Therefore, the two groundwater units should be treated as separate flow systems.

Available bathymetric data indicate that the deep aquifer does not discharge to the Duwamish Waterway. Based on the bathymetry data presented by David Evans and Associates (David Evans and Associates, Inc., 2003), the bottom of the Duwamish Waterway is at an elevation of about -40 to -45 ft MSL near River Mile 1.5. Given that the elevation of the top of the deep aquifer is at about -90 ft MSL in the vicinity of the facility (and appears to be greater than this depth nearer to the Duwamish), it is unlikely that the deep aquifer discharges to the river. It is more likely that the deep aquifer discharges to Elliot Bay, to the northwest of the facility. This would result in a significantly longer flow path for deep aquifer groundwater. This conclusion is also consistent with the increased salinity observed in the deep aquifer.

Although historic data indicate several constituents exceed cleanup levels in the Deep Aquifer Remediation Area, more recent data and observed trends indicate that organic COCs, including VOCs and SVOCs, may not exceed cleanup levels in the Deep Aquifer Remediation Area. Concentrations of several metals exceed cleanup levels in the Deep Aquifer Remediation Area; the same metals exceed cleanup levels in the area upgradient of the Deep Aquifer Remediation Area. Selenium exceeds cleanup levels in the deep aquifer, but selenium concentrations in the water table, shallow, and intermediate depth intervals beneath the facility are below cleanup levels, indicating that the observed deep aquifer selenium is not related to facility releases.

Given the expected flow path for deep aquifer groundwater (to Elliot Bay rather than the Duwamish) and the generally low constituent concentrations observed in the deep aquifer, it is expected that natural attenuation will be more significant in the deep aquifer than in the shallower groundwater. Additionally, given the depth of the unit and the low concentrations of organic constituents observed in the well samples, it is considered unlikely that facility releases have significantly affected geochemistry in the deep aquifer, resulting in the dissolution of metals. Many of the metals observed in the deep aquifer are likely due to the naturally reducing conditions observed in the groundwater.

2.4 OUTSIDE AREA CURRENT CONDITIONS

Chlorinated VOCs were selected as the primary indicator COCs in preliminary SWFS documents based on their distribution, persistence, mobility, and toxicity. Indicator COCs have been routinely monitored in groundwater monitoring wells near and downgradient of the barrier wall since its installation. In the 2005 HCIM Annual Report, PSC assessed trends in the concentrations of indicator constituents TCE, *cis*-1,2-DCE, and vinyl chloride in groundwater from wells in the vicinity of the facility. The qualitative and statistical trend analysis performed on the monitoring results for 2005 and first half of 2006 indicate that groundwater quality downgradient of the barrier wall in the depth intervals above the silt-confining unit is improving. TCE, *cis*-1,2-DCE, and vinyl chloride concentrations measured in groundwater samples from wells located downgradient of the wall generally are decreasing or remaining constant.

The only exception to this general trend in concentration is the area east of the SAD property at CG-149-WT, a water table depth interval well. Groundwater results from this well showed sudden increases in TCE, *cis*-1,2-DCE, and vinyl chloride concentrations. Concentrations of these indicator constituents peaked in the third quarter of 2005; however, since then indicator COC concentrations detected at CG-149-WT have decreased during the first two quarters of 2006 monitoring. The concentrations of these indicator COCs at CG-149-WT are substantially higher than those observed at other wells located near the barrier wall and along Denver Avenue South. They are also higher than the intermediate depth interval well collocated with CG-149-WT, CG-149-68, which has consistently shown concentrations of TCE, *cis*-1,2-DCE, and vinyl chloride two to four orders of magnitude lower than those detected in CG-149-WT.

3.0 REMEDIATION OBJECTIVES

As previously discussed, the SWFS Area has been separated into two general areas for the purposes of the SWFS: (1) the HCIM Area and (2) the Outside Area. As discussed in Technical Memorandum No. 2, the HCIM and Outside Areas were further subdivided into individual soil and groundwater remediation areas based on several factors, including the nature and distribution of impacts, previously implemented interim measures, site ownership, and land use. Different remediation objectives must be considered for the HCIM Area and the Outside Area due to the significant differences in soil and groundwater conditions between the two areas, differences in property ownership and accessibility, and the issues affecting attainment of cleanup levels within a reasonable timeframe. The general remediation objectives that apply to the entire SWFS Area, as well as remediation objectives specific to the HCIM and Outside Areas, are presented below.

3.1 GENERAL OBJECTIVES

The remediation objectives presented in the RI Report and approved by Ecology can be applied to the entire SWFS Area. These general remediation objectives are summarized as 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 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.

3.2 HCIM AREA REMEDIATION OBJECTIVES

Several features specific to the HCIM Area will affect remediation and development of remediation alternatives. This area includes the source areas associated with the facility and also the highest observed constituent concentrations in soil and groundwater. Groundwater concentrations suggest that DNAPL is likely present in two areas of the HCIM Area, although DNAPL has not been observed in soil borings or monitoring wells to date. As discussed in Section 5.3 of Technical Memorandum No. 1, subsurface stratigraphy and vertical distribution of COC concentrations indicate that DNAPL ganglia are likely distributed throughout the soil profile and are associated with the numerous silt and fine-grained sand lenses within the HCIM Area. The portion of the HCIM area that was the former RCRA facility was investigated during the RI; however, this property was known to be heavily contaminated. As a result, the investigations focused primarily on the edges of the most heavily contaminated area, since it was assumed that heavy contamination by a wide variety of COCs existed in the subsurface throughout most of the former facility. This fact is not obvious when the RI is reviewed because of the tendency to avoid installing borings (and potential migration pathways) in the most heavily impacted areas. The result is there is very little documentation of the potential presence of DNAPL since PSC avoided drilling through the known DNAPL areas due to concerns of potentially creating a vertical migration pathway to deeper aquifers.

The conceptual model for contaminant distribution within the former facility area is based on a thorough understanding of the site history (presented in the RI), the known releases from the USTs in the North field area, the drum storage activities conducted on site in the late 1970s and early 1980s, and indications of DNAPL concentrations in groundwater from monitoring wells. The location of the barrier wall on the TASCO, SAD, and Aronson properties was partially based on concentrations of VOCs indicating the potential presence of DNAPL. The northwest portion of the HCIM Area, which encompasses a portion of the TASCO and Aronson properties, clearly had VOC concentrations of groundwater well above levels suggesting DNAPL at depths down to the intermediate silt. Similar concentrations were found in groundwater along the SAD/PSC property line, although only in the water table and shallow depth intervals.

Based on recent off-site investigation work along the SAD property line and on UPRR property, the soils in areas where drums were stored can be expected to have high concentrations of VOCs, SVOCs, TPH, PCBs, and metals. Since drum storage and other waste management activities were conducted over much of the facility at various times, soil and groundwater should be assumed to be impacted throughout the portions of the former facility area inside the HCIM barrier wall.

Based on the constraints and considerations discussed above, PSC developed the following remediation objectives for the HCIM Area in addition to the general remediation objectives that apply to the entire SWFS Area:

- 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 (the installation of a subsurface barrier wall and a groundwater extraction and pretreatment system) has proven effective in controlling the discharge of impacted groundwater from the facility.

- To the extent practicable, reduce constituent concentrations in groundwater to below remediation levels, and ultimately cleanup levels, within the shortest practicable timeframe.
- Ensure that any remedial actions implemented within the HCIM Area are compatible with the HCIM barrier wall.
- Support future redevelopment and reuse of the Facility and the TASCO properties for industrial purposes.

3.3 OUTSIDE AREA REMEDIATION OBJECTIVES

Similar to the HCIM Area, the nature of the Outside Area will affect remediation efforts and the development of practicable remedial alternatives. The area is densely developed and includes public and private landowners. The area is characterized by mixed land use, including industrial, commercial, and residential development. A portion of the UPRR Argo Rail Yard is included in the Outside Area. The area also includes busy public streets and many active subsurface utilities. The large number of independent property owners and tenants may significantly complicate obtaining access agreements to private properties to perform remediation or monitoring activities.

In general, releases from the PSC facility did not affect Outside Area soil, with the noted exceptions of the adjacent UPRR rail yard and portions of the PSC facility located outside the barrier wall. The highest COC concentrations in groundwater are typically found immediately downgradient of the HCIM barrier wall, with some lower concentration "hot spots" located farther downgradient.

Based on the constraints and considerations discussed above, PSC developed the following remediation objectives for the Outside Area in addition to the general remediation objectives established for the entire SWFS Area:

- Attain remediation levels at the CPOC (refer to Technical Memorandum No. 1) 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 and reasonably expected future land uses within the Outside Area;

- Do not create nuisance conditions or conditions adverse to remediating downgradient source areas; and

- Be compatible with the existing interim measures (both the HCIM and the IPIMs).

4.0 POTENTIALLY APPLICABLE REMEDIATION TECHNOLOGIES

Section 4 presents the potentially applicable remediation technologies considered in this SWFS to address the exposure pathways associated with the concentrations of COCs in soil and groundwater located in 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 COCs and applicable remediation technologies, the technologies are described for the remediation areas within both the HCIM Area and the Outside Area. Institutional controls for both soil and groundwater are discussed in Section 4.4. Technologies were selected and evaluated relative to the specific remediation considerations for the two areas and for the remediation areas defined within the HCIM Area and the Outside Area. The potential remediation technologies are screened against the evaluation criteria listed in Section 4.1. Section 4.6 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 4-1 through 4-4 present the remediation technologies that were considered for the SWFS and the technology screening results.

4.1 TECHNOLOGY SCREENING CRITERIA

The technologies described in Sections 4.1, 4.2, and 4.4 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 remediation objectives presented in Section 3 of this Technical Memorandum and physical site characteristics. The criteria used for screening remediation technologies are as follows:

- **Technology Development Status:** (bench, pilot, or full scale): This criterion refers to 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 (especially environments similar to the SFWS Area) would be favored over technologies with a more restricted application record.

- **Performance Record:** This criterion refers to the technology's 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:** This criteria refers to the 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:** This criterion refers to 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) might be difficult to implement due to the associated logistical and administrative challenges; it is possible that in select cases some of these technologies might not be practicably implementable. 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. However, technologies that arrest or interrupt natural degradation will not be discounted if they achieve desirable end results. Finally, technologies that are compatible with existing interim measures, specifically, the existing HCIM barrier wall, would be favored.

4.2 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 destruction, removal, or containment of contaminants. In situ remediation technologies for soil are described in Section 4.2.1 and ex situ technologies in Section 4.2.2. The screening results for these technologies are provided in Tables 4-1 and 4-2 for the HCIM and Outside Areas, respectively.

4.2.1 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.

4.2.1.1 Bioventing

Bioventing stimulates the natural biodegradation of aerobically degradable compounds in soil by providing oxygen to existing soil microorganisms. 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 VOCs. Its applicability to halogenated hydrocarbons, high molecular weight SVOCs, PCBs, and inorganics is very limited. Due to the variety of COCs present in HSRA-1, this technology would only provide partial remediation. For HSRA-2 and OSRA-1, -2, and -3, where the predominant COCs are chlorinated VOCs, this technology would not be effective.

Monitoring for soil vapors must be conducted to ensure that volatile compounds do not migrate into indoor air. Vapor monitoring requirements in the HCIM Soil Remediation Areas would not need to be extensive under present conditions, but would become more significant after redevelopment of the areas. For OSRA-1 and OSRA-3, vapor monitoring would potentially be required in the SAD building the UPRR building, and, possibly, the Aronson warehouse. Within the HCIM and Outside Soil Remediation Areas, there is very little available vadose zone to implement bioventing. This technology was rejected for use in the SWFS.

4.2.1.2 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. Enhancements to the approach can include the addition of acclimated microorganisms (bioaugmentation) and/or alternative oxygen sources such as hydrogen peroxide or aboveground aeration chambers. 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 a number of years to accomplish remedial goals. In some cases, bioremediation rates diminish before remediation goals are met, leaving residuals in place at lower concentrations but potentially at concentrations that still greatly exceed cleanup levels. Enhanced bioremediation has been demonstrated effective for non-halogenated VOCs and the lighter, non-halogenated SVOCs as well as fuel hydrocarbons. It has not been proven effective on inorganics, PCBs, or chlorinated compounds in soil and actually may interfere with the natural degradation of these compounds. Frequently, groundwater capture systems are required to capture infiltrating aqueous solutions that are applied to stimulate biological activity. On the basis of these limitations, this technology is not considered applicable in any of the soil remediation areas and has been rejected.

4.2.1.3 Chemical Oxidation

In situ chemical oxidation (ISCO) involves the application of a chemical oxidant, such as permanganate, ozone, Fenton's Reagent, or hydrogen peroxide, into the subsurface to react with organic contaminants. The ISCO reaction by-products are nonhazardous compounds that are more stable, less mobile, and/or inert (Siegrest, 2000). ISCO results in 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. Although typically applied to impacted groundwater, chemical oxidants may also be applied to vadose zone soils through the use of infiltration galleries, vertical or horizontal injection wells, or direct push injection points with forced advection to rapidly move the oxidant into the subsurface.

The rate and extent of oxidation of a target COC are dictated by several factors: (1) the properties of the chemical itself; (2) its susceptibility to oxidative degradation; and (3) the matrix conditions, most notably the concentration of oxidant and of other oxidant-consuming substances (such as natural organic matter, reduced minerals, 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. Subsurface heterogeneities and preferential flow paths may result in inefficient treatment. Dispersion and groundwater advection assist groundwater ISCO treatment systems with achieving oxidant contact with contaminants. In the vadose zone, however, distribution of the oxidant relies solely on injection under pressure and vertical migration, resulting in the need for more closely spaced injection points.

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

The geologic conditions for HSRA-1and -2, and for OSRA-1, -2, and -3, are essentially the same. The limited depth of the vadose zone (less than about 10 feet) would limit the cost effectiveness of this technology; an extensive distribution network would be needed to distribute reactant and the limited depth would result in a high cost for treating a small soil volume. For HRSA-1 and -2, access would be readily available and the significant safety concerns from handling the hazardous chemicals needed for chemical oxidation could be addressed. For OSRA-1, -2, and -3, safety issues from handling hazardous oxidation chemicals would be significant since these areas are actively used for industrial purposes. On the basis of these limitations, this technology was rejected for all soil remediation areas.

4.2.1.4 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 practicable, 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 both HSRA-1 and -2 and the OSRA-1, -2, and -3, this technology would only address a small percentage of the COCs present, and would leave key COCs in place. As noted above for chemical oxidation, an extensive distribution system would be required to distribute the soil-washing reagent throughout the vadose zone. Due to the narrow applicability of this technology and the high infrastructure requirements for its application to all soil remediation areas, this technology has been rejected.

4.2.1.5 Soil Vapor Extraction

The use of in situ SVE has a long and successful history for remediation of source area VOC-impacted 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 source to remove VOCs, including TCE, which is likely a continuing source of groundwater contamination. Removal of VOCs 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 spatial/lateral extent of effectiveness of individual vapor extraction wells. This technology was successfully implemented within the HCIM Area as an interim measure until the effectiveness of the SVE system decreased to the point that the system was finally shut down (PSC, 1998).

This technology would address and remediate the key volatile COCs within both HSRA-1 and -2, and the OSRA-1, -2, and -3. However, it would not be effective for metals or SVOCs; potential risks related to these two COC classes are substantially lower than the potential risks associated with VOCs, which would be remediated by SVE. The limited depth of the vadose zone within all soil remediation areas would limit the radius of influence of individual SVE wells, thereby requiring more wells. Due to its proven effectiveness and the potential for this technology to address the key COCs, this technology has been retained for use in the SWFS. This technology will be considered potentially applicable to the HCIM Soil Remediation Areas and the Outside Soil Remediation Areas.

4.2.1.6 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 for SVOCs and PCBs and no expected effectiveness for 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.

Since the key volatile COCs within HSRA-1 and -2 and OSRA-1,-2, and -3 are VOCs, this technology would have limited effectiveness unless VOCs are removed prior to implementing S/S. For the soil remediation areas within the HCIM Area, stabilization would result in excess soil which could need to be disposed of as a dangerous waste, substantially increasing implementation costs. This technology would leave persistent COCs (metals, SVOCs, and PCBs) within the vadose zone; it would not reduce toxicity or volume, and would only reduce mobility. Finally, S/S could not be implemented in soil remediation areas located near the barrier wall without risking the integrity of the existing containment. This technology was rejected for all soil remediation areas

4.2.1.7 High Temperature Volatilization

High temperature volatilization remediation technologies consist of heating contaminated soil in order to volatilize organic contaminants. This heating can also be achieved by injection of steam or hot air or by radio-frequency heating or 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 can be effective for VOCs and many SVOCs; however, it has limited effectiveness on PCBs and little to no effect on inorganics. High soil moisture content (e.g., within the capillary fringe) tends 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. Some soil contaminants likely remain in the subsurface due to non-uniform heating or strong sorption.

Implementation of this technology in the Outside Soil Remediation Areas could create unacceptable inhalation risks if mobilized vapors are not completely collected and controlled. Steam injection and other high temperature volatilization technologies could not be implemented in proximity to the HCIM barrier wall due the potential for adverse impacts to the wall material. Soil heating may also create adverse impacts on underground utilities, such as fiber optic cables, gas lines, and sanitary sewers; plastics sensitive to heating may be used in underground utilities. The presence of the barrier wall would limit the area available for implementation of this technology. Thermal heating of Outside Area soils may adversely affect the performance of the existing IPIM. In addition, steam injection adds significant volumes of water to the subsurface and may flush contaminants from vadose zone soil downward to the water table. For these reasons, this technology has been rejected for the HCIM Soil Remediation Areas and the Outside Soil Remediation Areas.

4.2.1.8 Cap/Surface Cover

Various caps and surface covers can be used to minimize exposure at the surface to waste materials, to reduce vertical infiltration of surface water into wastes that could generate contaminated leachate, and to 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. For many site, cap/surface cover is combined with subsurface barrier walls to provide a comprehensive engineered barrier to effectively contain affected soil.

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. A variety of subsurface barriers can be combined with caps, including slurry walls, sheet-pile walls, grout curtains, cement-bentonite walls, soil-cement walls, or barrier walls constructed of proprietary materials such as Impermix®.

Most of HSRA-1 currently has a microsilica concrete cap over the former asphalt, asphalt cover, or concrete cover. 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 existing cover system over HSRA-1 is sloped and stormwater capture and conveyances (swales and drain inlets) are present to reduce surface water ponding. For long-term effectiveness of the microsilica cap, periodic maintenance would be needed to fill cracks and reduce the potential for surface water infiltration. HSRA-2 is covered with asphalt. This cover system prevents human exposure to underlying waste materials, limits erosion and runoff of impacted soil, and reduces (but does not eliminate) the infiltration of surface water (thus reducing the potential for soil COCs to leach into groundwater). The existing cap/surface cover for HSRA-1 is complemented by the existing HCIM barrier wall that is keyed into the uppermost aquitard. The existing cap/cover system and the existing subsurface barrier wall effectively contain affect HCIM Area soil. Capping/surface cover has been retained as a potential technology for application to both HCIM Soil Remediation Areas and for the three Outside Soil Remediation Areas.

4.2.2 Ex situ Soil Remediation Technologies

Remediation of soil using ex situ technologies requires excavation of affected soil for treatment using above-grade techniques. These technologies are typically used only for remediation of shallow hot spots rather than widely distributed or deep contamination.

4.2.2.1 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.

Biopile treatment requires excavation of affected soil and available surface area to conduct the treatment. For the HSRA-1, most of the soil has been impacted and would require biopile treatment. The limited area available to conduct biopile treatment would make implementation of this technology difficult. Additionally, biopile treatment of soil from HSRA-1 would cause VOCs to volatilize, creating significant short-term risks. Biopile treatment would primarily remediate TPH and some SVOCs, leaving the halogenated VOCs and metals untreated. Therefore, this technology would not provide complete treatment for soils in HSRA-1 and -2 and in OSRA-1, -2, and -3. Soils from all soil remediation areas treated using Biopiles would require appropriate engineering controls (e.g., capping for HSRA-1) if the soils were returned to the excavations. This would require reconstruction of the cover that is presently in place above the soil remediation areas. If biopile treated soil is not returned to the excavations, it would be necessary to dispose of the material in a secure landfill. Partial treatment of the soil in biopiles does not justify the highly invasive excavation needed to implement this technology; it has been rejected for all five soil remediation areas.

4.2.2.2 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. Soil washing is generally considered a media transfer/ volume reduction 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.

As noted above, in situ soil washing was rejected as a potential technology for all five soil remediation areas. Ex situ soil washing would only provide partial remediation of soils from the five soil remediation areas included in the SWFS and would require invasive and expensive excavation. While the constituents treated by this technology are different from those that would be treated by bioremediation in biopiles, the degree of remediation achieved would be similar (i.e., many COCs would remain in soils, requiring appropriate post-treatment management). For these reasons, this technology has been rejected for all soil remediation areas.

4.2.2.3 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 composed of silicates from pozzolanic-based materials like fly ash, cement kiln dust, pumice, or blast furnace slag) and Portland cement. These materials chemically react with water to form a solid 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. However, PCBs have been successfully immobilized by S/S. Nuisance conditions (dust, noise, odors) and loss of VOCs to air may occur during implementation of this technology.

Ex situ S/S is not considered applicable to any of the soil remediation areas defined for the SWFS for the reasons presented above for in situ S/S. Additionally, this technology would require extensive excavation of soil, which is not justified for partial remediation. Ex situ S/S has been rejected as a potential remediation technology for all soil remediation areas included in the SWFS.

4.2.2.4 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 either 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 successful application of this technology to the HCIM Soil Remediation Areas and the Outside Soil Remediation Areas is low due to the variety of COCs that need to be treated. This technology could successfully address VOCs and the lighter SVOCs, but would likely not achieve cleanup standards for the heavier SVOCs. Thermal desorption would not remediate PCBs, PAHs, and metals; therefore, it would only accomplish partial remediation. As noted previously, partial remediation of the soils does not justify excavation of soils for thermal treatment. This technology has been rejected for all five soil remediation areas.

4.2.2.5 Off-Site Disposal

Excavation and off-site disposal is a technology that involves excavation of either all or select hot spot areas of soil above the water table that exceed the cleanup levels. This could potentially 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 placed in the excavation 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. Therefore, the consideration of this potential soil remediation technology is limited to vadose zone soils for the purpose of this SWFS.

Excavation of portions of the HCIM Area would be extremely difficult due to the existing microsilica concrete cap (estimated to be approximately 3 feet thick), which would have to be saw cut, broken, and removed from the area. In addition, excavation near the HCIM perimeter would threaten the integrity of the existing barrier wall. UPRR prohibits excavation within 12 feet of the centerline of an active railroad track and may require shoring for excavations outside this area (UPRR, 2004). Therefore, excavation and soil removal within the adjacent UPRR rail yard would be limited to those areas at least 12 feet from the centerline of an active track. In addition, excavation of contiguous properties not owned by PSC would require obtaining access or easements from private property owners.

Unlike many of the other ex situ remediation methods, excavation with off-site landfill disposal comprehensively addresses all soil COCs. While this remediation method may not be applicable to all soils within HSRA-1 and -2 (it would require demolition of the existing cap and surface pavement), it may be applicable to address hot spots within HSRA-1 and -2. Since a significant portion of HCIM Soil Remediation Area is covered by a building, this method would have limited applicability. Soil excavated from HSRA-1 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. In addition, significant short-term risks would be created due to dust generation, volatilization, and transportation that would need to be addressed in the remedial design. This technology has been retained for potential application to the two HCIM Soil Remediation Areas for possible hot spot removal.

For some of the Outside Soil Remediation Areas, the constraints to excavation and disposal that are present for the HCIM Soil Remediation Areas are not present. For HSRA-1 and HSRA-2, surface improvements would not limit access for excavation. Underground utilities and the barrier wall would affect excavation, requiring the work to be done in a manner that would not cause damage. Landfills capable of accepting the excavated soil are located within acceptable distances. This technology has been retained for OSRA-1 and -2. Due to extensive building cover, this remediation method technology is rejected for OSRA-3.

4.3 HCIM AND OUTSIDE AREAS GROUNDWATER REMEDIATION TECHNOLOGIES

Several general technologies have been considered to address groundwater impacts within the remediation areas defined for 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 are evaluated in this SWFS. The potentially applicable remediation technologies are described below and listed in Tables 4-3 and 4-4. Screening results for the groundwater remediation technologies are summarized in Tables 4-3 and 4-4.

4.3.1 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 observed during pilot testing.

This technology performs well for organic compounds that can be readily degraded aerobically, including VC. The technology does not work well for most halogenated VOCs that degrade via anaerobic degradation pathways. It also is ineffective for 1,4-dioxane. 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. The iron also may cause fouling of aeration wells. 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 address the majority of COCs within the HCIM Area; therefore, biosparging is rejected as a potential remediation technology for the HCIM Groundwater Remediation Area. Outside the HCIM Area, this technology could only be applied farther downgradient where only VC and/or petroleum compounds remain above cleanup levels, since it would interfere with natural degradation reactions for the most significant COCs. For these reasons, this technology has been rejected for the Outside Area Groundwater Remediation Areas.

4.3.2 Oxygen Enhancement with Hydrogen Peroxide or ORC®

Oxygen supporting aerobic degradation of VC and other COCs amenable to aerobic biodegradation (non-halogenated VOCs, some SVOCs, and TPH) can also be delivered to impacted groundwater using chemicals such as Oxygen Release Compound (ORC) or hydrogen peroxide. As noted above, aerobic biodegradation is not effective for 1,4-dioxane. ORC is a proprietary chemical developed and sold by Regenesis; similar products are offered by other vendors. ORC is a peroxide compound that slowly degrades in water, releasing oxygen. Hydrogen peroxide is a highly reactive, oxidizing compound that rapidly decomposes 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.

Since this technology promotes aerobic biodegradation, it would interfere with natural attenuation of the halogenated VOCs. Therefore, it has been rejected for potential application to the HCIM Groundwater Remediation Area and the Outside Area Groundwater Remediation Areas for the reasons presented above for biosparging. This technology may be applicable downgradient of the SWFS Area.

4.3.3 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^{TM} process or through groundwater recirculation systems using the Super-Ox ^{TM} technology. These technologies have been shown to promote the degradation of TCE, cis-1,2-DCE, and VC. These technologies are generally not effective for non-halogenated VOCs, SVOCs, TPH, PCBs, and metals; they are also ineffective for degradation of 1,4-dioxane. 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 and has not been applied in source areas.

This technology creates significant safety hazards due to handling of a fuel gas and pure oxygen. While safety precautions can be taken, significant potential for fire or explosion would remain under any conditions. Based on its suitability for treating source areas and the safety concerns, this technology is rejected for the HCIM Groundwater Remediation Area. Co-metabolic bioremediation is rejected for the Outside Area Groundwater Remediation Areas due to safety reasons, which would be particularly acute in the highly developed urban environment.

4.3.4 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. It would also contribute to the degradation of many non-halogenated VOCs, some SVOCs, and TPH, but anaerobic degradation for these constituents is slow. Reductive dechlorination will not address inorganics (metals), PCBs, and 1,4-dioxane concentrations in groundwater within the HCIM Area. In addition, mobilization of metals due to reducing conditions created by anaerobic biostimulation may increase metals concentrations in groundwater. However, since groundwater conditions are already strongly reducing at and downgradient from the facility, it is not expected that biostimulation of reductive dechlorination would substantially affect metals concentrations in groundwater.

As outlined in Section 2.0 of this Technical Memorandum, natural bioattenuation of VOCs is already occurring at the Site. This also indicates that indigenous organisms can support reductive dechlorination of the chlorinated COCs. Injection of electron donors into the impacted groundwater could potentially be needed to maintain favorable conditions for further reductive dechlorination. 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.

Enhanced anaerobic bioremediation through biostimulation has been retained for potential application in the HCIM Groundwater Remediation Area and in the Outside Area Groundwater Remediation Areas. This technology addresses the key COCs and is compatible with ongoing natural biological processes in affected groundwater.

4.3.5 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 full reductive dechlorination. 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 may 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.

Aerobic bioaugmentation has been rejected for the HCIM Groundwater Remediation Area and the Outside Area Groundwater Remediation Areas due to its potential to interfere with anaerobic processes that are actively degrading halogenated VOCs in affected groundwater.

The microbe usually added for anaerobic biostimulation, *Dehalococcoides ethogenes,* has been identified in affected groundwater; therefore, addition of *Dehalococcoides ethogenes* would likely have little benefit. However, anaerobic bioaugmentation has been retained as a potentially applicable technology if the existing microflora require supplementation to achieve full reductive dechlorination and monitored natural attenuation of chlorinated VOCs in the HCIM and Outside Area Groundwater Remediation Areas. This technology could be implemented in the event that existing colonies of *Dehalococcoides ethogenes* are not sufficient to fully degrade all site COCs to non-toxic products.

4.3.6 Monitored 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. The potential drawbacks of sole reliance on this technology include potentially longer remediation periods when compared to active groundwater remediation technologies. Select COCs present within the HCIM Area may not be amenable to natural attenuation, including inorganics (metals), PCBs, 1,4-dioxane, and higher end SVOCs.

Biodegradation of the chlorinated solvents present within the SWFS Area is currently observed and accounts for the presence of VC in the groundwater. The wide distribution 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 substantial biodegradation, is currently occurring throughout the SWFS Area. Monitored natural attenuation may be used either in conjunction or following implementation of more active groundwater remediation technologies at a site. The selection of a remedial strategy for the SWFS Area 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.

Monitored natural attenuation has been retained as a technology for the HCIM Groundwater Remediation Area and for the Outside Area Groundwater Remediation Areas (including the deep aquifer). For many of the most significant COCs, natural attenuation provides a permanent approach for remediation.

4.3.7 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. Since this technology relies primarily upon biodegradation to achieve remediation objectives, recalcitrant COCs (such as 1,4-dioxane) would not be effectively remediated.

The potential for application of phytoremediation in the SWFS Area is extremely limited by the depth of groundwater contamination, the current land use, and the expected future land use. This technology would not be effective for groundwater below the water table depth interval. The heavy urban development would prevent application of the technology within the entire SWFS Area. Therefore, this technology has been rejected for the HCIM Groundwater Remediation Area and for the Outside Area Groundwater Remediation Areas.

4.3.8 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 in situ air 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 result in a vapor intrusion threat to building occupants and residents located above or nearby the air sparging system. Additionally, SVOCs, TPH, PCBs, and metals would not be remediated by this technology. The addition of oxygen to the water could have adverse effects on the naturally anaerobic degradation process that has been documented to be occurring within the VOC areas. For these reasons, this technology has been rejected for all groundwater remediation areas included in the SWFS.

4.3.9 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 permanganate (potassium or sodium) 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. 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, suppressing 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, as many COCs (such as 1,4-dioxane) are recalcitrant to chemical oxidation. Additionally, the technology would not effectively remediate highly sorbed COCs that have diffused into the interbedded silt layers. Due to the generally diluted nature of the Outside Area, chemical oxidation would not be cost-effective. This technology has been retained for potential application to the HCIM Groundwater Remediation Area. Since chemical oxidation is a technology designed for use at or near the source area, it has been rejected for the Outside Area Groundwater Remediation Areas.

4.3.10 Thermal Treatment

Thermal treatment includes adding steam through injection wells or applying an electrical current into an aquifer to vaporize volatile and some semivolatile contaminants in groundwater. High molecular weight constituents (e.g., PCBs and PAHs) and non-volatile constituents (e.g., 1,4-dioxane or inorganics) would not be effectively remediated by this technology. 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 potentially applicable to shallow and deep contaminated areas and readily available mobile equipment can be used.

This technology is not applicable to the Outside Area Groundwater Remediation Areas due to the size and current land use of the area. Thermal remediation would be difficult to implement in these areas due to the number of landowners and the heavy development, which would make vapor collection the key component in order to avoid creating new risks or exacerbating existing risks. Implementation within a large percentage of the HCIM Area would be difficult due to the existing microsilica concrete cap and concerns regarding the potential for this technology to negatively impact the HCIM barrier wall (causing desiccation of the clay component of the wall). This technology has been rejected for the Outside Area Groundwater Remediation Areas and for the HCIM Groundwater Remediation Area.

4.3.11 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 portions of the SWFS Area where chlorinated solvents were released, this technology may interfere with the active natural anaerobic biodegradation processes that have been documented in affected groundwater. However, in-well air stripping would create an aerobic zone conducive to degradation of VC, non-halogenated VOCs, and many light SVOCs. In addition to the potential to interfere with existing natural biological processes within the SWFS Area, other potential problems associated with in-well stripping include chemical fouling due to high iron concentrations in groundwater. In well air stripping has been rejected for the HCIM Groundwater Remediation Area and the Outside Area Groundwater Remediation Areas because it would interfere with active biodegradation of chlorinated VOCs and would not remediate many COCs, such as metals, TPH, PCBs, and 1,4-dioxane.

4.3.12 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. Site COCs that would not be addressed by this technology include nonhalogenated VOCs, SVOCs, PCBs, TPH, and most of the metals. This technology also would not remediate 1,4-dioxane. 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.

In general, PRBs are potentially applicable immediately downgradient of TCE source areas; however, given the extensive surface development of the SWFS Area, 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 as part of a remedy. For these reasons, PRBs have been rejected for the HCIM Groundwater Remediation Area and for the Outside Area Groundwater Remediation Areas.

4.3.13 Emulsified Zero-Valent Iron

Emulsified zero-valent iron (EZVI) is an emerging remediation technology that has shown potential promise in laboratory studies in treating dissolved-phase chlorinated solvents and DNAPLs. EZVI is composed of nano- or micro-scale zero-valent iron emulsified in biodegradable vegetable oil and a food-grade surfactant (Quinn et al., 2005). The exterior of the oil membrane emulsion droplets have hydrophobic properties similar to DNAPL, and therefore, are miscible with DNAPL. Chlorinated VOCs diffuse through the oil membrane and undergo reductive dechlorination in the presence of zero-valent iron. In this reaction, the ZVI is essentially consumed; the ZVI becomes oxidized and has no further reactivity. In addition, the vegetable oil and surfactant in EZVI act as long-term electron donors and promote anaerobic biodegradation. It is expected that EZVI can be delivered to the subsurface through direct push injection, or hydraulic or pneumatic fracturing, although this has not been done to date in a full scale application. Potential drawbacks to this technology include:

- High cost compared to similar in situ technologies (e.g., ISCO);
- Difficulties in obtaining effective distribution in the subsurface, especially at sites with complex hydrostratigraphy, such as the PSC site; and
- Limited information regarding the suitability of this technology for full-scale implementation in uncontrolled environments (i.e., outside the laboratory).

During a literature search, only limited information on this technology was available from laboratory column and small-scale pilot studies. No instances of full-scale implementation were identified. Geomatrix has been evaluating this technology at a number of sites with both bench-scale and pilot-scale studies. At this point in the technology development process, the nano-scale iron has been found to be too reactive. Due to its high reactivity, the ZVI can be fully reacted during transportation to the site. Pilot scale field experience at a site found that in freshly mixed EZVI, the ZVI reacted before it could migrate to the target zone. Reaction times for EZVI have been typically complete within a few hours of injection, which does not allow sufficient time for the material to disperse in the aquifer. In addition, laboratory studies have shown very limited migration of the EZVI even in coarse materials. As a result of these obstacles this technology does not show sufficient promise in treating chlorinated solvent and DNAPL sites without more research, testing, and development. Since EZVI is not a proven technology, it has been rejected for all groundwater remediation areas and will not be considered further for the SWFS.

4.3.14 Groundwater Extraction and Treatment (Pump and Treat)

Groundwater extraction followed by ex situ treatment has two possible applications in the SWFS Area: (1) COC mass removal, and (2) hydraulic control to prevent downgradient migration of impacted groundwater. For either application, this technology requires the installation of extraction wells to intercept impacted groundwater. Extracted groundwater would then be treated and either reinjected or discharged to surface water. For the surface water discharge configuration, the treated groundwater would either be discharged to the King County POTW or discharged to the Duwamish Waterway via a NPDES permit. Discharge to the King County POTW would be the preferred option for the SWFS Area due to the expense required to treat the extracted groundwater to the more stringent NDPES discharge limits, as well as the expense of constructing a below grade discharge pipeline to the Duwamish Waterway (located approximately 0.75-mile from the Facility and 0.5-mile from 4th Avenue South).

Groundwater extraction for COC mass removal would likely be costly within the Outside Area due to the dilute COC concentrations (compared to the HCIM Area) and the areal extent of impacted groundwater. It is unlikely that a groundwater pumping system would be capable of maintaining a sufficient extraction rate within the HCIM Area to effect significant COC mass removal. The low permeability barrier wall that surrounds the HCIM Area and the surface cover that limits infiltration significantly reduce groundwater recharge to the area and the volume of groundwater available for extraction; high pumping rates would simply dewater the area rather than increasing the rate of COC removal. Although treated effluent could be reinjected near the upgradient edge of the HCIM Area to flush contaminants toward the extraction wells, reinjection has several potential drawbacks. Extraction and treatment processes would likely aerate the groundwater and result in adverse impacts to ongoing natural attenuation processes. In addition, significantly greater O&M costs would be required to meet the higher treatment standards for reinjection than the less stringent standards for discharge to the POTW. Groundwater extraction is unlikely to effectively address DNAPL within the

HCIM Area or the adsorbed dissolved phase constituents associated with these DNAPL sources.

Migration of impacted groundwater could be controlled within the Outside Area by implementing hydraulic control with a groundwater extraction program in which impacted groundwater is extracted to establish a hydraulic depression that prevents downgradient migration of groundwater. Groundwater extraction for hydraulic control 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 extend laterally across the area of impacted groundwater. Reinjecting the groundwater downgradient of the extraction wells would create a zone of elevated water levels, re-enforcing the hydraulic barrier created by the extraction wells. As previously discussed, however, reinjection of the treated groundwater may adversely impact ongoing natural attenuation processes and would have significantly higher O&M costs (compared to discharge to the POTW). Groundwater extraction has been used effectively for source control and for controlling migration of impacted groundwater plumes.

Groundwater extraction requires 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. Substantial property access would also be needed to provide for collection of the recovered groundwater if implemented as a downgradient barrier. This technology is best suited for controlling migration of impacted groundwater in the vicinity of HCIM Area (source area) and is currently used as one component of the HCIM. This technology addresses all groundwater constituents within the capture zone of the extraction system. Due to the presence of 1,4-dioxane in Outside Area groundwater and the recalcitrance of 1,4-dioxane to other remediation methods, this technology has been retained for potential application in OWTRA-2 and -3 and in OSIRA-2 and -3.

4.3.14.1 Air Stripping

Air stripping is an ex situ groundwater treatment technology used in pump and treat systems. This technology is generally used to support groundwater extraction 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. This technology is not effective for

SVOCs, TPH, PCBs, and metals. It is not effective for removal of 1,4-dioxane. Generally, pH adjustment of the influent groundwater 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 require further treatment to meet specified permit requirements or may be discharged directly to the atmosphere, depending on mass limitations for atmospheric discharge. It is common to apply granular activated carbon or thermal oxidation to the off-gas for treatment.

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.

This technology has been retained for the SWFS. It is currently being used as part of the groundwater extraction component of the HCIM. Therefore, it has been retained for the HCIM Groundwater Remediation Area. It has also been retained for OWTRA-2 and -3 and for OSIRA-2 and -3, since it may be necessary for groundwater extraction.

4.3.14.2 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 commonly used for groundwater extraction systems. It is effective for most VOCs, SVOCs, and TPH. It is not effective for most metals, but is effective for some. Carbon adsorption is not effective for 1,4-dioxane. 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.

Activated carbon treatment of groundwater may be applicable for treatment of groundwater recovery systems. Therefore, this technology has been retained for the HCIM Groundwater Remediation Area and OWTRA-2 and -3 and for OSIRA-2 and -3.

4.3.15 Containment

Containment can be achieved by hydraulic containment, physical containment, or a combination of the two methods. Hydraulic containment is accomplished by operating extraction wells at a rate sufficient to capture affected groundwater and preventing further migration. Hydraulic containment technology is discussed in Section 4.3.14. 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 barrier wall and extraction system have been proven effective at controlling migration of contaminants from the HCIM Area. Therefore, this technology has been retained for the HCIM Groundwater Remediation Area. Due to the size of the impacted groundwater area and the large number of property owners that would be affected for installation of a barrier wall within the Outside Area, this technology has been rejected for the Outside Area Groundwater Remediation Areas.

4.3.16 Dynamic Underground Stripping

Dynamic underground stripping (DUS) is essentially a method of in situ thermal treatment that combines several technologies to remediate organic compounds in soil and groundwater. Steam injection is conducted on the periphery of the subsurface contamination to vaporize

VOCs and drive them toward centrally located vapor extraction wells. Electrical heating of finer grained units mobilizes VOCs, which then migrate to coarser grained soil layers for removal by SVE. Underground imaging using electrical resistance tomography (ERT) is used to delineate the heated areas, ensure cleanup, and provide process control. This technology is most effective for VOCs; its effectiveness decreases as molecular weight increases. Therefore, it has limited effectiveness for SVOCs, TPH, and PCBs and is ineffective for metals and 1,4-dioxane.

This technology is not applicable to the Outside Area, due to the size and current land use of the area. This technology may interfere, at least temporarily, with ongoing biodegradation processes within the HCIM Area. Treated soils and aquifer materials remain at elevated temperatures for years following remediation cessation. In follow-up to a pilot-scale implementation of DUS at a Lawrence Livermore National Laboratory site, groundwater temperature within the treatment area was found to be approximately 100ºF ten years after the last DUS treatment. Implementation within a large percentage of the HCIM Area would be difficult due to concerns regarding the potential for this technology to negatively impact the HCIM barrier wall (causing desiccation of the clay component of the wall). For these reasons, this technology has been rejected for the HCIM Groundwater Remediation Area and the Outside Area Groundwater Remediation Areas.

4.3.17 Surfactant Enhanced Aquifer Remediation

SEAR is the injection of surfactants coupled with conventional groundwater extraction methods to enhance the recovery of organic contaminants, including DNAPLs. Surfactants are injected into the aquifer to increase the aqueous solubility and mobility of contaminants and promote the removal of these contaminants from the subsurface by a pump-and-treat system. Extracted groundwater undergoes ex situ treatment to separate the contaminants and groundwater from the surfactant, which can then be re-injected. Since this technology relies upon mobilizing COCs, the recovery of the surfactant and impacted groundwater is of primary concern for SEAR. Therefore, it is important to fully characterize hydrogeology prior to implementing SEAR. This technology is potentially effective for SVOCs and TPH, and would have limited to low effectiveness for VOCs. It also would not be effective for COCs with high solubility, such as 1,4-dioxane, and would function essentially as a pump and treat system. In general, SEAR and similar technologies have not been found to be highly effective, particularly at sites with highly sorbed constituents.

This technology is not applicable to the Outside Area due to the diffuse nature and size of the downgradient plume. Potential barriers to the implementation of this technology within the HCIM Area are similar to drawbacks associated with conventional pump-and-treat systems, and include:

- Subsurface heterogeneities can interfere with the effective delivery and recovery of the surfactant solution. Aquifer heterogeneities may create preferential flow paths and result in significant channeling of the injected fluids, bypassing zones of contamination (Battelle, 2002).

- Low permeability soils (present in lenses within the intermediate depth interval) are difficult to treat due to challenges associated with distributing and recovering the surfactants from the soils.

Therefore, SEAR has been rejected for the HCIM Groundwater Remediation Area and for the Outside Area Groundwater Remediation Areas.

4.3.18 Co-Solvent Flooding

Co-solvent flooding is similar to, and may be used in conjunction with, SEAR. A co-solvent, typically a low molecular weight alcohol such as ethanol or propanol, is injected into the impacted aquifer to enhance the dissolution of DNAPL components into the aqueous phase. The co-solvent and dissolved phase organics are then recovered with conventional groundwater extraction methods and treated ex situ. The selection of an appropriate co-solvent is an iterative process that involves bench tests and possibly several pilot studies. Due to the high solubility nature of the co-solvents typically used (i.e., alcohols), this technology may leave very high concentrations of the co-solvent in groundwater. It also would not be effective for COCs with high water solubility, such as 1,4-dioxane. The design and effectiveness of the groundwater recovery component is or primary importance for implementation of this technology.

This technology is not applicable to the Outside Area Groundwater Remediation Areas due to the diffuse nature and size of the Outside Area plume. Potential barriers to the implementation of co-solvent flooding within the HCIM Area are the same as SEAR. According to the EPA's remediation technology screening website (www.clu-in.org), co-solvent flooding is difficult to implement in fine-grained soils due to the difficulty of distributing fluids in the soil; fine-grained soils are present as lenses within the deeper portions of the shallow depth interval and within the intermediate depth interval. Subsurface heterogeneities may result in poor contact of the co-solvent with contaminants, and subsequently, poor mass removal. For these reasons, co-solvent flooding has been rejected for the HCIM Groundwater Remediation Area and for the Outside Area Groundwater Remediation Areas.

4.4 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. Until these groundwater cleanup levels are achieved, vapor intrusion mitigation technologies must be implemented and maintained to protect these occupants from unacceptable VOC exposures. Remediation technologies that may be implemented to reduce existing groundwater concentrations below cleanup levels were discussed in Section 4.3 and screened on Tables 4-3 and 4-4.

In response to a June 28, 2001, letter from the EPA and Ecology that required PSC to implement interim groundwater measures in the SWFS Area, PSC developed and implemented the IPIM approach. This approach is a tiered process by which groundwater concentrations are compared to action levels, additional data (e.g., indoor air samples) are collected if necessary, and mitigation systems are installed if warranted. The IPIM process was evaluated in Technical Memorandum No. 3 for inclusion as part of the final preferred cleanup action in the SWFS Area. Based on the results of this evaluation, PSC intends to include the vapor intrusion assessment and mitigation (VIAM) approach proposed in Technical Memorandum No. 3 as presumptive mitigation measure in the final preferred cleanup action. The VIAM incorporates all of the elements of the IPIM with some modifications and additions, most notable a process to determine whether vapor intrusion mitigations systems can be shut down and potentially removed. Please refer to Technical Memorandum No. 3 for additional details.

4.5 RETAINED REMEDIATION TECHNOLOGIES

The technologies discussed in Section 4.2 and 4.3 were screened against the criteria described in Section 4.1 to identify technologies to be used in developing remedial alternatives for soil and groundwater in the HCIM Soil Remediation Areas, Outside Soil Remediation Areas, HCIM Groundwater Remediation Area, and Outside Area Groundwater Remediation Areas. The technology screening, including the rationale for retention or rejection, are summarized in Tables 4-1 through 4-4 and in Sections 4.2 and 4.3. Technologies were either retained or rejected based upon their prior application history, ability to meet the remediation objectives, suitability for the specified remediation areas, and an evaluation against the screening criteria of Section 4.1. Because this SWFS is intended to be a focused feasibility study, this technology screening step is intended to produce a very short list of only the most applicable, proven, and promising technologies for further consideration.

As discussed in Technical Memorandum No. 2, soils within the HCIM and Outside Areas were both subdivided into separate soil remediation areas. In addition, a single groundwater remediation area was defined for the HCIM Area. Groundwater defined for the Outside Area include three water table depth interval remediation areas, three shallow/intermediate depth interval remediation areas , and one deep aquifer remediation area. As noted on Tables 4-1, 4-2, and 4-4 and in the text of Sections 4.2 and 4.3 of this Technical Memorandum, soil and groundwater remediation technologies were screened for potential use in each of the remediation areas. Soil remediation technologies evaluated for the HCIM Area were rejected only if they did not meet the criteria presented in Section 4.1 for all three individual soil remediation areas. Similarly, soil remediation technologies evaluated for the Outside Area were only rejected if they did not meet the screening criteria presented above. Groundwater remediation technologies were screened similarly for the HCIM Groundwater Remediation Area and the Outside Area Groundwater Remediation Areas. The retained remediation technologies are listed in Table 4-5 for soil and in Table 4-6 for groundwater.

5.0 INSTITUTIONAL CONTROLS

Although institutional controls are not a remediation technology and do not result in site cleanup, they 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, it is very difficult to implement institutional controls due to the requirement of negotiations with property owners. In addition, even if agreements can be reached with property owners, it may be difficult to enforce institutional controls on property not owned by the liable party. Public notices, zoning overlays, or similar means may be employed when the responsible party is unable to obtain restrictive covenants on property not owned by the responsible party (following a good-faith effort in accordance with WAC 173-340-440(8)(c)).

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.

6.0 REMEDIAL ALTERNATIVE DEVELOPMENT

Remedial alternatives addressing the project scope and objectives have been developed from the potentially applicable remediation technologies identified in Section 4. The following subsections briefly describe the remedial alternatives for the HCIM and Outside Areas. Detailed descriptions, analysis of the alternatives, and the selection of the recommended remedial alternative will be presented in Technical Memorandum No. 5.

6.1 HCIM AREA

Based on the potentially applicable remediation technologies identified during the technology screening, five potential remedial alternatives were developed for HCIM Area soil and groundwater. Although not listed in the following brief alternative descriptions, the VIAM approach discussed in Technical Memorandum No. 3 is incorporated into each remedial alternative under consideration for the HCIM Area to mitigate potential impacts associated with the vapor intrusion pathway.

As described in previous technical memoranda prepared for this SWFS, the HCIM Area is a complex site with a very wide variety of COCs (organics, inorganics, volatiles, semi-volatiles, non-volatiles), complex hydrostratigraphy that includes interbedded silt layers, and DNAPL ganglia (in some areas). Due to the long history of facility use, groundwater and DNAPL constituents have diffused into the interbedded and interstitial silt over many decades. Releases to groundwater above the silt layer (i.e., within the water table, shallow, and intermediate depth intervals) have also caused a localized alteration of geochemistry, causing dissolution of naturally occurring metals present in the saturated zone matrix. The construction of the HCIM barrier wall to contain areas of DNAPL and impacted groundwater in the vicinity of the source areas adds an additional feature to the site that must be considered in the development of remedial alternatives for the SWFS. The barrier wall is located upgradient of the expected location for the CPOC (the CPOC is described in TM2). Thus, HCIM containment will support attainment of SWFS cleanup levels at the CPOC; it should be emphasized that the SWFS cleanup levels developed in TM1 were intended to apply at the CPOC. These conditions collectively contribute to a highly complex site with unique and difficult remediation issues.

The presence of DNAPL ganglia presents two very significant problems that will affect remediation of the HCIM Area. DNAPL has been found to be very difficult to remove from the subsurface, particularly when present as ganglia. Residual DNAPL present in the formation interstices and in dead-end pores within the interbedded silt represents a significant and persistent source of chlorinated VOCs that would cause groundwater to exceed cleanup levels for a very long time. Secondly, non-chlorinated constituents and SVOCs are very soluble in DNAPL. Thus, these materials would preferentially dissolve into the DNAPL and persist at the site for as long as DNAPL is present. The constituents dissolved into the DNAPL would be gradually released to groundwater as the DNAPL dissolves; this phenomenon could contribute to exceedance of cleanup levels for absorbed non-chlorinated constituents. Thus, the presence of DNAPL beneath the Georgetown facility could cause long-term exceedance of cleanup levels for chlorinated and non-chlorinated COCs.

The residual chlorinated and non-chlorinated organic COCs present in groundwater and adsorbed onto interbedded silts present within the shallow and intermediate depth intervals represent a long-term secondary source of groundwater COCs. Both chlorinated and non-chlorinated organic COCs have diffused into the silts for several decades. This diffusion has occurred under a concentration gradient based on the existing or higher ambient groundwater concentrations. If dissolved-phase concentrations are reduced, the concentration gradient would reverse and adsorbed constituents would diffuse from the silt to the groundwater, potentially causing cleanup and/or remediation levels to be exceeded in the dissolved phase. Since the concentration gradient for desorption would be lower than the gradient that caused adsorption, the back-diffusion process would be slower than the adsorption process. Thus, it is likely that back-diffusion process contributing to dissolved-phase concentrations of organic COCs would last longer than the approximately 40 years of sorption time (i.e., desorption may occur for more than 50-60 years after remediating dissolved-phase constituents).

While some metals were likely released due to facility operations, several metals are present in groundwater due to changes in groundwater geochemistry caused by releases of organic constituents and subsequent aerobic microbial respiration that depleted the groundwater of dissolved oxygen. The depleted oxygen conditions changed the groundwater geochemistry from oxidizing and conducive to aerobic degradation to anoxic and reducing and conducive to anaerobic degradation. Metals, such as arsenic, iron, and manganese, exhibit higher solubility under reducing conditions than under oxidizing conditions. These metals are also present in the naturally-occurring minerals present within the saturated zone. The reducing conditions caused by biodegradation of the released organic constituents has contributed to the observed concentrations of several metals. It is expected that more oxidizing conditions will occur after the organic constituent concentrations decrease sufficiently, which would reduce dissolved metals concentrations, thereby limiting mobility and potential risks. For metals with solubilities that are not strongly influenced by redox conditions (e.g., barium, copper, nickel), the only technically possible in situ remediation technology other than containment is chemical fixation to immobilize the metals. Implementation of chemical fixation would likely require removal of all surface cover followed by deep soil mixing (down to and including the aquitard) over the entire HCIM Area. Since many dissolved metals adsorb to silts; the interbedded silts may be a long-term secondary source for metals in groundwater and would limit the effectiveness of pump and treat technology for the metals. Containment is the preferred approach for metals.

A preliminary evaluation of remediation levels for the HCIM Area was performed based on an earthquake scenario for the barrier wall and conservative modeling. This evaluation indicates that existing groundwater concentrations in the HCIM Area are below the estimated remediation levels for the HCIM Area. Additional details regarding calculation of the remediation levels and the earthquake scenario are presented in Appendix B. These remediation levels apply to the HCIM Area under present conditions (i.e., with the barrier wall and groundwater recovery systems in place) and will apply under future conditions, as the barrier wall is expected to have a long useful life. Thus, partial failure of the barrier wall due to an earthquake would not be expected to create risks to human health and the environment at the Duwamish Waterway.

Given an unlimited restoration time, several technologies may be capable of attaining SWFS cleanup levels within the HCIM Area, although at extremely high cost. It should be noted that the SWFS cleanup levels were developed for application at the CPOC, which is located outside and downgradient of the HCIM Area. However, an unlimited restoration is not considered reasonable; given the expected restoration time for the Outside Area, a restoration time of about 20 to 40 years could be considered reasonable for the HCIM Area. Based on the conditions described above and the time over which released constituents have equilibrated with the subsurface environment, it is expected that only excavation of the entire HCIM Area (i.e., excavation inside the barrier wall to remove all material above the deep aquifer) would be likely to attain SWFS cleanup levels inside the HCIM Area within a 20 to 40 year time frame. Constituents adsorbed to silts and present within dead-end pores would not be directly accessible to chemical oxidation, bioremediation, or other technologies under development (but not proven) such as SEAR or EZVI. Thermal processes applied at the full depth of affected media (i.e., to 90–100 ft bgs) would be unlikely to achieve sufficient removal of constituents either adsorbed to silts or present in dead-end pores within the interbedded silts to prevent subsequent diffusion to groundwater. In situ heating and heat penetration are not expected to be uniform within the existing hydrostratigraphy; fully uniform and full heat penetration would be necessary to achieve removal adequate to achieve contaminant removal.

Since diffusion into the silts has occurred over a period of time exceeding 40 years, it is expected that diffusion from the silts would be likely for at least 40 years subsequent to any remediation. Since the cleanup levels are very low, almost any back diffusion from the silts would cause the cleanup levels to be exceeded.

6.1.1 HCIM Area Remediation Alternatives

Several technologies have been retained that could reduce total contaminant mass within the HCIM Area to concentrations below the remediation levels, although they will not necessarily reduce groundwater concentrations to cleanup levels developed for outside the HCIM Area due to the factors described above. These technologies include excavation, containment, natural attenuation, enhanced biodegradation, soil vapor extraction, and groundwater extraction.

Five remedial alternatives have been developed for the HCIM Area that incorporate one or more of the retained technologies. These alternatives are briefly described below. Table 6-1 lists the five alternatives (HA-1 through HA-5) and summarizes which technologies are included in each alternative. In addition, Table 6-1 shows which specific technologies apply to the remediation areas. Complete descriptions and a full evaluation of the practicability of these alternatives in achieving the remediation objectives will be presented in Technical Memorandum No. 5.

Alternative HA-1: This alternative relies on containment and monitored natural attenuation to address soil and groundwater impacts within the HCIM Area. The following elements are included in Alternative HA-1:

- The existing barrier wall isolating and enclosing near-facility impacted soil and groundwater;
- The existing groundwater recovery and pretreatment system;
- Surface cover;
- The existing groundwater monitoring wells and program; and
- Institutional controls.

The existing barrier wall and groundwater recovery/treatment system would be used to contain and control off-site migration of Facility COCs. The existing or equivalent future surface cover would be maintained to prevent contact with impacted soil and prevent erosion and runoff of affected soil. While the surface cover is not intended to present a barrier to surface water infiltration and recharge, the cover would promote runoff and limit infiltration. Active biodegradation processes within the HCIM Area would permanently degrade and destroy biodegradable components present within the saturated zone. It is expected that biodegradation of many non-chlorinated organic constituents will proceed simultaneously with degradation of the chlorinated constituents. Other non-chlorinated organic COCs are expected to degrade aerobically in the water table depth interval. Institutional controls are included in the alternative to ensure continued groundwater monitoring and maintenance of the cap and barrier wall systems, as well as to restrict future site and groundwater use.

This alternative comprehensively addresses HSRA-1 and -2 and the HCIM Groundwater Remediation Area. This alternative would not achieve SWFS cleanup levels but is expected to achieve remediation levels developed for within the HCIM Area (see Appendix B). It is expected that this alternative would attain remediation objectives, including attainment of SWFS cleanup levels at a CPOC located outside the barrier wall. This alternative is based on present conditions and remedial actions that have been implemented at the facility. It will be used in the SWFS as a baseline to assess potential benefits that may accrue from other potential remedial actions included in the other remedial alternatives.

Alternative HA-2: This alternative supplements the containment and natural biodegradation processes on Alternative HA-1 by adding anaerobic biostimulation to accelerate biodegradation of chlorinated COCs. The following elements are included in this alternative:

- The existing barrier wall isolating and enclosing near-facility impacted soil and groundwater;
- The existing groundwater recovery and pretreatment system;
- Surface cover;
- Electron donor injection into affected HCIM Area groundwater;
- The existing groundwater monitoring wells and program; and
- Institutional controls.

The barrier wall, surface cover, monitoring system, and institutional controls would contribute to this alternative as described above for Alternative HA-1. However, the rate of biodegradation would be accelerated by injection of electron donor into impacted groundwater, increasing biological activity. The areas that would be addressed by biostimulation are identified as potential DNAPL areas on Figure 2-2. It is expected that several injections of electron donor material would be required to fully implement this alternative. This alternative would provide more rapid degradation of facility COCs. The final results achieved by this alternative would be similar to those achieved by Alternative HA-1.

This alternative comprehensively addresses HSRA-1 and -2 and the HCIM Groundwater Remediation Area. This alternative would not achieve SWFS cleanup levels (originally developed for applicability at the CPOC) but is expected to achieve remediation levels for the HCIM Area. However, it is expected that it would attain remediation objectives, including attainment of cleanup levels at a CPOC located outside the barrier wall.

Alternative HA-3: This alternative combines the elements of Alternative HA-2 with SVE to address affected soil. The following elements are included in this alternative:

- The existing barrier wall isolating and enclosing near-facility impacted soil and groundwater;
- The existing groundwater recovery and pretreatment system;
- Surface cover;
- Partial site dewatering and SVE;
- Electron donor injection into affected HCIM Area groundwater;
- The existing groundwater monitoring wells and program; and
- Institutional controls.

The physical/hydraulic containment, biostimulation, and surface cover elements described previously would be incorporated into this alternative to provide the functions previously described. This alternative would actively address affected soils and shallow, residual saturation by partially dewatering the contained area; it is expected that the water level could be drawn down as much as 10 to 20 feet below the normal water level. Dewatering would be accomplished by installation of new recovery wells distributed over the enclosed area and placed within known groundwater hot spots. Several SVE wells would be completed within the vadose and water table depth intervals to recover volatile COCs. It is expected that the SVE system would recover adsorbed VOCs and shallow residual DNAPL. The active remediation elements included in this alternative would be implemented in a phased approach. Dewatering and SVE would be implemented initially. After SVE ceases to be effective, the groundwater elevation within the HCIM Area would be allowed to recover to present levels. Biostimulation would be implemented during and after groundwater recovery.

This alternative adds aggressive soil remediation to the groundwater remediation and containment includes in Alternative HA-1 and Alternative HA-2. The alternative would attain remediation objectives for the soil and groundwater remediation areas identified for the HCIM Area. It is expected that this alternative would not attain cleanup levels or remediation levels for HCIM Area soil or groundwater, but would support attainment of cleanup or remediation levels at a CPOC.

Alternative HA-4: This remedial alternative is similar to Alternative HA-3, but uses hot spot excavation to provide rapid removal of contaminated soil serving as a source of groundwater contamination. The following elements are included in this alternative:

- The existing barrier wall isolating and enclosing near-facility impacted soil and groundwater;
- The existing groundwater recovery and pretreatment system;
- Surface cover;
- Partial site dewatering and SVE;
- Excavation and offsite disposal of highly impacted soil;
- Electron donor injection into affected HCIM Area groundwater;
- The existing groundwater monitoring wells and program; and
- Institutional controls.

The physical/hydraulic containment, biostimulation, and surface cover elements described above for Alternative HA-2 would be incorporated into this alternative. Dewatering and SVE would be used to remove soil contaminants and shallow, residual DNAPL, using the approach described in Alternative HA-3. Within the two potential DNAPL areas shown on Figure 2-2, highly impacted soil above the depressed groundwater level would be excavated for offsite disposal, following removal of surface cover. Enhanced bioremediation would be implemented to promote biodegradation of chlorinated constituents remaining in groundwater after completing hot spot soil excavation and disposal.

The remediation elements included in this alternative would be implemented in a phased approach:

1. The HCIM Area would be dewatered and the SVE program would be implemented. to improve the effectiveness of SVE.
2. After completing SVE, the depressed groundwater level would be maintained and hot-sport soils would be excavated for offsite disposal.
3. After backfilling the excavations and repairing surface cover, biostimulation would be implemented by injection of electron donor to promote recovery of biological activity and rapid biodegradation of chlorinated VOCs.

This alternative would provide aggressive soil and groundwater remediation for the HCIM Area in addition to providing effective containment. The alternative would attain remediation objectives for the soil and groundwater remediation areas identified for the HCIM Area. It is expected that this alternative would not attain cleanup levels or remediation levels for HCIM Area soil or groundwater, but would support attainment of cleanup or remediation levels at a CPOC.

6.2 OUTSIDE AREA

Based on the potentially applicable remediation technologies identified during the technology screening, four potential remedial alternatives were developed for Outside Area soil and groundwater. Although not listed in the following brief alternative descriptions, the VIAM approach discussed in Technical Memorandum No. 3 is incorporated into each remedial alternative under consideration for the Outside Area to mitigate potential impacts associated with the vapor intrusion pathway. Table 6-2 lists the four alternatives (Alternatives OA-1, OA-2, OA-3, and OA-4) and shows which technologies are included for each alternative. In addition, Table 6-2 shows which specific technologies apply to the remediation areas. More complete descriptions and a full evaluation of these alternatives will be presented in Technical Memorandum No. 5.

Alternative OA-1: This alternative relies on MNA to address groundwater impacts within the Outside Area and existing surface cover to address soil constituents and potential exposure pathways. Additional groundwater monitoring wells would be installed to supplement the existing monitoring well network.

The SAD Property contains the OSRA-3, and two groundwater remediation areas, including the OWTRA-1 and the OSIRA-1. The general SAD property area includes a 15-foot-wide strip of PSC property that is located between the barrier wall and the SAD property line. The current concrete and asphalt cap on the PSC facility and pavement on the SAD property would be used to prevent contact with impacted soil and control surface water infiltration. Institutional controls would be required to ensure continued groundwater monitoring and maintenance of the cap system, as well as to restrict future groundwater use. Monitored natural attenuation is included to address COCs in the water table and shallow/intermediate depth intervals.

The UPRR property contains OSRA-1, and two groundwater remediation areas, including the OWTRA-2 and the OSIRA-2. On the UPRR property institutional controls would be required to ensure continued groundwater monitoring and to restrict future groundwater use. Monitored natural attenuation is included to address COCs in the water table and shallow/intermediate depth intervals.

The South Lucile Street Area in included in OSRA-2, and OWTRA-2, and OSIRA-2. The current concrete and asphalt cap on the PSC facility would be used to prevent contact with impacted soil and control surface water infiltration. Institutional controls would be required to ensure continued groundwater monitoring and maintenance of the cap system, as well as to restrict future groundwater use. Monitored natural attenuation is included to address COCs in the water table and shallow/intermediate aquifer zones.

Monitored natural attenuation is included in this alternative to address COCs in the water table, shallow/intermediate, and deep aquifer depth intervals. The specific remediation areas to be addressed by this alternative include the OWTRA-3, the OSIRA-3, and the DARA. In accordance with Ecology requests, the COCs for the DARA have been reviewed to identify those COCs that presently exceed cleanup levels. Based on this review, the DARA is particularly suited to MNA, since only iron, BEHP, and VC presently exceed cleanup levels in the DARA. Of these constituents, only BEHP and VC may be related to operations conducted at the Georgetown facility. Both are considered likely to attenuate primarily via biodegradation prior to discharge to either Elliot Bay or the Duwamish Waterway. Iron is likely present in the DARA due to geochemical conditions; facility releases are low in concentration and are highly unlikely to have affected the geochemistry in the DARA.

Alternative OA-2: This alternative includes all components of Alternative OA-1, with the addition of excavation and off-site disposal of unacceptably impacted vadose zone soils in the UPRR rail yard associated with historic releases from the PSC facility (i.e., soils in OSRA-1).

Alternative 3 (OA-3): The third alternative incorporates all the elements of OA-2. This alternative also includes reductive dechlorination (biostimulation) to accelerate the naturally occurring anaerobic biodegradation of chlorinated VOCs in OWTRA-1 (downgradient of the HCIM barrier wall and extending beneath the SAD property). A soil vapor extraction system has also been included in the alternative to address targeted soils in OSRA-3.

Wells would be installed to inject and distribute electron donor to treat the water table groundwater depth interval. Additional monitoring wells would be installed as appropriate downgradient of the treatment area to monitor treatment progress.

For this alternative, monitored natural attenuation would address COCs in the water table and shallow/intermediate depth intervals in the Outside Area (i.e., within OWTRA-2 and -3 and OSIRA-2 and -3). While it is not the intention of Alternative OA-3 to biostimulate other remediation areas, the addition of substrate to the groundwater within OWTRA-1 may promote additional biodegradation within downgradient groundwater.

Alternative OA-4: The last alternative for the Outside Area combines all elements of Alternative OA-3 with a pump and treat system designed to intercept groundwater impacted by 1,4-dioxane within OSIRA-3. Since 1,4-dioxane is not amenable to treatment methods that are effective for the other groundwater COCs, a pump and treat system designed to intercept and contain the 1,4-dioxane impacted groundwater has been included in this alternative. This approach would prevent further migration of the impacted groundwater to receptors located in the Duwamish Waterway.

7.0 REFERENCES

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TABLES

TABLE 2-1

PREDICTED CONCENTRATIONS AT DUWAMISH WATERWAY, DOWNGRADIENT WELLS

PSC Georgetown
Seattle, Washington

Well	Groundwater Flow Distance[1] (ft)	Constituent	EPC[2] (µg/L)	Predicted Concentration (µg/L)	Groundwater Cleanup Level[3] (µg/L)
113-S-1	4,000	Vinyl chloride	8.50	0.0052	2.04
		Trichloroethylene	1.30	0.023	0.79
		Tetrachloroethylene	1.60	0.000019	0.20
112-S-1	4,100	Vinyl chloride	32.10	0.012	2.04
		Trichloroethylene	6.36	0.051	0.79
		Tetrachloroethylene	1.93	0.000017	0.20
		cis-1,2-Dichloroethylene	172.00	0.010	72.71
CG-124-WT	4,110	Vinyl chloride	24.16	0.050	2.04
		Trichloroethylene	26.64	0.22	0.79
		Tetrachloroethylene	8.39	0.000068	0.20
CG-126-WT	3,720	Trichloroethylene	19.12	0.20	0.79
		Tetrachloroethylene	1.86	0.000048	0.20
		Vinyl chloride	--	0.046	2.04
CG-127-WT	3,350	Trichloroethylene	12.10	0.19	0.79
		Tetrachloroethylene	0.43	0.000032	0.20
		Vinyl chloride	--	0.044	2.04
CG-128-WT	3,320	Tetrachloroethylene	0.50	0.000040	0.20
		Vinyl chloride	--	0.0044	2.04
CG-130-WT	2,950	Trichloroethylene	1.85	0.048	0.79
		Vinyl chloride	--	0.011	2.04
CG-131-WT	2,900	Vinyl chloride	17.20	0.31	2.04
		Trichloroethylene	50.86	**1.36**	0.79
CG-132-WT	3,100	Trichloroethylene	14.15	0.31	0.79
		Tetrachloroethylene	0.75	0.00011	0.20
		Vinyl chloride	--	0.071	2.04
CG-124-40	4,110	Vinyl chloride	5.32	0.0027	2.04
		Trichloroethylene	1.91	0.012	0.79
CG-125-40	3,750	Vinyl chloride	10.80	0.00008	2.04
CG-127-40	3,350	Vinyl chloride	12.56	0.00014	2.04
CG-131-40	2,900	Vinyl chloride	12.20	0.00044	2.04
CG-132-40	3,100	Vinyl chloride	8.09	0.00029	2.04
CG-133-40	2,225	Vinyl chloride	58.30	0.009	2.04
CG-134-40	2,575	Vinyl chloride	19.20	0.0047	2.04
CG-135-40	2,750	Vinyl chloride	7.06	0.00020	2.04
CG-135-50	2,750	Vinyl chloride	7.68	0.00074	2.04

Notes:

1. Distance to Duwamish Waterway measured along the groundwater flow path.
2. Exposure Point Concentration, as presented in Technical Memorandum No. 1.
3. Groundwater cleanup level protective of surface water, taken from Technical Memorandum No. 1. For the water table depth interval, this cleanup level may differ from the final SWFS cleanup level because it does not consider the inhalation pathway.
4. **Bold** indicates the predicted concentration at the Duwamish Waterway exceeds the cleanup level.
5. -- indicates that the EPC for that constituent did not exceed the cleanup level.

TABLE 4-1

REMEDIATION TECHNOLOGY SCREENING FOR HCIM AREA SOIL
REMEDIATION AREAS 1 AND 2

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	4.2.1.1	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 in moist soils that biodegrade aerobically. Low effectiveness for halogenated organics. Ineffective on PCBs, inorganics, and in dry soils.	TPH, non-halogenated VOCs, SVOCs	Effectiveness of in-situ degradation of halogenated VOCs and SVOCs is low. Technology is ineffective on PCBs and inorganics. Surface cover limits infiltration, creating dry conditions in vadose zone.	Low effectiveness on high molecular weight organic COCs (SVOCs, PCBs) and halogenated VOCs, and ineffective for inorganics. Poor effectiveness likely due to dry soil.	Reject
	Enhanced Bioremediation	4.2.1.2	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	Anaerobic bioremediation has been moderately effective on halogenated VOCs. Aerobic bioremediation has been moderately effective for SVOCs and effective for 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 area presently covered with concrete and asphalt. Sequential anaerobic/aerobic treatment would be needed to address most of the organic COCs.	Only moderately effective on halogenated organics and SVOCs. Likely ineffective on inorganics and PCBs. Very long treatment time likely.	Reject
In-Situ Physical/Chemical Treatment	Chemical Oxidation	4.2.1.3	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. Reaction only occurs in aqueous solution.	Full-Scale	Technology demonstrated to be effective under certain site conditions. Pilot test is required to evaluate feasibility and measure key design parameters. Ineffective for most inorganics.	Halogenated and non-halogenated VOCs and SVOCs	Handling of oxidant chemicals during remediation presents a safety concern. 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 some metals. This technology would require numerous penetrations of the surface cover currently installed over the HCIM Area.	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. Difficult to obtain effective distribution of oxidant in unsaturated soils.	Reject
	Soil Flushing	4.2.1.4	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 remediated using this technology.	Some inorganics and some organics, depending on site and constituent conditions.	Requires recovery of water (hydraulic capture) and surfactant and separation facilities. Recovered water requires treatment and disposal and management of treatment residuals. HCIM Area would require different surfactants to treat all COCs. Large injection galleries or trenches would require the existing concrete cover to be removed.	Technology is not proven effective. Requires extensive and complex fluids delivery system and recovered fluids treatment system. Would require removal of the concrete cover.	Reject
	Soil Vapor Extraction	4.2.1.5	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 gases are generally treated to control emissions using thermal destruction or adsorption technologies.	Full-Scale	Proven reliable and effective technology for VOCs. Not effective for SVOCs, PCBs, and inorganics.	VOCs	SVE was conducted at the facility for several years and approximately 19,000 pounds of solvents were removed. This activity was terminated wher it was shown that continued operation would yield diminishing returns.	SVE was already conducted at the facility as an interim measure. Additional SVE is not expected to remove significant additional VOCs from treated area, but may be effective for other areas.	Retain
	Solidification/ Stabilization	4.2.1.6	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 can be effective. Complete mixing can be difficult. Poor effectiveness for organics.	Inorganics	The volume increase due to stabilization or solidification reagents (bulk up) can be significant. Excess soil would require disposal as hazardous waste. Reagent delivery and mixing can be problematic for in-situ applications. Presence of solidified material could affect future site development by creating structural challenges for new buildings. Would require removal of the existing concrete cover.	Limited effectiveness for the majority of COCs. Would preclude subsequent implementation of other in-situ technologies (e.g., SVE). Would require removal of concrete cover.	Reject

TABLE 4-1

REMEDIATION TECHNOLOGY SCREENING FOR HCIM AREA SOIL
REMEDIATION AREAS 1 AND 2

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 Thermal Treatment	High Temperature Volatilization	4.2.1.7	Steam, electrical energy, or radio frequency energy 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	Effectiveness can be hindered by high organic carbon or high moisture content (e.g., soil in the capillary fringe). Would require extensive network of steam distribution points to heat soil effectively. Would require installation of numerous wells through the existing concrete cover. Could not be implemented in proximity to barrier wall due to possible heat damage to wall, thereby limiting the area that could be treated. Significant volumes of water are added to the subsurface, which may flush contaminants from unsaturated soil to groundwater. Dense development in vicinity of facility would require stringent control of hot vapors.	Ineffective on inorganics, limited effectiveness on PCBs. Requires management of air emissions and treatment residuals. Numerous penetrations of the existing concrete cover would be required. Could not be implemented in proximity to the barrier wall. Potential to mobilize contaminants to groundwater. Potential risks associated with active release of vapors if controls fail.	Reject
Ex-Situ Biological Treatment (assumes excavation)	Biopiles	4.2.2.1	Excavated soils are mixed with soil amendments and placed on a treatment area that includes leachate collection systems and some form of aeration to support bioremediation of organic constituents in excavated soils. 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. Ineffective for inorganics.	Non-halogenated VOCs, TPH, some SVOCs	Would require extensive site excavation and soil management and removal o existing concrete cover. Extensive shoring and supporting systems would be required for excavations near existing structures and containment wall. Some impacted soils would likely remain in place due to the presence of existing structures/buildings. Emission control measures (e.g., tenting site) would likely be required during excavation. Treatability tests required to assess feasibility. RCRA treatment permit would likely be required.	Unproven effectiveness on halogenated VOCs and PCBs. Ineffective on inorganics. Large excavation would disrupt existing facility cover. Increased worker and public exposure risk associated with excavation and treatment process.	Reject
Ex-Situ Physical/Chemical Treatment (assumes excavation)	Soil Washing	4.2.2.2	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 o existing concrete cover. Extensive shoring and supporting systems would be required for excavations near existing structures and containment wall. Some impacted soils would likely remain in place due to the presence of existing structures/buildings. Emission control measures (e.g., tenting site) would likely be required during excavation. 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. RCRA treatment permit would likely be required.	Soil washing may not be effective for complex mixture of organics and inorganics. Large excavation would disrupt existing facility cover. Extensive shoring and supporting systems would be required for excavations near existing structures and containment wall. Worker and public exposure risks associated with excavation and treatment process.	Reject
Ex-Situ Physical/Chemical Treatment (assumes excavation)	Solidification/ Stabilization	4.2.2.3	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. Poor effectiveness for organics.	Inorganics	Would require excavation and soil management and removal of existing concrete cover. Extensive shoring and supporting systems would be required for excavations near existing structures and containment wall. Some impacted soils would likely remain in place due to the presence of existing structures/buildings. Emission control measures (e.g., tenting site) would likely be required during excavation. 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. RCRA treatment permit would likely be required.	Large excavation would disrupt existing facility cover. Extensive shoring and supporting systems would be required for excavations near existing structures and containment wall. 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 4-1

REMEDIATION TECHNOLOGY SCREENING FOR HCIM AREA SOIL
REMEDIATION AREAS 1 AND 2

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**
Ex-Situ Thermal Treatment (assumes excavation)	Thermal Desorption	4.2.2.4	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. Not effective for inorganics.	VOCs, SVOCs, TPH, PCBs	Would require excavation and soil management and removal of existing concrete cover. Extensive shoring and supporting systems would be required for excavations near existing structures and containment wall. Some impacted soils would likely remain in place due to the presence of existing structures/buildings. Emission control measures (e.g., tenting site) would likely be required during excavation. 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. RCRA treatment permit would likely be required.	Large excavation would disrupt existing facility 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). Increased worker and public exposure risk associated with excavation.	Reject
Containment	Cap/Surface Cover	4.2.1.8	Surface caps constructed of asphalt concrete, Portland cement concrete, or flexible membrane liners prevent direct exposure to soil contaminants, control erosion, 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 or asphalt concrete surface cover has been installed across the entire HCIM Area. These low-permeability covers prevent direct contact with and erosion of impacted soil. These cover systems also promote runoff and limit infiltration of surface water to the subsurface.	Facility surface is currently covered by micro-silica concrete or asphalt concrete cover. This system is performing well and prevents direct exposure to and erosion of COCs in covered areas. In addition, the cover system limits surface water infiltration through impacted soils.	Retain
Excavation/Disposal	Excavation and Off-Site Disposal	4.2.2.5	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 o existing concrete cover. Extensive shoring and supporting systems would be required for excavations near existing structures and containment wall. Some impacted soils would likely remain in place due to the presence of existing structures/buildings. Emission control measures (e.g., tenting site) would likely be required during excavation.	Capable of addressing all contaminants in vadose zone soil within the HCIM Area. Least administratively, logistically, and technically complex ex-situ remediation technology. Potential applicable to hot spots.	Retain

TABLE 4-2

REMEDIATION TECHNOLOGY SCREENING FOR THE OUTSIDE AREA SOIL
REMEDIATION AREAS 1, 2, AND 3

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	4.2.1.1	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 in moist soils that biodegrade aerobically. Low effectiveness for halogenated organics and in dry soils. Ineffective for PCBs and inorganics.	TPH, non-halogenated VOCs, SVOCs	Effectiveness of in-situ degradation of halogenated VOCs and SVOCs is low. Ineffective for PCBs and inorganics. Requires easement or access agreements from each affected property owner. Thin vadose zone would require dense injection network for full coverage.	Low effectiveness on high molecular weight organic COCs (SVOCs, PCBs) and halogenated VOCs. SVE (retained) would treat all COCs addressed by this technology more cost-effectively.	Reject
	Enhanced Bioremediation	4.2.1.2	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	Anaerobic bioremediation has been moderately effective on halogenated VOCs. Aerobic bioremediation has been moderately effective for SVOCs and effective for 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 each affected property owner. Sequential anaerobic/aerobic treatment would be needed to address most of the organic COCs.	Only moderately effective on halogenated organics and SVOCs. Likely ineffective on inorganics and PCBs. SVE (retained) would treat all COCs addressed by this technology more cost-effectively.	Reject
In-Situ Physical/Chemical Treatment	Chemical Oxidation	4.2.1.3	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. Not effective for most inorganics.	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 some metals. Requires easement or access agreements from each affected property owner.	Oxidant volumes can be large if high soil oxidant demand. Difficult to obtain effective distribution of oxidant in unsaturated soils. Complex logistics due to multiple property accesses for hazardous chemicals. Potential safety issues.	Reject
	Soil Flushing	4.2.1.4	Water, or water containing an additive (e.g., surfactant) 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 remediated using this technology.	Some inorganics and some 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.	Technology has poor performance record and is unproven. Complex logistical issues to construct and operate fluid delivery and recovered fluids treatment system.	Reject
	Soil Vapor Extraction	4.2.1.5	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 gases are generally treated to control emissions using thermal destruction or adsorption technologies.	Full-Scale	Proven reliable and effective technology for VOCs. Not effective for SVOCs, PCBs, and inorganics.	VOCs	Implementation over the entire area 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. Requires easement or access agreements from affected public and/or private property owners.	Difficult to implement SVE over a large area covered by numerous businesses and residences. However, it may be effective in a few discrete areas with high soil vapor concentrations and no access limitations.	Retain

TABLE 4-2

REMEDIATION TECHNOLOGY SCREENING FOR THE OUTSIDE AREA SOIL
REMEDIATION AREAS 1, 2, AND 3

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	4.2.1.6	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 can be effective but are unproven in the long term. Effective and complete mixing can be difficult. Poor effectiveness for organics.	Inorganics	The volume increase due to stabilization or solidification reagents (bulk up) can be significant. Reagent delivery and effective mixing can be problematic for in-situ applications. Presence of solidified material could affect future site development by creating structural challenges for new buildings. Some untreated soil may remain in place due to existing structures and utilities. Requires easement or access agreements from both each affected property owner.	Poor effectiveness for majority of COCs. Would preclude subsequent implementation of most other treatment technologies. Access and logistics issues to construct the required infrastructure are extremely complex.	Reject
In-Situ Thermal Treatment	Steam Injection	4.2.1.7	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	Effectiveness can be hindered by high organic carbon or high moisture content (e.g., soils within the capillary fringe). Would require extensive network of steam distribution points to heat soil effectively. Requires easement or access agreements from each affected property owner. Would be difficult to install due to the large number of underground utilities. Potential safety issues due to vapors. Significant volumes of water would be added to the subsurface, potentially flushing contaminants from unsaturated soil to groundwater.	Ineffective on inorganics, limited effectiveness on PCBs. Requires management of air emissions and treatment residuals. Access issues to construct the required infrastructure are logistically complex. Risk issues for vapors and potential interference with the IPIM. Potential to mobilize contaminants to groundwater.	Reject
Ex-Situ Biological Treatment (assumes excavation)	Biopiles	4.2.2.1	Excavated soils are mixed with soil amendments and placed on a treatment area that includes leachate collection systems and some form of aeration to support biodegradation of organic constituents in excavated soils. 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.	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/utilities. Treatability tests required to assess feasibility. Excavation would be difficult due to the large number of underground utilities. Requires easement or access agreements from each affected property owner. Emission control measures (e.g., tenting excavation) may be required. RCRA treatment permit may be required.	Unproven effectiveness on halogenated VOCs and inorganics. Access issues for excavation and to construct the required infrastructure are logistically complex. Worker and public exposure risks associated with excavation and treatment. SVE (retained) would treat all COCs addressed by this technology more cost-effectively.	Reject
Ex-Situ Physical/Chemical Treatment (assumes excavation)	Soil Washing	4.2.2.2	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, some inorganics, TPH	Would require extensive excavation and soil management. Some impacted soils would likely remain in place due to the presence of existing structures/buildings/utilities. Treatability tests required to assess feasibility. Excavation would be difficult due to the large number of underground utilities. Requires easement or access agreements from each affected property owner. Emission control measures during excavation (e.g., tenting) may be required. RCRA treatment permit may be required.	Soil washing may not be effective for complex mixture of organics and inorganics. Worker and public exposure risk associated with excavation and operations. Access issues to construct the required infrastructure and for excavation are logistically complex.	Reject
Ex-Situ Physical/Chemical Treatment (assumes excavation)	Solidification/ Stabilization	4.2.2.3	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. Limited effectiveness with organics.	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. 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. Emission control measures during excavation (e.g., tenting) may be required. RCRA treatment permit may be required.	Not proven effective for many organic COCs. Post-treatment waste remains a long- term management issue. Volume increase (bulk up) results in off-site disposal of waste. Worker and public exposure risks associated with excavation and operation. Access issues for excavation and operations are logistically complex.	Reject

TABLE 4-2

REMEDIATION TECHNOLOGY SCREENING FOR THE OUTSIDE AREA SOIL
REMEDIATION AREAS 1, 2, AND 3
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**
Ex-Situ Thermal Treatment (assumes excavation)	Thermal Desorption	4.2.2.4	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. Not effective on inorganics.	VOCs, SVOCs, TPH, PCB	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. Emission control measures during excavation (e.g., tenting) may be required. RCRA treatment permit may be required.	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). Increased worker and public exposure risk associated with excavation.	Reject
Containment	Cap/Surface Cover	4.2.1.8	Surface caps constructed of asphalt concrete, portland cement concrete, or flexible membrane liners prevent direct exposure to soil contaminants, control erosion, 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 impacted materials, erosion control, and for reducing infiltration of surface water through waste, limiting leaching of COCs to groundwater.	VOCs, SVOCs, TPH, PCBs, inorganics	Concrete or asphalt covers provide excellent protection against direct exposure to COCs and erosion/runoff of impacted sediment runoff. Asphalt or concrete covers will reduce infiltration and aid in the collection and capture of storm water. Effective for contiguous areas where COCs exceed cleanup levels. Readily implemented for property owned by PSC. Access agreements required for affected property owners.	Portions of the facility in the Outside Area are covered by micro-silica concrete or asphalt concrete cover. This system is performing well. Access agreements could probably be obtained to install suitable cover for non-PSC property.	Retain
Disposal Excavation	Excavation and Off-Site Disposal	4.2.2.5	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/utilities. Excavation would be difficult due to the large number of public and private entities requiring approval. Emission control measures during excavation (e.g., tenting) may be required. Some impacted areas can probably be accessed with reasonable logistical and access issues.	This technology could potentially be used to remove surficial soil contamination in some portions of the Outside Area, the UPRR rail yard.	Retain

TABLE 4-3

REMEDIATION TECHNOLOGY SCREENING FOR HCIM AREA GROUNDWATER
PSC Georgetown
Seattle, Washington

General Response Actions	Remediation Technologies	Section	Technology Description	Technology Characteristics				Rationale for Retention or Rejection	Screening Result
				Technology Development Status	General Performance Record	Site Contaminants Addressed	Site-Specific Issues Affecting Technology or Implementation		
In-Situ Biological Treatment	Enhanced Biodegradation with Biosparging	4.3.1	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. Not effective for inorganics or halogenated VOCs. Primarily used at petroleum impacted sites.	VC, SVOCs, TPH, BTEX	Active natural biological degradation of chlorinated VOCs (e.g., 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. Poor air distribution would result in intermediate depth interval.	May result in significant iron fouling. The technology would inhibit the ongoing anaerobic biological degradation at the facility. Aerobic conditions would interfere with degradation of chlorinated VOCs, which are key COCs. May be usable as a contingent technology after chlorinated VOCs are substantially reduced in concentration.	Retain
	Oxygen Enhancement with Hydrogen Peroxide or ORC	4.3.2	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. Performance is similar to but less effective than biosparging.	VC, SVOCs, TPH	Active natural biological degradation of chlorinated VOCs (e.g., TCE) would be inhibited by the addition of oxygen. Injection of ORC or hydrogen peroxide would require numerous injection wells. Potential iron fouling due to the aerobic environment.	The technology addresses a limited set of COCs and would inhibit ongoing biological degradation. Aerobic conditions do not readily degrade chlorinated COCs. Biosparging provides similar results at lower cost.	Reject
	Co-Metabolic Treatment	4.3.3	Chlorinated organic degradation by aerobic co-metabolization with alkane substrates such as ethane by indigenous microbes. 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	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 safety issues. Will not reduce all COC concentrations to below cleanup levels.	Significant safety concerns and the potential for iron fouling are the basis for rejecting this technology.	Reject
	Reductive Dechlorination Biostimulation (Anaerobic)	4.3.4	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 proper conditions for degradation of chlorinated solvents.	Chlorinated VOCs	Multiple injections of electron donor are typically required. Monitoring is required to confirm effectiveness. This technology alone may not be capable of attaining cleanup levels for VOCs, particularly due to presence of NAPL. Does not address metals, PCBs, and many non-chlorinated organics.	May be effective at accelerating the active naturally occurring anaerobic degradation process within the HCIM Area. Addresses key COCs (chlorinated solvents).	Retain
	Bioaugmentation	4.3.5	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 COCs.	TCE is already actively degrading in the HCIM Area groundwater. However, bioaugmentation is retained as a potential supplemental technology for reductive dechlorination and existing natural attenuation processes.	Retain
	Monitored Natural Attenuation	4.3.6	Intrinsic attenuation of groundwater constituents via the natural processes of biodegradation (aerobic and/or anaerobic), 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 active within the HCIM Area. Potentially longer remediation times when compared to more active technologies. May not address higher end SVOCs. Potentially long restoration time.	Natural attenuation is a viable process with documented evidence that natural attenuation is active within the HCIM Area.	Retain

TABLE 4-3

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	4.3.7	Dense plants and trees can supply nutrients to promote microbial growth that reduce contaminant concentrations in groundwater or plants can directly uptake contaminants in groundwater. Mostly applicable to shallow groundwater.	Full-Scale	Has been proven effective at sites with appropriate conditions.	VOCs, TPH, SVOCs, Metals	Implementation of this technology would require the removal of the concrete 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 prevent use of site during remediation.	Would require the removal of the concrete cover. Difficult to apply phytoremediation due to the number of COCs in HCIM groundwater. Cannot address shallow/intermediate groundwater.	Reject
	Air Sparging	4.3.8	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. Similar to biosparging but relies primarily on volatilization.	Full-Scale	Has been effectively used at VOC-impacted sites. Difficult to implement for deep groundwater.	VOCs, TPH, SVOCs	Active 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. Would not be appropriate to intermediate depth interval due to silt lenses.	The technology would inhibit the naturally occurring VOC biodegradation. Would require an extensive SVE system with long-term operation and maintenance to capture all off-gas.	Reject
	Chemical Oxidation	4.3.9	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 effective, while others have been unsuccessful in attaining cleanup objectives. Not effective for most metals.	VOCs, SVOCs	Active natural biological degradation of chlorinated VOCs would be inhibited by the addition of chemical oxidants. High reduced iron concentrations at the site will exert a large oxidant demand, affecting efficiency of treatment. May be difficult to obtain effective oxidant distribution in intermediate groundwater zone due to heterogeneities. Would not remove DNAPL.	Can address source areas but treatment may be limited due to subsurface heterogeneities. Potentially applicable to hot spots. Would not attain cleanup levels.	Retain
	Thermal Treatment	4.3.10	Temperature in the saturated zone is increased by injecting steam or applying an electrical current. The increased temperature volatilizes organic compounds, which would be collected from the vadose zone using SVE.	Full-Scale	Mixed performance record. Some applications have been effective, while others have been unsuccessful in attaining cleanup objectives. Not effective for inorganics.	VOCs, TPH, SVOCs	This technology would require numerous steam injection points or heating elements and an off-gas treatment system to capture the volatilized contaminants. Iron fouling is likely. The energy requirement to treat (heat) deeper groundwater has high costs. Technology could not be used in proximity to the existing containment wall due to potential adverse impacts. Not expected to effectively remove DNAPL.	Potential for iron fouling and the high energy requirements to heat deep groundwater provide the basis to reject this technology. Could not be used in proximity to HCIM barrier wall, limiting area available for thermal remediation.	Reject
	In-Well Stripping	4.3.11	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. Groundwater in radius of influence is aerated.	Full-Scale	Mixed performance record. Some applications have been very effective, while others have been unsuccessful in attaining cleanup objectives.	VOCs, TPH	The active natural biological degradation of chlorinated VOCs would be inhibited by the addition of oxygen (in well aeration). High iron levels at the sit would likely cause iron precipitate and/or biological fouling of the air stripping wells. Vapor controls needed to capture volatilized contaminants. Minimal effectiveness in the intermediate depth. Ineffective for SVOCs and inorganics.	This technology has a mixed performance record, would inhibit the active biological VOC degradation, and may result in significant iron fouling. Would not address DNAPL. Would require long-term operation and maintenance.	Reject
	Passive/Reactive Treatment Walls	4.3.12	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.	Chlorinated VOCs, some Metals	This technology would not be effective at treating HCIM Area contaminants because the HCIM barrier wall is 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 HCIM barrier wall. Does not address DNAPL or complex mixture of COCs. Difficult to implement for intermediate depth.	Reject

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REMEDIATION TECHNOLOGY SCREENING FOR HCIM AREA GROUNDWATER

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Seattle, Washington

General Response Actions	Remediation Technologies	Section	Technology Description	Technology Characteristics				Rationale for Retention or Rejection	Screening Result
				Technology Development Status	General Performance Record	Site Contaminants Addressed	Site-Specific Issues Affecting Technology or Implementation		
In-Situ Physical/Chemical Treatment	Emulsified Zero Valent Iron	4.3.13	Zero valent iron emulsified in vegetable oil and surfactant is injected into groundwater. Zero valent iron causes abiotic reductive dechlorination and vegetable oil and surfactant act as long-term electron donors for biotic reductive dechlorination.	Bench/Pilot Scale	No full-scale implementations. May be suitable for treatment of DNAPL/source areas after development is completed. ZVI component has been unstable. .	Chlorinated VOCs	Difficult to obtain effective distribution of EZVI in subsurface due to heterogeneities. Implementation potentially more costly than chemical oxidation. Technology has very limited pilot-scale record, no instances of full-scale implementation were identified. This technology would require numerous injection points. Would not address many site COCs and difficult to implement in intermediate depth.	Not proven technology, no instances of full-scale implementation identified. ZVI has been unstable.	Reject
	Dynamic Underground Stripping	4.3.16	Combination of technologies, includes steam injection at periphery of contamination to drive COCs to centrally located vapor extraction wells. Electrical heating used to mobilize VOCs from finer grained units. Underground imaging used to delineate treated areas and for process control.	Pilot Scale	Effective to reduce chlorinated VOCs only in groundwater pilot tests. Unproven potential technology.	VOCs, TPH, SVOCs	Long-term increase in subsurface temperatures may interfere with existing natural biodegradation processes. Could not be implemented in proximity to HCIM barrier wall due to possible impacts.	May inhibit existing natural biodegradation processes. Could not be used in proximity to HCIM barrier wall. No proven applications.	Reject
	Solvent Enhanced Aquifer Remediation (SEAR)	4.3.17	Surfactants are injected to increase the solubility and mobility of organic contaminants, including NAPLs. Surfactants and contaminants are then recovered with conventional pump-and-treat methods. The surfactants are separated from the groundwater and contaminants and reinjected.	Full-Scale	Has been used to enhance recovery of chlorinated VOCs and DNAPLs. Limited full scale applications.	VOCs, SVOCs, TPH	Subsurface heterogeneities can interfere with effective delivery and recovery of surfactants. Aquifer heterogeneities create preferential flow paths, resulting in significant channeling of injected fluids, bypassing zones of contamination. Low permeability soils are difficult to treat with this technology. Would not be effective in intermediate depth interval due to heterogeneities.	Preferential flow paths due to aquifer heterogeneities prevent effective distribution/recovery of surfactants limiting effectiveness.	Reject
	Co-Solvent Flooding	4.3.18	Co-solvents, typically ethanol or propanol, are injected to enhance dissolution and recovery of DNAPL components. Co-solvent and dissolved phase organics are recovered with conventional groundwater extraction methods.	Full-Scale	Has been used to enhance recovery of DNAPL. Limited prior full scale applications.	VOCs, SVOCs	Technology is difficult to implement at sites with fine grained soils or complex hydrogeology due to the difficulty of distributing and recovering the co-solvent. Heterogeneities create preferential flowpaths, limiting contact with impacted media.	Preferential flow paths due to aquifer heterogeneities prevent effective distribution and recovery of solvents. Would leave residual co-solvents as contaminants. Ultra-high purity co-solvents required to avoid introducing new COCs.	Reject
Groundwater Extraction and Treatment (Pump and Treat)	Hydraulic Control	4.3.14	Groundwater extraction wells are installed to create a hydraulic gradient to control contaminant migration. Extracted water is then treated and discharged.	Full-Scale	Has been effectively used to control contaminant migration. Is a long-duration technology. Cannot attain cleanup levels.	VOCs, SVOCs, TPH, PCBs, inorganics	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. Active biological activity in groundwater contributes to well fouling.	Potentially effective long-term approach for containing source area (HCIM Area) groundwater COCs.	Retain
	Mass Reduction	4.3.14	Groundwater extraction wells are installed in source areas to aggressively remove contaminated groundwater, thereby reducing contaminant mass. Extracted water is then treated and discharged.	Full-Scale	Has been effectively used to remove contaminants. Is a long-duration technology. Not effective to attain cleanup levels	VOCs, SVOCs, TPH, PCBs, inorganics	The barrier wall and surface cover reduce groundwater recharge to the HCIM Area and would limit the effectiveness of groundwater extraction for mass reduction. Groundwater extraction has not been successful at sites with DNAPLs, which act as an ongoing source of dissolved COCs. Significant long-term O&M costs may make in-situ technologies preferential.	The effectiveness of groundwater extraction for mass reduction would be limited by the HCIM barrier wall. Not effective for removal of DNAPLs. High long-term O&M costs. Difficult to discharge high volume of treated groundwater.	Reject
Physical Containment	Barrier Wall	4.3.15	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, inorganics	Barrier wall is in place as part of the existing HCIM. Has been proven effective.	Has been documented to be effective at containing site contaminants during operation of the HCIM.	Retain

TABLE 4-3

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**
Ancillary/Support Technologies	Air Stripping	4.3.14.1	This technology is used in conjunction with pump and treat systems. 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	This technology is currently in use as part of the existing groundwater HCIM. Used to treat groundwater that is extracted to control contaminant migration. Presence of reduced iron causes significant fouling and maintenance requirements.	Has been effective in reducing VOC concentrations in extracted groundwater during operation of the HCIM.	Retain
	Adsorption	4.3.14.2	This technology is used in conjunction with pump and treat systems. Extracted groundwater or VOC-containing air 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 vapor streams during the SVE and barrier wall HCIMs.	VOCs, SVOCs, TPH	This technology is currently in use as part of the existing groundwater HCIM. Used to treat vapor stream from air stripping treatment of extracted groundwater and previously from SVE. Presence of VC requires use of specialty absorbents.	Has been effective at reducing VOC concentrations in air stripper off-gas during operation of the HCIM.	Retain
	Advanced Oxidation	4.3.14.3	This technology is used to support pump and treat remediation. Extracted groundwater is passed through a specially designed advanced oxidation unit. Advanced oxidation processes typically use ultraviolet light (uv) and hydrogen peroxide to aggressively oxidize organics. Treatment products are typically carbon dioxide, water, and HCl.	Full-Scale	Has been effectively used to treat groundwater, including 1,4-dioxane. Inorganics such as iron can foul the reaction tubes, limiting effectiveness of uv transmittance and the resulting oxidation reactions.	VOCs, SVOCs, TPH	The presence of 1,4-dioxane may require use of this technology for treatment of recovered groundwater.	Has been effective at reducing VOC concentrations in air stripper off-gas during operation of the HCIM.	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
8. EZVI - Emulsified zero valent iron

TABLE 4-4

REMEDIATION TECHNOLOGY SCREENING FOR OUTSIDE AREA GROUNDWATER
REMEDIATION AREAS 1, 2, 3, AND DEEP AQUIFER

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	4.3.1	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. Not effective for inorganics or halogenated VOCs.	VC, SVOCs, TPH, BTEX	Active natural anaerobic biological degradation of chlorinated VOCs (e.g., TCE) would be inhibited by the addition of oxygen. The addition of oxygen could potentially stimulate growth of iron-reducing bacteria, which could 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/or acquiring property for the air injection system would complicate implementation. The technology could potentially exacerbate the vapor intrusion pathway by volatilizing the VOCs.	The technology would inhibit active anaerobic biological degradation at the site. Aerobic conditions do not readily degrade chlorinated VOCs. Based on groundwater data, there are no locations that could be remediated with this technology without interfering with the ongoing anaerobic biodegradation of chlorinated VOCs.	Reject
	Oxygen Enhancement with Hydrogen Peroxide or ORC	4.3.2	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	Active natural biological degradation of chlorinated VOCs (e.g., TCE) would be inhibited by the addition of oxygen to the Outside Area groundwater. Access to affected public lands and private properties to make the required injections would be necessary, making implementation more complex. Iron and manganese fouling due t the introduction of oxygen could limit the ability to distribute the chemicals in the area of the impacted groundwater.	Based on groundwater data, there are no locations that could be remediated with this technology without interfering with the ongoing anaerobic biodegradation of chlorinated VOCs.	Reject
	Co-Metabolic Treatment	4.3.3	Chlorinated organic degradation by aerobic co-metabolization with alkane substrates such as ethane by indigenous microbes. 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	Would require numerous wells 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 (alkane) and oxygen present significant 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 complex.	Significant safety concerns associated with use in an urban mixed-use environment.	Reject
	Reductive Dechlorination Biostimulation (Anaerobic)	4.3.4	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 proper conditions for degradation of chlorinated solvents. Not effective for non-chlorinated VOCs and SVOCs.	Chlorinated VOCs	Multiple injections of electron donor may be required and substantial monitoring would be required to confirm treatment effectiveness. Logistically less complex than technologies that require permanent easements for installation of treatment equipment Anaerobic biodegradation of VOCs is active at the site; this technology is complementary to the observed natural degradation.	Should be effective at reducing chlorinated VOCs and accelerating the naturally occurring anaerobic biodegradation process. Less logistically complex than alternatives that require significant constructed infrastructure for implementation. Addresses key COCs.	Retain

TABLE 4-4

REMEDIATION TECHNOLOGY SCREENING FOR OUTSIDE AREA GROUNDWATER
REMEDIATION AREAS 1, 2, 3, AND DEEP AQUIFER

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	Bioaugmentation	4.3.5	Injection of specialty, non-indigenous microbes to enhance biodegradation. Microorganisms are commercially available for anaerobic degradation of chlorinated VOCs.	Full-Scale	Has been effective for biodegradation of chlorinated solvents. Requires application of specific microbial seed. May require repeated application.	Chlorinated VOCs	Non-indigenous organisms may not compete successfully with indigenous organisms. TCE degradation is already occurring and well documented in Outside Area groundwater. Periodic injections of microbes and ongoing monitoring across the expansive Outside Area groundwater would require access for affected public and private property owners.	Biodegradation of TCE is already actively degrading in Outside Area groundwater. However, bioagmentation is retained as a potential technology to supplement reductive dechlorination and existing natural attenuation processes (if necessary).	Retain
	Natural Attenuation	4.3.6	Intrinsic attenuation of groundwater constituents via the natural processes of biodegradation (aerobic and/or anaerobic), 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 active within Outside Area groundwater, resulting in the generation of VC. VC appears to also be naturally attenuating as groundwater flows southwest from the source area. Technology has potentially longer remediation times when compared to more active technologies. May not address higher end SVOCs.	Natural attenuation is a viable process. There is documented evidence that natural attenuation is active within Outside Area groundwater.	Retain
In-Situ Physical/Chemical Treatment	Air Sparging	4.3.8	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, SVOCs	Active natural biological anaerobic degradation of chlorinated VOCs would be inhibited by the addition of oxygen. This technology must be used in conjunction with soil vapor extraction to capture volatilized contaminants. 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.	Based on groundwater data, there are no areas of Outside Area groundwater that could be remediated with this technology without interfering with the ongoing anaerobic biodegradation of TCE . Potential for vapor inhalation risks.	Reject
	Chemical Oxidation	4.3.9	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	Usually applied to source areas or hotspots. Mixed performance record. Some applications have been effective, while others have been unsuccessful in attaining cleanup objectives. Not effective for inorganics.	VOCs, SVOCs	Active natural biological degradation of chlorinated VOCs would be suppressed by the addition of chemical oxidants. High iron concentrations at the site will exert a large oxidant demand, reducing efficiency of treatment. Development of private property access as well as public easements would be required to support injection and monitoring activities. Technology not cost effective for treatment of diffuse groundwater concentrations. Requires handling on injection of hazardous chemicals.	The technology will suppress the natural occurring biological VOC degradation in Outside Area groundwater. High oxidant demand and diffuse groundwater concentrations make treatment of the Outside Area costly. Access issues to safely conduct this work are significant.	Reject
	Thermal Treatment	4.3.10	Temperature in the saturated zone is increased by injecting steam or applying an electrical current. The increased temperature volatilizes organic compounds, which would be collected using SVE.	Full-Scale	Usually applied to source areas or hotspots. Mixed performance record. Some applications have been very effective, while others have been unsuccessful in attaining cleanup objectives. Not effective for dilute areas.	VOCs, TPH, SVOCs	This technology would require numerous steam injection points and an off-gas collection treatment system to control the volatilized contaminants. Iron fouling is likely. The energy requirement to treat (heat) deeper diffuse groundwater is likely cost-prohibitive. Access issues make implementation of this technology complex.	Technology could not be implemented in proximity to HCIM barrier wall. Potential for creating unacceptable risks due to volatilization of VOCs.	Reject

TABLE 4-4

REMEDIATION TECHNOLOGY SCREENING FOR OUTSIDE AREA GROUNDWATER
REMEDIATION AREAS 1, 2, 3, AND DEEP AQUIFER

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	In-Well Stripping	4.3.11	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. Groundwater in radius of influence is aerated.	Full-Scale	Mixed performance record. Some applications have been very effective, while others have been unsuccessful in attaining cleanup objectives.	VOCs, TPH	Active natural biological degradation of chlorinated VOCs would be inhibited by the addition of oxygen. High iron levels at the site would likely cause iron precipitate and/or biological fouling of the air stripping wells. Logistics of obtaining access from private and public entities for installation, operation, and maintenance would be complex. Minimal effectiveness for intermediate depth interval.	Would inhibit the existing naturally occurring biological VOC degradation and may result in significant iron fouling. Complex implementation issues.	Reject
	Passive/Reactive Treatment Walls	4.3.12	Contaminant concentrations in groundwater are reduced as the groundwater flows through the permeable reactive barrier containing zero valent iron. Barrier either spans the plume (vertically and laterally) or uses a funnel and gate approach to limit lateral extent of barrier.	Full-Scale	Has been effectively used to reduce chlorinated VOC concentrations in groundwater.	Chlorinated VOCs, some metals	Implementation across the Outside Area 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 prevent implementation. 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.	May not be feasible to install barrier to intermediate groundwater depth. Extensive property acquisition requirements and potential issues caused by alterations to groundwater flow patterns make this technology very costly and difficult to implement. Not cost effective for low concentration plumes.	Reject
	Emulsified Zero Valent Iron	4.3.13	Zero-valent iron emulsified in vegetable oil and surfactant are injected into groundwater. Zero-valent iron causes results in reductive dechlorination and vegetable oil and surfactant act as long-term electron donors for anaerobic biodegradation.	Bench/Pilot Scale	Limited study - technology is under development. No full-scale implementations identified. ZVI has been unstable in pilot applications. Unproven technology.	Chlorinated VOCs	Difficult to obtain effective distribution of EZVI in subsurface due to heterogeneities. Technology has very limited pilot-scale record, no instances of full-scale implementation were identified. Numerous injection points needed, requiring access from affected property owners.	Not proven technology. Difficult to effect distribution in subsurface due to heterogeneities. Extensive property access requirements.	Reject
	Dynamic Underground Stripping	4.3.16	Combination of technologies, includes steam injection along plume periphery to drive COCs to central vapor extraction wells. Electrical heating used to mobilize VOCs from finer grained units. Underground imaging used to delineate treated areas and for process control.	Pilot Scale	Effective under at least one pilot scale study to reduce chlorinated VOCs in groundwater. Developing technology; unproven.	VOCs, TPH, SVOCs	Long-term increase in subsurface temperatures may interfere with existing, active biodegradation processes. Could not be implemented in proximity to HCIM barrier wall due to possible adverse impacts. No full-scale implementations. Could exacerbate vapor inhalation risks.	May inhibit existing natural biodegradation processes. Could not be used in proximity to HCIM barrier wall. No proven applications. Potential vapor inhalation risks.	Reject
	Solvent Enhanced Aquifer Remediation (SEAR)	4.3.17	Surfactants are injected to increase the solubility and mobility of organic contaminants, including NAPLs. Surfactants and contaminants are then recovered with conventional pump-and-treat methods. The surfactants are separated from the groundwater and contaminants and reinjected. Primarily used in source areas.	Full-Scale	Has been used to enhance recovery of chlorinated VOCs and DNAPLs. Limited applications; primarily considered for source areas.	VOCs, SVOCs, TPH	Subsurface heterogeneities can interfere with effective delivery and recovery of surfactants. Aquifer heterogeneities create preferential flow paths, resulting in significant channeling of injected fluids, bypassing zones of contamination. Low permeability soils are difficult to treat with this technology. No source areas known with in the Outside Area.	Preferential flow paths due to aquifer heterogeneities prevent effective distribution/recovery of surfactants limiting effectiveness. No known source areas within the Outside Area.	Reject
	Co-Solvent Flooding	4.3.18	Co-solvents, typically ethanol or propanol, are injected to enhance dissolution and recovery of DNAPL components. Co-solvent and dissolved phase organics are recovered with conventional groundwater extraction methods. Typically used for source areas.	Full-Scale	Has been used to enhance recovery of DNAPL components in the source area.	VOCs, SVOCs	Technology is difficult to implement at sites with fine grained soils or complex hydrogeology due to the difficulty of distributing and recovering the co-solvent. Heterogeneities create preferential flowpaths limiting contact with impacted media. No known source areas.	Preferential flow paths due to aquifer heterogeneities prevent effective distribution and recovery of solvents. No known source areas within the Outside Area.	Reject

TABLE 4-4

REMEDIATION TECHNOLOGY SCREENING FOR OUTSIDE AREA GROUNDWATER
REMEDIATION AREAS 1, 2, 3, AND DEEP AQUIFER

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**
Groundwater Extraction and Treatment (Pump and Treat)	Hydraulic Control	4.3.14	Groundwater extraction wells are installed to create a hydraulic gradient to control contaminant migration. Extracted water is then treated and discharged.	Full-Scale	Has been effectively used to control contaminant migration. Requires ongoing operation and maintenance. Is a long-duration technology. Cannot attain cleanup levels.	VOCs, SVOCs, TPH, inorganics	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 over the entire area. 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.	Implementation of a multi-well extraction and treatment system for the entire area is logistically complex and not administratively implementable. Property would need to be acquired and easements obtained. Disposal of large amounts of extracted water would also pose a significant challenge. Use in a few, discrete areas is possible.	Retain
	Mass Reduction	4.3.14	Groundwater extraction wells are installed to remove contaminated groundwater, thereby reducing contaminant mass. Extracted water is then treated and discharged.	Full-Scale	Has been used to remove contaminants in source areas. Requires ongoing operation and maintenance. Is a long-duration technology. Not effective to attain cleanup levels or in diffuse plumes.	VOCs, SVOCs, TPH, inorganics	Significant long-term O&M costs may make active In-Situ technologies preferable. Long-term property access would be needed to install, operate, and maintain the extraction and treatment components in areas not owned by PSC. Reinjection would not be feasible. Large volumes of treated water would likely not be accepted by King County (POTW) and NPDES permitting would be necessary.	Implementation of a multi-well extraction and treatment system is logistically complex, and would not likely attain cleanup levels. High long-term O&M costs. Inappropriate for diffuse plume in Outside Area.	Reject
Physical Containment	Barrier Wall	4.3.15	Placement of a barrier wall that physically restricts flow of groundwater. The wall must be keyed into lower confining unit to be effective. Often this technology is applied in conjunction with groundwater extraction to provide full hydraulic control.	Full-Scale	Has been effectively used to contain contaminated groundwater. A variety of construction methods and wall compositions are available for this technology.	VOCs, SVOCs, TPH, inorganics	Due to the areal extent of the impacted downgradient groundwater, the presence of multiple property owners, and numerous underground utilities, it is not feasible to totally enclose the Outside Area groundwater.	Barrier walls are administratively and technically infeasible, given the multiple property owners and interests within the Outside Area groundwater and the heavy surface and subsurface development.	Reject

TABLE 4-4

REMEDIATION TECHNOLOGY SCREENING FOR OUTSIDE AREA GROUNDWATER
REMEDIATION AREAS 1, 2, 3, AND DEEP AQUIFER

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**
Ancillary/Support Technologies	Air Stripping	4.3.14.1	This technology is used in conjunction with pump and treat systems. 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	This technology is currently in use as part of the existing groundwater HCIM. Used to treat groundwater that is extracted to control contaminant migration. Presence of reduced iron causes significant fouling and maintenance requirements.	Has been effective in reducing VOC concentrations in extracted groundwater during operation of the HCIM. However, implementation over the entire outside area would be logistically complex, require significant O&M, and not be administratively implementable. Use in a few, discrete areas is possible.	Retain
	Adsorption	4.3.14.2	This technology is used in conjunction with pump and treat systems. Extracted groundwater or VOC-containing air 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 vapor streams during the SVE and barrier wall HCIMs.	VOCs, SVOCs, TPH, PCBs	This technology is currently in use as part of the existing groundwater HCIM. Used to treat vapor stream from air stripping treatment of extracted groundwater and previously from SVE. Presence of VC requires use of specialty absorbents.	Has been effective at reducing VOC concentrations in air stripper off-gas during operation of the HCIM. However, implementation over the entire outside area would be logistically complex, require significant O&M, and not be administratively implementable. Use in a few, discrete areas is possible.	Retain
	Advanced Oxidation	4.3.14.3	This technology is used to support pump and treat remediation. Extracted groundwater is passed through a specially designed advanced oxidation unit. Advanced oxidation processes typically use ultraviolet light (uv) and hydrogen peroxide to aggressively oxidize organics. Treatment products are typically carbon dioxide, water, and HCl.	Full-Scale	Has been effectively used to treat groundwater, including 1,4-dioxane. Inorganics such as iron can foul the reaction tubes, limiting effectiveness of uv transmittance and the resulting oxidation reactions.	VOCs, SVOCs, TPH	The presence of 1,4-dioxane may require use of this technology for treatment of recovered groundwater.	Has been effective at reducing VOC concentrations in air stripper off-gas during operation of the HCIM.	Retain

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

TABLE 4-5

RETAINED SOIL REMEDIATION TECHNOLOGIES

PSC Georgetown Facility
Seattle, Washington

Potentially Applicable Technology		**HCIM Area**		**Outside Area**		
General Response Actions	**Remediation Technologies**	**Soil Remediation Area 1**	**Soil Remediation Area 2**	**Soil Remediation Area 1**	**Soil Remediation Area 2**	**Soil Remediation Area 3**
Containment	Surface Cover	X	X	X	X	X
In-Situ Physical/Chemical Treatment	Soil Vapor Extraction	X	X	X	X	X
Excavation and Disposal	Off-Site Disposal	X	X	X	X	

TABLE 4-6

RETAINED GROUNDWATER REMEDIATION TECHNOLOGIES

PSC Georgetown Facility
Seattle, Washington

Potentially Applicable Technology		HCIM Area	Outside Area						
General Response Actions	Remediation Technologies	Groundwater Remediation Area	Water Table Remediation Area 1	Water Table Remediation Area 2	Water Table Remediation Area 3	Shallow/Int. Remediation Area 1	Shallow/Int. Remediation Area 2	Shallow/Int. Remediation Area 3	Deep Aquifer Remediation Area
In-Situ Biological Treatment	Reductive Dechlorination Biostimulation (Anaerobic)	X	X						
	Monitored Natural Attenuation	X	X	X	X	X	X	X	X
	Bioaugmentation	X	X	X		X	X		
In-Situ Physical/ Chemical Treatment	Chemical Oxidation	X							
Groundwater Extraction and Treatment (Hydraulic Control)	Groundwater Extraction (Pump and Treat)	X						X	
Ancillary/Support Technologies [1]	Air Stripping	X						X	
	Adsorption	X						X	
	Advanced Oxidation							X	
Physical Containment	Barrier Wall	X							

Notes:

1. These technologies would be used in conjunction with groundwater extraction (hydraulic control) to treat the extracted groundwater prior to discharge.

TABLE 6-1

SUMMARY OF REMEDIAL ALTERNATIVEES FOR HCIM AREA SOIL AND GROUNDWATER

PSC Georgetown
Seattle, Washington

Remedial Alternative	Remediation Area	Soil and Groundwater			Soil		Groundwater		
		VIAM Program	Cover/Institutional Controls	Subsurface Barrier Wall	Excavation & Disposal	Soil Vapor Extraction	MNA	Biostimulation	Pump & Treat
Alternative HA-1	HSRA-1	♦	♦	♦					
	HSRA-2	♦	♦	♦					
	WTGWI	♦	♦	♦			♦		♦
	SGWI		♦	♦			♦		♦
	IGWI		♦	♦			♦		♦
Alternative HA-2	HSRA-1	♦	♦	♦					
	HSRA-2	♦	♦	♦					
	WTGWI	♦	♦	♦			♦	♦	♦
	SGWI		♦	♦			♦	♦	♦
	IGWI		♦	♦			♦	♦	♦
Alternative HA-3	HSRA-1	♦	♦	♦		♦			
	HSRA-2	♦	♦	♦					
	WTGWI	♦	♦	♦			♦	♦	♦
	SGWI		♦	♦			♦	♦	♦
	IGWI		♦	♦			♦	♦	♦
Alternative HA-4	HSRA-1	♦	♦	♦	♦	♦			
	HSRA-2	♦	♦	♦					
	WTGWI	♦	♦	♦	♦		♦	♦	♦
	SGWI		♦	♦			♦	♦	♦
	IGWI		♦	♦			♦	♦	♦

Notes:
♦ = indicates that the technology has been included in the remedial alternative.
VIAM = Vapor Intrusion Assessment and Mitigation as discussed in the Feasibility Study Technical Memorandum No. 3.
HSRA = HCIM Area Soil Remediation Area
WTGWI = Water Table Groundwater Interval
SGWI = Shallow Groundwater Interval
IGWI = Intermediate Groundwater Interval

TABLE 6-2

SUMMARY OF REMEDIAL ALTERNATIVES FOR OUTSIDE AREA SOIL AND GROUNDWATER

PSC Georgetown
Seattle, Washington

		Soil and Groundwater		**Soil**		**Groundwater**		
Remedial Alternative	**Remediation Area**	**VIAM Program**	**Cover/Institutional Controls**	**Excavation & Disposal**	**Soil Vapor Extraction**	**MNA**	**Biostimulation**	**Pump & Treat**
Alternative OA-1	OSRA-3	♦	♦					
	OWTRA-1	♦	♦			♦		
	OSIRA-1		♦			♦		
	OSRA-1		♦					
	OSIRA-2		♦			♦		
	OSRA-2	♦	♦					
	OWTRA-2	♦	♦			♦		
	OWTRA-3	♦				♦		
	OSIRA-3					♦		
	DARA					♦		
Alternative OA-2	OSRA-3	♦	♦					
	OWTRA-1	♦	♦			♦		
	OSIRA-1		♦			♦		
	OSRA-1		♦	♦				
	OSIRA-2		♦			♦		
	OSRA-2	♦	♦					
	OWTRA-2	♦	♦			♦		
	OWTRA-3	♦				♦		
	OSIRA-3					♦		
	DARA					♦		
Alternative OA-3	OSRA-3	♦	♦		♦			
	OWTRA-1	♦	♦				♦	
	OSIRA-1		♦			♦		
	OSRA-1		♦	♦				
	OSIRA-2		♦			♦		
	OSRA-2	♦	♦					
	OWTRA-2	♦	♦			♦		
	OWTRA-3	♦				♦		
	OSIRA-3					♦		
	DARA					♦		
Alternative OA-4	OSRA-3	♦	♦		♦			
	OWTRA-1	♦	♦				♦	
	OSIRA-1		♦			♦		
	OSRA-1		♦	♦				
	OSIRA-2		♦			♦		
	OSRA-2	♦	♦					
	OWTRA-2	♦	♦			♦		
	OWTRA-3	♦				♦		
	OSIRA-3					♦		♦
	DARA					♦		

Notes:
♦ = indicates that the technology has been included in the remedial alternative.
VIAM = Vapor Intrusion Assessment and Mitigation as discussed in the Feasibility Study Technical Memorandum No. 3.
OSRA = Outside Area Soil Remediation Area
OWTRA = Outside Area Water Table Remediation Area
OSIRA = Outside Area Shallow/Intermediate Remediation Area
DARA = Deep Aquifer Remediation Area

FIGURES

Explanation

- ⬚ Barrier Wall
- ☐ Parcel Boundary
- 🟥 Outside Soil Remediation Area 1
- 🟦 HCIM Soil Remediation Area 2
- 🟪 HCIM Soil Remediation Area 1
- 🟩 Outside Soil Remediation Area 2
- 🟦 Outside Soil Remediation Area 3
- 🟨 Site Wide Feasibility Study Area

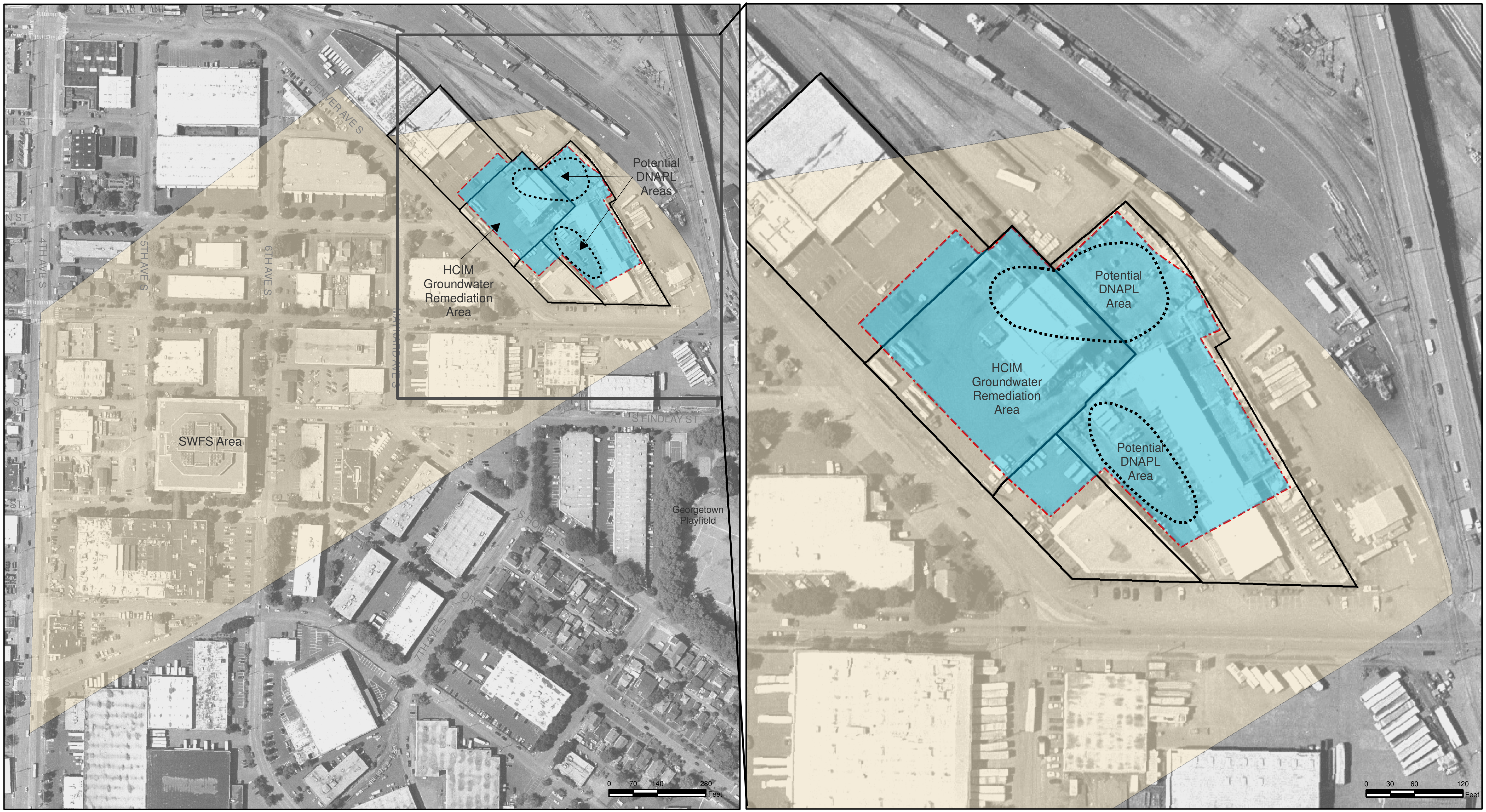
N

SOIL REMEDIATION AREAS
PSC Georgetown
Seattle, Washington

By: APS
Date: 10/05/2006
Project No. 8770

Geomatrix
Figure 2-1

S:\8770_2006\006_TechMemo4\Figure 2-1_SoilREmediationAreas.mxd



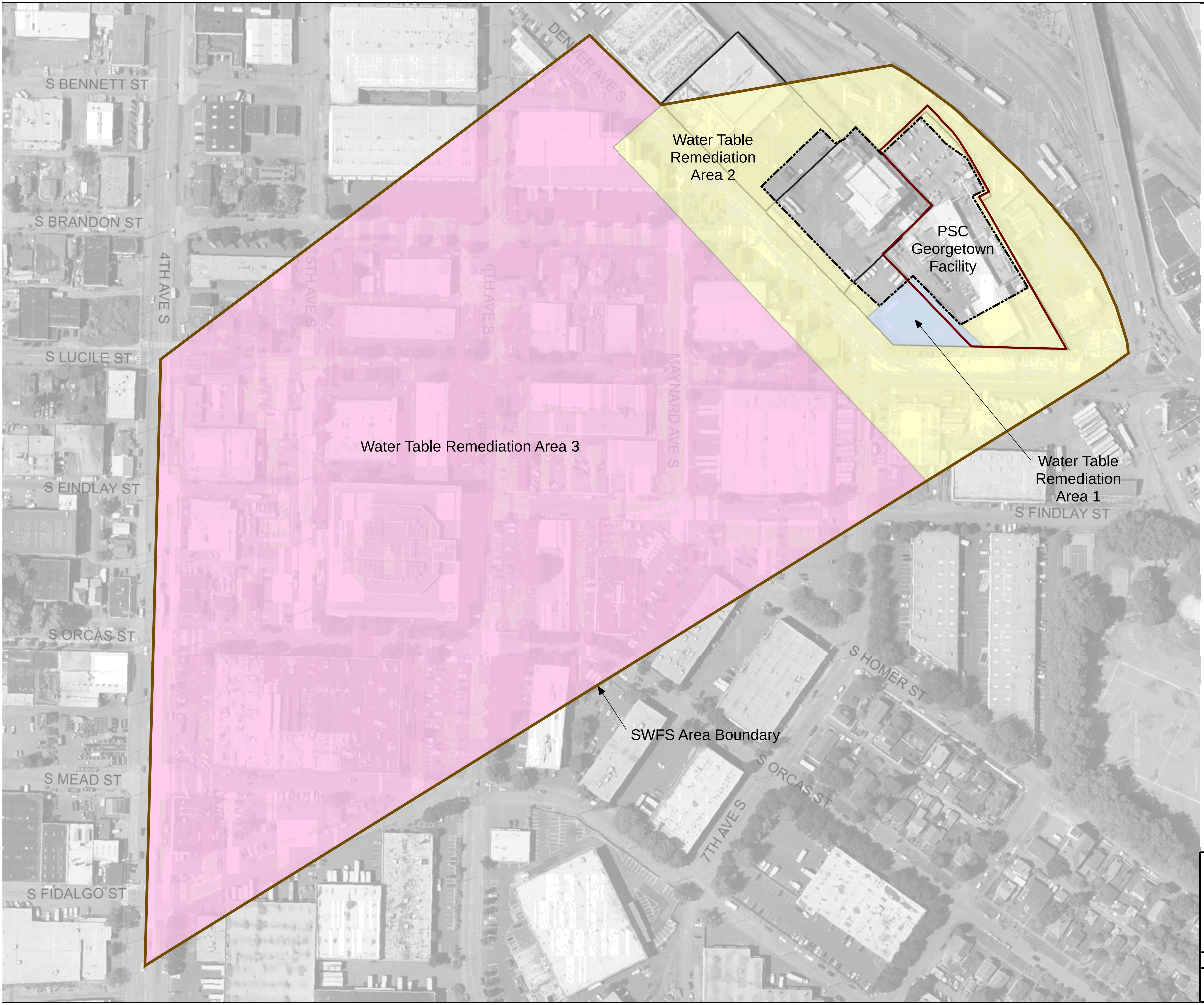
Explanation

- ▭ Barrier Wall
- ▭ Parcel Boundary
- 🟦 HCIM Groundwater Remediation Area
- ⋯ Potential DNAPL area
- 🟨 Site Wide Feasibility Study Area

HCIM GROUNDWATER REMEDIATION AREA
PSC Georgetown
Seattle, Washington

By: jem	Date: 10/05/2006	Project No. 8770
Geomatrix		Figure 2-2

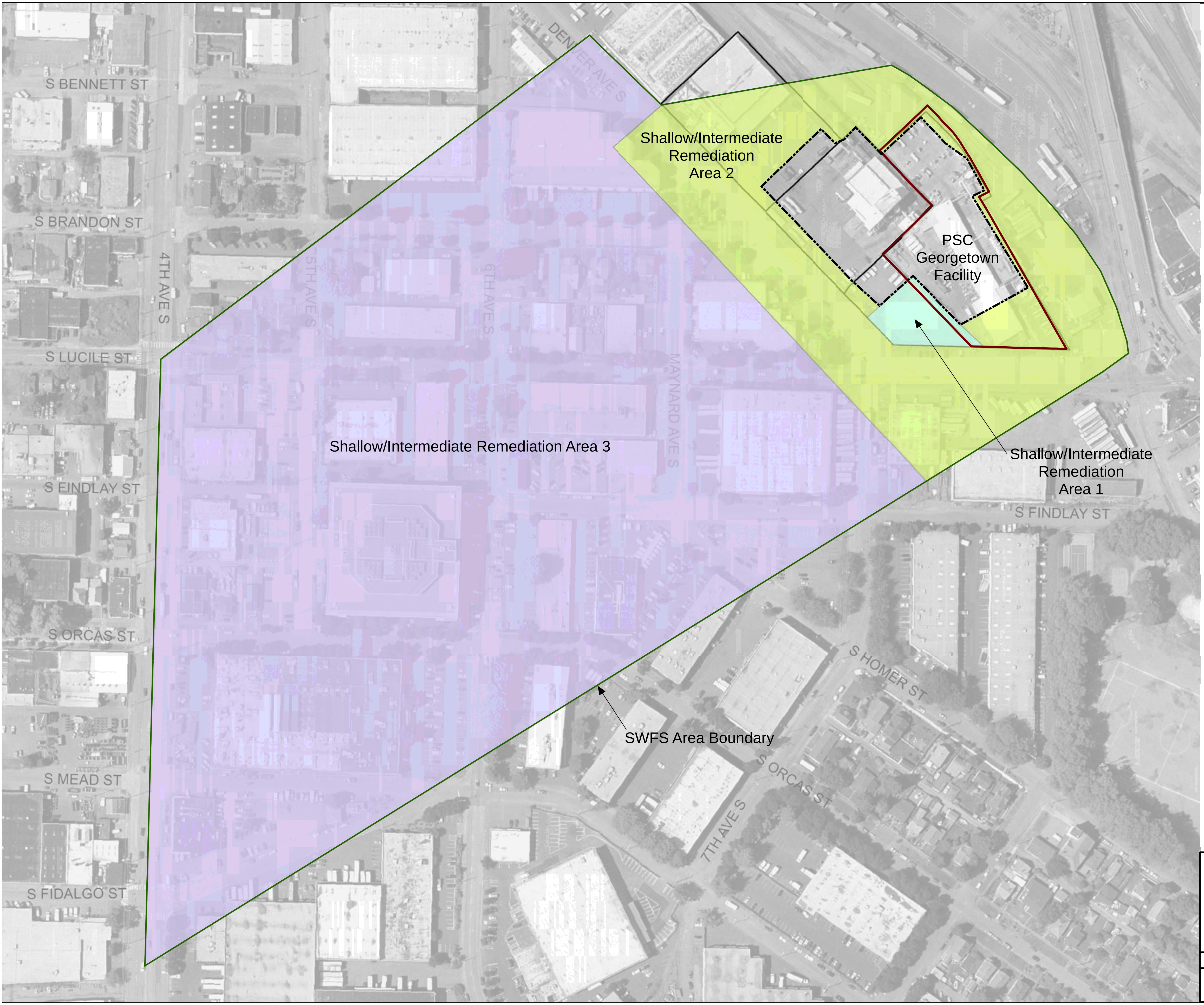
S:\8770_2006\006_TechMemo4\Figure 2-2_HCIM_GW-REMED-AREA.mxd



OUTSIDE AREA WATER TABLE
REMEDIATION AREAS
PSC Georgetown Facility
Seattle, Washington

By: APS	Date: 10/05/2006	Project No. 8770
Geomatrix		Figure 2-3

S:\8770_2006\006_TechMemo4\Figure 2-3_OA_WT_RemedAreas.mxd



LEGEND:

- -··-··- HCIM barrier wall
- ━ Fence (from Goldsmith & Associates 3/05 survey)
- ☐ Parcel Boundary
- 🟦 Shallow/Intermediate Remediation Area 1
- 🟩 Shallow/Intermediate Remediation Area 2
- 🟪 Shallow/Intermediate Remediation Area 3

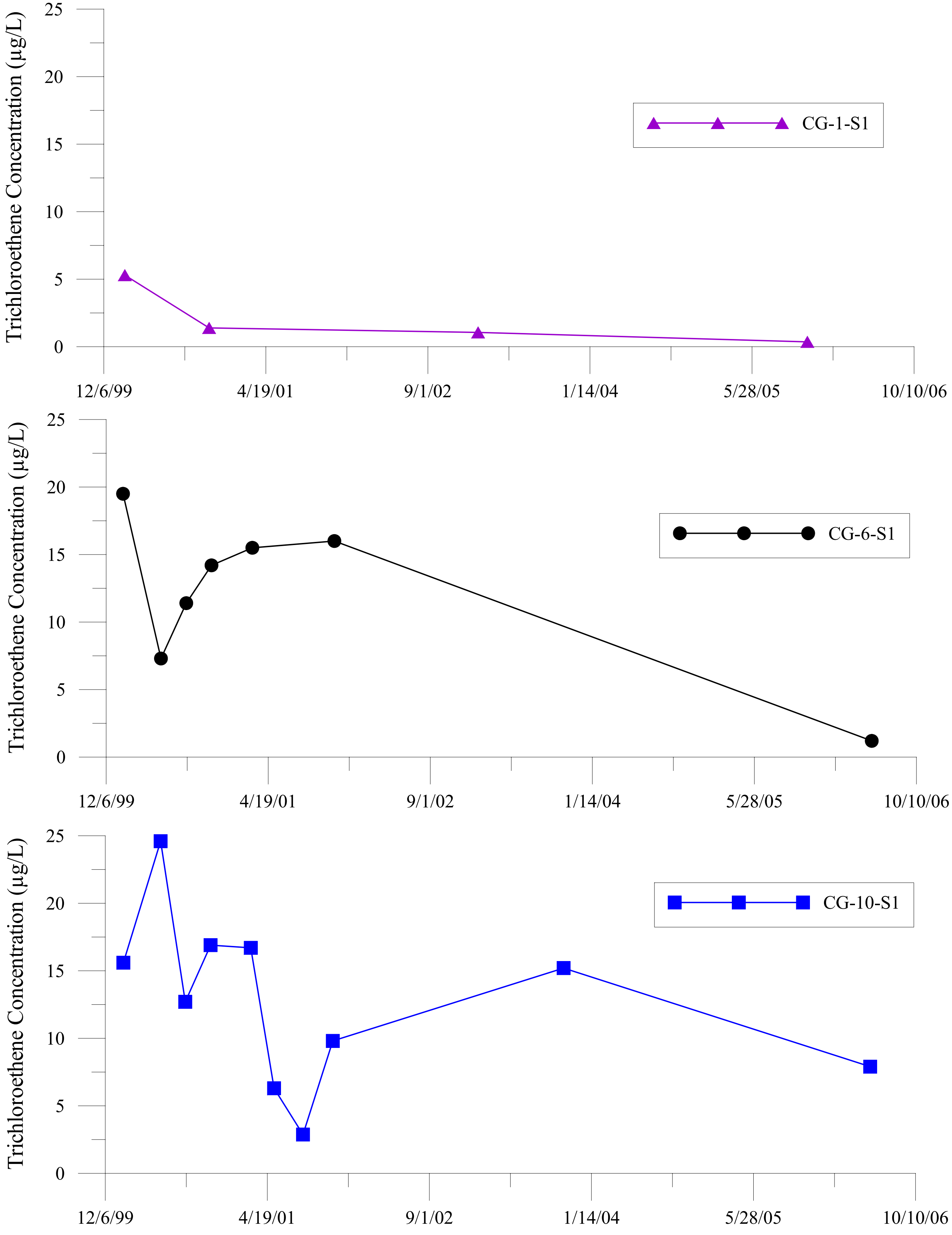
OUTSIDE AREA
SHALLOW/INTERMEDIATE
REMEDIATION AREAS
PSC Georgetown Facility
Seattle, Washington

By: APS	Date: 10/05/2006	Project No. 8770
Geomatrix		Figure 2-4

S:\8770_2006\006_TechMemo4\Figure 2-4_OA_SHnINT_RemedAreas.mxd

APPENDIX A

Trend Plots

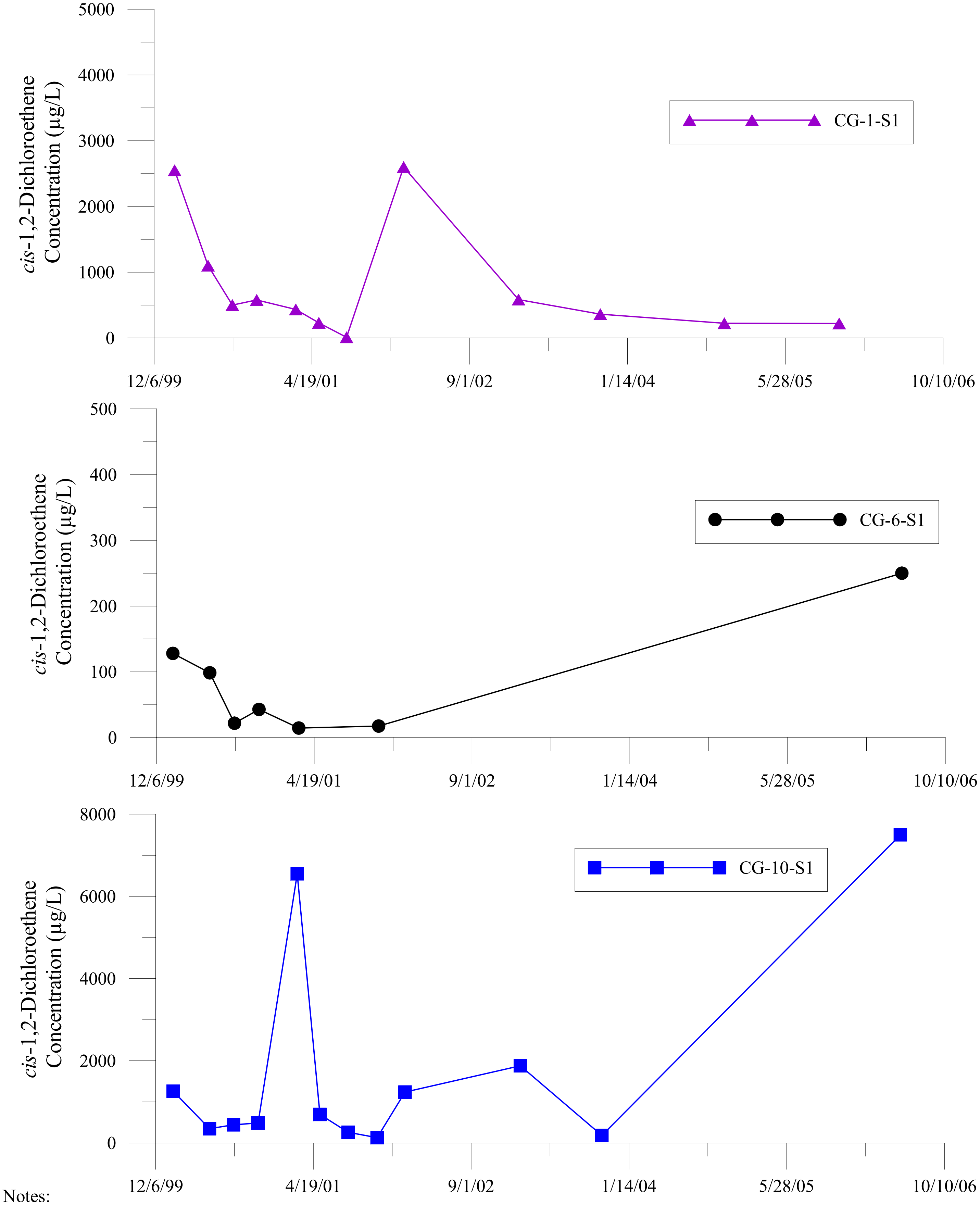


Notes:
Non-detect values excluded from plots.
Data from May 2006 sampling event are considered preliminary (unvalidated).

Geomatrix

TRICHLOROETHENE CONCENTRATION TRENDS
WATER TABLE INTERVAL - HCIM AREA
PSC Georgetown
Seattle, Washington

Project No.	8770
Figure	A-1



Notes:

Non-detect values excluded from plots.

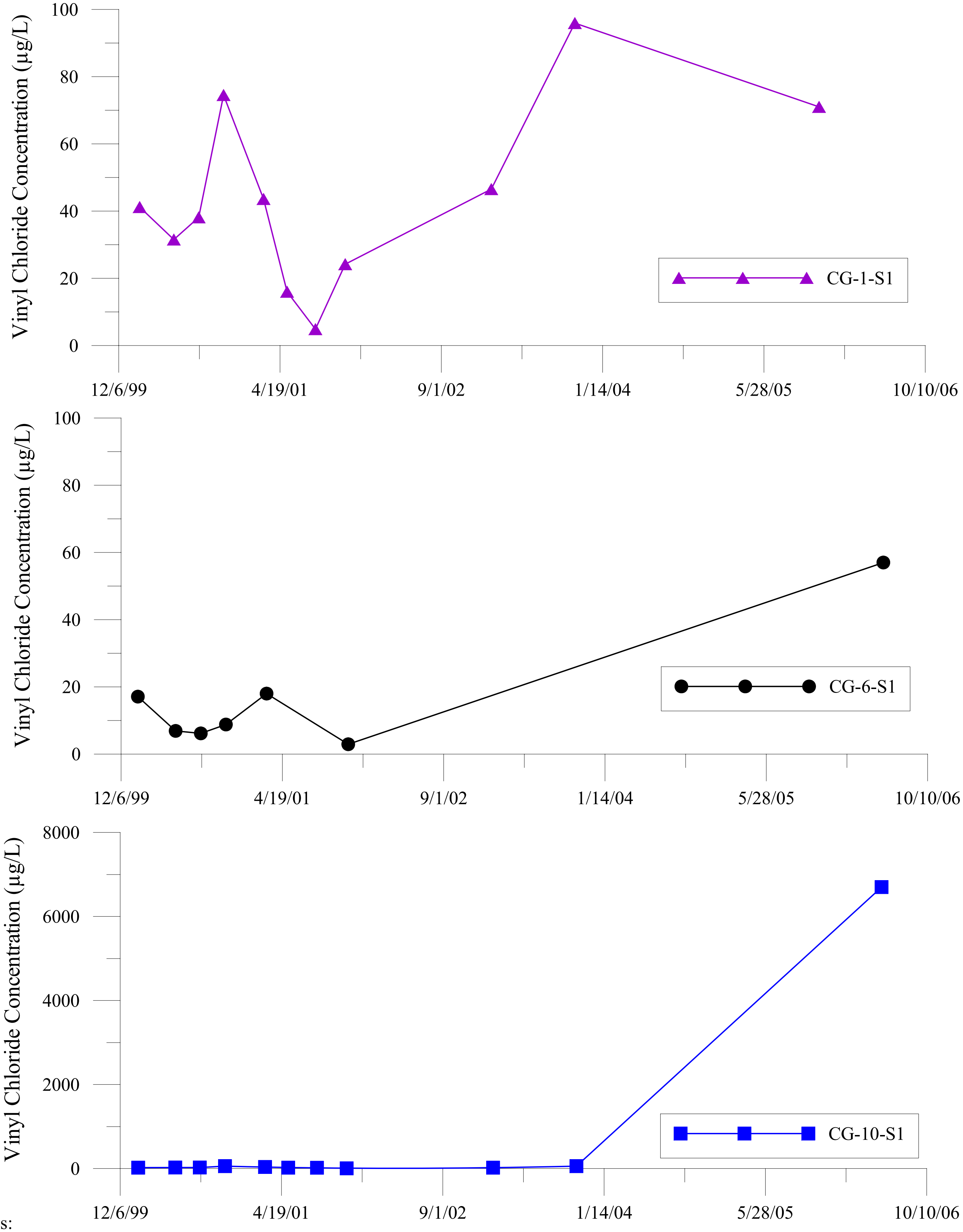
Data from May 2006 sampling event are considered preliminary (unvalidated).

Geomatrix

***CIS*-1,2-DICHLOROETHENE CONCENTRATION TRENDS**
WATER TABLE INTERVAL - HCIM AREA
PSC Georgetown
Seattle, Washington

Project No.
8770

Figure
A-2



Notes:

Non-detect values excluded from plots.

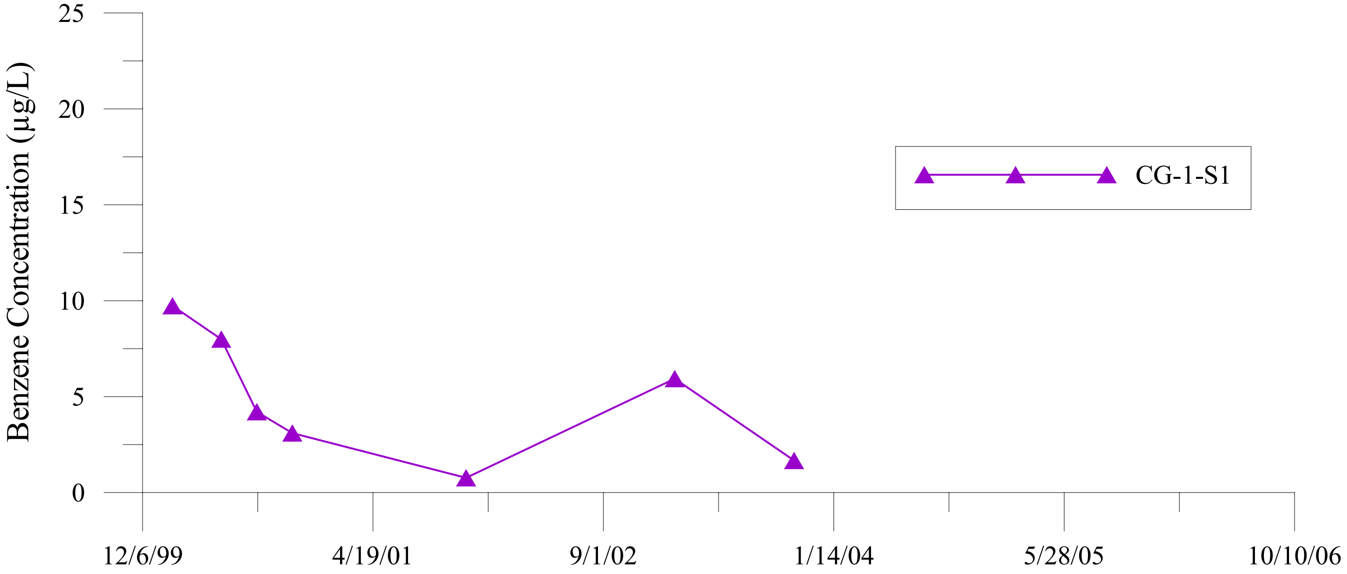
Data from May 2006 sampling event are considered preliminary (unvalidated).

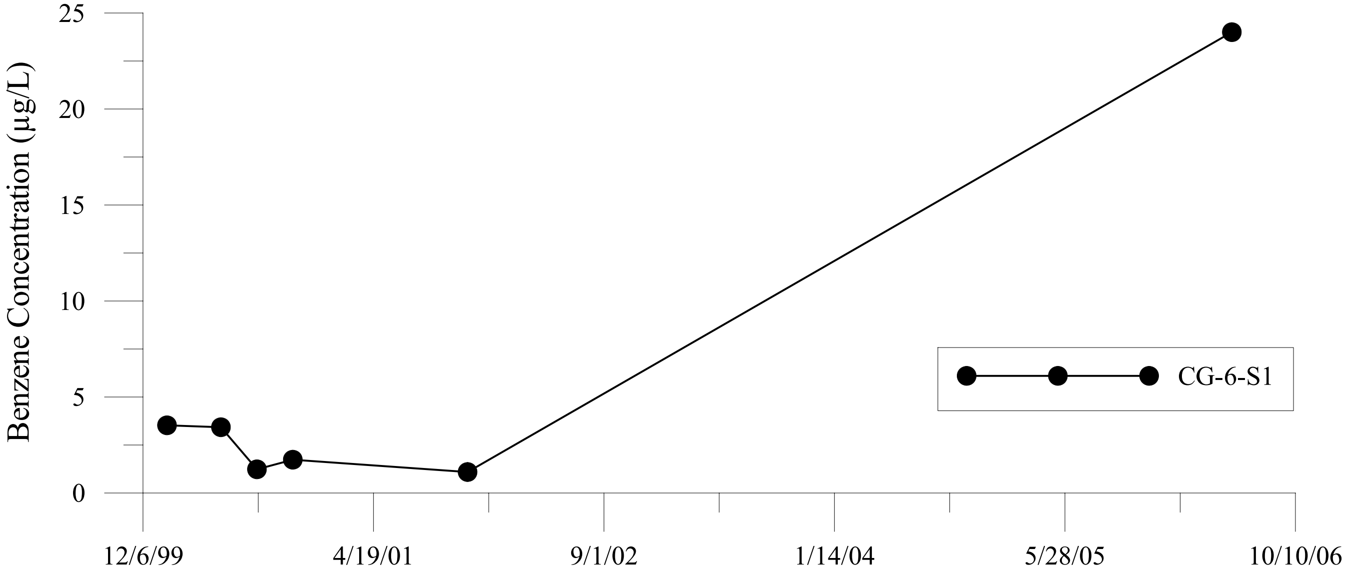
Geomatrix

VINYL CHLORIDE CONCENTRATION TRENDS
WATER TABLE INTERVAL - HCIM AREA
PSC Georgetown
Seattle, Washington

Project No. 8770

Figure A-3





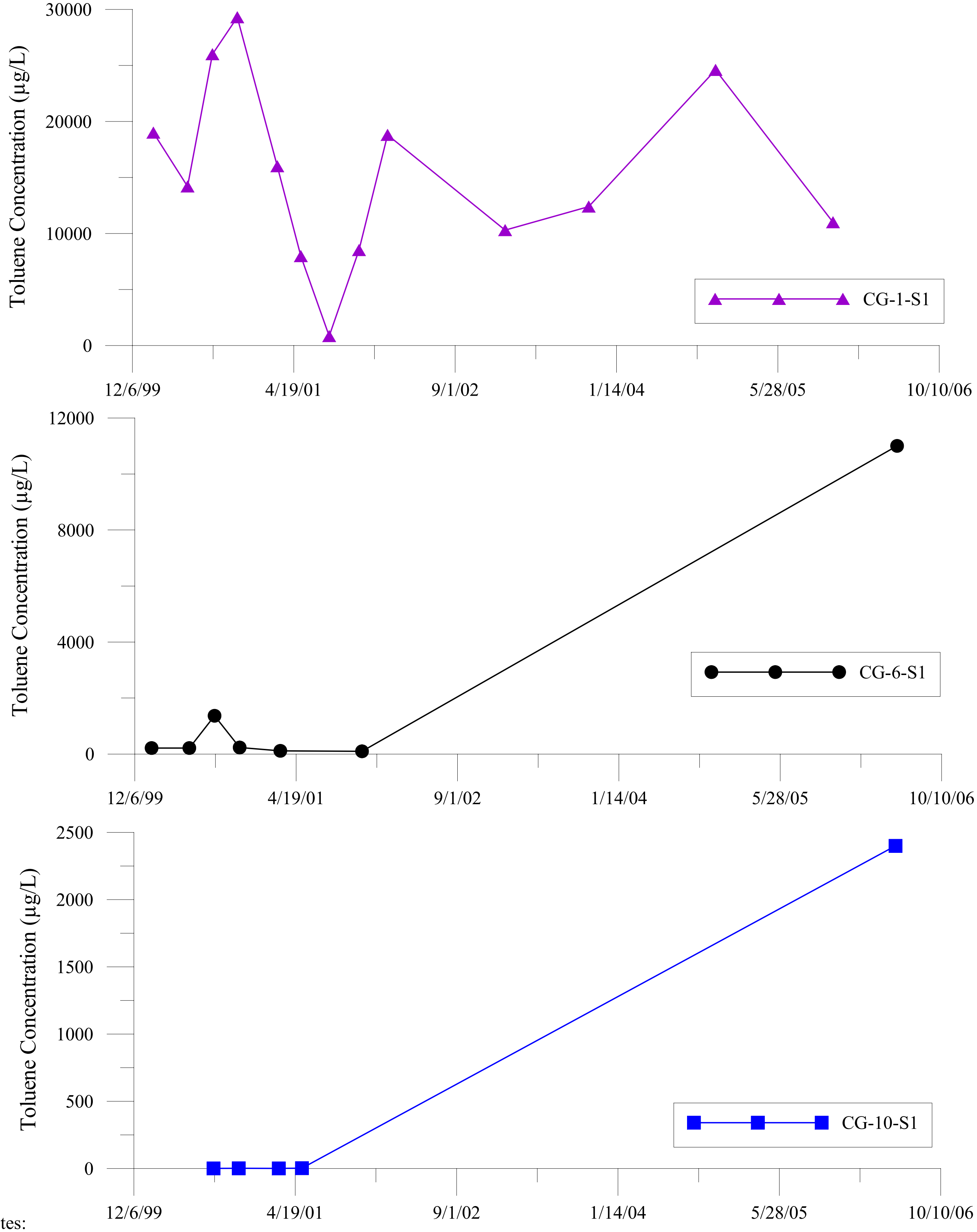
Benzene was not detected at CG-10-S1

Notes:
Non-detect values excluded from plots.
Data from May 2006 sampling event are considered preliminary (unvalidated).

Geomatrix

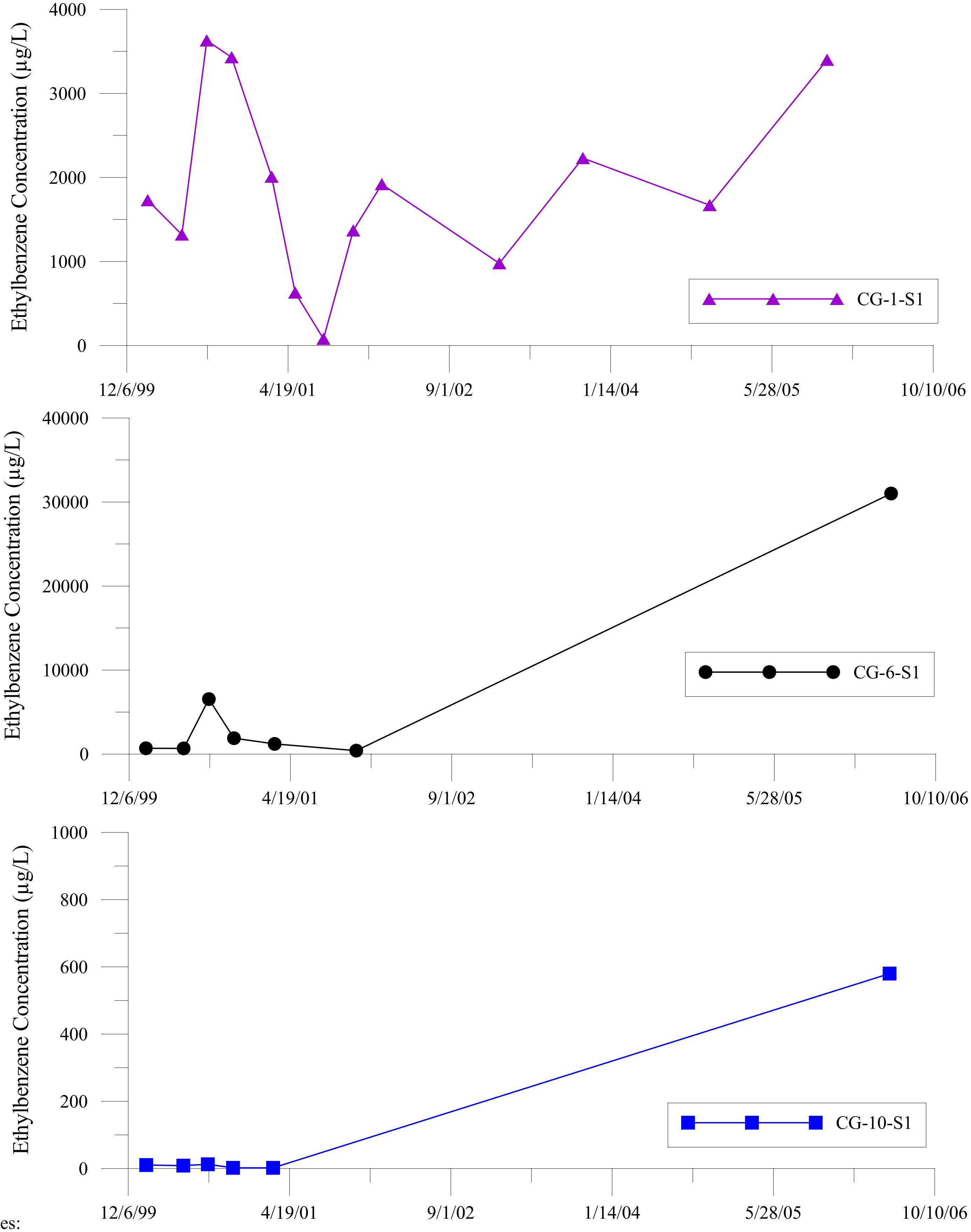
BENZENE CONCENTRATION TRENDS
WATER TABLE INTERVAL - HCIM AREA
PSC Georgetown
Seattle, Washington

Project No.	8770
Figure	A-4



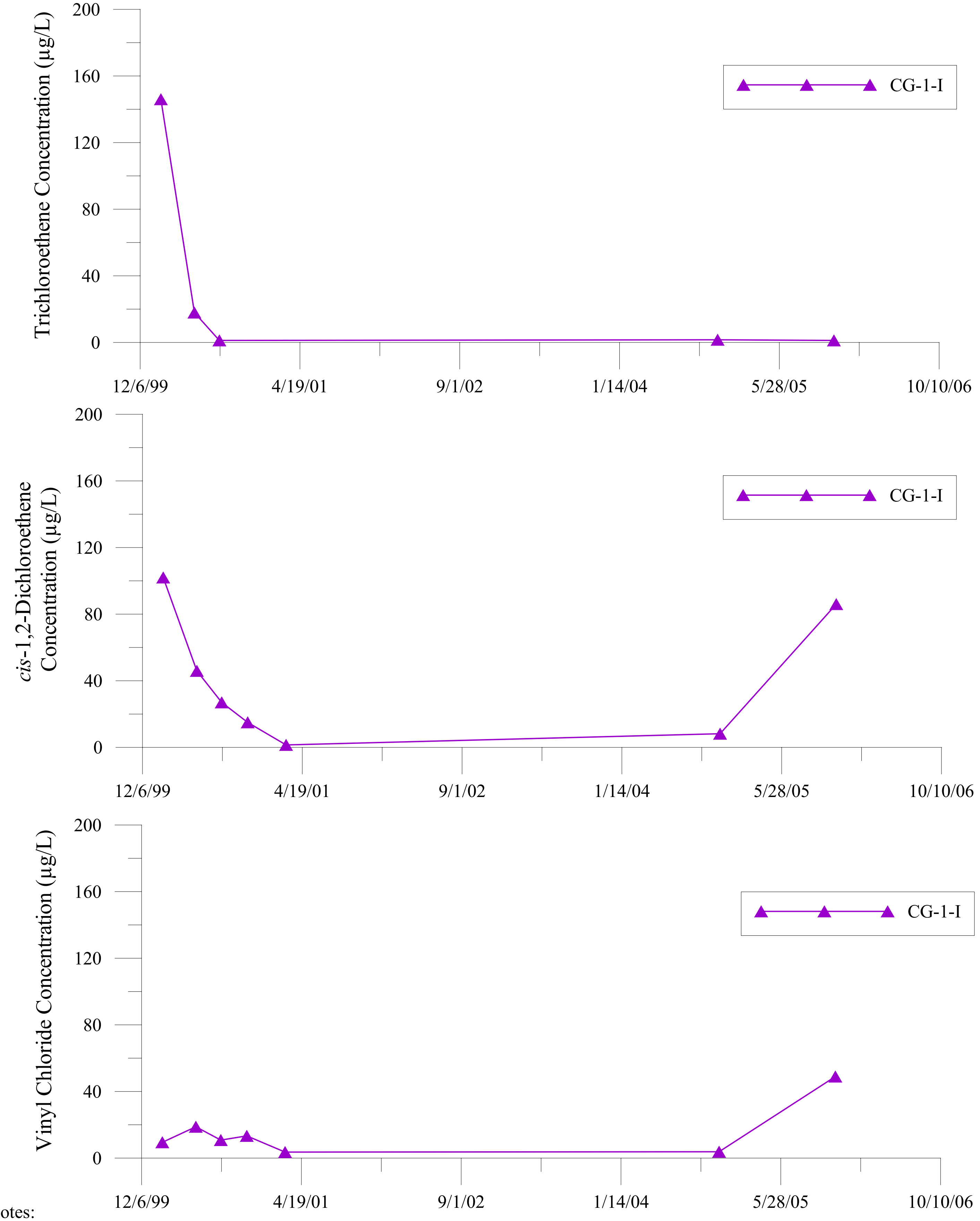
Notes:
Non-detect values excluded from plots.
Data from May 2006 sampling event are considered preliminary (unvalidated).

Geomatrix	**TOLUENE CONCENTRATION TRENDS** **WATER TABLE INTERVAL - HCIM AREA** PSC Georgetown Seattle, Washington	Project No. 8770
		Figure A-5



Notes:
Non-detect values excluded from plots.
Data from May 2006 sampling event are considered preliminary (unvalidated).

Geomatrix	**ETHYLBENZENE CONCENTRATION TRENDS** **WATER TABLE INTERVAL - HCIM AREA** PSC Georgetown Seattle, Washington	Project No. 8770 Figure A-6



Notes:

Non-detect values excluded from plots.

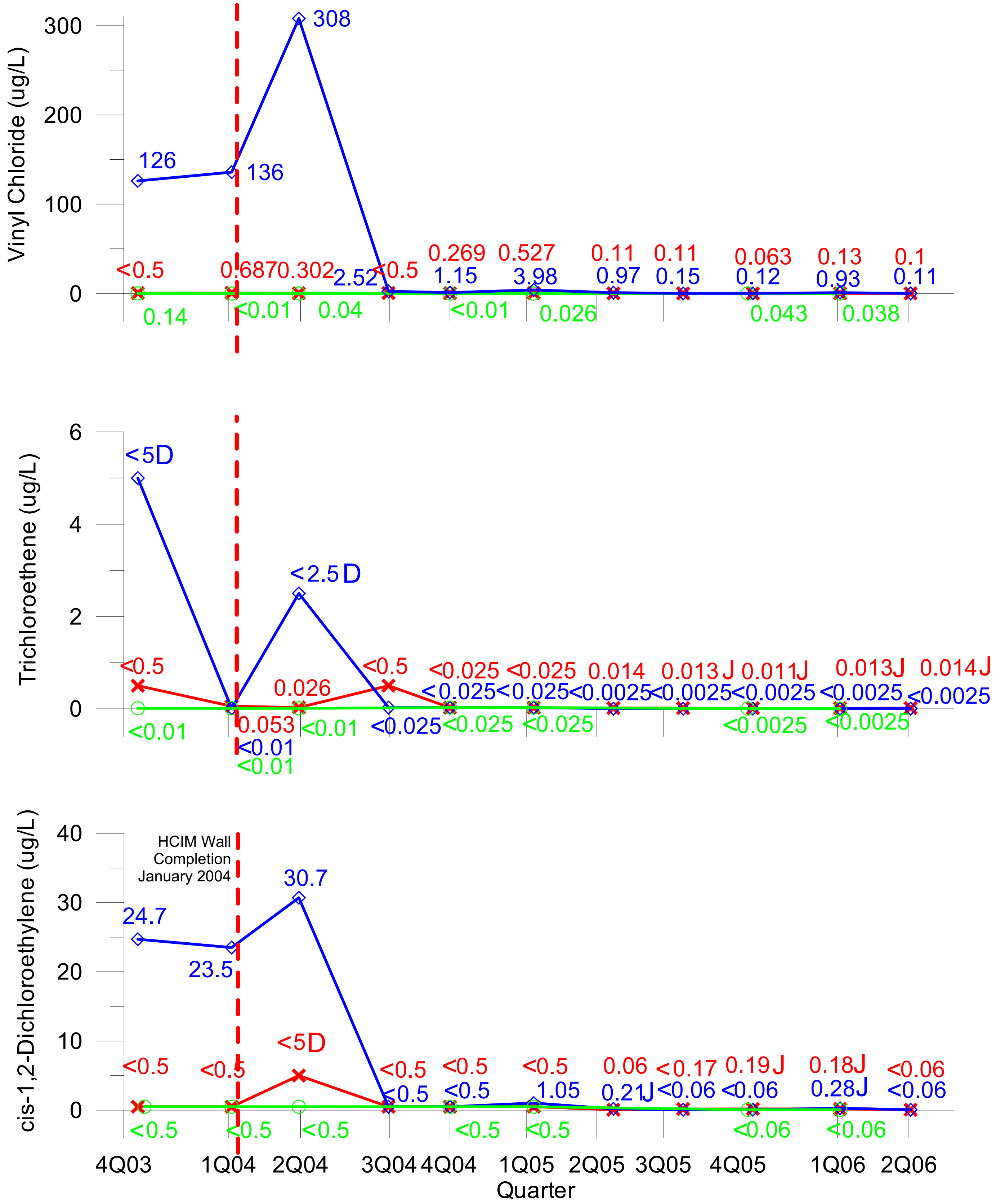
Data from May 2006 sampling event are considered preliminary (unvalidated).

Geomatrix

CONCENTRATION TRENDS
INTERMEDIATE INTERVAL - HCIM AREA
PSC Georgetown
Seattle, Washington

Project No. 8770

Figure A-7



Note: Non-detects were plotted as one-half the detection limit value.

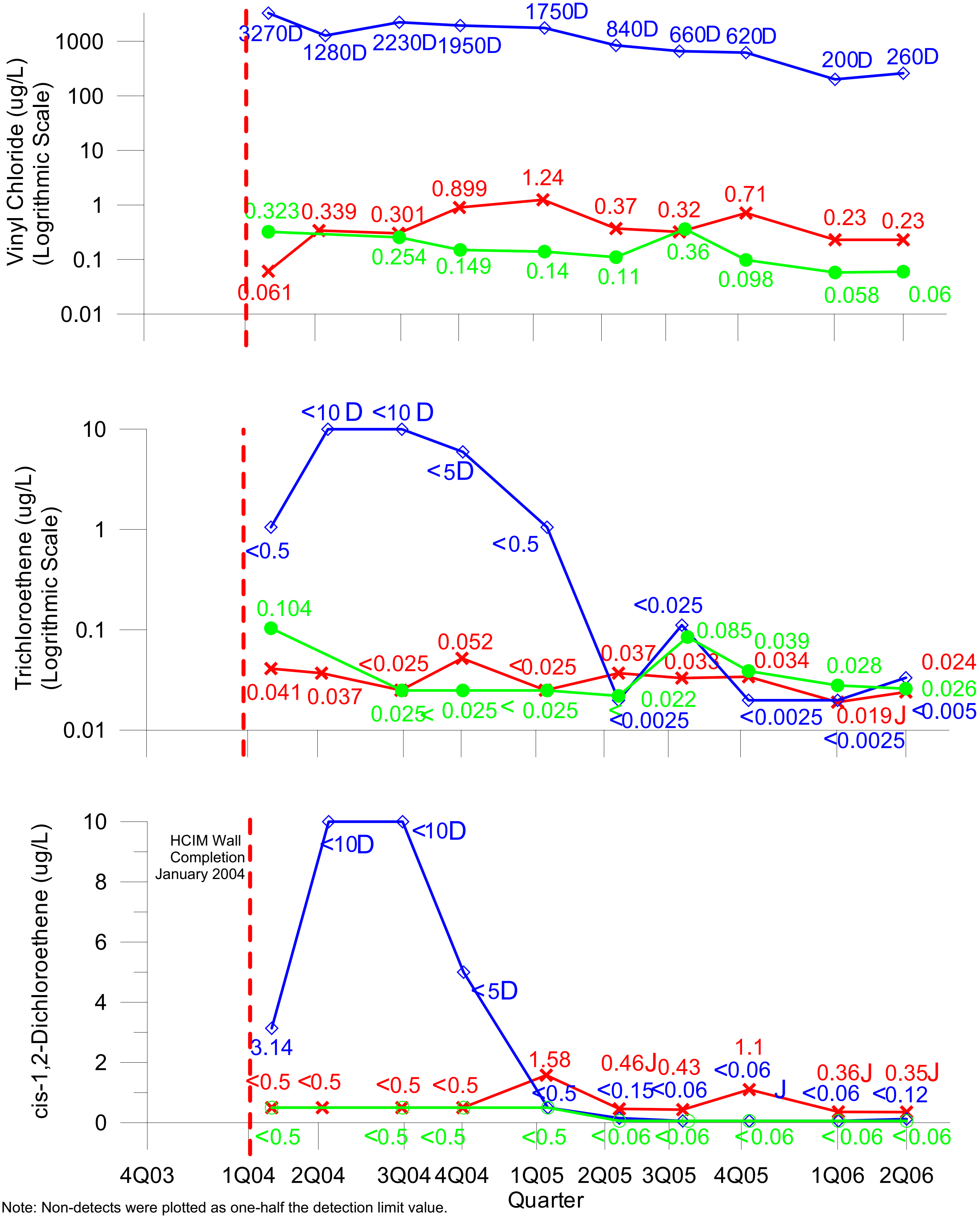
PSC

Well Clusters CG-114 & 115
4Q03 through 2Q06
PSC Georgetown

CG-115-WT
CG-115-75
CG-114-75

Figure 26

2Q06



Note: Non-detects were plotted as one-half the detection limit value.

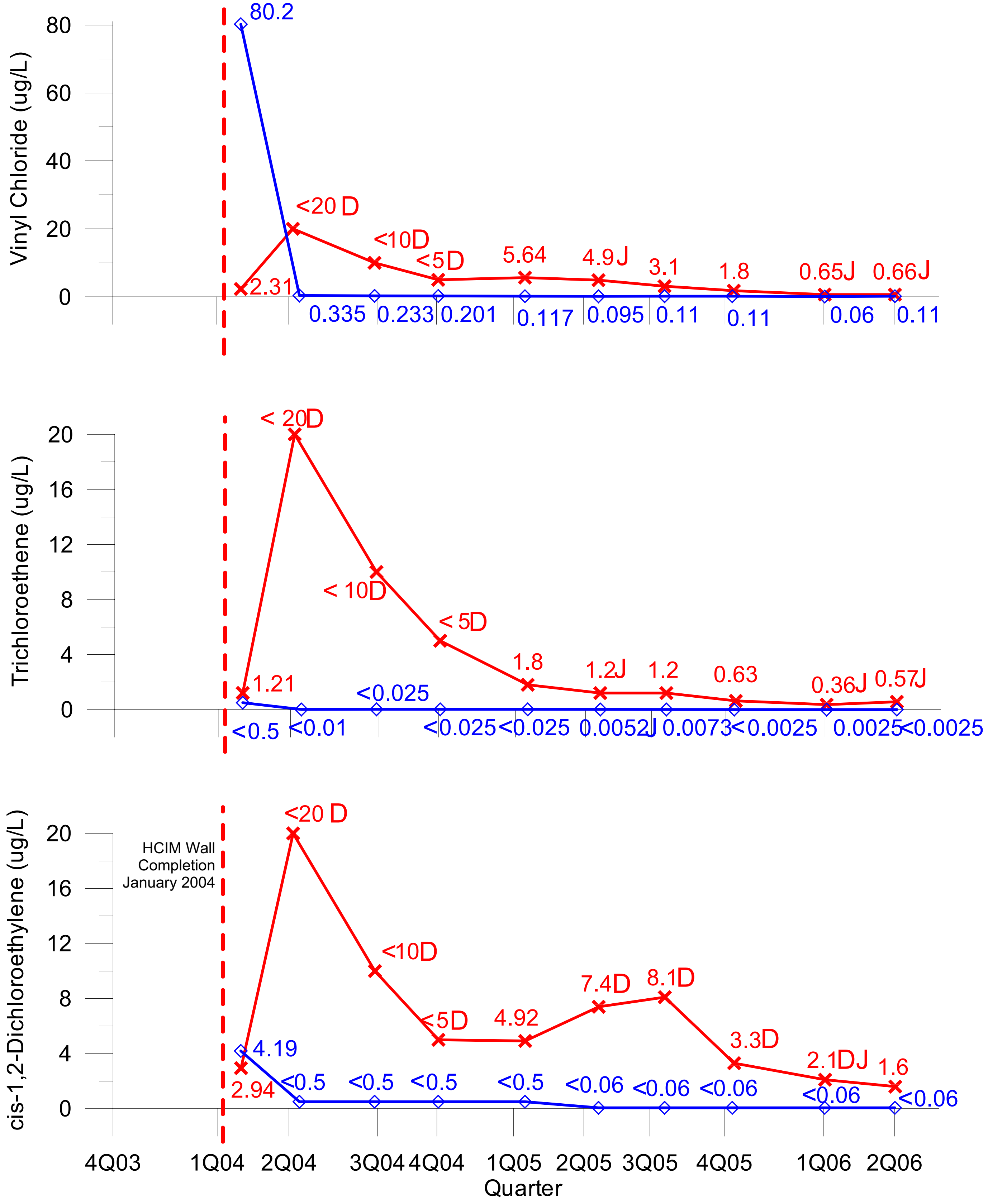
PSC

Well Cluster CG-116
4Q03 through 2Q06
PSC Georgetown

× CG-116-WT
◇ CG-116-80
● CG-116-127

Figure 27

2Q06



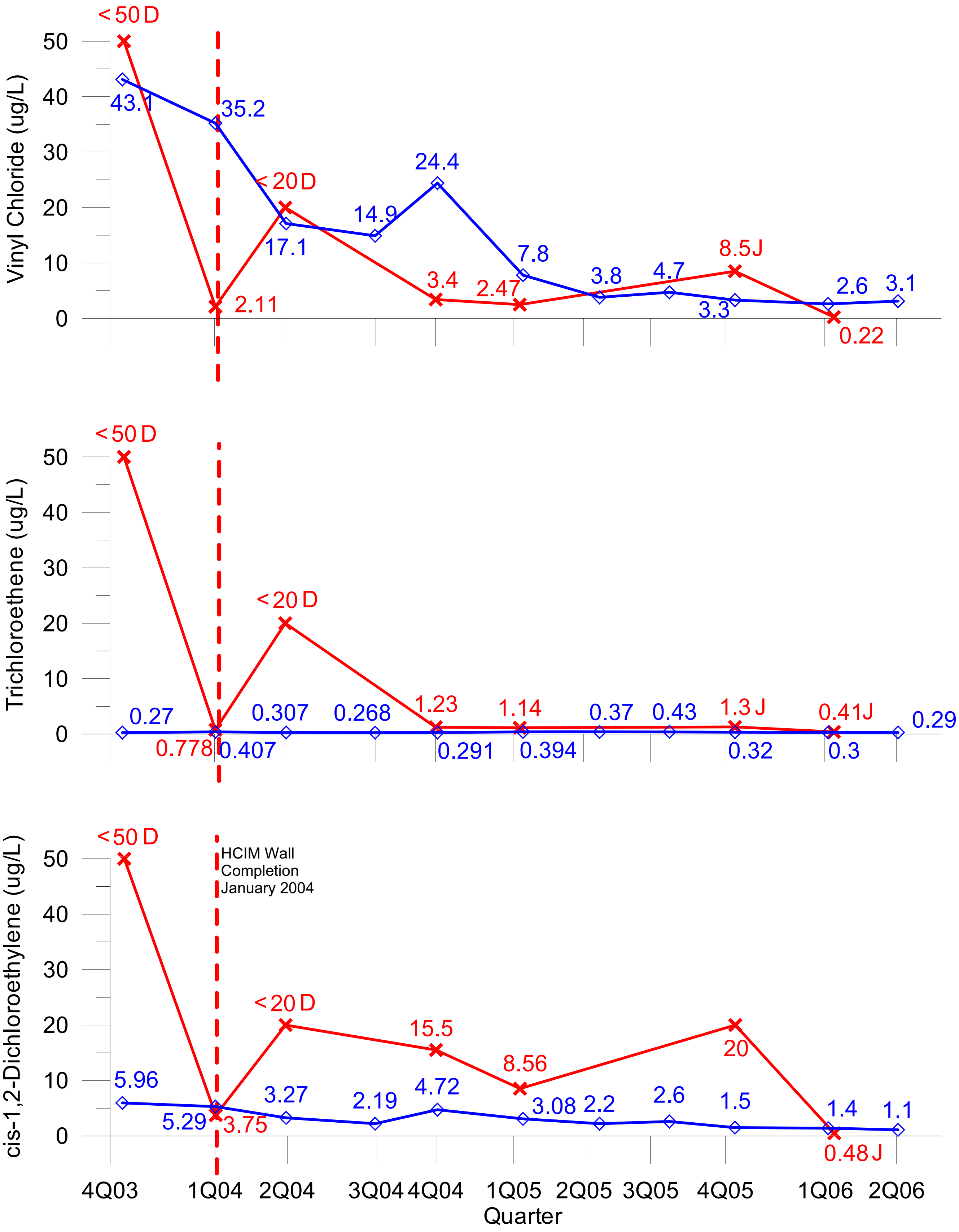
Note: Non-detects were plotted as one-half the detection limit value.

Well Cluster CG-118
4Q03 through 2Q06
PSC Georgetown

Legend
✕ CG-118-WT
◇ CG-118-79

Figure 28

2Q06



Note: Non-detects were plotted as one-half the detection limit value.

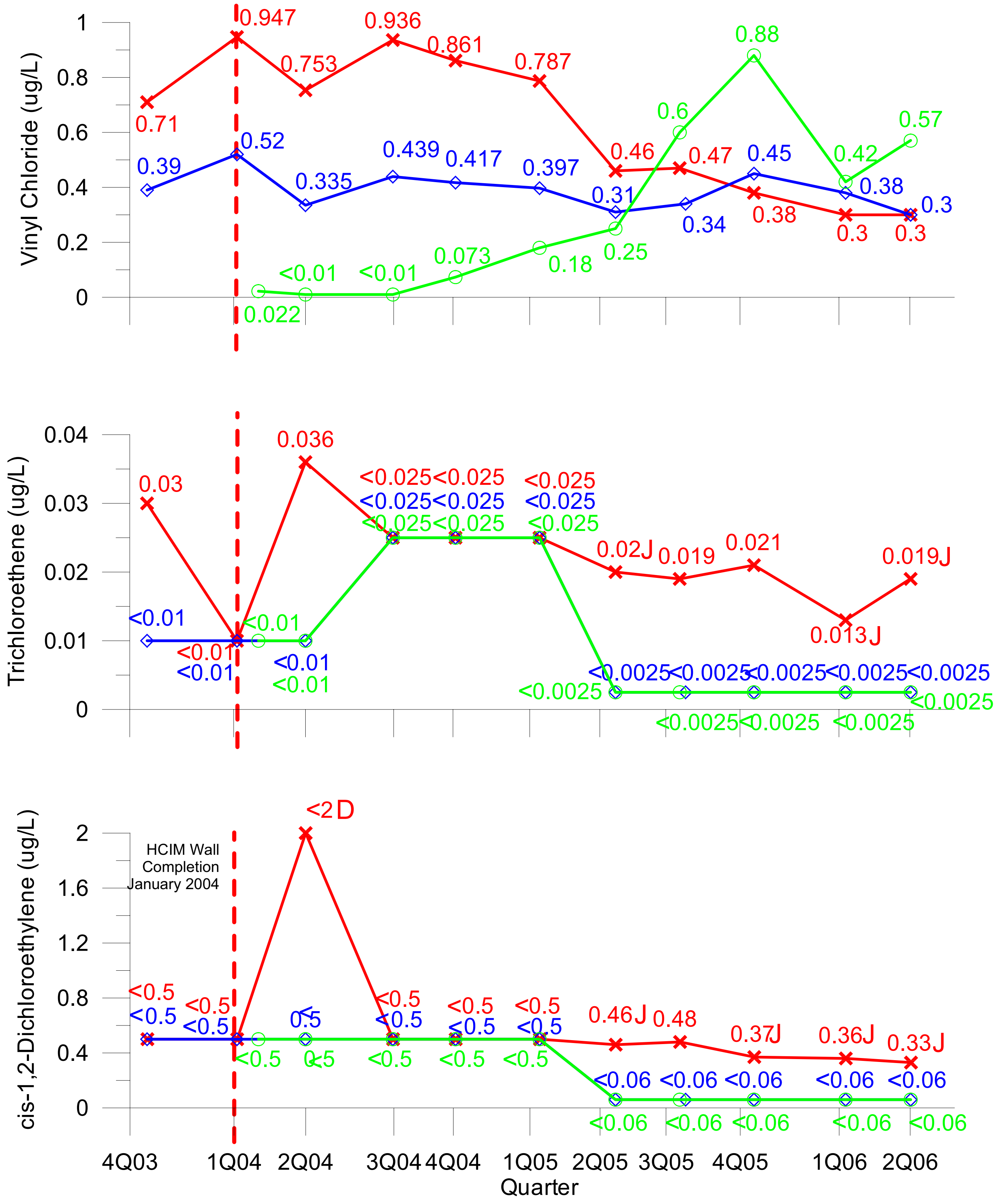
PSC

Well Cluster CG-113 & 119
4Q03 through 2Q06
PSC Georgetown

✕	113-S-1
◇	CG-119-40

Figure 29

2Q06



Note: Non-detects were plotted as one-half the detection limit value.

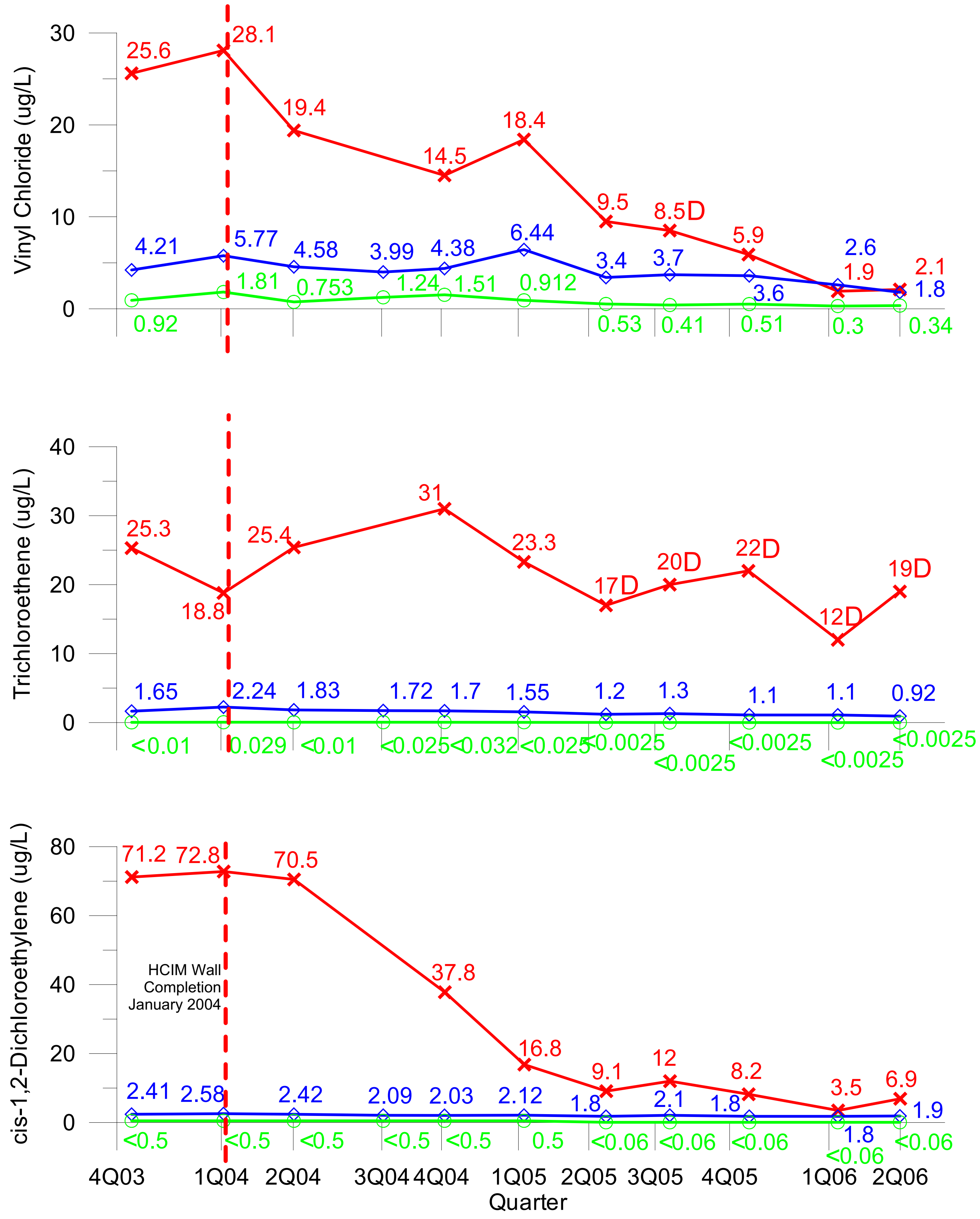
PSC

Well Cluster CG-121
4Q03 through 2Q06
PSC Georgetown

✕ CG-121-40
◇ CG-121-70
○ CG-121-93

Figure 30

2Q06



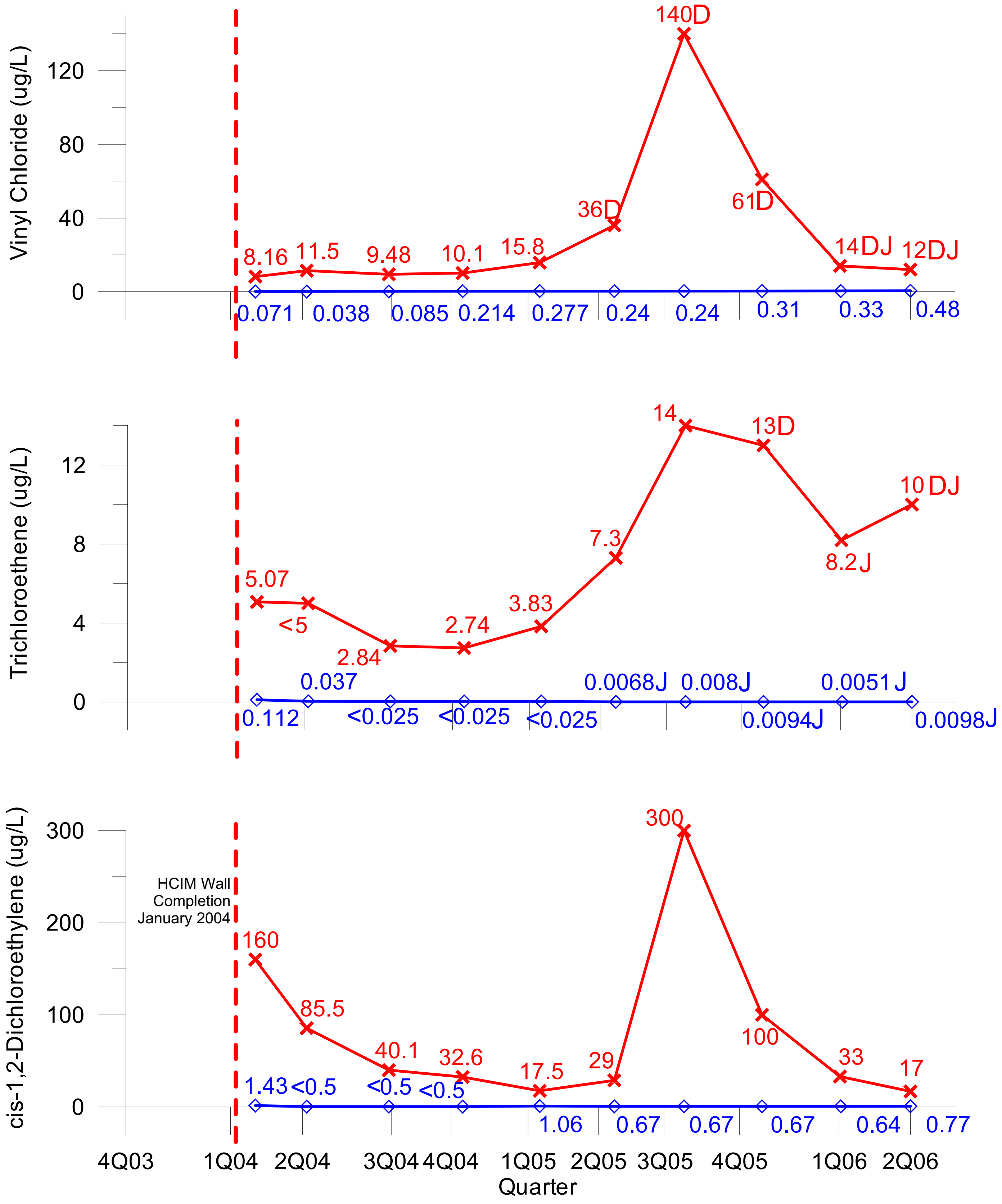
Note: Non-detects were plotted as one-half the detection limit value.

Well Cluster CG-124
4Q03 through 2Q06
PSC Georgetown

✕	CG-124-WT
◇	CG-124-40
○	CG-124-70

Figure 31

2Q06



Note: Non-detects were plotted as one-half the detection limit value.

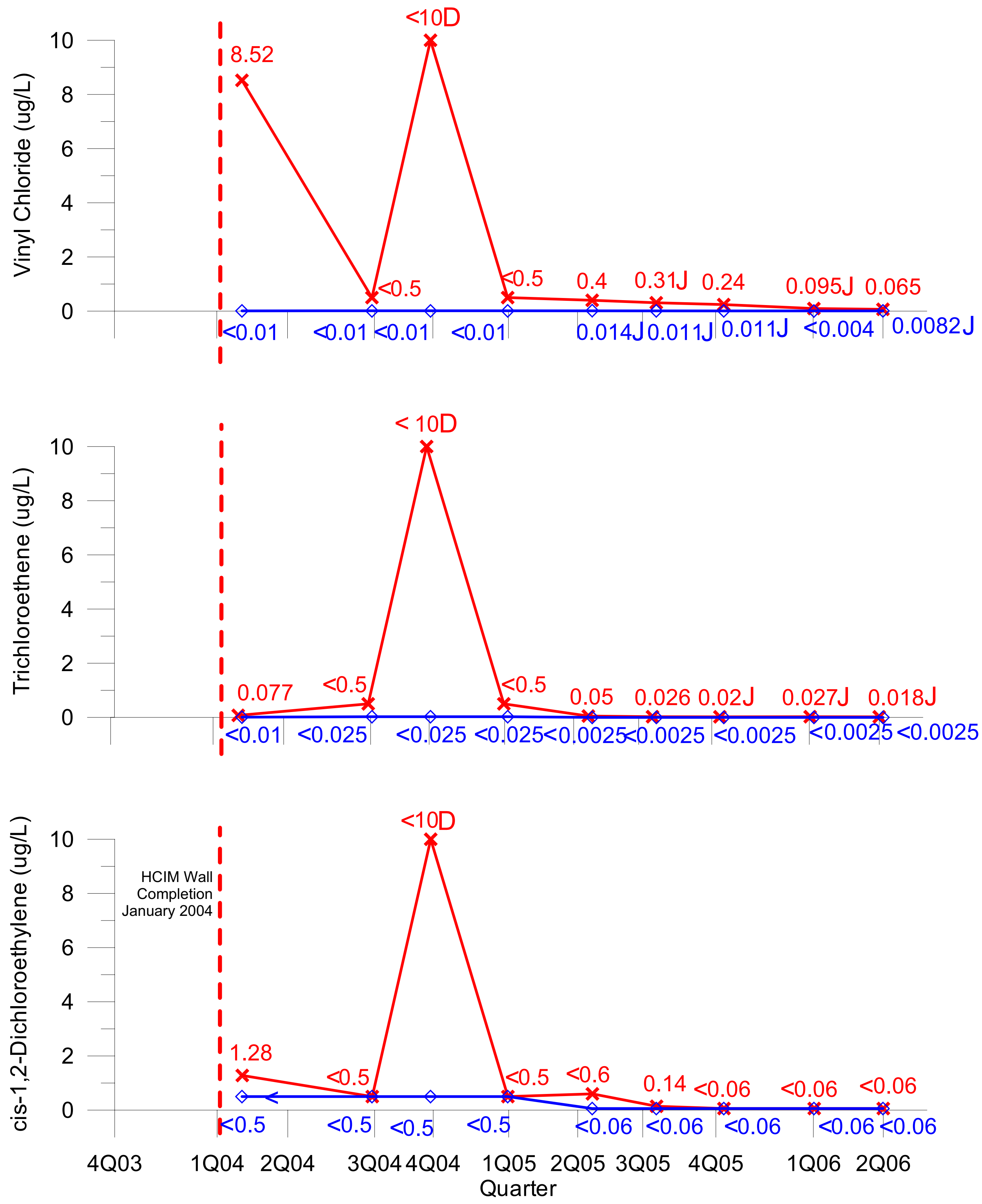
Well Cluster CG-149
4Q03 through 2Q06
PSC Georgetown

✕ CG-149-WT

◇ CG-149-68

Figure 32

2Q06



Note: Non-detects were plotted as one-half the detection limit value.

Well Cluster CG-153
4Q03 through 2Q06
PSC Georgetown

✕	CG-153-WT
◇	CG-153-79

Figure 33

2Q06

APPENDIX B

HCIM Area Remediation Levels

APPENDIX B
PRELIMINARY REMEDIATION LEVEL EVALUATION
HCIM AREA

A preliminary evaluation was performed to assess potential remediation levels for the HCIM Area. The purpose of this evaluation was to assess potential effects that may result from failure of the existing HCIM barrier wall that presently isolates HCIM Area groundwater from the surrounding environment. Remediation levels conservatively calculated for the HCIM Area could be used to establish remediation criteria for affected groundwater inside the barrier wall in the event of a breach of the HCIM barrier wall. Remediation levels were estimated based on a conceptual model incorporating an assumed failure for the barrier wall and using the fate and transport model BIOCHLOR to assess the fate and transport. The estimation approach, modeling approach, and results are summarized below.

CONCEPTUAL MODEL

In order to estimate remediation levels for the area located inside the conditional point of compliance (HCIM barrier wall), it is necessary to establish a scenario for failure of the barrier wall. The barrier wall is expected to have a very long life, as it is constructed of earthen materials that are not likely to degrade in the subsurface environment. Structural failure of the barrier wall due to an earthquake is considered the most likely cause of failure for the barrier wall. The following assumptions were made for the conceptual model of the failure:

1. Barrier wall failure caused a narrow (on the order of 1-foot in width), vertically oriented crack formed in the downgradient side of the barrier wall, exposing affected HCIM Area groundwater to the ambient environment.
2. The maximum concentrations of PCE, TCE, 1,2-DCE, and VC detected in the water table and shallow depth intervals within the HCIM Area were exposed at the point of the crack.
3. Groundwater within the Outside Area had been remediated to or below cleanup levels prior to failure of the barrier wall.

The assumption of a single failure was made to accommodate the capabilities of BIOCHLOR; this model cannot accommodate multiple sources. The effect of multiple cracks can be assessed semi-quantitatively by adding results from modeling of a single crack. The assumption that the maximum detected COC concentrations would be exposed by the crack is a highly conservative assumption; it is more likely that any exposed concentrations would be lower. The size of the break in the wall is also considered conservative since it implies a serious break and displacement. The assumption that ambient COC concentrations were negligible simplifies modeling and acknowledges the low probability for wall failure. This conceptual model was used to assess remediation levels for the HCIM Area.

FATE AND TRANSPORT MODELING

Modeling of the exposed HCIM Area constituents was done using BIOCHLOR. The groundwater flow and natural attenuation parameters used in Technical Memorandum No. 1 were used for this modeling, including the hydraulic conductivity, hydraulic gradient, half lives, and dispersivity. Source area concentrations were selected as the maximum detected concentrations in groundwater in the HCIM area. To evaluate the effects of the width of the barrier wall failure on model results, the model was run twice using a failure (source area) width of 0.5 feet and 2 feet. Input parameters are summarized in Table B-1. The wall would be expected to remain generally intact (with some cracking) and it would continue to impede groundwater flow, forcing water to flow around the HCIM Area and creating a stagnation zone along the downgradient side. By ignoring this stagnation zone and assuming that groundwater flow through the assumed wall failure and at the downgradient edge of the wall is the same as in areas not affected the by wall, the modeling is considered conservative. Actual groundwater flow rates immediately downgradient of the barrier wall would be substantially lower than assumed for modeling purposes. Thus, the modeling approach used for this preliminary assessment of remediation levels for the HCIM Area is considered conservative.

RESULTS

Based on the conceptual model of the failure scenario outlined above and modeling using BIOCHLOR, the concentrations were predicted for discharge to the Duwamish Waterway. The modeling predicted that the highest detected TCE concentration inside the barrier wall would naturally attenuate to a concentration at the Duwamish Waterway of about 0.01 µg/L for a 6-inch failure and 0.05 µg/L for a 2-foot wide failure (approximately 1 to 6% of its preliminary SWFS cleanup level, 0.788 µg/L). The predicted concentration of VC at the Duwamish (assuming release of the maximum detected concentration within the HCIM Area, and including sequential biodegradation of PCE, TCE, and 1,2-DCE) would be about 0.003 µg/l for a 6-inch failure and 0.012 µg/L for a 2-foot wide failure (about 0.1 to 0.6% of its preliminary SWFS cleanup level, 2.04 µg/L). These preliminary results indicate that multiple cracks in the barrier wall would be unlikely to cause an exceedance of cleanup levels at the Duwamish

Waterway. These results also indicated that remediation levels for the HCIM Area would be greater than the maximum detected concentrations in groundwater.

This preliminary evaluation was also used to calculate remediation levels for these constituents. The remediation levels, which are potential concentrations that would naturally attenuate to preliminary SWFS cleanup levels if released from the HCIM Area through a 6-inch wide failure in the barrier wall are as follows:

PCE	18,000 µg/L
TCE	37,000 µg/L
1,2-DCE	>1,100,000 µg/L
VC	>2,800,000 µg/L

Modeled remediation levels for 1,2-DCE and VC exceeded the aquatic solubility limits for these compounds. Remediation levels listed above for 1,2-DCE and VC are instead based on the solubility limits presented in Ecology's CLARC database. Based on these results, existing HCIM Area groundwater concentrations are protective of surface water under a barrier wall failure scenario and will remain protective.

TABLE B-1

BIOCHLOR MODEL INPUT PARAMETERS

PSC Georgetown Facility
Seattle, Washington

Parameter	Value	Units
Advection		
Hydraulic Conductivity	0.032	cm/s
Hydraulic Gradient	0.0017	ft/ft
Effective Porosity	0.3	unitless
Seepage Velocity	187.6	ft/yr
Dispersion		
α_x	41.6	Feet
α_y	4.2	Feet
α_z	0	Feet
Adsorption		
Soil Bulk Density	1.51	kg/L
Fraction Organic Carbon	0.001	unitless
Model Dimensions		
Model Length	3,800	Feet
Model Width	500	Feet
Source Area Width	0.5 to 2	Feet
Source Area Depth	30	Feet
Simulation Time	1,000	Years
Source Area Concentration		
PCE	282	µg/L
TCE	612	µg/L
cis-1,2-DCE	14,500	µg/L
VC	10,400	µg/L
Partitioning Coefficient		
PCE	265	L/kg
TCE	94	L/kg
cis-1,2-DCE	35.5	L/kg
VC	18.6	L/kg
Biodegradation Half Life		
PCE	1.2	Years
TCE	3.0	Years
cis-1,2-DCE	0.65	Years
VC	0.82	Years