Final Remedial Investigation Report
Former Building 2220 Site
(a.k.a. Swan Manufacturing Company Site)

Prepared for

Port of Vancouver
P.O. Box 1180
Vancouver, WA 98666

May 7, 2009 | 275-1940-006

Prepared by

Parametrix

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CITATION

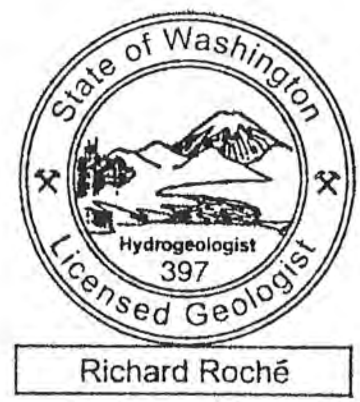
Parametrix. 2009. Final Remedial Investigation Report
Former Building 2220 Site
(a.k.a. Swan Manufacturing Company Site). Prepared by
Parametrix, Portland, Oregon. May 7, 2009.

CERTIFICATION

The technical mateial and data contained in this document were prepared under the supervision and direction of the undersigned, whose seal, as a licensed hydrogeologist licensed to practice as such, is affixed below.

Prepared by Rick Wadsworth

Prepared by Rick Malin, LHG



Approved by Richard Roché, LHG

EXECUTIVE SUMMARY

Since 1998, the Port of Vancouver, U.S.A. (the Port) has been conducting a remedial investigation and feasibility study (RI/FS) at the former Building 2220 site (a.k.a. the Swan Manufacturing Company [SMC] site) to address trichloroethylene (TCE) and other related volatile organic compounds (VOCs) in soil and groundwater in the project area.

This Final RI Report has been prepared to provide a comprehensive summary of SMC site-related investigations and interim remedial actions completed from 1998 through early 2007. In addition, this report is intended to provide a basis for the completion of a feasibility study and the selection of a final site remedy. Information included in this Final RI Report meets Washington State Department of Ecology (Ecology) requirements included in Washington Administrative Code (WAC) 173-340-710.

VOC contamination was first discovered near the SMC site by the City of Vancouver in 1997 as part of the Mill Plain Boulevard Extension Project. The site was originally referred to as the Building 2220 site because this building was located near the area where the contamination was discovered. However, based on the findings of the RI and interim actions, it was determined that the site should be referred to as the SMC site, not the Building 2220 site. From 1956 to 1964, electric heaters were manufactured by SMC at the site. Sheet metal was formed, cleaned, painted, and assembled into heaters. The sheet metal parts were cleaned using a VOC vapor degreasing tank prior to painting. The VOCs associated with these operations were the source of the contamination detected at the SMC site.

Two other sources of VOCs in groundwater have been identified near the SMC site: the Cadet Manufacturing Company (Cadet) site and the ST Services site. The contaminant plumes from the SMC, Cadet, and ST Services sites are commingled in the project area. The Port acquired the Cadet property on May 29, 2006, as part of a settlement agreement. The Port has assumed responsibility for cleanup of the Cadet site. The ST Services site is located on Port of Vancouver property. ST Services is in process of completing an RI/FS for their leasehold.

There are two regional hydrogeologic units in the project area: the unconsolidated sedimentary aquifer (USA) and the underlying Troutdale gravel aquifer (TGA). VOC contamination is present in three zones of the USA within the project area. In the shallow and intermediate USA zones, dissolved TCE originating from the Cadet- and ST Services-sourced plumes has commingled with the SMC site plume. The commingled plume from the SMC and Cadet source areas has migrated to the east and south in response to groundwater withdrawal, primarily at the Great Western Malting (GWM) wellfield. The GWM pumping wells effectively capture the commingled plume and prevent the contamination from SMC and Cadet from reaching the Columbia River. Air strippers treat groundwater pumped from the GWM wells prior to use at the GWM facility.

The deep USA zone is mostly contained in an erosional trough located beneath the SMC and Cadet sites. Contamination in this zone includes low concentrations of TCE (typically less than 10 µg/l). The VOC contamination has only impacted the top portion of the TGA. The presence of VOCs in the TGA appears to have occurred at locations where the Troutdale Formation has allowed contaminant migration via percolation from the USA consistent with the regional model. There is no VOC plume in the TGA. Depth-specific data indicate that the extent of this type of VOC migration is limited to the upper 10 feet of the Troutdale Formation.

From 1998 to 1999, the Port completed an interim action for soil that included the excavation and treatment of approximately 13,800 yd^3 of VOC-contaminated soil from the SMC site source area. From 2002 to 2004, the Port completed an interim action for groundwater that included injecting Fenton's Reagent and potassium permanganate to treat VOCs in groundwater in the SMC site source area.

In addition to interim actions completed by the Port at the SMC site, interim actions were implemented by Cadet on the Cadet site and within the North Fruit Valley Neighborhood (NFVN). In October 2003, Cadet installed an air sparging and soil vapor extraction (AS/SVE) system under Cadet's manufacturing building. In 2004 and 2005, Cadet installed seven recirculating groundwater remediation wells (RGRWs) at the Cadet facility and in the North Fruit Valley Neighborhood (SFVN) to treat impacted groundwater beneath the area. In addition, Cadet installed in-home soil vapor vacuum (SVV) systems in six houses in the North Fruit Valley Neighborhood to mitigate VOCs detected in indoor air. ST Services has also conducted remedial investigations and interim actions under a separate Agreed Order with Ecology.

The concentrations of TCE in the shallow USA zone have decreased significantly since 2002. The most significant TCE concentration reductions have occurred in the shallow USA zone east of the Cadet facility, in the NFVN. The decrease in TCE concentrations occurred after interim actions were initiated at the SMC and Cadet sites. TCE concentrations are also decreasing in the intermediate USA zone.

The risk assessment indicates that the concentrations of VOCs in the plume of contaminated groundwater originating from the SMC site exceed acceptable drinking water criteria. In addition, the risk assessment model suggests a potential risk associated with indoor air. However, the allocation between the subsurface contribution and background source contribution of VOCs to indoor air is unknown. The residual soil contamination at the SMC site does not pose an unacceptable risk to potential receptors. The results of the risk assessment indicate that additional remedial actions are necessary for groundwater at the site to protect human health and/or the environment, which should be evaluated in an FS.

The RI is complete. As part of the RI, the Port installed 326 borings and 110 monitoring wells, and collected and analyzed 355 soil samples, 2,465 water samples, 270 soil gas samples, 80 indoor air samples, and 21 outdoor air samples. Sufficient information has been collected to prepare an FS for the SMC site.

The following recommendations are based on the conclusions of the RI:

1. An FS should be prepared to evaluate alternatives for further reducing the concentrations of VOCs in groundwater impacted by the SMC site. The FS should be a combined FS for the SMC and Cadet sites in order to evaluate alternatives on a project area basis.
2. Groundwater and soil gas monitoring should be continued to document stability of the commingled plumes. In addition, results from the monitoring should be used to refine the FS, including further assessment of the potential risks associated with outdoor and indoor air.
3. The FS should include an analysis of alternatives for treating the residual TCE that may be present in one relatively small area of the fine-grained sand layer located in the saturated zone beneath the SMC site.
4. Pumping at the GWM wells should be continued until the final corrective action is implemented to maintain capture of the commingled TCE plume.
5. Operation of the air strippers associated with the GWM wells should be continued to remove TCE from groundwater prior to use.

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APPENDICES

1. INTRODUCTION

On behalf of the Port of Vancouver, U.S.A. (the Port), Parametrix has prepared this Final Remedial Investigation (RI) Report for the former Building 2220 site (a.k.a. the Swan Manufacturing Company site or the SMC site). The SMC site is adjacent to and west of the intersection of Fourth Plain Boulevard (or Lower River Road) and Mill Plain Boulevard in Vancouver, Washington (Figure 1-1).

Since 1998, the Port has been conducting a remedial investigation and feasibility study (RI/FS) in the SMC site project area to address trichloroethylene (TCE) and other related volatile organic compounds (VOCs) in soil and groundwater. The SMC site project area is shown on Figure 1-2. Parametrix prepared the Remedial Investigation Report, Former Building 2220 Site (Parametrix 2002a) for RI activities conducted from 1998 through 2001 and submitted it to the Washington Department of Ecology (Ecology) in August 2002.

In April 2006, the Port submitted a Draft Remedial Investigation Update Report, Former Building 2220 Site (Parametrix 2006c) to Ecology and the Washington Department of Health (DOH) to document RI activities conducted from 2002 through 2005. DOH and Ecology provided comments related to these 2002 and 2006 RI reports in letters dated August 15, 2006 (DOH 2006) and September 29, 2006 (Ecology 2006a). In March 2007, a Final Remedial Investigation Report was prepared to provide a comprehensive document for all remedial investigation activities conducted through 2006. Ecology and DOH provided comments in letters dated July 28, 2008 (Ecology 2008a) and June 23, 2008 (DOH 2008).

This report includes additional information based on the Ecology and DOH comments. However, it should be noted that this Final RI Report only includes data through December 2006 as was presented in the March 2007 report. Data collected since that time has been submitted to Ecology on an ongoing basis. The current data does not change the understanding of site conditions or conclusions presented in this Final RI Report. The Ecology and DOH comment letters, and Port responses to the letters, including supporting information, is included in Appendix K.

Information included in this Final RI Report meets Ecology requirements included in Washington Administrative Code (WAC) 173-340-710. Ecology approval completes the RI phase of the project. Based on the recommendations of the RI, a Feasibility Study (FS) will be prepared for the SMC site. The FS will also include an evaluation of remedial alternatives for the adjacent Cadet Manufacturing Company site, which is discussed in Section 2.7.1.

1.1 PURPOSE

This Final RI Report has been prepared to:

1. Provide a comprehensive summary of SMC site-related investigations and interim remedial actions completed from 1998 through 2006. A majority of the information included in this Final RI Report was previously submitted to Ecology in other reports and/or technical memorandums listed in Section 14.
2. Address Ecology and DOH comments related to the 2002 RI Report and 2006 Draft RI Update Report.
3. Provide a basis for completion of a Feasibility Study (FS) and selection of a site remedy.

Activities completed since the submittal of the 2002 RI Report include installation of additional monitoring wells, quarterly groundwater monitoring, soil gas monitoring, indoor air monitoring, outdoor air monitoring, and interim remedial actions at the SMC site source area. Several investigations were initiated to further characterize the distribution and migration of contaminants in the project area, including activities that examined groundwater flow using project-wide water level information and stable isotope analysis to determine the source of contaminants.

In addition to the 2002 RI Report, detailed background information and data used to support the conclusions presented in this Final RI Report are included in the following reports:

Final Groundwater Interim Action Report (Parametrix 2004b)

Groundwater Model Summary Report (Parametrix 2004d)

Other Potential Sources Report (Parametrix 2005a)

Draft Comprehensive Vapor Intrusion and Indoor Air Monitoring Plan (Parametrix 2007; 2009)

1.2 REPORT ORGANIZATION

The remaining sections of this Final RI Report are organized as follows:

Section 2 — Site Background – Describes the SMC site and discusses the regulatory framework of the remedial investigation.

Section 3 — Pre-RI Work Plan Phase Investigations – Includes a summary of Pre-RI Work Plan phase investigations completed between January and February 1998.

Section 4 — Pre-RI Work Plan Soil Interim Actions – Includes a summary of soil interim actions completed by the Port in 1998 and 1999 to treat contaminated soil in the vicinity of Building 2220.

Section 5 — Remedial Investigation Summary – Includes a summary of previous RI activities and a chronology of activities and events conducted at the SMC site.

Section 6 — Interim Actions – Summarizes interim actions completed at the site.

Section 7 — Geologic/Hydrogeologic Conditions – Summarizes the geologic and hydrogeologic conditions at the site.

Section 8 — Groundwater Modeling Summary – Summarizes the groundwater model prepared for the site.

Section 9 — Stable Isotope Evaluation – Summarizes the current understanding of water quality conditions based on isotope data.

Section 10 — Nature and Extent of Contamination – Summarizes the current understanding of the nature and extent of contamination.

Section 11 — Risk Assessment Summary – Summarizes the risk assessment process and conclusions.

Section 12 — Conclusions – Draws conclusions about the sources of TCE in groundwater, groundwater flow direction, and the extent of TCE impacts.

Section 13 — Recommendations

Section 14 — References – Lists the references cited in this report.

2. SITE BACKGROUND

The following sections describe the location and history of the SMC site, discovery of the release at the SMC site, the regulatory framework of remedial investigations and cleanup activities at or near the SMC site, and a summary of other source areas near the SMC site.

2.1 SITE LOCATION AND DESCRIPTION

The SMC site is adjacent to and west of the intersection of Fourth Plain Boulevard and Mill Plain Boulevard in Vancouver, Washington (Figure 1-2). The site is located in the southwest quarter of Section 21, Township 2 North, Range 1 East. The southern portion of the site is currently being used as a staging area for metal rebar products. The remainder of the site is unoccupied, except for a portion covered by Mill Plain Boulevard.

Current land use zoning in the vicinity of the SMC site is predominately Heavy and Light Industry. There is Single Family Residential land use zoning to the north and to the east of the SMC site. Future land use in the vicinity of the SMC site includes an increase in Light Manufacturing to the north of Fourth Plain Boulevard. Port property is zoned for continued use as Heavy and Light Manufacturing; these designations are not expected to change. Low Density Residential land use is anticipated to continue to the north and east of the SMC site (i.e., the North and South Fruit Valley Neighborhoods) (Clark County 2005).

It should be noted that the Port changed building number designations in 2006. This report uses the "old" building designations for consistency with previous reports. For reference, Table 1-1 includes the old and new building designations.

2.2 DEFINITION OF SITE

The Port's Agreed Orders, discussed in more detail in Section 2.6, define the SMC site as follows: "The Port of Vancouver/Building 2220 Site, also known as the former Swan Manufacturing Site, is located between 2001 and 2501 West Fourth Plain, near the southwest corner of Fourth Plain and Kotobuki Way, in an industrial-zoned area at the Port of Vancouver."

For the purposes of this Final RI Report, the term "project area" is used to describe the area around the SMC site that includes Port-owned property and property owned by others. Information about the project area has been used to define the physical characteristics, including geology and hydrogeology, that influence the migration of contaminants in the subsurface and to develop a numerical groundwater flow model. The project area includes an extensive monitoring well network to evaluate the groundwater flow. Figure 1-2 shows the SMC site and the project area. Figure 2-1 shows the current groundwater monitoring well network in the project area.

2.3 HISTORICAL USE OF THE SMC SITE

The site history is summarized in the following sections.

2.3.1 Ownership

Prior to the 1930s, the SMC site was used for agricultural purposes. Wembly Amusement Corporation owned the property from 1934 to 1943. In 1943, the U.S. Government, acting through the Vancouver Housing Authority (VHA), purchased the site and surrounding property and built two-story townhouse units to house Vancouver shipyard workers during

World War II. As part of the VHA's property development, a grocery store and daycare center were also constructed.

The 1948 flooding of the Columbia River destroyed the housing units, although the grocery store and daycare center remained. The grocery store property was purchased by the Port in 1986 and was used for storage until 1997, when the Port demolished the building.

In 1953, Ernest and Josephine Christensen purchased the daycare building property. The Christensen's operated the Vancouver Fast Freight Company; however, it is not known whether the property was used as part of the Vancouver Fast Freight operations.

From 1956 to 1964, the Christensen's leased the property to SMC, an electric heater manufacturer that conducted industrial activities in the former daycare building. In 1964, SMC transferred its operations to a new facility at 2500 Fourth Plain Boulevard, discontinuing operations at the SMC site. Cadet purchased SMC in 1972 and continues to operation at the 2500 Fourth Plain facility. The Cadet facility is located approximately 1,000 feet northwest of the SMC site, just north of Fourth Plain Boulevard.

Between 1965 and 1982, the former SMC building was used by various eating establishments. The last known occupant of the former SMC building was Raggs Tavern. The Port purchased this property in 1982 and added it to the Automotive Services, Inc. (ASI) leasehold after the former SMC building was demolished in 1986.

In the early 1970s, the Port built Building 2220 immediately to the south of the former SMC site. Building 2220 was leased to ASI. The building was demolished in February 1998 as part of the soil interim actions (Parametrix 2002a). The former locations of the SMC building and Building 2220 are shown on Figure 2-2.

2.3.2 Previous Industrial Use of SMC and Building 2220 Sites

2.3.2.1 Swan Manufacturing Company (SMC) Site

From 1956 to 1964, electric heaters were manufactured by SMC at the site. Sheet metal was formed, cleaned, painted, and assembled into heaters. The sheet metal parts were cleaned using a TCE vapor degreasing tank prior to painting. Parametrix's understanding of the SMC degreasing operations is based on the deposition of Mr. Don Nelson, a former employee at the SMC facility (Nelson 1999). According to Mr. Nelson, the degreasing operation consisted of a vapor degreasing tank and two rinse tanks. The degreasing tank was set into a concrete pit in the floor of the building. TCE in the tank was heated and metal parts were suspended in TCE vapors over the degreasing tank. The TCE condensed on the colder metal and dripped back into the tank (along with oil and dirt on the metal). After degreasing, the metal parts were transferred to the two rinse tanks, where the parts were rinsed to remove any remaining TCE. The parts were then dried and painted.

Maintenance of the TCE degreasing tank occurred about every six months. The two rinse tanks were drained through a valve and pipe assembly. The rinse water was not recycled. It is not known where the pipe drained (whether to a septic tank or a drainfield). City of Vancouver records indicate that the municipal sanitary sewer system was not extended to the vicinity of the SMC site until approximately the 1970s.

TCE in the degreaser was recycled every six months by transferring the TCE to a separator where dirt and oil were removed. Accumulated sludge was removed from the sides and bottom of the tank, placed in drums, and stored outside along the south side of the SMC facility. In some cases, the drums did not have lids. The drums were stored in this manner until they were removed for disposal. The frequency of disposal is unknown.

Occasionally, TCE was spilled while the degreasing tank was being refilled. This spilled TCE would accumulate in a sump below the degreasing tank. In order to remove the spilled TCE, water was added to the sump, and the mixture of water and TCE was pumped into barrels. These uncovered barrels were also stored outside along the south side of the building.

2.3.2.2 Building 2220 Site

In the early 1970s, the Port built Building 2220 immediately to the south of the former SMC site (Figure 2-2). From 1972 to 2000, Automotive Services, Inc. (ASI), an automobile importing company, leased various Port buildings located to the south and east of the SMC site. The former locations of the buildings leased by ASI are included on Figure 2-3. ASI is no longer a tenant of the Port.

ASI's operations included new automobile processing, car washing, automobile transport truck maintenance and parking, and automobile body refinishing and painting. Newly imported automobiles were processed and loaded on transport trucks to be distributed to local automobile dealerships. Automobile preparation included removing protective coatings (cosmoline), washing, fueling, installing air conditioning units, and adding exterior finishes such as hubcaps, striping, and roof racks.

ASI's automotive body shop was located in Building 2220. ASI operations conducted in other buildings located south and east of the SMC site included: Building 2240 (truck maintenance); Building 2273 (carwash); Building 2274 (undercoating building); and Building 2271 (shipping and receiving). Building 2230 was also leased by ASI, but the operations in that building are unknown.

Building 2220 was demolished in February 1998 as part of soil interim actions completed by the Port. These interim actions are summarized in Section 4.2. Buildings 2271, 2273, and 2274 were demolished as part of ASI's cleanup activities, which are discussed in Section 2.4. ASI reported to the Port in 1998 that it did not use chlorinated solvents at the Building 2220 site.

2.4 DISCOVERY OF RELEASE

TCE was first discovered by the City of Vancouver (the City) in 1997 as part of the Mill Plain Boulevard Extension Project (Mill Plain project) (EMCON 1997). The Mill Plain project involved the extension and rerouting of Mill Plain Boulevard, a major arterial road in Vancouver, Washington. Figures 1-2 and 2-3 show the location of the completed roadway project. The City planned to acquire property from the Port as part of the project, including a portion of the SMC site.

The former SMC building was demolished by the Port in 1986, 11 years prior to the contaminant discovery. At the time of contaminant discovery, Building 2220 was the only structure present near the SMC site. Building 2220 was demolished as part of the Port's soil interim action in February 1998. The former locations of the SMC building and Building 2220 are shown on Figure 2-2.

The 1997 City of Vancouver's environmental investigation included the collection of soil and groundwater samples from probe borings completed in two areas of the Port property: 10 probe borings (labeled SB-301 through SB-310) near the Fourth Plain Boulevard and Mill Plain Boulevard Extension intersection, and 10 probe borings (labeled SB-201 through SB-210) near buildings used by ASI (EMCON 1997). The City of Vancouver's probe boring locations are shown on Figure 2-3. The former ASI building locations are also shown on Figure 2-3. The findings of the investigation are summarized below.

Fourth Plain Boulevard and Mill Plain Boulevard Extension Intersection Area

Soil samples collected from probe borings SB-301 through SB-310 were analyzed for total petroleum hydrocarbons, volatile organic compounds (VOCs), polynuclear aromatic hydrocarbons (PAHs), and metals (arsenic, barium, cadmium, chromium, lead, mercury, selenium, and silver). A groundwater sample was collected from boring SB-306 and analyzed for the same parameters as the soil samples. Analytical results identified soil and groundwater contamination in the Mill Plain Extension right-of-way, near the SMC site. Soil samples collected from boring SB-306, completed near Port Building 2220 and the former SMC site, contained TCE at a maximum concentration of 800 micrograms per kilogram (μg/kg), exceeding Washington's Model Toxics Control Act (MTCA) Method A Cleanup Standard. The groundwater sample collected from boring SB-306 contained TCE and tetrachloroethylene (PCE) at concentrations of 68,000 micrograms per liter (μg/l) and 1,100 μg/l, respectively. Analytical results for compounds detected in soil samples collected from probe borings SB-301 through SB-310 are summarized below.

SB-301 through SB-310 Soil Analytical Results

Analyte	Frequency of Detection	Detected Concentration Range in Soil
TCE	1/3	800 μg/kg
Heavy Oil Range Petroleum Hydrocarbons	1/10	65 mg/kg
Total Carcinogenic PAHs	2/10	0.011- 0.062 mg/kg
Barium	10/10	54 – 240 mg/kg
Chromium	10/10	6.0 – 18.0 mg/kg
Lead	4/10	6.9 – 11 mg/kg

Analytical results for compounds detected in the groundwater sample collected from probe boring SB-306 are summarized below. No PAHs were detected in the groundwater sample.

SB-306 Groundwater Analytical Results

Analyte	Concentration in Groundwater
TCE	68,000 μg/l
PCE	1,100 μg/l
Cis-1,2-dichloroethene	64 μg/l
Trans-1,2-dichloroethene	1.0 μg/l
1,1,2-Trichloroethane	9.2 μg/l
Chloroform	8.5 μg/l
Carbon Tetrachloride	5.4 μg/l
Gasoline Range Petroleum Hydrocarbons	0.41 mg/l
Barium	0.036 mg/l
Chromium	0.11 mg/l
Lead	0.0059 mg/l

The extent of TCE and PCE contamination in soil and groundwater could not be defined using these limited data. Therefore, the City of Vancouver requested that the Port conduct additional site characterization activities to determine the extent of contamination near the Fourth Plain Boulevard and Mill Plain Boulevard Extension intersection. The Port completed the initial additional site characterization activities in an expedited manner to minimize potential schedule impacts to the Mill Plain Extension project. Subsequent investigation activities are summarized in Sections 3 and 4.

ASI Buildings Area

Probe borings SB-201 through SB-210 were completed near Building 2273 (ASI carwash), Building 2274 (ASI undercoating building), and Building 2271 (ASI shipping and receiving). The probe boring locations are included on Figure 2-3. These buildings were located approximately 600 feet south of the SMC site. ASI used hot water and kerosene fuel, as a solvent, to remove cosmoline from the undersides of new automobiles at the car wash (Building 2273).

Soil samples collected from probe borings SB-201 through SB-210 were analyzed for total petroleum hydrocarbons, VOCs, PAHs, and metals (arsenic, barium, cadmium, chromium, lead, mercury, selenium, and silver). A groundwater sample was collected from boring SB-209 and analyzed for the same parameters as the soil samples. Analytical results identified diesel and heavy oil-range petroleum hydrocarbons in soil at concentrations exceeding the MTCA Method A Cleanup Standards. This contamination was not related to the former SMC site, and was addressed by ASI under Ecology's Voluntary Cleanup Program. Ecology issued a Letter of No Further Action for the cleanup of petroleum hydrocarbon-related soil contamination (Ecology 2001). As previously stated, Buildings 2271, 2273, and 2274 were demolished as part of ASI's cleanup activities.

2.5 DRINKING WATER SOURCES NEAR THE PROJECT AREA

The Port maintains three production wells located adjacent to the east side of the Great Western Malting leasehold (see Figure 2-1 for location). The wells are used to supply fire suppression, irrigation, and drinking water to selected Port properties. Wells 1 and 2 were constructed in 1929, with Well 2 reconstructed in 1962. Well 3 was constructed in 1950 to provide water to Fort Vancouver Plywood (Mundorff 1964). Historically, it is understood that Wells 1, 2, and 3 operated on a continuous basis, producing at a rate of 1,200 to 1,500 gpm, to provide water to Port tenants and Fort Vancouver Plywood (Mundorff 1964; Port of Vancouver 1995). Production rates started to decrease in the mid-1980s when Wells 1 and 2 were no longer operated on a continuous basis. Pumping of Well 3 began to decrease in the early 1990s as mill operations were reduced. Fort Vancouver Plywood abandoned its facility in 1996, and Well 3 became a Port backup water supply well.

Based on quarterly sampling reports, the Port wells currently meet the Safe Drinking Water Act MCLs for VOCs and are acceptable for continued use. The GWM facility utilizes pumping wells to obtain groundwater for use in its production process. Air strippers, paid for by the Port and installed and operated by GWM, treat the groundwater pumped from these wells prior to use at the GWM facility.

2.6 PRELIMINARY CONTAMINANTS OF POTENTIAL CONCERN

Information related to the site history, analytical results from the City of Vancouver's Mill Plain project environmental investigation, and a review of MTCA regulations were used to identify contaminants of potential concern (COPCs). Although TCE and PCE were the primary chlorinated solvents detected in soil and groundwater samples collected by the City, the potential that other chlorinated solvents were present in the groundwater could not be eliminated. Furthermore, natural degradation of PCE and TCE could also result in associated chemicals being present in soil and/or groundwater. Therefore, the preliminary contaminants of potential concern included:

- TCE
- PCE
- cis-1,2-Dichloroethene (cis-1,2,-DCE)
- 1,1-Dichloroethene (1,1-DCE)
- Vinyl chloride

The risk assessment (Appendix I) includes an evaluation of groundwater, soil, soil gas, and indoor and outdoor air data to identify the full list COPCs at the site. Section 5.1 summarizes the COPCs selected for the site.

2.7 REGULATORY FRAMEWORK

The Port has entered into two Agreed Orders with Ecology. The first Agreed Order (No. 98TC-S337), issued in November 1998, included requirements to perform an RI/FS to define the extent of soil and groundwater contamination and to conduct soil interim actions. This first Agreed Order was issued by Ecology on the basis of the information developed during the Pre-RI Work Plan investigation and acknowledged the Port's Pre-RI Work Plan efforts to:

- Mitigate threats to human health and the environment, including dismantling/removal of Building 2220.
- Characterize, excavate, and stockpile 13,800 cubic yards of TCE-impacted vadose zone soil.
- Characterize TCE impacts to groundwater.

The Agreed Order also included a requirement to conduct an interim action for the stockpiled vadose zone TCE-impacted soil.

The Port entered into a second Agreed Order with Ecology (No. 01TCPVA-3257) in October 2001. This Agreed Order acknowledged that the Port had completed substantial parts of the original Agreed Order, including:

- RI/FS Work Plan
- Several phases of soil and groundwater investigations
- Implementation of an Interim Action Work Plan For Trichloroethylene-Impacted Soil
- Interim Action Report For Trichloroethylene-Impacted Soil

The second Agreed Order required the Port to complete the remaining parts of the original Agreed Order (i.e., the groundwater RI/FS for groundwater impacts) and to implement groundwater interim actions to mitigate the groundwater source area. Additional requirements of the second Agreed Order included a Groundwater Interim Action Work Plan, Final Work Plan Implementation and an Interim Action Report. All of these requirements were completed by 2004.

The Port's RI/FS is being conducted in accordance with MTCA requirements summarized in WAC 173-340-350. Cleanup standards for the SMC site will be established as part of the FS. In general, this Final RI Report uses a TCE concentration of 5 micrograms/liter (µg/l) to evaluate the spatial distribution of TCE in groundwater. However, site-specific groundwater cleanup target levels will be developed during the FS process. Any references to a 5 µg/l concentration in this report should not be construed as selection of a cleanup level for TCE at the SMC site.

The term "TCE-impacted" in this document is intended to be inclusive of other chemicals that are generally found to be associated with TCE from the SMC site. These other chemicals include, but are not limited to, tetrachloroethene (PCE), cis-1,2-dichloroethene (cis-1,2,-DCE), 1,1-dichloroethene (1,1-DCE), and 1,1-dichloroethane (1,1-DCA).

2.8 OTHER SOURCES

Two other sources of TCE (and other VOCs) in groundwater have been identified near the SMC site; the Cadet Manufacturing Company (Cadet) site and the Support Terminals Services (ST Services) site (Figure 1-2). In 2005, ST Services was purchased by Valero. While the focus of this Final RI Report is on the SMC site, it should be noted that these two other source areas impact the interpretation of site data and nature and extent of contamination in the SMC project area. Remedial investigations are ongoing at the Cadet and ST Services sites, and resulting documentation can be found in Ecology files. The Cadet and ST Services sites are discussed throughout this Final RI Report, primarily in Section 8, Groundwater Modeling Summary; Section 9, Stable Isotope Evaluation; and Section 10, Nature and Extent of Contamination.

The following provides a brief description of the Cadet and ST Services sites in order to establish their relationship with the SMC site. Additional detailed information on these sites can be found in the Other Potential Sources Report (Parametrix 2005a) and in numerous Ecology file reports prepared by the Cadet and ST Services environmental consultants.

2.8.1 Cadet Manufacturing Company Site

The Cadet site is located at 2500 Fourth Plain Blvd (Figure 2-4). The Cadet site, currently occupied by an electric heater manufacturing facility, is a known source of VOCs in the groundwater beneath the facility and the adjacent North Fruit Valley Neighborhood (NFVN). Contamination from this source has commingled with the plume of VOC contamination originating from the SMC site in the Port area to the east of the SMC site. Figure 2-4 shows the groundwater monitoring well network in the vicinity of the Cadet site. Figure 2-1 includes the entire well network for the project area.

In January 2000, Cadet entered into an Agreed Order (No. 00TCPVA-847) with Ecology to conduct investigations and interim remedial actions for VOCs in the subsurface at the Cadet site. Cadet documented its investigations in a Draft Remedial Investigation Report (AMEC 2003) and a Remedial Investigation Update Report (AMEC 2005b). Contaminants detected in groundwater samples collected during Cadet's investigations include TCE, PCE, chloromethane, chloroform, 1,1-dichloroethene (1,1-DCE), cis-1,2-dichloroethene (cis-1,2-DCE), 1,1,1-trichloroethane (1,1,1-TCA), 1,1-dichloroethane (1,1-DCA), methylene chloride, 1,1,2-trichloroethene (1,1,2-TCE), 1,3-dichlorobenzene, and 1,4-dichlorobenzene. TCE and PCE were detected in groundwater samples at maximum concentrations of 78,000 µg/l and 70,000 µg/l, respectively. These concentrations were detected prior to Cadet's implementation of interim remedial actions to reduce contaminant concentrations in groundwater. Remedial actions implemented by Cadet include the installation of an air sparging and soil vapor extraction (AS/SVE) system under Cadet's manufacturing building, which has been operating since October 2003. In 2004 and 2005, Cadet also installed seven recirculating groundwater remediation wells (RGRWs) at the Cadet facility and in the NFVN to treat impacted groundwater beneath the area. In addition, Cadet installed in-home soil vapor vacuum (SVV) systems in six houses in the NFVN to mitigate VOCs detected in indoor air. Figure 2-5 shows the locations of the AS/SVE, RGRWs, and SVV systems.

The Port acquired the Cadet property on May 29, 2006, as part of a settlement agreement. The Port has assumed responsibility for cleanup of the Cadet site.

2.8.2 ST Services

The ST Services site is located on Port property (Figure 2-6). The ST Services terminal, leased from the Port, has been in continuous operation as a bulk storage and chemical handling facility (including by GATX, prior to ST Services) since approximately 1960.

Several phases of investigation and remedial activities have been conducted at the site between 1991 and 2007 under an Agreed Order between Ecology and ST Services. Investigation activities included soil borings, a soil gas survey, aquifer evaluation, and the collection of soil and groundwater samples. A network of groundwater monitoring wells has been installed at the site, including multi-level groundwater monitoring wells (MGMS), interim action pilot study wells, interim remedial action measure system wells, and one well located near the former Carborundum site. Groundwater monitoring has been conducted at the site since 1993. Figure 2-6 shows the groundwater monitoring well network in the vicinity of the ST Services site.

Three source areas for the release of VOCs to the subsurface have been identified at the ST Services site (Ash Creek 2006a):

- An area located between Warehouses 13 and 15, beneath the rail siding north of these warehouses, and extending south toward the sea wall
- An area located beneath the rail siding off the northeast corner of Warehouse 9
- An area located near the south truck loading rack, between the tank farm and the sea wall

The locations of the three source areas are included on Figure 2-6. The largest source area is the area located between Warehouses 13 and 15 (Ash Creek 2006a).

The primary chlorinated solvent constituent detected in groundwater at the site is PCE (detected at a maximum concentration of 151,000 µg/l). However, other VOCs detected at the site include TCE, 1,1-DCA, cis-1,2-DCE, 1,1,1-TCA, and vinyl chloride. In general, the highest concentrations of VOCs in groundwater have been detected in the shallow zone between 35 and 45 feet below ground surface (bgs); these concentrations occur in groundwater monitoring wells located near the probable source areas between Warehouses 13 and 15 (Figure 2-6). However, relative to the soil source areas, the distribution of elevated concentrations of VOCs in shallow groundwater across the site is large. PCE was detected at a maximum concentration of 73,000 µg/l in monitoring well MW-7, and at 5,000 µg/l in monitoring well MW-9. Monitoring wells MW-7 and MW-9 are located along the rail spur, north of the site (Figure 2-6).

In 2000, ST Services implemented an Interim Remedial Action Measure (IRAM) to reduce VOC concentrations in groundwater beneath the site. The IRAM consisted of a line of injection wells near the railroad spur and a group of extraction wells near the river. The system was designed to treat shallow groundwater (less than 45 feet deep) with PCE concentrations exceeding 1,000 μg/l. The IRAM system pumped groundwater from the extraction wells to a treatment system where potassium permanganate was added. The water was then filtered and pumped into the injection wells, with the objective of creating a treatment cell between the injection and pumping wells. The IRAM system was shut down in 2005.

Based on the findings of an Interim Action Analysis prepared for the ST Services site in November 2006 (Ash Creek 2006b), enhanced bioremediation and soil vapor extraction are recommended as an interim action for the source area located between Warehouses 13 and 15. This interim action will be focused on addressing the potential migration of vapors to the breathing spaces and reducing the relatively high concentrations of VOCs that could migrate to the Columbia River (Ash Creek 2006b).

Based on the data from the ST Services and Port monitoring wells, TCE and PCE are migrating from the ST Services site to the north-northeast. This interpretation is based on the following:

- The highest concentrations of TCE and PCE are detected at the ST Services site.
- TCE and PCE concentrations progressively decrease with distance to the northeast of the ST Services site.
- Plume migration to the northeast in this area is consistent with the understood groundwater flow direction in the area (Ash Creek 2006a).

Additional information on the extent of VOC contamination from the ST Services source area is described in Sections 8 and 9 of this report.

2.8.3 Other Potential Sources

Parametrix reviewed regulatory databases, historical information, Ecology files, Port files, and other relevant information to identify other potential sources of TCE and/or associated chemicals in the project area. Details and results of the evaluation are included in the Other Potential Sources Report (Parametrix 2005a). The objective of the file review was to evaluate whether there are known sources of TCE that could be contributing TCE to groundwater in the vicinity of the SMC site. This information is critical to the success of the Port's work, since another source of TCE could adversely impact the success of the Port's final remedy for the SMC site.

Other than the Cadet and ST Services sites described above, the following sites were identified as potential sources of chlorinated solvents in the vicinity of the SMC site. However, these sites do not appear to have contributed to the chlorinated solvents captured by GWM pumping wells.

- 2001 NE Roosevelt Street
- Burlington Northern Railroad
- Inman Oil

Based on the findings of the Other Potential Sources Report, none of these sites represent a significant impact to the design, implementation, and/or effectiveness of the potential remedies for the SMC site (or Cadet and ST Services final remedies) (Parametrix 2005a).

3. PRE-RI WORK PLAN PHASE INVESTIGATIONS

Parametrix was retained by the Port in December 1997 to evaluate and characterize the source of the chlorinated solvent contamination identified by the City of Vancouver. Subsurface investigations and a soil interim action (discussed in Section 4) were completed during the Pre-RI Work Plan phase, which included all work completed by the Port prior to preparation of the RI work plan. The scope of work for each investigation was prepared to further characterize the nature and extent of contamination. The Port completed the Pre-RI Work Plan phase activities in an expedited manner to minimize potential schedule impacts to the Mill Plain Boulevard Extension project.

The Pre-RI Work Plan phase investigations included the following:

- Environmental Assessment
- Second Site Investigation
- Third Site Investigation

The Pre-RI Work Plan phase investigations were completed between January and February 1998. The findings from the Pre-RI Work Plan phase conducted at the SMC site are documented in the Preliminary Summary of Investigation Activities Report (Parametrix 1998a) and summarized in the following sections.

3.1 MILL PLAIN BOULEVARD EXTENSION PROJECT ENVIRONMENTAL ASSESSMENT (EA)

In December 1997, Parametrix initiated an Environmental Assessment (EA) for the chlorinated solvent contamination identified by the City of Vancouver. The EA was conducted prior to entering into an Agreed Order with Ecology.

The EA included two phases to evaluate the extent of chlorinated solvent and petroleum hydrocarbon contamination detected in soil during the Mill Plain Boulevard Extension project. Field activities were completed in January 1998.

The first phase of the EA was focused on further characterizing subsurface soil in the vicinity of Port Building 2271. Soil samples collected by the City of Vancouver near Port Building 2271 contained diesel and heavy oil-range petroleum hydrocarbons at concentrations exceeding MTCA Method A Cleanup Standards. The EA included the excavation of eight test pits (designated T1 through T8) near the Port Building 2271. Test pit locations are shown on Figure 3-1. Nineteen soil samples collected from the eight test pits were analyzed for total petroleum hydrocarbons-diesel extended (TPH-Dx) using Ecology-approved methods. Soil analytical results are summarized in Table 3-1. Petroleum hydrocarbons were not detected in any of the soil samples. A groundwater sample was collected from test pit T5 and analyzed for VOCs using EPA Method 8021. No VOCs were detected in the groundwater sample (Table 3-1). Laboratory reports are included in Appendix A.

The second phase of the EA was focused on further characterizing the areas to the north and east of Building 2220. This is the area where TCE was detected in soil and groundwater samples collected from boring SB-306 by the City of Vancouver. The EA included completing 18 probe borings to a depth of 25 feet bgs in the vicinity of City of Vancouver sample location SB-306. Boring locations are included on Figure 3-1. Thirty-four soil and 16 groundwater samples were collected and analyzed for VOCs using EPA Method 8021. Soil and groundwater samples collected during the EA were designated 306xx. The "306" designated samples collected in the vicinity of City of Vancouver sample SB-306, while “xx” designated the sample number.

The analytical results for soil and groundwater samples collected during the second phase of the EA are summarized in Tables 3-2 and 3-3. TCE was detected at concentrations exceeding the MTCA Method A Cleanup Standard (500 µg/kg) in 16 of the 34 soil samples. Concentrations of TCE ranged from 90 µg/kg to 17,000 µg/kg. PCE was detected at a concentration exceeding the MTCA Method A Cleanup Standard (500 µg/kg) in one of the 34 samples. Concentrations of PCE ranged from 150 µg/kg to 1,100 µg/kg in four of the 34 samples. The soil samples with detectable concentrations of TCE and PCE were collected from 3 to 19 feet bgs. Note that the MTCA Method A Cleanup Standard for TCE and PCE have since been modified to 16 µg/kg and 50 µg/kg, respectively. References to the previous cleanup standards are included in this report to present the rational for cleanup actions occurring at that time.

TCE and PCE were detected in groundwater samples at maximum concentrations of 42,600 µg/l and 590 µg/l, respectively. Cis-1,2-DCE was also detected in three of the groundwater samples at a maximum concentration of 26 µg/l. Laboratory reports are included in Appendix A.

The extent of VOC contamination in soil and groundwater could not be defined based on the results of the EA.

3.2 SECOND SITE INVESTIGATION

The second site investigation was initiated in January 1998 to further characterize the extent of VOC contamination in soil and groundwater in the vicinity of Building 2220. The activities of the second investigation focused on further evaluating the following:

- Extent of VOC soil contamination in the area adjacent to Building 2220, a suspected source area
- Building 2220 as a potential source area for VOC contamination
- Extent of VOC soil contamination in the Mill Plain Boulevard right-of-way
- Building 2240 as a potential source area for VOC contamination
- Extent of VOCs in groundwater

Laboratory reports for samples collected during the second site investigation are included in Appendix A.

3.2.1 Soil Contamination Adjacent to Building 2220

Seven probe borings were completed in the vicinity of Building 2220 in an attempt to identify the source area(s) and further define the extent of the VOC contamination. The borings were designated with an “S” for source. Boring locations for S-1 through S-7 are included on Figure 3-2.

Soil samples were collected from 2 feet, 5 feet, 7 feet, 12 feet, and 17 feet bgs in the “S” borings. TCE and PCE were detected in soil samples collected from “S” borings at maximum concentrations of 7,480 µg/kg and 250 µg/kg, respectively. However, a specific source area for the contamination was not identified during this investigation. As discussed in Section 4.2.2, the source for the contamination was discovered in February 1998 during investigation of a concrete slab located directly north of former Building 2220. Soil analytical results are summarized in Table 3-4.

Two probe borings (labeled B-1 and B-2) were completed inside Building 2220 through the concrete floor to evaluate whether a source for the VOC contamination was located under this building. A third boring, B-3, was drilled adjacent to the north side of Building 2220 in a paint shed to evaluate the shed as a potential source for VOCs. Boring locations are included on Figure 3-2.

Soil samples were collected from 2 feet, 5 feet, 7, feet, 12 feet, and 17 feet bgs in the “B” borings. TCE and PCE were detected in soil samples collected from “B” borings at maximum concentrations of 2,940 μg/kg and 130 μg/kg, respectively. However, a specific source area for the soil contamination was not identified. Soil analytical results are summarized in Table 3-4.

Groundwater samples were collected from borings B-1, B-2, and B-3. TCE and PCE were detected in the groundwater samples collected from all three borings at maximum concentrations of 67,000 µg/l and 4,800 µg/l, respectively. Cis-1,2-DCE was detected in the groundwater samples collected from B-1 and B-2 at a maximum concentration of 360 µg/l. Analytical results are summarized in Table 3-5.

3.2.2 Soil Contamination in Mill Plain Boulevard Right-of-Way

Eighteen probe borings were completed along a planned storm water utility corridor in the Mill Plain Boulevard right-of-way. The borings were designated with a “T” for trench. Boring locations are included on Figure 3-2.

Soil samples from the “T” borings were collected from between 2 feet and 17 feet bgs. TCE and PCE were detected in soil samples collected from “T” borings at maximum concentrations of 3,650 μg/kg and 170 μg/kg, respectively. Soil analytical results are summarized in Table 3-4.

3.2.3 Building 2240 Source Evaluation

Eleven probe borings were completed near Building 2240 (ASI Maintenance Building) to evaluate if a source for the VOC contamination was located under this building, and to further define the eastern extent of the contamination. The borings were designated with a “P” for plume. Boring locations are included on Figure 3-2.

Soil samples from the “P” borings were collected from 5 feet, 7, feet, 12 feet, and 17 feet bgs. VOCs were not detected in soil samples collected from the “P” borings. The data indicated that the source of the VOC contamination was not located under Building 2240. Soil analytical results are summarized in Table 3-4.

3.2.4 Extent of VOCs in Groundwater

Three borings (B-4, B-5, and B-6) were drilled to 80 feet bgs using a hollow-stem auger to further define the vertical extent of VOCs in groundwater. Four shallow water table monitoring wells (MW-1, MW-2, MW-3 and MW-4) were installed in late January 1998. In addition, groundwater samples were collected from the 11 probe borings (labeled “P”) that were completed adjacent to and east of the Building 2240 (discussed in previous section) to further define the eastern extent of the groundwater contamination. Boring and well locations are included on Figure 3-2.

Depth-specific groundwater samples were collected from borings B-4, B-5, and B-6 using a hydropunch sampler from depths of 20 feet, 40 feet, 60 feet, and 80 feet bgs. Sampling depth was limited by the drilling method, which could not penetrate deeper than 100 feet bgs into the formation because of the presence of large gravels.

TCE was detected in groundwater samples collected from 20 feet bgs in B-4, B-5, and B-6 at concentrations ranging from 6,520 µg/l to 75,000 µg/l. The concentrations of TCE were highest in the groundwater samples collected from 20 feet bgs, and generally were significantly lower in the deeper samples. TCE was detected in groundwater samples collected from 80 feet bgs in B-4, B-5, and B-6 at concentrations ranging from 113 µg/l to 16,900 µg/l. PCE and cis-1,2-DCE were detected in the groundwater samples collected from B-4 and B-5 at a maximum concentrations of 703 µg/l and 122 µg/l, respectively. Analytical results are summarized in Table 3-5. Monitoring wells were not constructed in these borings, which were subsequently decommissioned in accordance with Ecology regulations.

Shallow water table monitoring wells MW-1, MW-2, MW-3 and MW-4 were installed in late January 1998. The borings were drilled using hollow-stem auger technology. The wells were installed to evaluate assumed background water quality conditions (MW-1) and TCE impacts to the east (MW-2 and MW-3) and south (MW-4) of the site. TCE was detected in groundwater samples from MW-2, MW-3 and MW-4 at concentrations of 5,400 µg/l, 8,900 µg/l and 4.58 µg/l, respectively. TCE was not detected in the groundwater sample from MW-1. PCE and cis-1,2-DCE were detected in the groundwater sample from MW-4 at concentrations of 0.887 µg/l and 0.802 µg/l, respectively. No other VOCs were detected. Analytical results are summarized in Table 3-5.

Groundwater samples were collected from the 11 “P” borings at a depth of approximately 25 feet bgs. TCE, PCE, cis-1,2-DCE, 1,1-dichloroethane (1,1-DCA), and 1,1,1-TCA were detected at maximum concentrations of 230 µg/l, 13 µg/l, 20 µg/l, 1.9 µg/l, and 3.1 µg/l, respectively, in the groundwater samples collected from the “P” borings. Analytical results are summarized in Table 3-5.

The vertical and horizontal extent of VOC contamination in groundwater could not be defined based on the results of the second site investigation.

3.3 THIRD SITE INVESTIGATION

The third site investigation was initiated in February 1998 to further characterize the extent of VOC contamination in soil and groundwater in the vicinity of Building 2220. In addition, review of historic aerial photographs indicated the presence of hummocky soils to the west of Building 2220. Hummocky soils suggested disturbance of the area, and the potential for “dumping” or “burial” activities. Therefore, the third investigation included an assessment of the hummocky soil area as a potential source area. As discussed in Section 3.3.3, no evidence of dumping or burial activities was encountered.

Laboratory reports for samples collected during the third site investigation are included in Appendix A.

3.3.1 Investigation of Off-Site Impacts to the East and North of Building 2220

Twenty seven probe borings were completed in the Fruit Valley Neighborhood (FVN) to evaluate the potential off-site impacts of TCE to soil and groundwater to the north and east of Building 2220. For project purposes, the FVN was divided into the North and South Fruit Valley Neighborhood, with the divide being Fourth Plain Boulevard.

Twenty probe borings were completed in the North Fruit Valley Neighborhood (NFVN) to evaluate the potential off-site impacts of TCE to soil and groundwater to the north of Building 2220. In addition, seven probe borings were completed in the South Fruit Valley Neighborhood (SFVN) to evaluate the potential off-site impacts of TCE to groundwater to the east of Building 2220. Boring locations are included on Figure 3-3 and summarized in the following table.

Fruit Valley Neighborhood Probe Borings

Location	Probe Boring Labels
NFVN - West 27th Street	W27th-1 through W27th-5
NFVN - West 28th Street	W28th-1 through W28th-2
NFVN - West 31st Street	W31st-1 through W31st-3
NFVN - Weigel Street	Weigel-1 through Weigel-5
NFVN - Unander Street	Unander-1 through Unander-5
SFVN - Alley between Thompson and Simpson Avenues	Alley-1 through Alley-7

TCE and PCE were detected in the soil samples collected from the NFVN borings at maximum concentrations of 71.7 µg/kg and 82.1 µg/kg, respectively (Table 3-6).

TCE, PCE, cis-1,2-DCE, 1,1-DCE, and 1,1,1-TCA were detected in the groundwater samples collected from the NFVN borings at maximum concentrations of 2,490 µg/l, 245 µg/l, 8.96 µg/l, 8.22 µg/l and 180 µg/l, respectively (Table 3-7). In addition, 1,4-dichlorobenzene, chloroform, and toluene were detected in the groundwater samples collected from the NFVN borings at maximum concentrations of 1.25 µg/l, 2.25 µg/l, and 2.46 µg/l, respectively (Table 3-7).

TCE, PCE, cis-1,2-DCE, and 1,1,1-TCA were detected in the groundwater samples collected from the SFVN borings at maximum concentrations of 263 µg/l, 12.1 µg/l, 6.2 µg/l, and 11.8 µg/l, respectively (Table 3-8).

It was not known at the time whether the VOCs detected at the Building 2220 site were the source of the contamination in the NFVN and SFVN. In addition, the VOC source at Cadet had not been identified at the time, and the groundwater flow direction in the Port area had not yet been determined.

3.3.2 Vertical Distribution of VOCs in Groundwater

Borings B-7, B-8, B-9, and B-10 were drilled to depths ranging from 227 to 234 feet bgs to further define the vertical distribution of VOCs in groundwater. Boring locations are included on Figure 3-4.

The borings were drilled using the cable tool drilling method to penetrate the gravels that limited the use of the hollow stem auger technology to 80 feet bgs. In addition, the cable tool method allows the boring's casing to be "telescoped." Telescoping is effective in preventing the downward migration of contamination during drilling by isolating contaminated material from the drilling equipment. During drilling, depth-specific groundwater samples were collected from approximately 20, 40, 60, 80, 100, 120, 160, and 200 feet bgs from temporary wells constructed in the boreholes. The groundwater samples were analyzed for VOCs by EPA Method 8021.

The analytical results for the depth-specific groundwater samples (summarized in Table 3-9) were used to design and install permanent deep monitoring wells MW-1d in B-7 and MW-5d in B-10. Monitoring well MW-1d was installed in an assumed background location. MW-5d was installed in the suspected source area to evaluate the vertical extent of TCE in groundwater.

The depth-specific samples enabled Parametrix to develop a vertical profile of VOCs at each well location. Taken together across the site, the depth-specific groundwater samples were used to generate a three-dimensional picture of the distribution of VOCs in the groundwater. The highest concentrations of TCE in the shallow groundwater were found to the north and east of Building 2220 (i.e., B-1, B-2, B-5, B-6, B-9, B-10, 306-02, 306-05, and 306-06). TCE concentrations from these borings ranged from 10,100 µg/l to 75,000 µg/l. Since these were the highest concentrations detected, these data indicated the borings were close to the source area.

As summarized in Table 3-9, concentrations of TCE decreased with depth in the upper portion of the unconsolidated sedimentary aquifer (USA). Based on the TCE distribution, three distinct groundwater quality zones within the USA were defined based on the distribution of TCE:

- A shallow zone of highly contaminated groundwater, located above 80 feet bgs.
- An intermediate zone of groundwater with TCE concentrations less than 5 µg/l, located approximately between 80 feet and 140 feet bgs.
- A deep zone with moderately contaminated groundwater, located from 140 feet to 220 feet bgs.

3.3.3 Investigation of Area of Hummocky Soil

Eight probe borings, labeled S-8 through S-15, were completed to the west of Building 2220, in the area of hummocky soil identified in aerial photographs. Hummocky soils suggested disturbance of the area, and the potential for historic “dumping” or “burial” activities. The borings were designated with an “S” for source because they were completed near the suspected source area. Boring locations for S-8 through S-15 are included on Figure 3-4.

Soil samples were collected for VOC analysis (EPA Method 8021) from 2, 5, 7, and 12 feet bgs in the borings. TCE was detected in 11 of the 32 soil samples collected from S-8 through S-15, at concentrations ranging from 50 µg/kg to 580 µg/kg. No other VOCs were detected in the soil samples. Soil analytical results are summarized in Table 3-10.

Groundwater samples collected from borings S-9, S-11, S-12, and S-14 were analyzed for VOCs. TCE and PCE were detected in the groundwater samples collected from the borings at maximum concentrations of 4,500 µg/l and 70 µg/l, respectively. Methylene chloride was detected in the groundwater sample collected from S-12 at a concentration of 47 µg/l. Although not indicated on the laboratory report prepared by the mobile laboratory that completed the analysis, the detection of methylene chloride is suspected to be the result of laboratory contamination. Analytical results are summarized in Table 3-9.

Based on the relatively low concentrations of TCE detected in soil, the area of hummocky soils was not considered a source for the VOC contamination.

4. PRE-RI WORK PLAN SOIL INTERIM ACTION

Based on the findings of the Pre-RI Work Plan investigations, and the proposed scope and schedule for the Mill Plain Boulevard Extension Project, the Port completed soil interim actions to treat contaminated soil in the vicinity of Building 2220. Soil interim actions were performed with oversight from Ecology and in accordance with MTCA's Independent Remedial Action Program (IRAP) requirements. Soil cleanup activities included:

- Excavating and stockpiling TCE-impacted soil with concentrations greater than 500 µg/kg (MTCA Method A cleanup standard for TCE in soil at that time).
- Treating the stockpiled soil using Enhanced Soil Vapor Extraction (ESVE) until TCE concentrations in the soil were below the MTCA Method A cleanup standard.

The soil excavation and on-site stockpiling of TCE-impacted soils were completed in March and April 1998. Excavation was completed in an expedited manner to allow construction of the Mill Plain Boulevard Extension project. In 1999, after evaluating treatment alternatives for the stockpiled soil, treatment was completed (Parametrix 1999b).

4.1 SOIL INTERIM ACTION RATIONALE AND CLEANUP STANDARDS

The Port completed soil interim actions in the vicinity of Building 2220 to eliminate a source of TCE in the environment. Soil interim actions were performed with oversight from Ecology. The rationale for the soil interim action and cleanup standards are discussed below.

4.1.1 Soil Interim Action Rationale

The primary reasons for the soil interim actions were as follows:

- **Source Control**. The soil in the vicinity of Building 2220 contained significant concentrations of TCE (maximum of 17,000 µg/kg). TCE was detected in soil to depths of approximately 17 feet bgs. Note that soil samples were not collected below 17 feet bgs during this investigation. Due to seasonal fluctuations, the groundwater table was anticipated to rise to the depth of the TCE-impacted soil. During times of seasonally high groundwater, the TCE in the soil would be expected to dissolve into the groundwater, resulting in the continued release of TCE and degradation of the groundwater resources in the vicinity of the Building 2220 site.
- **Groundwater Resource Protection, Potential Concern for Public Health**. The groundwater in the vicinity of the Building 2220 site is used by the Port as a potable drinking water source (see Section 2.5). The Port did not identify receptors for the groundwater contamination; however, there were concerns that continued groundwater degradation would occur if the TCE-impacted soil remained in-place.
- **Project Schedule Constraints, Uncertainty Associated with In-Situ Treatment Methods**. Various in-situ treatment methods are available to treat solvent-impacted soil "in-place." Because the City of Vancouver needed to complete the Mill Plain project within a mandated schedule or risk loss of federal funding for the project, sufficient time was not available to conduct bench scale or pilot studies to evaluate and adequately fine-tune the performance of these in-situ techniques. Therefore, it was uncertain whether the in-situ techniques would adequately remediate the TCE-impacted soil. Furthermore, the Port risked incurring significant cost if these in-situ techniques were utilized and proved unsuccessful (i.e., the costs associated with

remediating the soil after construction of the Mill Plain Boulevard Extension would greatly exceed the cost to excavate and stockpile the soil).

- **Worker Protection**. TCE concentrations in the Mill Plain Boulevard right-of-way were greater than the 500 µg/kg MTCA Method A Cleanup Standard. Thus, workers associated with the Mill Plain project could potentially have been exposed to hazardous levels of TCE if the contaminated soil was left in-place.
- **City of Vancouver Concerns**. The City of Vancouver was purchasing the Port property necessary to construct the Mill Plain Boulevard Extension Project. To avoid claims and damages associated with the TCE-impacted soil, the City required that the property be in a condition sufficient to receive a No Further Action (NFA) letter from Ecology.
- **Possible impacts on the ability to conduct future remediation once the road was constructed**. Once the Mill Plain Boulevard Extension was constructed, the ability to access soil and water at the site would be impaired, due to the presence of the roadway. Therefore, the Port implemented interim actions prior to construction.

4.1.2 Numeric Cleanup Standards

Cleanup levels are numeric expressions of remedial action objectives (RAOs) and specify the maximum acceptable concentration of a chemical to which the human or ecological receptors may be exposed via a specified exposure pathway (e.g., ingestion) under a specified exposure scenario (e.g., industrial). RAOs are site-specific goals that identify risk pathways that remedial actions should address and that identify acceptable exposure levels for residual contamination. The RAO for TCE and PCE-impacted soil was 500 µg/kg.

MTCA defines cleanup standards (A, B and C) for simple and complex sites, depending on the numbers and types of contaminants and the different environmental media (soil, groundwater, air, sediments, etc.) impacted by the contaminants.

Under MTCA, the use of Method A, B, and C cleanup standards are addressed in WAC 173-340-700. “Routine” site remediation may use tabulated cleanup standards under Method A [WAC 173-340-700(3)(a)], which are appropriate for remediation of TCE-impacted soils. Under Method A, cleanup levels are established at concentrations at least as stringent as specified in state and federal laws, and are presented in Table 1, 2, or 3 of WAC 173-340. Method B is the standard method for establishing cleanup levels that are at least as strict as state or federal laws, and are calculated using risk equations specified in 173-340-720 through -750. Method C cleanup levels may be used where it can be demonstrated that the remedy complies with applicable state and federal laws, and are calculated through the use of a risk assessment to define acceptable cleanup levels. Method C levels are used where all practicable treatment methods are utilized, institutional controls are implemented, and Method A or B cleanup levels are below technically possible concentrations [(173-340-706(1)(c)].

Ecology has established additional requirements for setting cleanup levels. Of particular concern to Ecology is cross-media contamination (e.g., the migration of a contaminant from soil to groundwater, or soil to air). In cases where the migration of hazardous substances from one media (e.g., soil) may cause the contamination of a second media (e.g., groundwater), the use of Method B or C standards may not be appropriate [(173-340-700(4)(b)]. Ecology requires that cleanup levels must be established at concentrations that prevent violations of cleanup levels for other media following implementation of the cleanup action (i.e., the residual concentration of a contaminant cannot pose a threat to another media). In these cases, Ecology has typically used a value 100 times the groundwater protection standard to establish a soil cleanup level (Ecology 1996). In the case of TCE and PCE, which have federally mandated groundwater protection standards of 5 µg/l (EPA 1996b), the use of the 100 times policy results in a soil cleanup standard of 500 µg/kg, the Method A cleanup standard (at that time). Therefore, using the Method B or Method C levels for TCE was not appropriate because of the documented groundwater contamination. The Method A standard was the only standard applicable to the SMC site soil interim action. These standards are considered sufficient for protection of all the potential exposure pathways, including direct human contact with TCE-impacted soil and contaminant migration from the soil via air, stormwater runoff, and groundwater.

A remedial action that achieves these cleanup standards does not require long-term maintenance and monitoring, nor does it require restrictions on site use or other institutional controls. A remediation alternative that reliably prevents exposure to soil with contaminant concentrations above these cleanup standards achieves the RAOs for soil at the SMC site.

4.1.3 Non-Numeric Performance Objectives

Besides meeting numerical standards, interim actions must be conducted in a manner that protects the environment during implementation of the interim action. The environmental implications of poorly maintained remedial actions were also of concern. As discussed previously, cross-media transfer of contaminants can result in the contamination of the second media. Also, the release of chlorinated solvents into surface waters can degrade wildlife habitat and impact water quality (surface and groundwater). To address potential groundwater and surface water impacts during remedial actions, the following performance objectives were needed:

- Prevent water quality impacts to surface water via stormwater runoff during soil excavation
- Ensure State Environmental Policy Act (SEPA) compliance
- Protect worker health during implementation

4.2 EXCAVATION OF TCE-IMPACTED SOIL

The Port conducted the first phase of the soil interim action, consisting of the excavation and stockpiling of soil with TCE concentrations greater than 500 µg/kg, the MTCA Method A cleanup standard (at that time), under Ecology's IRAP program. The Port prepared the necessary SEPA documentation, provided notice of the removal action to the public, and secured the required permits to perform the work. Building 2220 was demolished in early February 1998 to facilitate removal of the TCE-impacted soil.

Excavation and stockpiling of the TCE-impacted soil began the week of February 23, 1998. During soil excavation, a concrete slab was discovered directly north of former Building 2220. Investigation of the concrete slab is discussed in Section 4.2.2. With the exception of a small area of TCE-impacted soil that was discovered and excavated in April 1998, excavation of the TCE-impacted soil in the vicinity of Building 2220 was completed the week of March 23, 1998.

Because of the "hourglass" shape of the soil impacted by TCE, clean overburden also had to be removed to excavate TCE-contaminated soil at 17 feet bgs. As it was excavated, the clean soil was separated from the TCE-impacted soil and stockpiled as "clean" soil. Approximately 13,800 cubic yards (yd^3) of TCE-impacted soil were excavated and stockpiled on the SMC site. Also excavated were approximately 6,300 yd^3 of clean overburden; 4,100 yd^3 of this soil were placed as backfill in the excavation. The remaining 2,200 yd^3 stockpile of clean overburden soil were used as fill material at other Port locations.

Photographs of the excavation and backfilling work are included in Appendix B.

4.2.1 Soil Waste Designation

Ecology designated the TCE-impacted soil as a "problem waste." As a problem waste, the soil was not considered a hazardous waste subject to Ecology's Dangerous Waste Regulation, WAC 173-303. The problem waste designation was based on Ecology policy (Ecology 1993) that contaminated environmental media may be considered non-hazardous waste when the hazardous constituents fall below site-specific risk-based levels, and the media does not exhibit any other characteristics or meet the dangerous waste criteria (WAC 173-303-070). Documentation that the TCE-impacted soil was a "problem waste" was presented to Ecology on September 2, 1998 (Parametrix 1998b). Ecology's designation of the soil as a problem waste was documented in an October 20, 1998, letter to the Port (Ecology 1998).

4.2.2 Investigation of the Concrete Slab

In February 1998, during soil excavation for the interim action, a concrete slab was discovered directly north of former Building 2220, at a depth of approximately 1 foot bgs. The location of the concrete slab is shown on Figure 4-1. Information provided by Mr. Don Nelson (former SMC employee) indicated that the concrete slab was a remnant of the former SMC building. As discussed in Section 2.3.2.1, from 1956 to 1964 electric heaters were manufactured by SMC at the site. Sheet metal was formed, cleaned, painted, and assembled into heaters. The sheet metal parts were cleaned using a TCE vapor degreasing tank prior to painting.

A pipe was discovered leading from a concrete pit located within the slab to the south (outside) of the former SMC building. Mr. Nelson indicated that a TCE degreasing tank had occupied the pit and provided additional information about the industrial operations at the facility.

Based on information provided by Mr. Nelson and field observations, it was determined that the site should be referred to as the Swan Manufacturing Company or SMC site, not the Building 2220 site. The findings of the concrete slab investigation are summarized in the following sections.

4.2.2.1 Photographs

A series of photographs documenting the discovery and investigation of the concrete slab are included in Appendix B. Figure 4.1 shows an outline of the concrete slab and the location of the photographs taken during the investigation and excavation activities.

4.2.2.2 Samples from Concrete Slab and Discharge Pipe

Samples of soil and debris, designated "CS", were collected from a concrete-lined pit located in the former SMC facility concrete slab to help identify chemicals which were used at the facility. In addition, samples of green/gray material discovered in the discharge pipe from the concrete pit and soil under the pipe were collected for analysis. Sample locations are shown on Figure 4-2.

Three samples of the soil and debris inside the concrete pit were analyzed for VOCs (EPA Method 8021) and barium, cadmium, chromium, lead, silver, arsenic, selenium, and mercury (EPA Method 6010A/6020). Samples Slab Pit 1'-3' @ 1010 and Slab Pit 1'-3' @ 1023 are composite samples of the material found in the pit. The material was collected from depths between one and three feet. South Pit 1 is a discrete sample from the pit. Analytical results are included in Tables 4-1 and 4-2. Compounds detected in the samples collected from the concrete pit are summarized below.

Analyte	Concrete Pit Samples
TCE	1,190 – 2,600 μg/kg
PCE	178 – 300 μg/kg
Barium	195 – 218 mg/kg
Cadmium	1.07 – 7.06 mg/kg
Chromium	22.8 – 49.8 mg/kg
Lead	42.2 – 194 mg/kg
Arsenic	11.0 – 169 mg/kg
Mercury	0.164 – 0.18 mg/kg

During the excavation work, a pipe was observed to exit the slab area approximately 10 feet to the east of the concrete pit. The location of the pipe is shown on Figure 4-2 on the western portion of the slab. The pipe was routed to the south, toward the area where TCE-impacted soil was being excavated. A fine-grained green/gray material was observed inside the pipe. Samples of this green/gray material (Sample CS-15) and soil under the pipe (Sample CS-17) were collected and analyzed for VOCs (EPA Method 8021) and barium, cadmium, chromium, lead, silver, arsenic, selenium, and mercury (EPA Method 6010A/6020). Analytical results are included in Tables 4-1 and 4-2. Compounds detected in the samples of the material in the pipe and underlying soil are summarized below.

Analyte	Green/Gray Material in Pipe (Sample CS-15)	Soil Under Pipe (Sample CS-17)
TCE	38,600 μg/kg	4,100 μg/kg
PCE	3,310 μg/kg	817 μg/kg
Barium	566 mg/kg	379 mg/kg
Cadmium	36.2 mg/kg	5.66 mg/kg
Chromium	2,660 mg/kg	606 mg/kg
Lead	567 mg/kg	162 mg/kg
Arsenic	16.1 mg/kg	4.33 mg/kg
Mercury	0.528 mg/kg	0.119 mg/kg

The 38,600 μg/kg detected in the material in the pipe was the highest concentration of TCE detected in a non-water sample collected from the SMC site. As discussed in Section 4.2.2, the concrete slab (including the soil and debris from the pit and the subgrade piping) was removed from the site during the soil interim actions and disposed of at the landfill in Hillsboro, Oregon.

4.2.2.3 Samples Collected Adjacent to Concrete Slab

Three soil samples were collected for VOC analysis from depths of 0.5 to 1.0 feet bgs in the areas adjacent to the concrete slab (W Slab, E Slab and SW Slab). TCE was detected in these samples at concentrations ranging from 1,390 μg/kg to 8,120 μg/kg. The SW Slab (8,120 μg/kg) location was adjacent to boring location B-5, where the highest concentrations of TCE were previously detected in soil. PCE was also detected in these samples at concentrations ranging from 80.7 μg/kg to 655 μg/kg. Sample locations are included on Figure 4-2. Analytical results are summarized in Table 4-3.

4.2.3 Removal of SMC Concrete Slab

Based on the analytical results of samples collected from the concrete pit and the discharge pipe, the SMC concrete slab was removed to facilitate excavation of the TCE-impacted soil below the concrete slab. The majority of the slab was removed in March 1998. However, the pile of clean soil excavated as part of the interim action was located on the northeast section of the slab. Therefore, the northeast section of the SMC slab was removed in April 1998. The concrete slab was transported to Hillsboro Landfill for disposal on February 23 and 24, 1999. Disposal documentation is included in Appendix C.

4.2.3.1 Samples From Beneath the SMC Concrete Slab

Soil samples were collected from soil exposed when the concrete slab was removed as part of the TCE-impacted soil excavation process. These samples, generally collected from 0.5 to 1.0 feet below the base of the slab, were analyzed for VOCs. In addition, six of the soil samples were analyzed for metals to determine if the concentrations of cadmium, chromium, lead, and arsenic detected in the concrete pit and pipe samples extended to the soil under the slab. Locations for samples collected in March 1998 are included on Figure 4-2.

Analytical results for samples collected in March 1998 are included in Tables 4-3 and 4-4. Compounds detected in soil samples collected from beneath the SMC concrete slab and background soil metals concentrations in Clark County (Ecology 1994) are summarized below.

Analyte	Soil Samples from Under Slab	Average Metals Concentration Detected	Background Soil Metals Concentration in Clark County
TCE	98.5 – 8,120 μg/kg	-	-
PCE	69.6 – 655 μg/kg	-	-
Barium	116 – 194 mg/kg	155	Not Available
Cadmium	0.784 – 1.96 mg/kg	1.4 mg/kg	1 mg/kg
Chromium	16.6 – 31.5 mg/kg	24 mg/kg	27 mg/kg
Lead	15.8 – 45.8 mg/kg	21 mg/kg	17 mg/kg
Arsenic	5.01 – 11.0 mg/kg	8.4 mg/kg	6 mg/kg
Mercury	0.0838 – 0.147 mg/kg	0.08 mg/kg	0.04 mg/kg

Samples “Mid-Trench” and “South Cement Pad” were collected from the same general vicinity as the W Slab, E Slab, and SW Slab samples, from soil directly beneath the concrete slab. TCE was detected in the “Mid-Trench” and “South Cement Pad” samples at concentrations of 2,270 μg/kg and 2,970 μg/kg, respectively. PCE was also detected in “Mid-Trench” and “South Cement Pad” samples at concentrations of 210 μg/kg and 285 μg/kg, respectively.

Soil samples CS-1 through CS-8 were collected from under the central portion of the concrete slab. TCE and PCE were detected in these samples at maximum concentrations of 2,260 μg/kg and 258 μg/kg, respectively.

Soil samples CS-12 and CS-14 were collected from soil under the concrete pit, which extended approximately 3.0 feet below the surface of the concrete slab. TCE was detected at a concentration of 98.5 μg/kg in CS-12.

Soil samples Cinder Block Patio 1’ and Cinder Block Patio 5’ were collected from soil below cinder blocks in the concrete slab. Originally, it was thought that the cinder blocks were a part of a patio at the facility, and samples were designated accordingly. Mr. Nelson, however, indicated that the SMC facility’s drying ovens were placed on the cinder blocks. The Cinder Block Patio 1’ and Cinder Block Patio 5’ samples were collected from depths of 1.0 and 5.0 feet bgs. TCE was detected at a concentration of 465 μg/kg in Cinder Block Patio 1’. PCE was detected in Cinder Block Patio 1’ at a concentration of 69.6 μg/kg. CS-18 and CS-19 were also collected from this area after the concrete slab was removed on March 11, 1998. TCE and PCE were not detected in these samples.

Based on the concentrations of VOCs detected in soil samples collected from beneath the slab, the remedial excavation was extended north under the former SMC building location (Figure 4-3).

Based on the comparison of the concentrations of metals detected in soil samples collected from beneath the slab to background soil metals concentrations in Clark County, metals were eliminated as contaminants of potential concern.

4.2.3.2 Samples from Beneath the NE Section of SMC Concrete Slab

As discussed in Section 4.2.2, the majority of the SMC concrete slab was removed in March 1998. However, the pile of clean soil excavated as part of the interim action was located on the northeast section of the slab. Therefore, the northeast section of the SMC slab was removed on April 20 and 21, 1998, after the clean soil was used to backfill the excavation as shown on Figure 4-3.

Twenty-nine soil samples were collected from test pits excavated after the northeast portion of the concrete slab was removed. Eleven of these samples were collected from 0.5 to 1.0 feet below the base of the slab and analyzed for VOCs. Eighteen soil samples were also collected from deeper locations in the test pits (maximum sample depth of 14.8 feet bgs) to characterize the extent of VOCs in soil. Locations for samples collected from beneath the northeast section of the SMC slab are included on Figure 4-4.

Analytical results for soil samples collected from beneath the northeast section of the SMC slab are included in Table 4-5. TCE was detected at concentrations ranging from 121 to 1,790 μg/kg in eight of the soil samples. Four of the detected concentrations exceeded 500 μg/kg. On April 23, 1998, two remedial excavations were completed in the vicinity of the four test pits that contained soil with TCE exceeding 500 μg/kg (the MTCA soil cleanup level at that time). The TCE-impacted soil was added to the contaminated soil stockpile generated in March 1998. Results for verification samples collected after completing the remedial excavations are discussed in Section 4.2.4.

4.2.4 Verification Sampling

Soil Interim Action Verification sampling was conducted during the course of the interim removal actions to evaluate the effectiveness of the soil excavation.

4.2.4.1 Verification Samples from SMC Excavation

Due to the uneven distribution of TCE in the soil, the excavation was multi-sided and terraced (Figure 4-3). Verification samples were collected from the excavation's sidewalls. Soil samples were not collected from the excavation floor because the majority of the excavation floor was at or below the water table, and previously collected probe boring samples from the Pre-RI Work Plan investigations (discussed in Section 3.0) indicated that the terraced areas did not contain TCE.

Where verification sampling indicated TCE in soil at concentrations greater than 500 µg/kg, additional soil removal was conducted and the area re-sampled. Final verification sample locations are included on Figure 4-3. Analytical results for verification soil samples are included in Table 4-6. With the exception of S-050-17 (504 µg/kg), none of the final verification samples contained TCE in concentrations above the 500 µg/kg MTCA Method A cleanup standard (note that the MTCA soil cleanup level for TCE has since been modified to 16 µg/kg). Thus, the interim removal action was successful in meeting the cleanup standard (Parametrix 1999b).

4.2.4.2 Verification Samples from Remedial Excavations Completed Under NE Section of SMC Slab

Twelve verification soil samples were collected from the two remedial excavations completed in the vicinity of the four test pits that contained soil with TCE exceeding 500 μg/kg. Verification sample locations are included on Figure 4-4. The remedial excavations were approximately 1.5 to 2 feet deep. VOCs were not detected in any of the verification samples (see Table 4-7).

4.2.5 Temporary Storage of TCE-Impacted Soil

After TCE-impacted soil was removed from the excavation, it was placed in a bermed containment area formed with hay bales and lined and covered with plastic sheeting. The cover of the stockpile was inspected weekly, and adjustments were made as needed to protect the integrity of the cover system. The stockpile received a second cover in October 1998. The covered stockpile was located approximately 200 feet south of former Building 2220.

4.3 EXTENT OF TCE-IMPACTED SOIL REMAINING AFTER EXCAVATION

With the exception of a small area located to the south of the remedial excavation, all soil in the vadose zone associated with the SMC site that contained TCE at concentrations greater than 500 μg/kg was excavated and stockpiled for treatment. Figure 4-5 shows the remedial excavation and concentrations of TCE in soil left in-place. Analytical results for soil samples collected from areas outside the extent of the remedial excavation are summarized in Table 4-8.

TCE was generally not detected in samples of soil left in place in the vadose zone (samples collected from borings, test pits and final excavation) to the north, east, and west of the SMC remedial excavation.

TCE was detected at concentrations above 500 μg/kg in two soil samples collected to the south of the SMC remedial excavation. Final excavation verification sample S50 contained TCE at a concentration of 504 μg/kg. A soil sample collected from 17 feet bgs in boring S-7 contained TCE at a concentration of 4,600 μg/kg. However, this soil sample was collected below the water table (i.e. below vadose zone), and thus is not representative of soil conditions. The locations of S50 and S-7 are included on Figure 4-5. TCE was either not detected or detected at a maximum concentration of 260 μg/kg in samples of soil left in place (samples collected from borings, test pits and final excavation) to the south of the SMC remedial excavation. It should be noted that soil samples could not be collected below 17 feet bgs during this investigation due to the presence of the water table; soil contamination may be present below the vadose zone (see fine-sand layer investigation in Section 5.6.2).

4.4 DEVELOPMENT OF REMEDIAL ALTERNATIVES FOR STOCKPILED TCE-IMPACTED SOIL

Development of remedial alternatives for the TCE-impacted soil excavated from the SMC site was presented in the Interim Action Work Plan for Trichloroethylene Impacted Soil (Parametrix 1999a), as described below.

4.4.1 Remedial Action Objectives

After the TCE-impacted soil was excavated and stockpiled, and the area was determined to be suitable for road construction, an evaluation of treatment alternatives for the stockpiled soil was performed (Parametrix 1999a).

A remedial alternative for the TCE-impacted soil was presented in the Interim Action Work Plan for Trichloroethylene Impacted Soil (Parametrix 1999a). The development of a remedial alternative began with the identification of technologies and process options with the potential to meet the RAOs for the TCE-impacted soil. The following RAOs were identified for the stockpiled TCE-impacted soil:

- Prevent direct contact with TCE-impacted soil.
- Prevent inhalation of airborne dust from TCE-impacted soil.
- Prevent ingestion of TCE-impacted soil.
- Prevent leaching of TCE from TCE-impacted soil to groundwater at concentrations that would result in groundwater TCE concentrations greater than 5 µg/l.

To meet the RAOs for the SMC site, cleanup action standards were identified and divided into two general categories:

- Numeric cleanup standards for allowable concentrations of chemicals in media
- Non-numeric performance objectives that must be met by the cleanup actions

Both numeric cleanup standards and non-numeric performance objectives were identified to ensure that the RAOs for the site were met.

4.4.2 Numeric Cleanup Standards

As discussed in Section 4.1.2, cleanup levels are numeric expressions of RAOs and specify the maximum acceptable concentration of a chemical to which the human or ecological receptors may be exposed via a specified exposure pathway (e.g., ingestion) under a specified exposure scenario (e.g., industrial). RAOs are site-specific goals that identify risk pathways that remedial actions should address, and that identify acceptable exposure levels for residual contamination. The RAO for TCE and PCE-impacted soil was 500 µg/kg.

4.4.3 Non-Numeric Performance Objectives

Besides meeting numerical standards, interim actions must be conducted in a manner that protects the environment during implementation of the interim action. The environmental implications of poorly maintained remedial actions were also of concern. As discussed previously, cross-media transfer of contaminants can result in the contamination of the second media. Also, the release of chlorinated solvents into surface waters can degrade wildlife habitat and impact water quality (surface and groundwater). To address potential groundwater and surface water impacts during remedial actions, the following performance objectives were needed:

- Prevent water quality impacts to surface water via stormwater runoff during soil treatment.
- Ensure SEPA compliance.
- Protect worker health during implementation.

4.4.4 Removal and Treatment Actions – Compliance with RAOs

The Port’s soil removal and treatment actions were consistent with RAOs for the soil interim action, as demonstrated below.

1. Excavating and treating the TCE-impacted soil to concentrations less than the Method A cleanup standard resulted in compliance with the numeric cleanup standards for soil. An action that achieves these standards is considered sufficient for protection of all the potential exposure pathways.
2. Excavating and treating the TCE-impacted soil prevented cross-media transfer of contaminants from soil to groundwater. Therefore, the removal action prevented leaching of TCE from soil to groundwater.
3. After excavation, the TCE-impacted soil was placed in a containment cell constructed of hay bales and a high-density cross-laminated liner material. The stockpiled soil was also covered with this material. After treatment, the soil was used as fill on Port property. Thus, the excavation and treatment of the TCE-impacted soil met the non-numeric performance objective of preventing contaminant migration to surface waters.

4. Excavation and treatment of the TCE-impacted soil was performed by a qualified contractor under a Health and Safety Plan. Worker health and safety were monitored during implementation of the removal action by the contractor. In addition, Mill Plain project construction workers were not at risk because known areas of TCE-impacted soil were excavated from the right-of-way. Thus, the removal and treatment actions met the non-numeric performance objective of protecting worker health during implementation of the removal and treatment actions.
5. Prior to implementation of the removal action, the Port completed a SEPA checklist in compliance with SEPA requirements. Thus, the removal and treatment actions met the non-numeric performance objective for SEPA compliance.

4.4.5 Remedial Alternatives for Stockpiled TCE-Impacted Soil

The Port selected Enhanced Soil Vapor Extraction (ESVE) as the most cost-effective technology to treat the stockpiled TCE-impacted soil. To reach this decision, technologies and processes with the potential to meet the RAOs were screened against MTCA criteria using the "fatal flaw" approach described in more detail below. Treatment technologies were evaluated against the following criteria.

- **Effectiveness** – The potential effectiveness of the technology to (1) address site-specific conditions, including applicability to the TCE-impacted soil, (2) meet RAOs, (3) minimize human health and environmental impacts during implementation, and (4) provide proven and reliable remediation under the conditions at the SMC site.
- **Implementability** – The technical and administrative feasibility of implementing a technology. Technical considerations cover site-specific factors that could prevent successful use of a technology, such as physical interferences or constraints, practical limitations of a technology, conflicting schedules, land-use compatibility, and soil properties. Administrative considerations include the ability to obtain permits and the availability of qualified contractors, equipment, and disposal services.
- **Cost** – The capital, operation, and maintenance costs associated with the technology. Costs that are excessive when compared to the overall effectiveness of the technology may be one of several factors used to eliminate technologies. Technologies that provide as much effectiveness and implementability as another technology, but at greater cost, may be eliminated. At the screening level, the cost evaluation is based on engineering judgment of relative costs.

If a technology was rejected based on effectiveness, it was eliminated from further evaluation. Similarly, if a technology was effective, but not implementable, the technology was rejected and evaluation of cost was not undertaken. This "fatal flaw" approach streamlined the evaluation of technologies while maintaining the MTCA screening methodology.

The screening of potentially applicable technologies to remediate the TCE-impacted soil was conducted as part of the Interim Action Work Plan (Parametrix 1999a). The technologies retained for use in developing remediation alternatives for the stockpiled TCE-impacted soil were:

- Thermal desorption (on-site or off-site)
- Ex-Situ Biotreatment
- Ex-Situ Soil Vapor Extraction

4.4.6 Assembly of Alternatives

Presented below is a summary of the information presented in the Interim Action Work Plan (Parametrix 1999a). Based on MTCA regulations, applicable technologies were assembled into remediation alternatives capable of achieving the following goals:

- Protection of human health and the environment
- Compliance with cleanup standards
- Compliance with the applicable or relevant and appropriate requirements (ARARs) to the maximum extent feasible
- Use of permanent solutions to the maximum extent practicable (which includes consideration of cost-effectiveness)
- Minimization of the need for long-term maintenance and monitoring
- Reuse/recycling of treated soil.

Cleanup technologies were considered in the following order of descending preference under WAC 173-340-360(4):

- Reuse or recycling
- Destruction or detoxification
- Separation or volume reduction
- Immobilization of hazardous substances
- On-site or off-site disposal at an engineered facility
- Isolation or containment with attendant engineering controls
- Institutional controls and monitoring.

All of the alternatives considered for the TCE-impacted soil are presented in the Interim Action Work Plan (Parametrix 1999a). After screening, the following remediation alternatives for the stockpiled TCE-impacted soil were evaluated in detail:

- Alternative 1: No Action
- Alternative 2: Off-Site Landfill
- Alternative 3: Ex-Situ Biotreatment with Off-Site Landfill
- Alternative 4a: On-Site Thermal Desorption
- Alternative 4b: Off-Site Thermal Desorption
- Alternative 5: Ex-Situ Soil Vapor Extraction.

4.4.7 Evaluation of Alternatives

The retained alternatives listed above were evaluated against the following MTCA-prescribed criteria.

4.4.7.1 Threshold Evaluation

Under MTCA, remediation alternatives must meet the following threshold requirements [WAC 173-340-360(2)]:

- Protection of human health and the environment
- Compliance with cleanup standards
- Compliance with ARARs
- Provision for compliance monitoring.

4.4.7.2 Use of Permanent Solutions

WAC 173-340-360(3) specifies that the remediation alternatives must use permanent solutions to the maximum extent practicable. WAC 173-340-360(5) specifies that "Ecology recognizes that permanent solutions [defined at WAC 173-340-360(5)(b)] may not be practicable for all sites. A determination that a cleanup action satisfies the requirement to use permanent solutions to the maximum extent practicable is based on consideration of a number of factors." The specified factors, or criteria, are:

- Overall protectiveness
- Long-term effectiveness and reliability
- Short-term effectiveness
- Reduction in toxicity, mobility, and volume
- Implementability
- Cost.

4.4.7.3 Selection of a Remedial Alternative

The Interim Action Work Plan (Parametrix 1999a) presents the full evaluation of the retained alternatives. Based on an evaluation of the alternatives against the MTCA criteria, Alternative 6, Ex-Situ SVE, provided the most cost-effective solution for treatment of the stockpiled TCE-impacted soil. The estimated cost for each alternative is summarized in the following table.

Summary of Stockpiled Soil Remediation Costs

Alternative 1	No Action	$0
Alternative 2	Off-Site Landfill	$681,900
Alternative 3	Ex-Situ Biotreatment with Off-Site Landfill	$704,200
Alternative 4a	Off-Site Thermal Desorption	$813,750
Alternative 4b	On-Site Thermal Desorption	$906,000
Alternative 5	Ex-Situ Soil Vapor Extraction	$364,000

4.5 TREATMENT OF TCE-IMPACTED SOIL

The use of Ex-Situ Enhanced Soil Vapor Extraction (ESVE) to treat the stockpiled, TCE-impacted soil was approved by Ecology in a letter dated March 9, 1999 (Ecology 1999a).

4.5.1 ESVE System

Philip Services Corporation (Philip) was contracted by the Port to complete the soil treatment. The soil stockpile measured 260 feet by 115 to 156 feet and was approximately 12 to 15 feet in height. The construction of a Port access road (St. Francis Lane) required the western portion of the stockpile to be relocated. The relocated portion of the stockpile was moved to the eastern end of the stockpile and was used to construct the first (Cell 1) of three treatment cells of approximately 4,900 yd^3. The other two treatment cells (Cell 2 containing 4,600 yd^3 and Cell 3 containing 3,000 yd^3) were constructed by trenching into the stockpiled soils with a trackhoe to lay the piping system. The cells were treated one at a time, with a new cell constructed upon the successful treatment of the previous cell. Cell dimensions measured approximately 110 feet by 115 feet and were 12 feet in height.

The piping consisted of a series of air inlets (perforated PVC pipes) which were placed in the stockpiled soil to allow air into the soil. As needed, air was forced into the soil stockpile using these air inlets. A series of air extraction wells, also consisting of perforated PVC pipe, were also constructed to vent soil pore gases. Extraction wells were connected to a manifold and negative pressure was applied to induce air flow out of the stockpiled soil. The vacuum-inducing piping was installed at heights of three and eight feet above the ground surface and laterally spaced approximately 30 feet apart. A second set of pipes was also installed at a height of five feet above the ground surface and spread laterally in between vacuum pipes to introduce heated air into the treatment cells. The combined inlets and extraction wells allowed an average of approximately 362 to 377 cubic feet per minute of soil vapor to move along the induced flow path to the treatment system. The soil vapors removed from the treatment cells passed through a vapor/water separator prior to being treated using a 1,000-pound Granular Activated Carbon (GAC) unit. Captured TCE and other VOCs were destroyed during carbon regeneration. Influent and effluent air monitoring was conducted in order to evaluate the effectiveness of the treatment system.

4.5.2 Cell 1 Treatment

Treatment of Cell 1 was initiated on March 15, 1999. Vapor concentrations were measured with a photoionization detector (PID) at the influent prior to the GAC unit and at the effluent of the treatment system. In addition to PID readings, vapor samples were collected before and after the GAC unit in Tedlar bags and analyzed for TCE and PCE by EPA Method 8260. TCE was detected at a concentration of 5,120 micrograms per cubic meter ($\mu g/m^3$) in the initial influent sample collected on March 16, 1999. PCE was not detected above the reporting limit of 2,000 $\mu g/m^3$ in the initial influent sample. TCE and PCE were not detected in the effluent sample collected on March 16, 1999. TCE was detected at a concentration of 2,500 $\mu g/m^3$ in the influent sample collected on March 22, 1999, six days after treatment was initiated. PCE was not detected above the reporting limit. TCE and PCE were not detected in the effluent sample collected on March 25, 1999. Results of the treatment system vapor sampling are summarized in Table 4-9.

Sampling of Cell 1 soil was conducted on March 25 and 26, 1999. Treatment Cell 1 was subdivided into 22 subcells of approximately 215 to 249 yd^3 each. Soil samples collected from each of the 22 subcells within treatment Cell 1 were analyzed for TCE and PCE by EPA Method 8021B. Results of the confirmation soil sampling are summarized in Table 4-10. TCE was not detected in soil samples collected from eight of the subcells. TCE was detected at concentrations less than 500 µg/kg in soil samples collected from 12 of the subcells. Soil samples from two of the Cell 1 subcells (7 and 13) contained TCE at concentrations exceeding the performance standard of 500 µg/kg. The soil from Subcells 7 and 13 was incorporated into the treatment of Cell 2 during the construction of the treatment cell. Based on the analytical results, Ecology issued a letter dated May 26, 1999, allowing re-use of the treated soil as fill on Port property. A copy of this letter is included in Appendix D.

4.5.3 Cell 2 Treatment

Treatment of Cell 2 was initiated on April 21, 1999. TCE was detected at a concentration of 110,000 µg/m^3 in the initial influent sample collected on April 21. TCE was detected at concentrations of 33,000 µg/m^3 and 2,500 µg/m^3 in influent samples collected on April 27 and May 17, respectively. PCE was not detected in the influent samples. TCE or PCE were not detected in the effluent samples collected from the system (Table 4-9).

Sampling of the Cell 2 soil was conducted on May 10, 1999. Cell 2 was divided into 22 subcells of approximately 222 to 231 yd^3 each, including Subcells 7 and 13 from Cell 1. Soil samples collected from each of the 22 subcells within treatment Cell 2 were analyzed for TCE and PCE by EPA Method 8021B. Results of the confirmation soil sampling are summarized in Table 4-10. TCE was not detected in soil samples collected from 11 of the subcells, including Subcell 13, which contained soil originally from treatment Cell 1, Subcell 13. TCE was detected at concentrations less than 500 µg/kg in soil samples collected from 11 of the subcells, including Subcell 7, which contained soil originally from treatment Cell 1, Subcell 7. The combined total TCE and PCE concentration for Subcell 41 was 524.2 µg/kg, which exceeded the performance criteria. Subcell 41 was incorporated into treatment Cell 3. Based on the analytical results, Ecology issued a letter dated July 7, 1999, allowing re-use of the treated soil as fill on Port property. A copy of this letter is included in Appendix D.

4.5.4 Cell 3 Treatment

Treatment of Cell 3 was initiated in May 27, 1999. TCE and PCE were detected at concentrations of 42,000 µg/m^3 and 3,000 µg/m^3, respectively, in the initial influent sample collected on June 2. TCE was detected at concentrations of 5,350 µg/m^3, 6,300 µg/m^3, and 5,790 µg/m^3 in influent samples collected on June 8, June 15, and June 21, respectively. PCE was not detected in the influent samples collected on June 21. The effluent samples collected on June 2 and June 15 burst during transit. An effluent sample was not collected on June 8. Results of the treatment system vapor sampling are summarized in Table 4-9. Subcell 41 from Cell 2 was re-sampled on June 15. TCE and PCE were not detected in the soil sample.

Sampling of the Cell 3 soil was conducted on June 25, 1999. Cell 3 was divided into 12 subcells of approximately 232 to 248 yd^3 each. Soil samples collected from each of the 12 subcells within treatment Cell 3 were analyzed for TCE and PCE by EPA Method 8021B. Results of the confirmation soil sampling are summarized in Table 4-10. TCE was not detected in soil samples collected from 11 of the subcells. TCE was detected at a concentration of 801 µg/kg in the soil sample collected from Subcell 51. Treatment of the soil in Subcell 51 continued until it was re-sampled on July 8. TCE and PCE were not detected in the sample. The ESVE treatment system was shut down on July 13, 1999. Based on the analytical results, Ecology issued a letter dated August 24, 1999, allowing re-use of the treated soil as fill on Port property. A copy of this letter is included in Appendix D.

4.5.5 Final Placement of Treated Soil

The treated soil from Cell 1, Cell 2, and Cell 3 was used as fill material at Parcel 1A, located at Terminal 4 or under bridge abutements for a new Port entrance overpass.

5. REMEDIAL INVESTIGATION

Based in the findings of the Pre-RI Work Plan investigations and soil interim action, the Port entered into an Agreed Order with Ecology (No. 98TC-S337) in November 1998. This Agreed Order included requirements to perform an RI/FS to define the extent of soil and groundwater contamination originating from the SMC site, and to conduct soil interim actions for the stockpiled TCE-impacted soil. The remedial actions completed for the stockpiled TCE-impacted soil were discussed in Section 4.5.

Four phases of remedial investigation have been completed since 1998 to characterize the nature and extent of contamination associated with the SMC site. The scope of work for each phase was prepared to further characterize the nature and extent of contamination. Ecology approved all phases of work prior to implementation. The chronology of the remedial investigation phases is summarized in the table below.

Chronology of the Remedial Investigation

Remedial Investigation Phase	Time Frame
Phase I	July 1998 through Sept. 1999
Phase II	Oct. 1999 through Dec. 2000
Phase III	Jan. 2001 through Dec. 2001
Phase IV	Jan. 2002 through Feb. 2007

The findings from Phase I through III were previously documented in the 2002 RI Report and are summarized in the following sections. The findings from Phase IV of the RI are documented in Section 5.6.

5.1 CONTAMINANTS OF POTENTIAL CONCERN

The list of preliminary COPCs (Section 2.6) was updated based on additional information collected during the remedial investigation. The final list of COPCs was identified by using information related to the site history, analytical results from the Pre-RI and RI phases, and a review of MTCA regulations (WAC 173-340-703). The COPCs were identified during completion of the Risk Assessment in Appendix I. A summary of the COPCs by media is discussed below.

Groundwater: Analysis of chemical concentrations from all groundwater zones indicated that the following chemicals were detected above a frequency of detection (FOD) of 5% and/or at least one sample exceeded the MTCA Method B cleanup standards for groundwater: 1,1-dichloroethene, 1,2-dichloroethane, bromodichloromethane, carbon tetrachloride, cis-1,2-dichloroethene, dibromochloromethane, methylene chloride, tetrachloroethene, and trichloroethene. These chemicals were carried forward through the risk assessment for groundwater. In addition, 1,1-dichloroethane was assessed in the risk assessment, since this chemical is a known TCE degradation by-product (EPA 2001). Other chemicals exceeding a FOD of 5% but not exceeding MTCA Method B cleanup levels and not evaluated further in the risk assessment include: chloroform, trans-1,2-dichloroethene, and trichlorofluoromethane. These three chemicals are considered to be minor contributors to potential risks.

Soil: Only three VOCs (methylene chloride, tetrachloroethene, and trichloroethene) were detected in verification soil samples. These chemicals were further evaluated in the risk assessment for soil contact pathways for site workers and for the terrestrial ecological evaluation.

Soil Gas: The following chemicals were either detected at or above an FOD of 5%, exceeded the MTCA Method B cleanup level, or are known TCE degradation by-products: 1,1,1-trichloroethane, 1,1-dichloroethane, 1,1-dichloroethene, 1,2-dichloroethane, chloroethane, cis-1,2-dichloroethene, tetrachloroethene, trans-1,2-dichloroethene, trichloroethene, and vinyl chloride.

Indoor Air: The following chemicals were either detected at or above an FOD of 5%, exceeded the MTCA Method B cleanup level, or are known TCE degradation by-products and are further evaluated in the risk assessment: 1,1,1-trichloroethane, 1,1-dichloroethane, 1,1-dichloroethene, 1,2-dichloroethane, chloroethane, cis-1,2-dichloroethene, tetrachloroethene, trans-1,2-dichloroethene, and trichloroethene.

Outdoor Air: The following chemicals were either detected at or above an FOD of 5%, exceeded the MTCA Method B cleanup level, or are known TCE degradation by-products and are further evaluated in the risk assessment: 1,1,1-trichloroethane, 1,1-dichloroethane, 1,1-dichloroethene, 1,2-dichloroethane, chloroethane, cis-1,2-dichloroethene, tetrachloroethene, trans-1,2-dichloroethene, and trichloroethene.

5.2 REMEDIAL INVESTIGATION WORK PLAN

A Work Plan to conduct the RI/FS for the SMC site was submitted to Ecology on June 14, 1999 (Parametrix 1999b). The Work Plan included a scope of work for Phase I, a schedule, Sampling and Analysis Plan, Quality Assurance/Quality Control Plan, and Health and Safety Plan. The RI/FS Work Plan was approved by Ecology (Ecology 1999b).

The scope of work for Phase II of the RI was included in the Interim Data Report (Parametrix 2000). The scope of work for Phase III of the RI was included in the Phase II Interim Data Report (Parametrix 2001a). The scope of work for Phase IV of the RI was included in a letter to Ecology and in the Final Groundwater Interim Action Report (Parametrix 2004a and 2004b). Ecology approved all phases of work prior to implementation.

In general, the phases of work were designed to further characterize the nature and extent of VOC-impacted groundwater migrating from the SMC site. In addition, investigative activities were completed to evaluate the nature and extent of potential VOC impacts to soil gas and indoor and outdoor air. It should be noted that additional soil characterization was not completed as part of the RI Work Plan scope because the soil excavation had been completed to remove soil contamination in the vadose zone above the MTCA cleanup level of 500 µg/kg at that time. The focus of the investigation then shifted away from the relatively limited area of residual soil contamination to the broader groundwater issues. However, further soil characterization was completed during the fine sand layer investigation in 2004 (see Section 5.6.2).

The nature and extent of contamination were defined using the following field methods:

- Installation of probe borings
- Drilling and construction of monitoring wells
- Groundwater quality sampling from probe borings and monitoring wells
- Static water level measurements
- Aquifer testing

- Well surveys
- Indoor air sampling
- Soil gas sampling

During Phases I through III of the RI, monitoring wells were designated as shallow, intermediate, and deep, depending on the depth of installation. Wells monitoring groundwater quality at approximately 100 feet bgs are designated as intermediate or "i" wells (e.g., MW-4i); wells monitoring groundwater quality at approximately 200 feet bgs were designated as deep or "d" wells (e.g., MW-4d). Shallow or water table wells originally did not have a designator (e.g., MW-12); however, as the number of wells increased the designator "s" was used to identify shallow monitoring wells. As discussed in Section 7.2, the well designation and groundwater zone classification system has been retained but modified to consider the well screen depth and hydrogeologic units present in the project area.

Groundwater samples collected during each phase of the RI were analyzed for VOCs. Selected groundwater samples from Phases II and III were also analyzed for natural attenuation parameters to assess the viability of natural attenuation as a possible remedial technology.

It should be noted that the well screen intervals for groundwater wells completed at the site were selected on the basis of analytical data from existing wells, data gaps in the lateral and vertical placement of existing well screen locations, and the vertical distribution of the contaminants in the new wells. Some of the wells screens were installed to monitor the areas of highest concentrations, while other well screens where placed in areas with concentrations less than 5 µg/l in order to evaluate the vertical extent of contamination. This methodology enabled monitoring of the plume over time with respect to whether the commingled plume was expanding or contracting. The rational for the location and depth of the groundwater monitoring wells are discussed in each section, where necessary.

5.3 REMEDIAL INVESTIGATION - PHASE I

Phase I of the RI began in July 1998 and was completed in September 1999. The objectives of Phase I of the RI were to:

- Characterize the extent of groundwater contamination originating from the SMC site.
- Evaluate the Cadet facility as a potential source for VOC contamination.
- Evaluate if 1,1,1-TCA could be used to differentiate VOC contamination originating from the SMC and Cadet sites.
- Evaluate if Building 2350 was a potential source for VOC contamination.

5.3.1 Monitoring Well Installation

Twelve monitoring wells were installed during Phase I of the RI, including six shallow monitoring wells (i.e., water table), three intermediate monitoring wells (approximately 100 feet bgs), and three deep monitoring wells (approximately 200 feet bgs). The objectives of the monitoring well installations were to:

- Verify groundwater quality data collected during the Pre-RI Work Plan investigations.
- Refine the understanding of geologic and hydrogeologic conditions.

- Support the hydrogeologic assessment of the project area, including:
    - Groundwater flow directions and rates
    - Horizontal and vertical groundwater gradients
    - Interconnection of the aquifer with the Columbia River
    - Hydraulic conductivity of the aquifer.

5.3.1.1 Shallow Wells

Six shallow monitoring wells (labeled MW-6 through MW-11) were installed during the Phase I RI. As shown on Figure 5-1, monitoring wells MW-7 through MW-9 were drilled east of the SMC site, MW-6 and MW-10 were drilled southeast of the SMC site, and MW-11 was drilled southwest of the SMC site. These wells, which were installed as water table wells, were drilled using hollow stem augers to an approximate depth of 25 feet bgs. Well construction details are included in Table 5-1.

5.3.1.2 Intermediate Wells

Three intermediate monitoring wells (labeled MW-4i, MW-5i, and MW-8i) were installed during the Phase I RI. As shown on Figure 5-1, monitoring well MW-4i was drilled south of the SMC site, MW-5i was drilled in the SMC site source area, and MW-8i was drilled east of the SMC site. These wells were drilled using a cable tool rig and screened to depths ranging from 100 to 130 feet bgs.

During the drilling of the intermediate wells MW-4i and MW-8i, depth-specific samples were collected at intervals of 20 feet to evaluate the vertical distribution of VOCs in the groundwater. Analytical results for depth-specific samples collected during the drilling are summarized in Table 5-2 and summarized below.

Intermediate Wells

Monitoring Well	Depth of TCE Detections (feet bgs)	Range of TCE Concentrations (µg/l)	Well Screen Interval (feet bgs)
MW-4i	40 - 60	2.47 - 5.76	90 - 100
MW-8i	22 - 100	5.09 - 44.6	120 - 130

Screen intervals for the wells were selected based on the analytical results from discrete-depth samples. Well screens were installed at depths where TCE was not detected to define the vertical extent of TCE and monitor possible plume expansion. Well construction details are included in Table 5-1.

5.3.1.3 Deep Wells

Three deep monitoring wells (labeled MW-2d, MW-4d, and MW-12d) were installed during the Phase I RI. As shown on Figure 5-1, monitoring well MW-2d was drilled east of the SMC site, MW-4d was drilled south of the SMC site, and MW-12d was drilled west of the SMC site. These wells were drilled using a cable tool rig and screened to depths ranging from 216 to 232 feet bgs.

Well screens were placed at the base of the USA. Well construction details are included in Table 5-1.

During the drilling of deep wells MW-2d, MW-4d, and MW-12d, depth-specific samples were collected at intervals of 20 feet to evaluate the vertical distribution of VOCs in the groundwater. Analytical results for depth-specific samples collected during the drilling are summarized in Table 5-2 and summarized below.

Deep Wells

Monitoring Well	Depth of TCE Detections (feet bgs)	Range of TCE Concentrations (µg/l)	Well Screen Interval (feet bgs)
MW-2d	25 - 180	1.2 - 54.1	207 - 217
MW-4d	25 - 120	2.85 - 19.1	222 - 232
MW-12d	40 - 220	2.03 - 17.7	206 - 216

5.3.2 Monitoring Well Sampling

Groundwater samples were collected from the 12 monitoring wells installed during Phase I of the RI. Prior to sampling, the monitoring wells were developed and purged in accordance with procedures included in the RI Work Plan (Parametrix 1999b). In addition, groundwater samples were collected from eight monitoring wells installed during the Pre-RI Work Plan investigations. Monitoring wells sampled during the Phase I RI are summarized in the following table.

Phase I RI Monitoring Well Sampling

TYPE	LOCATION
Shallow Wells	MW-1 through MW-4, MW-6 through MW-11
Intermediate Wells	MW-4i, MW-5i and MW-8i
Deep Wells	MW-1d, MW-2d, MW-4d, MW-5d, and MW-12d

The analytical results for the groundwater samples collected in April 1999 are summarized in Table 5-3. The ranges of TCE concentrations detected in the monitoring zones are summarized below.

Range of TCE Concentrations

Monitoring Zone	Range of TCE Concentrations (µg/l)
Shallow Wells	<0.5 – 4,290
Intermediate Wells	<0.5 – 11.6
Deep Wells	<0.5 – 26.7

In addition to the SMC monitoring wells, two wells at the Rufener property were sampled in April 1999 to evaluate the extent of TCE in groundwater. The Rufener property included two domestic wells and one irrigation well that provided water for the Rufener Farm, located approximately 2/3 of a mile north of the Port. The two domestic water supply wells (labeled RW-1 and RW-2) were sampled. The locations of these wells are shown on Figure 2-1. TCE was detected at a concentration of 3.99 µg/l in the groundwater sample collected from RW-2. TCE was not detected in the groundwater sample collected from RW-1.

5.3.3 Probe Borings

Fifteen probe borings were completed during Phase I of the RI to evaluate:

- The Cadet facility as a potential source for VOC contamination
- If 1,1,1-TCA could be used to differentiate VOC contamination originating from the SMC and Cadet sites
- Building 2350 as a potential source for VOC contamination.

5.3.3.1 Cadet Facility Evaluation

Groundwater samples were collected from seven probe borings (labeled CM-PMX-1 through CM-PMX-7) completed directly east of the Cadet parking lot to evaluate the Cadet facility as a potential VOC source. Boring locations are included on Figure 5-1. Prior to installation of these borings, the Cadet facility was not identified as a source for VOC contamination. Groundwater samples were collected from the seven probe borings at the soil-water interface for VOC analysis. 1,1,1-TCA, 1,1-DCA, cis-1,2-DCE, PCE, and TCE were detected in the groundwater samples (Table 5-4). TCE was detected at concentrations ranging from 3.0 µg/l to 201 µg/l in groundwater samples collected from six of the borings.

The analytical results were used to identify the Cadet facility as a source for VOC contamination. Based on these findings, Cadet took over investigation of the Cadet facility.

5.3.3.2 1,1,1-TCA Evaluation

Groundwater samples were collected from three probe borings (labeled TCA-1, TCA-2, and TCA-3) completed in the SMC source area to determine if 1,1,1-TCA could be used to differentiate VOC contamination originating from the SMC and Cadet sites. Boring locations are included on Figure 5-1. Data collected during the Pre-RI Work Plan investigation indicated that 1,1,1-TCA was not present in the SMC site source. 1,1,1-TCA was detected at concentrations ranging from 0.5 µg/l to 36 µg/l in groundwater samples collected from six of the probe borings (CM-PMX-1 through CM-PMX-7) completed directly east of the Cadet parking lot (discussed in Section 5.3.3.1), suggesting the Cadet facility is the source of 1,1,1-TCA.

Groundwater samples were collected from the three SMC source area probe borings at the soil-water interface for VOC analysis. 1,1,1-TCA was not detected in the groundwater samples collected from probe borings TCA-1, TCA-2, and TCA-3 (Table 5-4). TCE was detected at concentrations ranging from 16,800 µg/l to 321,000 µg/l in groundwater samples collected from these probe borings. Cis-1,2-and PCE were also detected in these groundwater samples.

Based on the analytical results, 1,1,1-TCA was not present in the SMC source area and, therefore, could be used to differentiate VOC contamination originating from the SMC and Cadet sites. However, note that the reporting limit for 1,1,1-TCA in sample TCA-1 was 5,000 µg/l. The reporting limit for 1,1,1-TCA in samples TCA-2 and TCA-3 were 1 µg/l. The reporting limit for other VOCs for samples TCA-2 and TCA-3 were 100 µg/l. While it appears that quality control procedures were met by the laboratory, the discrepancy between the reporting limit for 1,1,1-TCA and the other VOCs in these samples raises some concern with sample quality. However, more than 1,000 groundwater samples have been collected since this preliminary investigation was completed in 1999 and have been used to define the source and extent of 1,1,1-TCA (see Section 10.3 Chemcial Markers).

5.3.3.3 Building 2350 Evaluation

Groundwater samples were collected from five probe borings (labeled SG-1 through SG-5) completed adjacent to Building 2350 to evaluate the building as a potential source for VOC contamination. Building 2350 was formerly occupied by Silgan, a tin can manufacturer. Boring locations are included on Figure 5-1.

Groundwater samples for VOC analysis were collected from the five probe borings at the soil-water interface. TCE was detected at concentrations of 1.42 µg/l and 26.7 µg/l in groundwater samples collected from two of the probe borings (Table 5-4). Cis-1,2-DCE and PCE were each detected in one groundwater sample.

Based on the relatively low concentrations of VOCs, and the proximity of Building 2350 to the Cadet and SMC sites, Building 2350 was not considered a source for VOC contamination.

5.3.4 Hydrogeologic Assessment

Several tasks were completed during the Phase I of the RI to further evaluate the hydrogeologic and hydraulic properties of the aquifer in the SMC project area.

5.3.4.1 Aquifer Testing

The objective of the aquifer testing was to evaluate the horizontal hydraulic conductivity of the aquifer. Hydraulic conductivity tests (i.e., slug tests) were performed on four shallow wells (MW-1, MW-6, MW-7, and MW-8), three intermediate wells (MW-4i, MW-5i, and MW-8i), and one deep well (MW-2d) to evaluate the horizontal hydraulic conductivity of the aquifer. The findings of the slug tests are detailed in the Interim Data Report (Parametrix 2000) and summarized below.

The calculated horizontal hydraulic conductivity of the shallow groundwater zone ranged from 1 x 10^{-2} cm/sec to 8 x 10^{-2} cm/sec, with the hydraulic conductivity for MW-8 estimated to be greater than 1 x 10^{-2} cm/sec (the water level recovery during the MW-8 testing was too fast to measure manually).

The calculated horizontal hydraulic conductivity of the intermediate groundwater zone ranged from 9 x 10^{-4} cm/sec to 2 x 10^{-2} cm/sec. Because the horizontal hydraulic conductivity could not be measured in the lower groundwater quality zone (water level recovery was too fast to measure during testing on MW-2d), the horizontal hydraulic conductivity is estimated to be greater than 10^{-2} cm/sec in the lower zone.

5.3.4.2 Groundwater/Surface Water Interconnectivity Study

An interconnectivity study was conducted to evaluate:

- The vertical gradient between the shallow and deeper parts of the aquifer
- The hydraulic connection between the shallow and deeper parts of the aquifer with the Columbia River
- Potential tidal and pumping effects on the groundwater system

The study consisted of placing pressure transducers in the MW-1 and MW-1d nested well pair, and recording water levels at 15-minute intervals for one month. These water-level data were plotted with the Columbia River stage elevation data to evaluate the interconnectivity, and the effects of river stage and pumping on the groundwater flow system in the project area. The findings of the interconnectivity study are detailed in the Interim Data Report (Parametrix 2000). Data collected during the study indicated that the shallow groundwater zone at the site is directly influenced by Columbia River stage elevations and precipitation events. In addition, the deep groundwater zone responds as rapidly to changes in the Columbia River stage elevation as the upper zone.

5.4 REMEDIAL INVESTIGATION - PHASE II

Phase II of the RI began in October 1999 and was completed in December 2000. The objectives of Phase II of the RI were to:

- Continue characterization of the extent of groundwater contamination originating from the SMC site.
- Evaluate the Great Western Malting (GWM) facility as a potential source for VOC contamination.
- Evaluate the Northwest Packing facility as a potential source for VOC contamination.
- Evaluate the southeastern extent of VOC contamination.

5.4.1 Monitoring Well and Piezometer Installation

Twenty-one monitoring wells were installed during Phase II of the RI, including thirteen shallow wells, four intermediate wells, and four deep wells. In addition, four shallow piezometers were installed to expand the existing monitoring well network in the SMC project area. The objectives of the monitoring well installations were to:

- Characterize the extent of TCE contamination in groundwater.
- Evaluate the natural attenuation potential of TCE in the aquifer.
- Refine the understanding of hydrogeologic conditions, including:
    - Groundwater flow directions and rates
    - Horizontal and vertical groundwater gradients
    - Interconnection of the aquifer with the Columbia River.

5.4.1.1 Shallow Wells

Thirteen shallow monitoring wells (labeled MW-5, MW-12, MW-13, MW-15, MW-16 through MW-18 and MW-20 through MW-25) were installed during the Phase II RI. As shown on Figure 5-2, monitoring wells MW-16, MW-20, MW-21 and MW-24 were drilled east of the SMC site, MW-17, MW-22, MW-23 and MW-25 were drilled southeast of the SMC site, MW-15 and MW-18 were drilled south of the SMC site, MW-5 was drilled southwest of the SMC site, and MW-12 and MW-13 were drilled west of the SMC site.

These wells, which were installed as water table wells, were screened to depths ranging from approximately 20 to 80 feet bgs. Well construction details are included in Table 5-1.

5.4.1.2 Intermediate Wells

Four intermediate monitoring wells (labeled MW-7i, MW-15i, MW-18i, and MW-19i) were installed during the Phase II RI. As shown on Figure 5-2, monitoring well MW-7i was drilled east of the SMC site and MW-15i, MW-18i and MW-19i were drilled south of the SMC site. These wells were screened to depths ranging from 90 to 139 feet bgs.

During the drilling of the intermediate wells MW-7i, MW-15i, MW-18i, and MW-19i, depth-specific samples were collected at intervals of 20 feet to evaluate the vertical distribution of VOCs in the groundwater. Depth-specific groundwater samples were collected from intermediate wells until TCE was not detected in at least two vertically successive samples. Analytical results for depth-specific samples collected during drilling are included in Table 5-5 and summarized below.

Intermediate Wells

Monitoring Well	Depth of TCE Detections (feet bgs)	Range of TCE Concentrations (µg/l)	Well Screen Interval (feet bgs)
MW-7i	20 - 100	7.71 - 1,950	80 - 90
MW-15i	40 - 140	2.52 - 23.8	129 - 139
MW-18i	40 - 140	1.27 – 12.2	120 - 130
MW-19i	50 - 130	2.1 - 30.2	120 - 130

Screen intervals for the wells were selected based on the analytical results from discrete-depth samples. Well screens were installed at depths where TCE was detected to monitor concentrations over time. Well construction details are included in Table 5-1.

5.4.1.3 Deep Wells

Four deep monitoring wells (labeled MW-13d, MW-14d, MW-16d, and MW-17d) were installed during the Phase II RI. As shown on Figure 5-2, monitoring wells MW-13d, MW-14d, MW-16d, and MW-17d were drilled west, southwest, east, and southeast of the SMC site, respectively. These wells were screened to depths ranging from 195 to 262 feet bgs.

During the drilling of deep wells MW-13d, MW-14d, MW-16d, and MW-17d, depth-specific samples were collected at intervals of 20 feet to evaluate the vertical distribution of VOCs in the groundwater. Analytical results for depth-specific samples collected during the drilling are included in Table 5-5 and summarized below.

Deep Wells

Monitoring Well	Depth of TCE Detections (feet bgs)	Range of TCE Concentrations (µg/l)	Well Screen Interval (feet bgs)
MW-13d	30 - 110	0.599 - 5.16	252 - 262
MW-14d	40 - 220	3.0 - 28.5	211 - 221
MW-16d	25 - 100	74.6 - 449	220 - 230
MW-17d	40 - 100	3.91 - 155	185 - 195

Screen intervals were installed in the wells to monitor the deep groundwater zone. Well construction details are included in Table 5-1.

5.4.1.4 Piezometers

Four piezometers (labeled P-1 through P-4) were installed during the Phase II RI to establish hydraulic control (water level measurement) points in the southwest part of the project area.

The locations of the piezometers are shown on Figure 5-2. The piezometers were drilled to a depth of approximately 30 feet bgs. Piezometer construction details are included in Table 5-1.

5.4.2 Monitoring Well Sampling

Groundwater samples were collected from the 21 monitoring wells installed during Phase II of the RI. Prior to sampling, the monitoring wells were developed and purged in accordance with procedures included in the RI Work Plan (Parametrix 1999b). In addition, groundwater samples were collected from 13 monitoring wells installed during the Pre-RI Work Plan investigations and Phase I of the RI. Monitoring wells sampled during the Phase II RI are summarized in the following table.

Phase II RI Monitoring Well Sampling

TYPE	LOCATION
Shallow Wells	MW-1, MW-2, MW-4 through MW-13, MW-15 through MW-25
Intermediate Wells	MW-4i, MW-5i, MW-7i, MW-8i, MW-15i, MW-18i, MW-19i
Deep Wells	MW-1d, MW-2d, MW-4d, MW-5d, MW-12d, MW-13d, MW-14d, MW-16d, MW-17d

The analytical results for the groundwater samples collected in November 2000 are summarized in Table 5-3. The ranges of TCE concentrations detected in the monitoring zones are summarized below.

Range of TCE Concentrations

Monitoring Zone	Range of TCE Concentrations (µg/l)
Shallow Wells	<0.5 – 18,400
Intermediate Wells	<0.5 – 351
Deep Wells	<0.5 – 27.5

In addition to the groundwater sampling, water level measurements were collected from the monitoring wells to evaluate the hydrogeology and hydraulic properties of the water bearing zones in the vicinity of the SMC site.

5.4.3 Probe Borings

Fifteen probe borings were completed during Phase II of the RI to evaluate:

- Great Western Malting (GWM) facility as a potential source for VOC contamination
- Northwest Packing facility as a potential source for VOC contamination
- The southeastern extent of VOC contamination

5.4.3.1 Great Western Malting (GWM) Facility Evaluation

VOCs were previously detected in the GWM water supply wells. Therefore, nine probe borings (labeled GWM-GP-1 through GWM-GP-9) were completed to evaluate the GWM facility as a potential source for VOC contamination. Boring locations are included on Figure 5-2. Groundwater samples for VOC analysis were collected from these nine probe borings at the soil-water interface (27-32 feet bgs) and from 20 feet below the soil-water interface. In addition, samples of perched water were collected from three of the borings for VOC analysis.

TCE was detected at concentrations ranging from 0.515 µg/l to 1.65 µg/l in three of the groundwater samples collected from the borings (Table 5-6).

Based on the low concentrations of VOCs and the low frequency of detection, the GWM facility was eliminated as a potential source for VOC contamination.

5.4.3.2 Northwest Packing Facility Evaluation

Five probe borings (labeled NWP-GP-1 through NWP-GP-5) were completed to evaluate the Northwest Packing facility as a potential source for VOC contamination. Boring locations are included on Figure 5-2. Groundwater samples were collected from the five probe borings at the soil-water interface (25-28 feet bgs) and from 20 feet below the soil-water interface for VOC analysis. In addition, samples of perched water were collected from three of the borings for VOC analysis.

Cis-1,2-DCE and PCE were detected at concentrations of 0.879 µg/l and 0.886 µg/l in one groundwater sample (Table 5-6). TCE was detected at concentrations ranging from 2.61 µg/l to 7.28 µg/l in two of the groundwater samples collected from the borings.

Based on the relatively low concentrations of VOCs and the low frequency of detection, the Northwest Packing facility was eliminated as a potential source for VOC contamination.

5.4.3.3 Southeastern Extent of VOC Contamination Evaluation

Six probe borings (labeled Kotobuki-01, Kotobuki-02, Mill Plain-01, Mill Plain-02, Mill Plain-03, and W20th-01) were completed to further evaluate the southeastern extent of TCE contamination. Boring locations are included on Figure 5-2. Groundwater samples for VOC analysis were collected from the six probe borings at the soil-water interface (28-32 feet bgs) and from 20 feet below the soil-water interface.

Cis-1,2-DCE and PCE were detected at low concentrations in the groundwater samples collected from the three probe borings completed along Kotobuki Way and West 20th Street (Table 5-6). In addition, TCE was detected at concentrations ranging from 1.36 µg/l to 20.9 µg/l in groundwater samples collected from the probe borings completed along Kotobuki Way and West 20th Street.

PCE was detected at concentrations of 1.23 µg/l to 1.42 µg/l in groundwater samples collected from two of the three probe borings completed along Mill Plain Boulevard (Table 5-6). TCE was not detected in groundwater samples collected from the three probe borings completed along Mill Plain Boulevard.

The analytical results for groundwater samples collected from the three probe borings completed along Mill Plain Boulevard were used to define the southeastern extent of TCE contamination.

5.5 REMEDIAL INVESTIGATION - PHASE III

Phase III of the RI began in January 2001 and ended December 2002. The objectives of Phase III of the RI were to:

- Characterize the extent of groundwater contamination originating from the SMC site.

- Evaluate the Tesoro, Panasonic, and ASI facilities as potential sources for VOC contamination.
- Characterize the SMC site source area.
- Evaluate natural attenuation potential of TCE in the aquifer.
- Evaluate VOC concentrations in soil gas.

5.5.1 Monitoring Well Installation

Four intermediate monitoring wells were installed during Phase III of the RI. The objective of the monitoring well installations was to further evaluate the eastern and southern extent of TCE contamination in the intermediate groundwater zone.

5.5.1.1 Intermediate Wells

Four intermediate monitoring wells (labeled MW-24i, MW-26i, MW-28i and MW-29i) were installed during the Phase III RI. As shown on Figure 5-3, monitoring wells MW-24i and MW-26i were drilled approximately 0.5 mile east of the SMC site. Monitoring wells MW-28i and MW-29i were drilled approximately 0.3 mile south of the SMC site. These wells were screened to depths ranging from 85 to 125 feet bgs.

During the drilling of intermediate wells MW-24i, MW-26i, MW-28i, and MW-29i, depth-specific samples were collected at vertical intervals of 20 feet to evaluate the distribution of VOCs in the groundwater. Depth-specific groundwater samples were collected from intermediate wells until TCE was not detected in at least two vertically successive samples. Analytical results for depth-specific samples collected during the drilling are included in Table 5-7 and summarized below.

Intermediate Wells

Monitoring Well	Depth of TCE Detections (feet bgs)	Range of TCE Concentrations (µg/l)	Well Screen Interval (feet bgs)
MW-24i	125	0.78	113 - 123
MW-26i	85 - 105	1.0 - 1.55	103 - 113
MW-28i	30 - 90	2.18 - 209	75 - 85
MW-29i	No Detections	<0.5	115 - 125

Screen intervals for the wells were selected based on the analytical results from discrete-depth samples. With the exception of MW-29i, well screens were installed at depths where TCE was detected to monitor concentrations over time. TCE was not detected in discrete depth samples. Therefore, the well screen for MW-29i was installed at a depth similar to MW-24i and MW-26i. Well construction details are included in Table 5-1.

5.5.2 Monitoring Well Sampling

Groundwater samples were collected from the four monitoring wells installed during Phase III of the RI. Prior to sampling, these monitoring wells were developed and purged in accordance with procedures included in the RI Work Plan (Parametrix 1999b). In addition, groundwater samples were collected from 33 of the monitoring wells installed during the Pre-RI Work Plan investigations and Phase I and II of the RI. Monitoring wells MW-E, MW-F, and MW-G, associated with the former Carborundum facility pond area, were also sampled during Phase III.

The analytical results for the groundwater samples collected in July 2001 are summarized in Table 5-3. The ranges of TCE concentrations detected in the monitoring zones are summarized below.

Range of TCE Concentrations

Monitoring Zone	Range of TCE Concentrations (µg/l)
Shallow Wells	<0.5 – 12,600
Intermediate Wells	<0.5 – 528
Deep Wells	<0.5 – 216

In addition to VOC analyses, specific groundwater samples collected from monitoring wells and samples collected from approximately 100 ft bgs during drilling of the intermediate wells were analyzed for additional parameters to assess the potential for natural attenuation of VOCs. The natural attenuation parameters and analytical methods used are as follows:

- Methane, ethane, and ethene using GC/FID methodology
- Sulfate using EPA Method 300.0
- Nitrate-Nitrogen using EPA Method 300.0
- Chloride using EPA Method 300.0
- Total Alkalinity using EPA Method 310.1
- Total Organic Carbon using EPA Method 415.1
- Dissolved Oxygen using field instruments
- Oxidation-Reduction Potential using field instruments
- Ferrous Iron using field instruments

The analytical results for natural attenuation parameters are summarized in Table 5-8 and will be used in the FS to assess natural attenuation as a final remedy.

In addition to the groundwater sampling, water level measurements were collected from the monitoring wells to further evaluate the hydrogeology and hydraulic properties of the water bearing zones in the vicinity of the SMC site.

5.5.3 Probe Borings

Thirty-two probe borings were completed during Phase III of the RI to:

- Evaluate the ASI facility as a potential source for VOC contamination.
- Evaluate the Tesoro facility as a potential source for VOC contamination.
- Evaluate the Panasonic facility as a potential source for VOC contamination.
- Further characterize the SMC site source area.

5.5.3.1 ASI Facility Evaluation

Two probe borings (labeled SO-1 and SO-2) were completed to evaluate the ASI facility as a potential source for VOC contamination. Boring locations are included on Figure 5-3. Groundwater samples were collected from the two probe borings at the soil-water interface (25 feet bgs) for VOC analysis.

Moderate concentrations of VOCs were detected in the groundwater samples collected from the borings (Table 5-9). However, based on the relatively low levels of VOCs, previous investigations at ASI by another party, and the proximity to the SMC and Cadet sites, the ASI facility was eliminated as a potential source for VOC contamination.

5.5.3.2 Tesoro Facility Evaluation

Three probe borings (labeled SO-5, SO-6 and SO-9) were completed to evaluate the Tesoro facility as a potential source for VOC contamination. Boring locations are included on Figure 5-3. Groundwater samples were collected from the three probe borings at the soil-water interface (25 feet bgs) for VOC analysis.

Low concentrations of VOCs were detected in the groundwater samples collected from the borings (Table 5-9). Based on the analytical results, the Tesoro facility was eliminated as a potential source for VOC contamination.

5.5.3.3 Panasonic Facility Evaluation

Two probe borings (labeled SO-7 and SO-8) were completed to evaluate the Panasonic facility as a potential source for VOC contamination. Boring locations are included on Figure 5-3. Groundwater samples were collected from the two probe borings at the soil-water interface (25 feet bgs) for VOC analysis.

1,1-DCA was detected at a concentration of 0.5 µg/l in the groundwater sample collected from SO-7 (Table 5-9). Cis-1,2-DCE, PCE, and TCE were detected at concentrations of 4.23 µg/l and 4.68 µg/l, 1.8 µg/l and 2.47 µg/l, and 28.6 µg/l and 38.3 µg/l, respectively, in the groundwater samples collected from borings SO-7 and SO-8.

Based on the relatively low concentrations of VOCs, the proximity of the Panasonic facility to the Cadet and SMC sites, and the historic use of the Panasonic site, the Panasonic facility was not considered a source for VOCs.

5.5.3.4 Additional SMC Site Source Area Evaluation

Twenty-five probe borings (labeled SO-3, SO-4, and DC-1 through DC-23) were completed to further evaluate the SMC site source area. Boring locations are included on Figure 5-3. Groundwater samples were collected from these 25 probe borings at the soil-water interface (25 feet bgs) for VOC analysis.

Cis-1,2-DCE was detected at concentrations ranging from 1.12 µg/l to 99 µg/l in 17 of the groundwater samples collected from these borings (Table 5-9). PCE was detected at concentrations ranging from 1.48 µg/l to 155 µg/l in 19 of the groundwater samples collected from these borings. TCE was detected at concentrations ranging from 261 µg/l to 17,100 µg/l in 25 of the groundwater samples collected from these borings.

5.5.4 South Fruit Valley Neighborhood Soil Gas Evaluation

Soil gas samples were collected to facilitate an evaluation of the potential risk from VOC inhalation (i.e., indoor and outdoor exposure) that could be posed to on-site workers and to residents living off-site in the South Fruit Valley Neighborhood (SFVN).

5.5.4.1 Sampling Method

Soil gas sampling methodology was conducted in accordance with the methods recommended by the EPA (EPA 1996a). The samples were collected by using a probe rig to push a 1.5-inch diameter rod to a depth of 4 feet bgs. The rod was then retracted approximately 6 to 12 inches to expose the soil interval from which samples were collected. The ground surface around the drill rod was sealed using hydrated bentonite prior to evacuating at least three volumes of air from the borehole. Vapor samples were then collected into 1-liter Summa canisters.

5.5.4.2 Soil Gas Borings

Soil gas samples were collected from 11 borings completed to the east of the SMC site, in areas underlain by groundwater contamination. Soil gas boring locations (labeled SG-1 through SG-11) are shown on Figure 5-3. Borings SG-1 through SG-4 were completed in the Fruit Valley Neighborhood. Borings SG-5 through SG-11 were completed on Port property. All soil gas samples except SG-3 were collected from beneath paved roads or parking lots where soil gas is likely to accumulate.

1,1,1-TCA was detected at concentrations of 24 $\mu g/m^3$ and 76 $\mu g/m^3$ in two of the soil gas samples (Table 5-10). PCE was detected at concentrations ranging from 38 $\mu g/m^3$ to 260 $\mu g/m^3$ in six of the soil gas samples. TCE was detected at concentrations ranging from 34 $\mu g/m^3$ to 2,800 $\mu g/m^3$ in five of the soil gas samples.

5.6 REMEDIAL INVESTIGATION - PHASE IV

Additional investigations were completed from 2002 through early 2007 to further characterize the nature and extent of contamination associated with the SMC site. In addition, specific investigations were completed to characterize areas where the contaminant plumes originating from the SMC, Cadet, and ST Services sites are commingled. These investigations were completed at the request of Ecology and constitute Phase IV of the RI.

In general, Phase IV activities were conducted to characterize groundwater conditions between the ST Services site and the SMC site, define the vertical extent of a fine-grained soil layer containing residual TCE within the SMC site groundwater source area, and refine the extent of the solvent plumes originating from the former SMC and Cadet facilities. Specific Phase IV RI activities included:

- Installation of additional shallow and intermediate depth monitoring wells
- Depth-specific groundwater sampling during drilling of additional intermediate USA zone monitoring wells
- Fine-grained sand layer investigation in the SMC groundwater source area
- Stable isotope analysis of groundwater samples
- Groundwater elevation measurements
- Installation of soil gas wells and soil gas monitoring

- Monitoring of outdoor air in the Port area and the SFVN
- Monitoring of indoor air at select properties in the Port area and the SFVN
- Investigation of the former Carborundum ponds area
- Investigation of deep monitoring well MW-5d
- Hydraulic system and water level analysis
- Quarterly groundwater monitoring

The following sections summarize the Phase IV investigation events completed through December 2006. In general, each of the investigation sections contains a description of the work completed and data obtained, and a brief evaluation of the relevant information. However, the use of the data and how the data fit into the overall understanding of the site are incorporated into the discussion presented in Section 10, Nature and Extent of Contamination.

5.6.1 Installation of Additional Monitoring Wells

Between February 2003 and November 2004, a total of 17 additional monitoring wells were installed in the project area. The purpose of the additional monitoring wells was to further define the northern extent of the ST Services-sourced VOC plume, perform an evaluation of possible additional contaminant sources in the project area, and provide additional data to assess horizontal and vertical gradients at the site.

5.6.1.1 Methods

The additional monitoring wells were installed consistent with the methods described in the RI Work Plan (Parametrix 1999b). In general, shallow monitoring wells were installed with the hollow stem auger-rig method. Intermediate depth wells were installed using the cable tool drilling method. During drilling of the intermediate wells, depth-specific groundwater samples were collected from temporary wells constructed in the boreholes and submitted for VOC analysis. The depth-specific groundwater samples were generally collected every 20 feet in each of the borings. The 20-foot interval was selected based on data requirements to define an approximate vertical contaminant profile, the total depth of the borings, and VOC data collected during previous investigations. The well screen interval for the temporary wells utilized a 1.5-foot PVC well screen packed in sand and bentonite above of the well screen to isolate the water interval. The sampling interval and methodology were approved by Ecology prior to initiating field activities (Parametrix 2002b; 2004a; 2004c). The sample results were utilized to define the vertical extent of VOC contamination in each borehole and to select the appropriate well screen depth.

Eight shallow depth (between 25 and 35 feet bgs) monitoring wells were installed: MW-19s, MW-28s, MW-32s, MW-33s, MW-35s, MW-36s, MW-37s, and MW-39s. Nine intermediate depth (between 70 and 155 feet bgs) monitoring wells were installed: MW-30i, MW-31i, MW-32i, MW-33i, MW-34i, MW-35i, MW-36i, MW-37i, and MW-38i. Figure 5-4 shows the location of the 17 additional monitoring wells, as well as the entire SMC project area monitoring well network. Monitoring well completion data is included in Table 5-1. Borings logs for the additional monitoring wells are included in Appendix E-1.

The monitoring wells were installed in two general areas (Figure 5-4). Shallow monitoring wells MW-32s and MW-33s and intermediate wells MW-30i, MW-31i, MW-32i, MW-33i, and MW-34i were installed to collect additional data near the northern extent of the

ST Services-sourced VOC plume. Shallow monitoring wells MW-19s, MW-28s, MW-35s, MW-36s, MW-37s, and MW-39s and intermediate monitoring wells MW-35i, MW-36i, MW-37i, and MW-38i were installed in the vicinity of GWM in order to further define the extent of the SMC/Cadet commingled VOC plume.

5.6.1.2 Depth-Specific Groundwater Sampling Results

Depth-specific groundwater samples were collected during drilling of the intermediate depth monitoring wells and analyzed for VOCs. The VOC analysis results were used to evaluate the vertical concentration profile in groundwater and to establish an appropriate screen interval for well completion. As discussed previously, the groundwater samples were collected at 20-foot intervals, and drilling continued until two consecutive samples indicated non-detect or very low (<5 µg/l) concentrations of TCE. The borings were then backfilled with bentonite and the well screen set at the interval with the highest TCE concentration. If high concentrations were detected in multiple samples at different depths, professional judgment, past contaminant information, and the data point needs were factored into the selection of the final well screen intervals.

The discrete-depth sampling intervals are included on the boring logs in Appendix E-1. Depth-specific groundwater sample results for monitoring wells with available data are presented in Table 5-11. The corresponding analytical laboratory reports are included in Appendix A. In addition, analytical results for the discrete-depth sampling are included on cross-sections in Figures 10-4 and 10-5. The following summarizes the results of the depth-specific groundwater sampling.

5.6.1.3 ST Services Plume Delineation Monitoring Wells

Analytical results from the depth-specific sampling were used to evaluate the TCE distribution near the ST Services site. The distribution of PCE, commonly detected at high concentrations in groundwater samples collected at and near the ST Services site, was also evaluated using analytical results from the depth-specific sampling.

In addition to reviewing analytical data, groundwater flow analysis was conducted in October through December 2006 using a series of transducers to further evaluate groundwater flow direction and dynamics in the USA. The results of the groundwater flow analysis, summarized in Section 7.3, confirmed that groundwater from part of the ST Services site flows to the northeast.

TCE Distribution

Analytical results from depth-specific groundwater samples collected during intermediate well construction indicated that TCE concentrations were highest in monitoring wells MW-31i and MW-32i, both immediately north of the ST Services site (Table 5-11). TCE was detected in MW-31i and MW-32i at concentrations of 167 µg/l and 133 µg/l, respectively. In general, concentrations of TCE were highest at shallow depths and decreased with depth. TCE was not detected in samples collected at 125 feet bgs in monitoring well MW-31i or at 120 feet bgs in monitoring well MW-32i. Depth-specific samples collected from monitoring well MW-33i, located north of monitoring wells MW-31i and MW-32i, indicated TCE at concentrations ranging from 0.56 µg/l to 25.5 µg/l, at depths from 35 to 135 feet bgs.

Monitoring well MW-30i indicated relatively low concentrations of TCE, between 1.19 µg/l and 6.42 µg/l, at depths ranging from 45 to 145 feet bgs. Similarly, TCE concentrations in monitoring well MW-34i ranged from 2.05 µg/l to 5.13 µg/l, at depths ranging from 60 to 160 feet bgs (Table 5-11).

PCE Distribution

Analytical results from depth-specific groundwater samples collected during intermediate well construction indicated that PCE concentrations were also highest in monitoring wells MW-31i and MW-32i, both immediately north of the ST Services site (Table 5-11). PCE was detected in MW-31i and MW-32i at maximum concentrations of 108 µg/l (85 feet bgs) and 170 µg/l (60 feet bgs), respectively. In general, concentrations of PCE were highest at shallow depths, while significant concentrations were not detected in samples collected at greater than 120 feet bgs.

Depth-specific samples collected from monitoring well MW-33i, located north of monitoring wells MW-31i and MW-32i, indicated PCE at concentrations ranging from 0.67 µg/l to 34.8 µg/l, at depths from 35 to 135 feet bgs.

Monitoring well MW-30i indicated relatively low concentrations of PCE, between 1.44 µg/l and 15.7 µg/l, at depths ranging from 45 to 145 feet bgs. Similarly, PCE concentrations in monitoring well MW-34i ranged from 0.65 µg/l to 11.4 µg/l, at depths ranging from 60 to 160 feet bgs (Table 5-11).

Plume Delineation

Depth-specific groundwater data collected from monitoring wells MW-30i through MW-34i suggest that the PCE and TCE plume originating from the ST Services source area is migrating to the northeast, toward the SMC site, at depths ranging between approximately 20 and 170 feet bgs (Figure 10-5). The distribution of both TCE and PCE in this area is similar (i.e., the relative concentration of PCE and TCE are similar at the same depths), supporting the belief that the PCE and TCE are sourced from the ST Services site. This data also indicate that the PCE and TCE concentration gradients decrease within the plume as the distance from the ST Services source area increases. The maximum concentrations of PCE and TCE are detected at greater depths as the distance from the source area increases. This suggests that the ST Services plume migrated deeper in the aquifer as its horizontal extent to the north-northeast increased. The plume has migrated along the top of the TGA as it moved to the north-northeast in response to pumping from GWM. The vertical thickness of the plume is greatest in the area of monitoring well MW-12d, where the top of the TGA drops in elevation (Figure 10-5). Additional investigation at the former Carborundum site (see Section 5.6.7.3) confirms the distribution of VOCs to the north-northeast of ST Services.

Further discussions of the ST Services source area are presented in Sections 8 and 9. A summary of recent groundwater monitoring results for the entire project area, including the additional monitoring wells, is presented in Section 5.6.10.3.

5.6.1.4 SMC/Cadet Plume Delineation Monitoring Wells

Shallow monitoring wells MW-19s, MW-28s, MW-35s, MW-36s, MW-37s, and MW-39s and intermediate monitoring wells MW-35i, MW-36i, MW-37i, and MW-38i, shown on Figure 5-4, were installed between the SMC site and GWM to further define the extent of the SMC/Cadet commingled VOC plume. Depth-specific groundwater samples were collected from the intermediate wells during drilling.

Maximum TCE concentrations detected in discrete depth samples collected from monitoring wells MW-35i, MW-36i, MW-37i, and MW-38i ranged from 37.2 µg/l (MW-35i at 140 feet bgs) to 79.6 µg/l (MW-36i at 100 feet bgs) (Table 5-11). The maximum concentration of TCE detected was in monitoring well MW-36i, which is closer to the SMC/Cadet source areas. The maximum TCE concentration detected in this well was also shallower (100 feet bgs) than the other monitoring wells (MW-35i, MW-37i, and MW-38i), suggesting that the depth where the maximum TCE concentrations are detected increases as the distance from the source area increases. The maximum TCE concentrations detected in monitoring wells MW-35i, MW-37i, and MW-38i indicated similar concentrations (ranging from 37.2 µg/l to 48.8 µg/l) and similar depths (ranging from 120 feet bgs to 150 feet bgs).

In general, TCE concentrations in all of the intermediate wells indicated similar vertical profiles of relatively low concentrations at shallow depths, increasing at approximately 100 to 140 feet bgs, and then decreasing significantly at depths greater than 150 feet bgs. The distribution of TCE (and other VOCs) in the discrete depth samples support the groundwater model and previous assumptions that the distribution of TCE in the subsurface is greatly influenced by the GWM pumping wells, which are screened from 50 to 129 feet bgs. TCE is being drawn deeper as distance from the source area increases and groundwater flows closer to the GWM pumping wells. As shown on Figures 7-8 and 10-6, the bottom of the deep USA/ top of the TGA is deeper in the area near monitoring wells MW-37i and MW-38i. VOCs have migrated deeper in this area due to the pumping of the GWM wells, which promoted migration of VOCs along the boundary of the deep USA and the less permeable TGA.

Further discussion of the SMC/Cadet commingled TCE plume is presented in Sections 8 and 9. A summary of recent groundwater monitoring results for the entire project area, including those from the additional monitoring wells, is presented in Section 10.5.

5.6.2 SMC Source Area Fine-Grained Sand Layer Investigation

The objective of the fine-grained sand layer investigation in the SMC source area was to define the extent of a fine-grained sand layer that was potentially limiting the effectiveness of the groundwater interim action. The investigation was conducted in accordance with the Work Plan Addendum (Parametrix 2004c).

Between January 2002 and February 2005, the Port conducted a Groundwater Source Area Interim Action using Fenton’s Reagent at the SMC source area (Section 6). Review of data from various sampling events indicated that the effectiveness of the treatment activities was limited by unknown conditions. Borings at the site suggested the presence of a fine-grained sand layer at approximately 20 to 23 feet bgs, that overlies a more coarse-grained material of higher permeability. Interpretation of the geology indicated that if a treatment injector were screened across both of these layers, the majority of the treatment reagent would be dispersed in the lower, coarse-grained layer due to its higher permeability, thus reducing the effectiveness of treatment in the fine-grained sand layer.

Further complicating the treatment effort was the uncertainty associated with the spatial distribution of the fine-grained sand layer. Its location had been defined only in the vicinity of monitoring well VMW-9. Based on analytical results for samples collected as part of the interim action verification sampling (discussed in Section 6), the majority of the residual TCE mass at the site is present in the fine-grained sand layer. To maximize the effectiveness of additional treatment, with the objective of removing the remaining TCE, additional investigation was initiated to define the extent of this layer in the SMC site source area.

Data presented in the Final Groundwater Interim Action Report (Parametrix 2004b) also demonstrated that Fenton’s Reagent was not treating all of the residual TCE released from the fine-grained sand layer. Rather, the TCE was mobilized from the residual and/or adsorbed TCE phase to the dissolved TCE phase. As a result, dissolved TCE concentrations were increasing in areas where phase change had occurred, but sufficient Fenton’s Reagent was not present to treat the newly released TCE. Based on available data, it was hypothesized that the majority of the remaining TCE mass is likely present as an adsorbed phase in the fine-grained sand layer. Adsorption occurs when molecules of TCE adhere to the surface of the grains of the aquifer material. Fine-grained materials, which have a large surface area to volume ratio, are capable of retaining a significant amount of adsorbed mass.

5.6.2.1 Methods

Characterization of the fine-grained sand layer in the source area was conducted in September 2004. The objective of the characterization activities was to use probe borings to define the extent of the fine-grained sand layer in the SMC site source area. The distribution of this layer in the SMC site source area was investigated by logging the boreholes and, at boring locations deemed most representative of the fine-grained sand layer, collecting continuous core samples from approximately 18 feet bgs to 25 feet bgs (Figure 5-5).

The probe borings were completed on approximately 20-foot centers in a grid established in the interim action source area. The grid was bounded by IMW-5 to the north, VMW-10 to the east, SSI-10 to the south, and VMW-2 to the west (Figure 5-5). Based on available data, the maximum concentrations of TCE were present in this area (Parametrix 2004b). The boring location (grid node B2) centered on VMW-2 was chosen as a known point to facilitate placement of other boring locations in the field.

Thirty-eight borings were installed to evaluate the spatial distribution of the fine-grained sand layer. At each boring location, soil was collected from the fine-grained sand interval to evaluate the distribution of TCE. The approximate water table depth during the investigation was 24 feet bgs. At five locations (B3, X1 through X4), soil samples were collected for analysis from both above and below the water table to evaluate TCE concentrations (Table 5-12). Soil samples were analyzed for PCE and TCE using EPA Method 5035A; six samples were also analyzed for total organic carbon (TOC) by EPA Method 9060 (modified).

5.6.2.2 Results

Analytical results for the fine-grained sand layer investigation are presented in Table 5-12. Table 5-12 identifies samples that were collected within the saturated zone and above the water table. Analytical laboratory reports are included in Appendix A. Boring logs for the fine-grained sand layer investigation are included in Appendix E-2.

The investigation results indicate that the fine-grained sand layer surface is irregular, due to the excavation of TCE-impacted soil from the source area in 1998. The thickness of the fine-grained sand layer ranges from approximately 1 to 12 feet, with the thickest portion observed in the vicinity of boring B2. Figure 5-5 shows the location of the borings and the cross section orientation of A-A’ and B-B’. Figures 5-6 and 5-7 show cross sections across the SMC source area of A-A’ and B-B’, respectively.

The maximum concentrations of PCE and TCE in soil samples collected were 3,550 micrograms per kilogram (µg/kg) (boring X2-Dry at 23 feet bgs; sample collected above the water table) and 33,600 µg/kg (boring C2 at 24 feet bgs; sample collected below the water table), respectively. The highest soil TCE concentrations were detected in areas where the fine-grained sand layer is thickest. The grid node sample locations and TCE concentrations are shown on Figure 5-5. The highest TCE concentrations in soil (maximum of 33,600 µg/kg) were detected at grid locations C2, X2, C3, and D3, near wells DSI-5-40 and VMW-9. The highest TCE concentrations in groundwater in the source area had previously been detected in samples collected from these wells in July 2004 and February 2005, suggesting that adsorbed TCE is present in the fine-grained sand layer near these wells.

Based on the TCE concentrations detected in soil samples collected during the investigation (Table 5-12), the majority of the adsorbed TCE remaining in the source area is in the fine-grained sand layer.

The findings of the fine-grained sand layer investigation were used to focus interim action Treatment Event 7, completed in October 2004. Additional information regarding interim actions conducted in the source area and verification sampling is included in Section 6.

5.6.3 Soil Gas Investigation – Port Tenant Property and SFVN

The objective of the soil gas investigations was to determine the presence of VOCs in soil gas near Port leaseholds and within the South Fruit Valley Neighborhood (SFVN). A summary of the investigations is presented below.

5.6.3.1 Port Tenant Soil Gas Wells

The Port tenant leasehold soil gas investigation was conducted in accordance with the Work Plan for Soil Gas Investigation, Former Building 2220 Site (Parametrix 2005b). The soil gas investigation included the installation of 10 soil gas wells (labeled POV-SG-1 through POV-SG-10) to evaluate soil gas near six Port tenant buildings located to the south and east of the former SMC site (Figure 5-8). In addition, soil gas well SG-16 was installed on Port property located directly west of the SFVN. In May and June 2005, Cadet Manufacturing installed soil gas wells SG-13, SG-14, SG-15, and SG-17 in the SFVN to further assess soil gas concentrations in the neighborhood (Section 5.6.3.5). Due to the presence of underground utilities, soil gas well SG-16 could not be installed in the SFVN location identified in a work plan prepared by Cadet's consultant (AMEC 2005a). Therefore, the Port agreed to install SG-16 on Port property. The location of SG-16 is also shown on Figure 5-8.

5.6.3.2 Port Tenant Soil Gas Well Installation

In July 2005, Parametrix supervised the completion of 11 soil gas monitoring wells on Port property (10 near tenant buildings and SG-16). For the purposes of evaluating soil gas content at discrete depths, each soil gas monitoring well was completed with three separate soil gas sample screens, which are isolated from each other to prevent migration of soil gas and potential cross-contamination. Each soil gas monitoring well includes a shallow screen at approximately 10 feet bgs, an intermediate screen at approximately 15 feet bgs, and a deeper screen at approximately 20 feet bgs (consistent with the methodology used for the Cadet soil gas wells in the NFVN). For soil gas wells in areas of deeper groundwater, additional screen intervals were added in a separate boring located adjacent to the original boring (this includes SG-10, which has a soil gas screen at 30 feet bgs). Well construction details are presented in the boring logs in Appendix E-3.

5.6.3.3 Port Tenant Soil Gas Sampling

After construction of the soil gas wells, quarterly sampling of the soil gas wells was initiated. A total of five quarters of sampling were completed between July 2005 and September 2006. Soil gas samples were collected from each soil gas well in accordance with the procedures described in the Ecology-approved Work Plan for Soil Gas Investigation (Parametrix 2005b). Filled Summa canisters were transported under chain-of-custody procedures to Columbia Analytical in Simi Valley, California. The soil gas samples were analyzed for VOCs using EPA Method TO15. The analytical results for soil gas testing are shown in Table 5-13. The analytical reports and data validation are included in Appendix A.

As shown in Table 5-13, VOCs were detected in each of the soil gas wells. The highest concentrations of VOCs in soil gas were detected in soil gas well POV-SG-04. TCE was detected at 10 feet bgs in soil gas well POV-SG-04 at concentrations ranging from 16,000 µg/m^3 to 23,000 µg/m^3. Concentrations of TCE were higher in the soil gas samples collected from 15 feet bgs (maximum concentration of 33,000 µg/m^3) and 20 feet bgs (maximum concentration of 46,000 µg/m^3).

The elevated concentration of TCE in soil gas well POV-SG-04 appears to be related to the high concentrations of TCE in groundwater in the area. POV-SG-04 is located adjacent to monitoring well MW-7, which has had TCE in groundwater samples at a maximum concentration of 2,220 µg/l. POV-SG-04 is also located directly downgradient from the former SMC source area.

The maximum concentrations of TCE detected in the remaining wells at 10 feet bgs ranged from 2 µg/m^3 to 6,300 µg/m^3. In general, higher concentrations were detected in deeper samples, which is due to the well screen being closer to the impacted groundwater.

Currently, there are no MTCA cleanup levels for soil gas. The primary consideration for evaluating soil gas is potential vapor intrusion to overlying structures or volatilization to outdoor air, both of which can create a complete exposure pathway. The results of the Port tenant soil gas investigation were used to select Port tenant buildings for indoor air sampling (see Section 5.6.5). In addition, an evaluation of the soil gas results and the relationship to potential indoor air conditions in overlying properties was completed in the Draft Comprehensive Vapor Intrusion Evaluation and Indoor Air Monitoring Plan (CAMP) submitted to Ecology in January 2007 (Parametrix 2007).

5.6.3.4 South Fruit Valley Neighborhood Soil Gas Wells

The SFVN soil gas investigation was a joint effort by Cadet and the Port. Cadet’s consultant (AMEC) completed the installation and sampling of four soil gas wells (labeled SG-13, SG-14, SG-15, and SG-17); well locations are shown on Figure 5-8. For reference, geologic cross-sections, which include the soil gas wells installed in the SFVN, are included as Figures 5-9 and 5-10. The investigation was completed in accordance with the Work Plan for Installation of Soil Gas Wells (AMEC 2005a).

5.6.3.5 SFVN Soil Gas Well Installation

During May and June 2005, AMEC supervised the installation of four permanent soil gas monitoring wells in the SFVN. Parametrix provided oversight of the installation. The wells were constructed in the same manner as wells located on the Port property and the NFVN. For the purposes of evaluating soil gas content at discrete depths, each well was completed with separate soil gas sample screens located at approximately 10, 15, and 20 feet bgs. The screens are isolated from each other to prevent migration of soil gas and potential cross-contamination. Each soil gas monitoring location includes an additional well installed adjacent to the original well. The additional wells in monitoring locations SG-13, SG-15, and SG-17 include a screen at approximately 30 feet bgs. The depth to groundwater is greater in the northeast portion of the SFVN (because ground elevation is higher). Therefore, soil gas monitoring location SG-14 includes a screen at approximately 40 feet bgs in the additional well, and a third well that is screened at approximately 50 feet bgs.

5.6.3.6 SFVN Soil Gas Sampling

After construction of the soil gas wells, quarterly sampling of the soil gas wells was initiated by Cadet and continued by the Port after the Port acquired the Cadet property on May 29, 2006. Six quarterly sampling events were completed between June 2005 and September 2006. Soil gas samples were collected from each soil gas well in accordance with the procedures described in the Work Plan for Installation of Soil Gas Wells (AMEC 2005a). Filled Summa canisters were transported under chain-of-custody procedures to Columbia Analytical in Simi Valley, California. The samples were analyzed for VOCs using EPA Method TO15. The analytical results for soil gas testing are shown in Table 5-14.

As shown in Table 5-14, VOCs were detected in each of the soil gas wells. The highest concentrations of VOCs in soil gas were detected in well SG-15. During June 2005 and September 2006, TCE was detected at 10 feet bgs in well SG-15 at concentrations between 940 µg/m^3 and 2,900 µg/m^3. Concentrations of TCE were highest in the soil gas samples collected from 30 feet bgs (maximum concentration of 23,000 µg/m^3).

The maximum concentrations of TCE detected in the remaining wells at 10 feet bgs ranged from 21 µg/m^3 to 520 µg/m^3. In general, higher concentrations were detected in deeper samples, due to the well screen being closer to the impacted groundwater.

Currently, there are no MTCA cleanup levels for soil gas. The primary consideration for evaluating soil gas is potential vapor intrusion to overlying structures or volatilization to outdoor air, both of which can create a complete exposure pathway. The results of the SFVN soil gas investigation were used to select houses for indoor air sampling (Section 5.6.4). In addition, an evaluation of the soil gas results and the relationship to potential indoor air conditions in overlying properties was completed in the CAMP submitted to Ecology in January 2007.

5.6.4 Indoor Air Investigation - SFVN

Based on the results of the soil gas sampling, Ecology required indoor air sampling in the SFVN. A neighborhood survey was completed in May 2005 (Parametrix 2006a), and the results of the soil gas sampling were used to select houses for indoor air sampling. Twenty-three residences were selected by Ecology and DOH for indoor air sampling. The list of residences was included in an Ecology email to the Port dated March 9, 2006. The residences selected included residences near soil gas wells that had elevated concentrations of VOCs, and residences with basements, crawlspaces, or other unique features which were thought likely to exhibit the worst case conditions. The indoor air investigation was conducted in accordance with the Ecology-approved Work Plan for Indoor Air Evaluation, South Fruit Valley Neighborhood (Parametrix 2006b).

The March 2006 and September 2006 sampling events were considered by Ecology and DOH to represent winter and summer conditions, respectively. Indoor air quality can change based on seasonal differences in subsurface conditions (e.g., change in groundwater levels), as well as residents' living routines (closed windows and doors in the winter, heating and cooling systems, etc.). The indoor air sampling events were conducted in the winter and summer to obtain data for a range of seasonal conditions. The following sections describe the indoor air sampling events conducted in the SFVN.

5.6.4.1 March 2006 Sampling Event

Parametrix completed several letters of inquiry, phone calls, and site visits to inform the residences of the requested sampling and to schedule the event. A total of 18 of the 23 residences agreed to have their home sampled during the initial event in March 2006. The indoor air sample locations are shown on Figure 5-11.

In general, one sample was collected in the living space and one sample in the basement or crawlspace from each residence. Samples were collected by placing a laboratory-supplied Summa canister, equipped with 24-hour controller, in each selected location. The samples were analyzed for VOCs by EPA TO15-SIM. Analytical results for the indoor air samples are summarized in Table 5-15. PCE and TCE analytical results for each residence are included on Figure 5-11.

Based on the sample results for the houses in the SFVN, Ecology and DOH determined that no short-term or immediate health threats were present. However, elevated concentrations of PCE and/or TCE were detected in samples collected from three SFVN homes: 2300 Thompson Street, 2311 Simpson Avenue, and 2314 Simpson Avenue.

PCE and TCE were detected at concentrations of 18 µg/m^3 and 1.9 µg/m^3, respectively in the living space of the 2300 Thompson Street residence. However, PCE and TCE were detected at concentrations of 0.16 µg/m^3 and 0.48 µg/m^3, respectively in the crawlspace. This suggested that, at least in part, the elevated concentrations in the living space could be from resident activities. Similar elevated levels of PCE and/or TCE were detected in the samples collected from the 2311 Simpson Avenue and 2314 Simpson Avenue properties. Both of these homes are located near soil gas well SG-15, which had elevated VOC concentrations.

Other than those cases discussed above, PCE and TCE concentrations detected in the remaining SFVN houses were all below 1 µg/m^3. 1,1-DCA, cis-1,2-DCE, and trans-1,2-DCE were not detected in any samples collected during March 2006. Vinyl chloride was detected in one sample (2300 Thompson Street).

5.6.4.2 May 2006 Sampling Event

The residence at 2201 Thompson Road was sampled in May 2006 at the request of the resident. The resident contacted Ecology and indicated that a "smell" was present in the bedroom of the house. The residence was constructed with a slab-on-grade foundation and does not include a basement or crawlspace. Therefore, indoor air samples were collected from the bedroom and living space.

TCE was detected at concentrations of 0.91 µg/m^3 and 1.2 µg/m^3 in the bedroom and living space, respectively. PCE was detected at concentrations of 0.37 µg/m^3 and 0.5 µg/m^3, respectively (Table 5-15).

5.6.4.3 September 2006 Sampling Event

The September 2006 indoor air monitoring event was conducted to provide a summer sampling event in order to compare results to the previous event conducted in the winter. Sixteen residences were sampled in September 2006. Two residences which were sampled in March 2006 could not be sampled during this event. The resident at 2215 Thompson elected not to complete additional indoor air sampling. The resident at 2218 Simpson could not be contacted through numerous letters, phone calls, and site visits. In addition, the resident located at 2201 Thompson Road had moved out since the last event (May 2006) and the new resident could not be contacted.

Sampling was completed using the same protocols as for the March 2006 event: one sample was collected in the living space, and one sample was collected in the basement or crawlspace of each residence.

TCE and PCE were detected in all residences sampled. TCE was detected at concentrations ranging from 0.048 µg/m^3 to 2.1 µg/m^3. PCE was detected at concentrations ranging from 0.046 µg/m^3 to 4 µg/m^3. 1,1-DCA, cis-1,2-DCE, trans-1,2-DCE and vinyl chloride were not detected in any samples collected during September 2006.

The Draft CAMP (Parametrix 2009) was prepared to evaluate indoor air conditions in the SFVN and provide cleanup levels and a future indoor air monitoring program. In addition, the indoor air results obtained during 2006 from the SFVN were used in the risk assessment (included as Appendix I).

Cleanup levels (levels at which below no further action is required) were proposed for all COPCs in the CAMP and are included on Table 5-15. These cleanup levels were approved by Ecology in an August 18, 2008 letter (Ecology 2008b). Several houses in the SFVN had concentrations exceeding the cleanup levels.

5.6.5 Port Tenant Indoor Air

Two Port tenant buildings (Buildings 2400 and 2401) were selected for indoor air analysis in February and August 2006. The buildings are identified on Figure 5-8 by old building numbers 2248 (new building number 2400) and 2224 (new building number 2401). Buildings 2400 and 2401 are approximately 8,000 square feet and 50,000 square feet in area, respectively.

Building 2400 was selected for indoor air sampling because it was near (less than 70 feet from) soil gas well POV-SG-04, which had soil gas concentrations of TCE detected at up to 23,000 µg/m^3 in the 10-foot level. In addition, Building 2400 is one of the smallest warehouses on Port property and was unoccupied at the time of both sampling events. Based on the size of the building and the fact that it was closed for a long period of time, it was expected that Building 2400 would represent the worst-case scenario for indoor air quality in the Port tenant buildings.

Building 2401 was selected to provide an additional sampling point and context for indoor air in the Port buildings. Building 2401 was empty during the February sampling event and occupied during the August 2006 sampling.

Building 2480, located north of Building 2400 and directly adjacent to soil gas well POV-SG-04, was also evaluated as a potential sampling location. However, due to very large cargo doors (approximately 20 feet wide by 15 feet tall) on either side of the building, the fact that the doors remain open during business hours (allowing significant air flow through the building), and the nature of operations in the building (truck repair and heavy use of oils, cleaners, etc.), it was determined that indoor air sampling would not yield meaningful results.

5.6.5.1 Analytical Results

Buildings 2400 and 2401 contain large open area warehouse space, and no closed office space is present in either building. Therefore, the sample containers (Summa canisters) were placed in the approximate center of the buildings to represent general indoor air quality. Controllers on the Summa canisters were set for a period of 24 hours. Samples were analyzed for VOCs by the EPA TO-15 SIM Method.

Sample results are shown in Table 5-16. PCE and TCE were detected in Building 2400 at maximum concentrations of 0.26 µg/m^3 and 1.2 µg/m^3, respectively. PCE and TCE were detected in Building 2401 at maximum concentrations of 0.13 µg/m^3 and 0.07 µg/m^3, respectively. The MTCA ambient air cleanup level for PCE and TCE is 0.42 µg/m^3 and 0.1 µg/m^3, respectively.

The indoor air sampling in the Port buildings was intended to be preliminary in nature, and the results should not be measured against standard residential criteria. Exposure of workers to any indoor air contamination is limited to working hours, and the typical work-life span at a particular building is generally much less than the assumptions used to generate residential criteria. For comparison purposes only, OSHA standards for an 8-hour permissible exposure limit (PEL) for TCE is 537,000 $\mu g/m^3$, the NIOSH Recommended Exposure Limit (REL; 10-hour time-weighted average) is 134,000 $\mu g/m^3$, and the American Conference of Governmental Industrial Hygienists (ACGIH; 8-hour time-weighted average) is 269,000 $\mu g/m^3$. Indoor air contamination resulting from vapor intrusion is evaluated using the MTCA indoor air cleanup levels. The risk associated with these occupational exposures is included in the risk assessment in Section 11. Based on the sample results, significant concentrations of VOCs are not present in Buildings 2400 and 2401.

5.6.6 Ambient Air Monitoring

As part of the soil gas and indoor air investigations, ambient air samples were collected in the SMC project area. The objectives of the ambient air sampling were to evaluate VOC concentrations in outdoor air in the project area and to use that information to evaluate background conditions. A total of five locations have been analyzed over five quarterly monitoring events (concurrent with the soil gas sampling). The locations were approved by Ecology and are shown on Figure 5-12. The ambient air monitoring was conducted in accordance with the procedures outlined in the Work Plan for Soil Gas Investigation, Former Building 2220 Site (Parametrix 2005b).

5.6.6.1 Methods

Ambient air samples were collected in August 2005 through September 2006, coincident with the soil gas sampling events. The ambient air samples were collected by placing a Summa canister equipped with a 24-hour controller at each location. Filled Summa canisters were transported under chain-of-custody procedures to Columbia Analytical in Simi Valley, California. The ambient air samples were analyzed for VOCs using EPA Method TO15-SIM. The analytical results for ambient air testing are shown in Table 5-17. The analytical reports and data validation are included in Appendix A.

5.6.6.2 Results

VOCs were detected at each of the ambient air monitoring locations (Table 5-17). TCE was detected at concentrations ranging from 0.036 $\mu g/m^3$ to 1.6 $\mu g/m^3$. The highest concentrations were generally obtained from the ambient samples collected near soil gas well SG-16.

The results of the ambient air sampling were used to evaluate background concentrations and potential impact on indoor air quality. The evaluation is presented in the CAMP (Parametrix 2007).

5.6.7 Former Carborundum Ponds Investigation

In July 2005, a subsurface investigation of the former Carborundum ponds site was conducted. The primary objectives of the investigation were to collect samples of baghouse dust from the former Carborundum ponds and to collect groundwater samples from the vicinity of the ponds to further characterize the extent of VOCs.

5.6.7.1 Background

The former Carborundum facility utilized two ponds, designated Pond B and Pond G, to contain slurried baghouse dust. The locations of the two former ponds, as shown on Figure 5-13, are based on drawings presented in an alternatives assessment for the former Carborundum facility (CH2M Hill 1995). Previous reports describe the baghouse dust as a black, silt-like material consisting primarily of silicon carbide fines, quartz, and coke (Standard Oil Company 1984; CH2M Hill 1995). The ponds were operated in series: slurried dust was discharged into the southeast corner of Pond B, moved through Pond B, and then discharged into the north corner of Pond G (Standard Oil Company 1984).

Characterization of the baghouse dust in the ponds was conducted in 1984 (Standard Oil Company 1984). Based on the investigation, the characterization report concluded that the baghouse dust in the former ponds did not contain significant concentrations of VOCs.

In 1994, three monitoring wells (designated MW-E, MW-F, and MW-G) were installed in the former Carborundum ponds area as part of a groundwater assessment (CH2M Hill 1994). As shown on Figure 5-13, wells MW-E and MW-G are located in the central areas of the former Ponds G and B, respectively. Well MW-F is located just outside of the former Pond B location. Based on the nature of the baghouse dust and previous analytical results, the primary contaminants of interest in the material were polycyclic aromatic hydrocarbons (PAHs) and metals (Standard Oil Company 1984; CH2M Hill 1994, 1995).

Groundwater samples were initially collected from monitoring well MW-F for VOC analysis in 1995. Groundwater samples from wells MW-E and MW-G were initially analyzed for VOCs in 2001. TCE has been detected at concentrations ranging from 100 µg/l to 191 µg/l in groundwater samples collected from MW-E since 2001. Significantly lower concentrations of TCE have been detected in groundwater samples from MW-F and MW-G. PCE has also been detected in groundwater samples from wells MW-E and MW-G, but generally not in samples from MW-F. The concentrations of PCE detected in these two wells is typically about half of the detected TCE concentrations.

A subsurface investigation was completed by SECOR for ST Services on March 23 and 24, 2005, to determine if VOC contamination at the ST Services site is migrating to the north, toward the former Carborundum ponds site. This investigation included the completion of 13 probe borings along or adjacent to the northern boundary of the ST Services site. The borings were advanced to an average depth of 45 feet bgs, where discrete groundwater samples were collected for VOC analysis. Figure 5-13 shows the approximate locations of the 13 borings, designated ST-SB-01 through ST-SB-13.

5.6.7.2 Methods

In July 2005, the Port completed an investigation that included thirty probe borings (CPOND-1 through CPOND-30) in the Carborundum ponds area. Probe boring locations are shown on Figure 5-13. Groundwater samples were collected from the top of the coarse sand zone that was encountered directly beneath a silt zone. This approach was consistent with the March 2005 sampling of probe borings (ST-SB-1 through ST-SB-13) completed by SECOR. The borings were drilled to depths ranging from approximately 20 feet to 25 feet bgs. Samples of the black baghouse dust material were collected from the borings.

Groundwater samples for VOC analysis (EPA Method 8260) were collected from 4-foot temporary well screens placed in CPOND-1 through CPOND-30. The screens were set in the medium to coarse sands present beneath the silt zone, at depths ranging from 29 to 45 feet bgs. In addition, eighteen samples of baghouse dust and one sample of slag were analyzed for

VOCs using EPA Method 5035A. In addition to the samples collected from the probe borings, a groundwater sample for VOC analysis was collected from existing General Chemical monitoring well GC-MW-12b.

5.6.7.3 Former Carborundum Investigation Results

Soil samples were inspected in the field and classified by soil type. The soil consisted primarily of silt and sandy silt, with some fine-grained sand and fine sandy gravel. Boring logs are included in Appendix E-4. Baghouse dust and/or slag were encountered in 19 probe locations, and ranged in thickness from 2 to 17 feet, with an average thickness of 6.7 feet. Table 5-18 summarizes the boring locations, sample depths, sample types, and thicknesses of the baghouse dust and slag encountered in the probe borings.

The VOC analytical results for groundwater and baghouse dust samples collected during the July 2005 subsurface investigation completed for the Port of Vancouver are summarized in Tables 5-19 and 5-20. None of the baghouse dust or slag samples contained chlorinated solvents.

Groundwater samples collected from below the baghouse dust indicate that PCE, TCE, and cis-1,2-DCE are present in groundwater in the area north of the ST Services site, including the vicinity of the former Carborundum ponds (Figures 5-14 and 5-15). The maximum concentrations of PCE and TCE were detected in CPOND-21, at 80.6 µg/l and 110 µg/l, respectively. The maximum concentration of cis-1,2-DCE was detected in CPOND-10 at a concentration of 108 µg/l. PCE, TCE, and cis-1,2-DCE were detected in groundwater samples collected from the General Chemical monitoring well GC-MW-12b.

The following conclusions are based on the previous and current investigations:

- The baghouse dust slurry material in the former Carborundum ponds is not a source for the chlorinated solvent contamination detected in groundwater. This conclusion is based on the lack of detectable concentrations of chlorinated solvents in the baghouse dust and slag samples collected from the former pond areas.
- Releases at the ST Services site are the source of the contamination detected in the vicinity of the former Carborundum ponds. This conclusion is based on the distribution of the contaminants, which shows high concentrations at the ST Services site and progressively decreasing concentrations of VOCs with increasing distance to the north.
- The concentrations of TCE and PCE detected in MW-E are anomalous compared to results for groundwater samples collected from nearby wells. The source of the anomaly has not been identified.

5.6.8 Monitoring Well MW-5d Investigation

A review of analytical results for groundwater samples collected from monitoring well MW-5d since 1998, and analytical data for other wells screened in the deep USA zone, suggested that the well casing of MW-5d was compromised. Specific observations included:

- Concentrations of TCE detected in groundwater samples from MW-5d significantly increased from 2003 to 2006. Concentrations of TCE detected in other monitoring wells screened in the deep USA zone remained stable during this period and were significantly lower than the TCE concentrations detected in MW-5d.

- Field inspection of MW-5d indicated that the PVC well casing was constricted at several points.
- The only identified source for the high concentrations of TCE detected at MW-5d was the groundwater located in the shallow USA zone above MW-5d, suggesting that shallow USA groundwater was leaking into MW-5d.

Therefore, an investigation of monitoring well MW-5d was initiated.

5.6.8.1 MW-5d BACKGROUND

Monitoring well MW-5d was constructed in May 1998 in a boring drilled to 234 feet bgs using the cable tool method. A well, consisting of 2-inch diameter Schedule 80 PVC with a 10-foot long slotted screen was set approximately 1 foot above the top of the TGA in the boring. Following installation of the well and placement of the sand pack, the boring was pressure grouted as the casing was removed to seal the annular space.

Figure 5-16 presents a time series plot of the concentrations of six volatile organic compounds (VOCs) detected in groundwater samples collected from monitoring well MW-5d. The figure illustrates the fluctuating pattern of TCE concentrations. Of the five VOCs commonly detected in MW-5d groundwater samples, only PCE showed a similar pattern.

Based on this information, a Well Evaluation scope of work (dated May 26, 2006) was submitted to Ecology to investigate the condition of well casing of MW-5d. The scope of work included a two-step process including: 1) a well casing leak evaluation and 2) discrete water column sampling.

5.6.8.2 Well Casing Leak Evaluation

The well casing leak evaluation for MW-5d well was designed to identify the location of a potential leak above the screen interval. The evaluation was to be completed by installing an inflatable packer equipped with a pressure gauge near the top of the well screen. An electrical submersible pump would be used to remove water in the casing above the packer. However, attempts to install the packer on July 28 and August 17, 2006, were unsuccessful due to constrictions in the PVC casing at approximately 136 and 150 feet bgs. Therefore, the well casing leak evaluation could not be completed using a packer and pump.

An attempt was made on September 25, 2006 to lower a video camera into the well to inspect the PVC casing. However, due to a constriction in the well casing, the video camera could not be advanced past a depth of approximately 11.4 feet bgs.

The well evaluation activities identified at least two areas where constrictions were present. An upper zone of constriction was present from approximately 7 to 12 feet bgs. This constriction zone was above the static water level in the well, which averages approximately 20 feet bgs. A second zone of constriction occurred at approximately 130 feet and extended down to at least 150 feet bgs. In addition, based on observations during the installation of pump equipment, a smaller constriction zone was also present at approximately 36 feet bgs.

5.6.8.3 Discrete Water Column Sampling

A series of groundwater samples were collected from well MW-5d in June and September 2006 to help evaluate the source for the elevated concentrations of TCE. Analytical results for these groundwater samples are summarized in the following table and discussed below.

MW-5d Analytical Results

Sample Date	Sample Method	TCE (µg/l)	PCE (µg/l)	cis-1,2-DCE (µg/l)
6/7/06	Low Flow – at screen	1,310	40.3	8.7
6/7/06	High Rate – at screen	309	11.4	6.2
9/11/06	Low Flow – at screen	8,770	233.0	<25.0
9/11/06	High Rate – top of water	6,450	182.0	<50.0
9/29/06	Low Flow – at screen	3,040	56.2	13.6
9/29/06	High Rate – at screen	1,690	49.6	11.2

June 7, 2006, Sampling Event

During the June 7, 2006, sampling event, a groundwater sample was collected using the standard low flow sampling method, with the pump set in the mid-section of the well screen. Five gallons of groundwater were purged from the well in 10 minutes prior to collecting the sample. Following collection of the low flow sample, the pump rate was increased to its maximum production rate of approximately 3.3 gpm. Approximately 50 gallons of groundwater were pumped in 15 minutes. The pump rate was reduced to the low flow rate prior to collecting a groundwater sample. The concentration of TCE detected in the groundwater sample collected after purging 50 gallons from the well (309 µg/l) was approximately 24% of the concentration detected in the low flow sample (1,310 µg/l). This suggested that the concentration of TCE detected in the groundwater sample collected using only the low flow sampling method (1,310 µg/l) was not representative of formation water screened by the well.

September 11, 2006, Sampling Event

During the September 11, 2006, sampling event, a groundwater sample was collected using the standard low flow sampling method, with the pump set in the mid-section of the well screen. Five gallons of groundwater were purged from the well in 14 minutes prior to collecting the sample. Following collection of the low flow sample, the pump was raised to the top of the water column in the well. Approximately 45 gallons were pumped from this location at a higher production rate. The volume of water in the well casing was approximately 33 gallons. A groundwater sample was then collected from the pump location. The concentration of TCE detected in the groundwater sample collected after purging 45 gallons from the well (6,450 µg/l) was approximately 74% of the concentration detected in the low flow sample (8,770 µg/l).

September 29, 2006, Sampling Event

During the September 29, 2006, sampling event, a groundwater sample was collected using the standard low flow sampling method with the pump set in the mid-section of the well screen. Five gallons of groundwater were purged from the well in 21 minutes prior to collecting a sample. Following collection of the low flow sample, the pump rate was increased. Approximately 54 gallons of groundwater were pumped in 21 minutes. The pump rate was reduced to the low flow rate prior to collecting a groundwater sample. The concentration of TCE detected in the groundwater sample collected after purging 54 gallons from the well (1,690 µg/l) was approximately 55% of the concentration detected in the low flow sample (3,040 µg/l).

The variability in the analytical results suggested that the elevated concentrations of TCE detected in groundwater samples collected from MW-5d were not representative of concentrations present in formation water screened by the well. The source of the elevated concentrations of TCE in MW-5d was believed to be contaminated groundwater in the shallow USA water entering the well through a crack, fracture, or a compromised thread seal in the PVC well casing. The concentrations of TCE and PCE detected in MW-5d were similar to concentrations in shallow USA wells located adjacent to MW-5d. Therefore, decommissioning and replacement of MW-5d was recommended and approved by Ecology. The following sections describe the decommissioning and installation activities.

5.6.8.4 MW-5d WELL DECOMMISSIONING

Monitoring well MW-5d was decommissioned in November 2006 by overdrilling the original boring. The decommissioning was consistent with the Decommission and Replacement of Monitoring Well MW-5d Work Plan (Parametrix 2006f), which was approved by Ecology prior to initiating the work (Ecology 2006b). This approach exceeded decommissioning requirements for resource protection wells as described in WAC 173-160-460.

Prior to overdrilling MW-5d, an attempt was made to pull the PVC well casing out of the boring using the drill rig. The purpose of this effort was to examine the condition of the PVC casing for potential cracks and/or a break location. A break point could represent a location where the well's PVC casing had been compromised (i.e., cracked or fractured). However, when PVC casing removal was attempted, only the top 11 feet were removed because the threaded connection to the rest of the casing came loose at this joint. No cracks or fractures were noted on the removed casing. This loose coupling location corresponds to the depth where the video camera encountered a constriction.

A steel casing step-down method was used to minimize the potential for dragging down or allowing the VOC contaminants present in the shallow zone groundwater in the area of MW-5d to migrate down via the overdrill boring or along the temporary steel casing. The step-down schedule used during the decommissioning of MW-5d exceeded the schedule detailed in the Work Plan (Parametrix 2006f).

5.6.8.5 MW-5d Purging and Sampling

Groundwater was pumped (air lifted) using air from the rotary rig drill stem during well decommissioning activities. Approximately 23,300 gallons of groundwater were pumped from the boring during the drilling activities. Approximately 21,000 gallons of this groundwater were generated while drilling from the surface to 213 feet bgs. The remaining 2,300 gallons were generated while drilling from 213 feet bgs to 229 feet bgs, where more consolidated material associated with the Troutdale Formation was encountered.

After reaching the target boring depth of 229 feet bgs, the 10-inch casing was pulled back approximately 6 feet to 223 feet bgs. Approximately 1,100 gallons of groundwater were then pumped from the boring to purge the section of the formation originally screened by well MW-5d, and to remove VOCs that may have entered the formation from the well.

After purging the boring, a submersible electric pump was inserted in the boring to approximately 223 feet bgs. Approximately 20 gallons of groundwater were purged using the pump, at a purging rate of approximately 1 gallon per minute. After purging activities were complete, the pump rate was reduced to a low, sustainable flow rate and a groundwater sample (labeled MW-5d Decom) was collected using the submersible pump for VOC analysis.

Based on the analytical results for groundwater sample MW-5d Decom, which suggested that the formation still contained VOCs associated with the former well, an additional 2,600 gallons of groundwater were purged from the boring. After pumping activities were complete, the submersible electric pump was re-inserted down the boring to approximately 223 feet bgs. Consistent with the first sampling event, approximately 20 gallons of groundwater were again purged using the pump, at a purge rate of approximately 1 gallon per minute. After purging activities were complete, a discrete groundwater sample (labeled MW-5d DECOM-B) was collected for VOC analysis using the submersible pump. Detected concentrations of VOCs are summarized below.

MW-5d Decommissioning Groundwater Analytical Results

Sample	Sample Date	Sample Rate	TCE (µg/l)	PCE (µg/l)	Cis-1,2-DCE (µg/l)	1,1,1-TCA (µg/l)	1,1-DCE (µg/l)	1,1-DCA (µg/l)
MW-5d Decom	11/2/06	Low Flow	63.0	7.51	5.96	1.49	< 1.00	< 1.00
MW-5d DECOM-B	11/3/06	Low Flow	34.6	5.51	5.50	1.27	0.590	0.830

5.6.8.6 MW-5d Well Boring Backfill

Based on the analytical results for groundwater sample MW-5d DECOM-B, the boring was backfilled in accordance with the procedures defined in the Work Plan (Parametrix 2006f). The boring was grouted from the bottom to approximately 40 feet bgs. Bentonite chips were then placed into the boring from approximately 40 feet bgs to 12 feet bgs while slowly and completely removing the casing. A large void was encountered between 12 feet bgs and 7 feet bgs. The void and the rest of the boring were backfilled with approximately 8 cubic yards of fine-grained sand slurry supplied by a local concrete distributor using a concrete mixer truck.

5.6.8.7 INSTALLATION OF REPLACEMENT WELL MW-5dR

Installation of replacement well MW-5dR was completed in November 2006, immediately after the decommissioning of MW-5d. MW-5dR is located approximately 20 feet southeast of the former MW-5d location (Figure 2-2). Replacement well MW-5dR was constructed as a 4-inch diameter well. The installation was consistent with the Decommission and Replacement of Monitoring Well MW-5d Work Plan (Parametrix 2006f), which was approved by Ecology prior to initiating the work (Ecology 2006b).

MW-5dR TGA Sampling

The TGA was encountered at approximately 229 feet bgs during the drilling of MW-5dR. The boring was advanced approximately 10 feet into the TGA. During advancement of the boring, three depth discrete groundwater samples (labeled MW-5dR-229, MW-5dR-234, and MW-5dR-239) were collected at the following depths and analyzed for VOCs:

- At the top of the TGA (approximately 229 feet bgs).

- 5 feet into the TGA (approximately 234 feet bgs).
- 10 feet into the TGA (approximately 239 feet bgs).

VOCs were not detected in the three discrete-depth groundwater samples except for toluene, which was detected in sample MW-5dR-229 at a concentration of 1.48 µg/l (Table 5-21).

MW-5dR Installation

Well MW-5dR was constructed in a manner consistent with the Work Plan (Parametrix 2006f) and the overall operating procedures described in the June 1999 SMC Site RI/FS Work Plan. The well string consisted of commercially manufactured 4-inch diameter, flush threaded, Schedule 80 PVC well screen and well casing. A ten-foot long screen with 0.020-inch horizontal machine-cuts completed with a threaded end cap made up the well string. Stainless steel centralizers were placed near the bottom and top of the screen interval and along the casing. Well construction details are included on the boring log (Appendix E-1).

A void was encountered at approximately 19 feet bgs during the grouting of the well. A gravel/bentonite pellet mixture consisting of approximately four 60-pound bags of pea gravel to one 50-pound bag of bentonite was used to fill the void. The well was completed with an aboveground lockable steel surface monument secured with a concrete seal to surface grade.

5.6.9 Groundwater Flow Analysis

In coordination with Clark Public Utilities (CPU), a transducer study was completed in October through December 2006 to better define groundwater gradients in the Columbia River Lowlands area, with a focus on the project area. The study used a series of transducers to further evaluate groundwater flow direction and dynamics in the USA in the vicinity of the Port. The results of the groundwater flow analysis are summarized in Section 7.3.

5.6.10 Groundwater Monitoring Summary

The Port conducts quarterly groundwater sampling to comply with Ecology’s request to develop a basis for water quality trend analysis. Beginning in 2002, annual and semiannual groundwater monitoring reports have been prepared to document the data collected during the four quarterly sampling events, typically conducted in February, May, August, and November, as part of the RI process. The groundwater monitoring reports present water level and water quality data, evaluate groundwater flow and contaminant distribution, and include trend and linear regression analysis. The following sections provide a summary of the information collected and present the current understanding of the site.

5.6.10.1 Monitoring Well Network

The SMC site monitoring well network currently consists of 58 shallow, intermediate, and deep groundwater monitoring wells, four shallow piezometers, and three former Carborundum facility wells. The shallow wells monitor water quality in the USA, the intermediate-depth wells monitor water quality in the middle to lower USA and the upper TGA, and the deep wells monitor water quality in the deep USA and TGA. These hydrogeologic units are described in detail in Section 7.

One SMC site monitoring well, MW-22, was abandoned in June 2002 because a sewer line was intercepted during installation, and a representative groundwater sample could not be collected from the well. A second monitoring well, MW-13, has not been sampled since November 2002 because it is screened in a perched water zone. As described in Section 5.6.1, two additional intermediate depth monitoring wells (MW-30i and MW-31i) were installed in 2003, and fifteen shallow- and intermediate-depth wells were installed in the summer and fall of 2004. The Port's monitoring network well locations are shown on Figure 2-1, and construction data for these wells are presented in Table 5-1. Boring logs for these wells are provided in Appendix E-1.

5.6.10.2 Water Level Measurements

Static water level (SWL) measurements were collected monthly until May 2002 and, with Ecology's approval, have been collected quarterly thereafter. SWL measurements are collected to assess seasonal and river stage influences on groundwater flow direction and rate. Water level data for 2002 to 2006 are presented in Table 5-22. Water level trends at shallow, intermediate, and deep monitoring wells, along with Columbia River stage for the period of record, are shown on Figures 5-17, 5-18, and 5-19.

The water level measurements obtained over the course of the remedial investigation demonstrate that groundwater levels in the SMC study area are affected by changes in Columbia River stage and seasonal precipitation. The river stage of the Columbia River is influenced by tidal fluctuations. As the base level of the Columbia River changes, groundwater levels in the study area change accordingly. Groundwater elevations are also shown to increase during periods of the year when precipitation is greatest, generally during the spring and winter months, and to decrease during dry periods of the year, typically during summer months (Figures 5-17, 5-18, and 5-19). However, as groundwater elevations change, the potentiometric gradient remains the same throughout the year due primarily to pumping at GWM. Groundwater flow direction in the study area is toward this wellfield. The three confirmed TCE sources in groundwater are contained by the capture zone created by pumping at GWM.

5.6.10.3 Groundwater Quality Sampling and Analysis

From 2002 to 2006, groundwater samples were collected from the SMC site monitoring wells and submitted for analysis of VOCs using EPA Method 8021B/8260B. Other constituents (carbon isotope, geochemistry data) were also analyzed in groundwater samples from selected wells during this time period.

Groundwater samples were collected in accordance with Ecology-approved methods (Parametrix 1999b). Passive diffusion bag (PDB) samplers and low-flow purging techniques were employed to collect samples for VOC analysis. PDB samplers were not used in wells where 1,1,1-trichloroethane (1,1,1-TCA) had been detected.

Table 5-23 shows the wells sampled from 2002 to 2006. All groundwater samples were analyzed for VOCs by EPA Method 8021B/8260B. Table 5-3 contains groundwater VOC data collected for the site. Laboratory data reports for 2002 to 2006 are included in Appendix A. Additional discussion of the distribution of contaminants in groundwater is presented in Section 10.

6. GROUNDWATER INTERIM ACTIONS

The Port implemented two groundwater interim actions in the project area, including:

- Installing air stippers and developing a pumping agreement with GWM to contain and treat the commingled VOC plume.
- Injecting oxidizing compounds below the groundwater table in the SMC site source area to destroy TCE.

The groundwater interim actions are summarized below.

6.1 GROUNDWATER CONTAINMENT AND TREATMENT AT GWM

The historical operation of the GWM production wells has provided containment of the commingled TCE plume and prevented the plume from entering the Columbia River. The Port has utilized the GWM production wells as an interim action by maintaining the production rate beyond that needed by GWM in their normal operations. The following sections summarize the historical groundwater use at GWM, the installation of a groundwater treatment system for the production well water, and the groundwater production rate agreement between the Port and GWM.

6.1.1 GWM Water Use

Historically, GWM has operated up to five water supply wells (wells #1 through #5) to provide water for their malting processes. These wells generally have been operated on a continuous basis, cycling quickly on and off dependent upon the water level in the GWM facility's water reservoir. The number of wells in operation at the facility at any one time has varied, depending on the needs of the facility. In recent years, wells #4 and #5 have been the primary wells operated.

Water produced from the wells is used in the malting processes (air washing, malt steeping, and germination) at the facility. Depending on the specific process, water used in the facility is either discharged to the Columbia River, to a wastewater lagoon, or lost to the atmosphere as vapor. The malt steeping and germination processes have generally accounted for approximately 50% of water used at GWM. The steeping water and germination cleaning water are considered "contact" or "process" waters and are discharged to an impoundment (located north of Fourth Plain Boulevard) for treatment prior to being routed to the Westside Wastewater Reclamation Facility. Water used to humidify the air for the germination process is discharged to the atmosphere via stacks or remains as moisture in the malt. Any excess water in the humidifier is considered non-contact water and is discharged to the Columbia River via GWM's NPDES permit.

Based on information from GWM, the total groundwater pumping rate at GWM reached a maximum of approximately 8,200 gallons per minute (gpm) on a continuous basis in 1978, following the installation of well #5. Operation of well #1 was discontinued in 1968. This production rate began to decrease in the late 1990s as drum house operations were reduced, and pumping of production wells #2 and #3 decreased (Hamachek 2003). Operation of wells #2 and #3 was discontinued in 2003. GWM currently maintains a pumping rate of 3,900 gpm from wells #4 and #5 under an agreement with the Port (discussed in Section 6.1.3).

6.1.2 Installation of Air Strippers

GWM first reported a detection of TCE in groundwater in 1989. Due to GWM's need for high quality malt products, GWM requested "clean" water from the Port under the terms of its lease with the Port. GWM requested the installation of groundwater stripping towers, as recommended by GWM's consultants, Maul Foster & Alongi, Inc. Under a settlement agreement, the Port agreed to pay for the installation of air stripping towers to treat the groundwater produced by GWM. The installation was completed by GWM.

The stripping towers were conservatively designed to treat chlorinated solvent concentrations greater than those detected in the groundwater at the time of installation. This was because of a GWM concern that an unknown "slug" of high concentration chlorinated solvent contamination from either the SMC or Cadet site could reach the stripping towers undetected and result in treated water of unacceptable quality.

GWM installed two groundwater stripping towers to remove TCE from the groundwater prior to its use in the malting facility. The towers are located on the north side of GWM's Compartment House 1. GWM began using the strippers in March 2001. Design parameters for the stripping towers include:

PARAMETER	UNITS
Flow Rate	2,500 gpm (each tower)
Target Chemical	TCE
Influent Concentration	25 µg/l
Effluent Concentration	< 0.1 µg/l

Groundwater from GWM wells #4 and #5 is routed to the stripper prior to use. These wells supply water used in the malting process. Groundwater quality monitoring at the facility indicates that to date, the stripping towers have functioned as designed.

6.1.3 Water Production Agreement

Analysis using the Port's groundwater flow and transport model indicated that a pump rate of approximately 3,900 gpm at GWM is required to maintain capture of the TCE plume. In December 2003, GWM notified the Port that GWM would be substantially reducing its rate of water usage in an effort to reduce operation costs. GWM had identified increased efficiency in water use as the primary way to cut operation costs. The drum house was taken off-line in October 2003. Historically, wells #2 and #3 had supplied water for drum house operations. GWM determined that it would need to pump wells #4 and #5 to obtain approximately 900 gpm for operation requirements.

In response to GWM's proposed reduction in water usage, the Port entered in an agreement where by GWM will operate production wells #4 and #5 at a constant combined pump rate of 3,900 gpm to provide for hydraulic control and capture of the groundwater plume. The Port agreed to pay GWM for costs incurred for pumping the additional 3,000 gpm. The Port currently pays for chlorine as well as other operations and maintenance costs related to pumping and treating groundwater at GWM.

6.2 SMC SITE SOURCE AREA TREATMENT

Interim actions were completed from 2002 to 2004 to treat VOCs in groundwater in the SMC site source area. The interim action for groundwater consisted of injecting Fenton's Reagent and/or potassium permanganate below the groundwater table in the source area. As discussed in Section 4.0, an interim action for soil was completed from 1998 to 1999 and included the excavation and treatment of approximately 13,800 yd^3 of VOC-contaminated soil from the SMC site source area. Groundwater interim actions and their effectiveness were documented in the Final Groundwater Interim Action Report (Parametrix 2004b) and are summarized below.

6.2.1 Treatment Area

The treatment area at the SMC site was defined in the Alternatives Analysis for Interim Action Report, Trichloroethylene Groundwater Source Area (Parametrix 2001b) as the area of groundwater containing TCE at concentrations exceeding 10,000 µg/l. EPA technical guidance indicates that the presence of dissolved TCE in groundwater at concentrations greater than 10,000 µg/l suggests the potential presence of DNAPL (EPA 1993). Although no visual evidence of DNAPL has been found in the SMC source area, the 10,000 µg/l level was used to ensure that potential source material was treated. Based on the distribution of dissolved TCE in the SMC source area, the treatment area was defined as approximately 17,220 square feet (ft^2) in size (Figure 6-1).

The treatment area was defined by groundwater samples from borings located in the vicinity of the former SMC building that contained TCE at concentrations exceeding 10,000 µg/l, including borings DC-3, DC-4, DC-5, B-5, B-6, B-9, TCA-1, and TCA-2. The locations of these borings are shown on Figure 6-1. With the exception of groundwater samples collected from boring B-5, the vertical extent of groundwater with TCE at concentrations greater than 10,000 µg/l was limited to 40 feet bgs.

Based on the concentration of TCE detected in the samples from the source area, two horizons were identified in the treatment area, a shallow saturated horizon across the entire treatment area and a deep saturated horizon (to an approximate depth of 100 feet bgs) around boring B-5, B-6, TCA-1 and TCA-2 in the central part of the treatment area (Figure 6-1). These two distinct horizons were used to develop an injection well network, shown on Figures 6-2 and 6-3. The injection wells and temporary direct-push injection points were used to deliver Fenton's Reagent and/or potassium permanganate to the subsurface.

6.2.2 Remedial Action Objective (RAO)

The Port's remedial action objective (RAO) for the groundwater source area was to destroy or remove, to the extent possible, TCE from the groundwater source area. The "extent possible" means the extent to which cleanup is effective and implementable and to which the costs are not disproportionate. These criteria are consistent with MTCA's "selection of cleanup" section, WAC 173-340-360(d), which cites a preference for permanent solutions.

6.2.3 Treatment Program

The Port's treatment program for the SMC site groundwater source area consisted of the following steps:

1. Establishing baseline groundwater quality conditions.
2. Treating the groundwater source area.

3. Verifying the effectiveness of the treatment program.
4. Completing treatment when TCE concentrations stabilized (i.e., successive verification sampling indicates relatively consistent TCE concentrations).

The treatment program was an iterative process, which included multiple treatment and sampling events, with the intent of focusing treatment on resilient parts of the source area.

The Port began treatment of the groundwater source area in January 2002. Seven treatment and twelve verification sampling events were completed between January 2002 and February 2005. In addition, three subsurface investigations were completed to evaluate the effectiveness of the treatment program in specific areas. The treatment, verification sampling, and subsurface investigation events are summarized in chronological order in the table below.

Treatment and Verification Sampling History

Event	Date
Baseline Sampling Event	December 27, 2001 through January 29, 2002
Treatment Event 1	January 28 through February 6, 2002
Verification Sampling Event 1	February 11 through March 4, 2002
Treatment Event 2	February 26 through March 6, 2002
Verification Sampling Event 2	March 11 through March 20, 2002
Treatment Event 3	April 25 through May 1, 2002
Verification Sampling Event 3	May 6 through June 4, 2002
Verification Sampling Event 4	August 5 through August 27, 2002
Treatment Event 4	September 19 through September 21, 2002
Verification Sampling Event 5	November 5 through November 15, 2002
Subsurface Investigation 1	January 30, 2003
Verification Sampling Event 6	January 30 through January 31, 2003
Verification Sampling Event 7	February 17 through March 24, 2003
Treatment Event 5	May 6 through May 13, 2003
Verification Sampling Event 8	June 16 through June 19, 2003
Subsurface Investigation 2	August 14, 2003
Verification Sampling Event 9	October 27 through October 30, 2003
Verification Sampling Event 10	January 14, 2004
Treatment Event 6	May 4 through May 11, 2004
Verification Sampling Event 11	July 6 and 7, 2004
Subsurface Investigation 3	September 2004
Treatment Event 7	October 6 through October 8, 2004
Verification Sampling Event 12	January 31 through February 4, 2005

6.2.4 Treatment Events

Dissolved TCE concentrations can increase after treatment. Therefore, multiple treatments were used to achieve the RAO. Each treatment event consisted of injecting an oxidant, either Fenton's Reagent or potassium permanganate, below the water table using a combination of injection wells and temporary direct-push injection points. The treatments were focused on reducing dissolved TCE in groundwater to concentrations less than 10,000 µg/l, which was indicative of successful treatment and achievement of the RAO.

As is typical of in-situ oxidizing treatments, the injection of oxidants can disrupt aquifer equilibrium conditions in two ways: 1) physical agitation of the aquifer, and 2) liberation of bound TCE from the soil matrix. Both of these actions can result in dissolved TCE concentrations that are initially higher immediately after treatment than the baseline concentrations. After mobilizing the bound TCE, subsequent treatments are aimed at destroying the newly librated dissolved TCE. After the final treatment, equilibrium conditions would be re-established naturally and TCE concentrations would be permanently decreased.

A total of seven treatment events were completed between January 2002 and October 2004 (Table 6-1). Tables 6-2 and 6-3 show the individual treatment injection volumes for each injection point for Fenton's Reagent and potassium permanganate, respectively. Figures 6-2 and 6-3 show the location of injection wells for the shallow saturated horizon and deep saturated horizon, respectively.

6.2.5 Groundwater Sampling

Groundwater sampling was used throughout the treatment program to evaluate the effectiveness of the interim action. Groundwater sampling included a baseline event, verification sampling, and was part of other subsurface investigations in the source area.

6.2.5.1 Baseline Sampling Event

Between December 27, 2001, and January 29, 2002, prior to any treatment, samples were collected from the source area to evaluate baseline groundwater quality conditions. Figure 6-4 shows groundwater concentrations and the approximate extent of TCE in the shallow horizon prior to any treatment events. Table 6-4 includes the analytical results for the baseline sampling event.

6.2.5.2 Verification Sampling Events

Groundwater samples were collected after treatment events to evaluate the effectiveness of the treatment and to focus subsequent injections of Fenton's Reagent on those areas where TCE concentration remained greater than 10,000 µg/l. Verification samples were collected from injector points, direct-push borings, and verification monitoring wells (VMWs). Figure 6-5 shows the locations of the verification sampling points. Different verification points were sampled during each verification event based on the location of treatment activities.

A total of 12 verification sampling events were completed between February 2002 and February 2005. Table 6-4 shows the analytical results for each of the 12 verification events. In addition, a number of the verification wells were sampled in February 2007 during the project area semi-annual monitoring event to further evaluate conditions in the source area (Table 6-4).

6.2.5.3 Subsurface Investigations

During the treatment program, three investigations were conducted to evaluate subsurface conditions that might have an impact on the effectiveness of the treatment. The subsurface investigations were conducted in January 2003, August 2003, and September 2004.

January 2003 Investigation

As summarized in Table 6-4, analytical results from verification sampling events 4 and 5 (August 2002 and November 2002) indicated that relatively high concentrations of TCE remained in groundwater in the vicinity of VMW-9 (114,000 µg/l to 119,000 µg/l). In general, TCE concentrations detected in groundwater samples collected from most of the other wells decreased after treatment. This observation raised a concern regarding the representativeness of the groundwater samples collected from VMW-9.

To evaluate whether VMW-9 was functioning properly, an investigation of subsurface conditions was conducted on January 30, 2003. The investigation included four probe borings adjacent to VMW-9 (approximately 2 feet from the well and on four sides of the well) to collect soil and groundwater samples for analysis. Soil samples were collected at the top of the saturated interval (20 to 24 feet bgs). The screen interval of VMW-9 is 16 to 26 feet bgs. Groundwater samples from the borings were collected from a depth equivalent to the screen interval of VMW-9.

Table 6-5 summarizes the results of the investigation. TCE was detected in the groundwater samples collected from the borings at concentrations ranging from 57,300 µg/l to 85,000 µg/l. These concentrations are similar to the concentrations of TCE previously detected in groundwater samples collected from VMW-9 (114,000 µg/l to 119,000 µg/l), suggesting that the well was functioning properly. The concentration of TCE detected in the saturated soil samples ranged from 7,270 µg/kg to 11,900 µg/kg. These data indicate relatively high concentrations of residual TCE in saturated soil adjacent to VMW-9.

The details of the investigation are documented in the Final Groundwater Interim Action Report (Parametrix 2004b).

August 2003 Investigation

A second investigation of subsurface conditions adjacent to well VMW-9 was conducted on August 14, 2003; this investigation included four probe borings adjacent to VMW-9. The purpose of this investigation was to evaluate whether TCE concentrations in saturated soil and groundwater had been reduced by treatment event 5. Table 6-5 summarizes the results of the investigation.

The concentrations of TCE detected in soil and groundwater samples were compared to the data collected in January 2003 to evaluate treatment effectiveness. The data indicated that the focused treatment in May 2003 had reduced TCE concentrations in saturated soil and groundwater.

The details of the investigation are documented in the Final Groundwater Interim Action Report (Parametrix 2004b).

September 2004 Fine-Grained Sand Layer Investigation

As discussed in Section 5.6.2, probe borings were used to investigate the fine-grained sand layer, which was identified during the investigation of subsurface conditions around VMW-9. The purpose of the investigation was to evaluate the lateral and vertical extent of the fine-grained sand layer, and the concentrations of TCE in saturated soil and groundwater in the layer. Section 5.6.2 presents a detailed discussion of the investigations. The results from this investigation are summarized below:

- The fine-grained sand layer is generally 3 feet to 5 feet thick, but varies from 1 foot to 12 feet thick, and is encountered at depths ranging from 13 feet to 24 feet bgs.

- Analytical data suggest that immobile residual TCE may be present in the fine-grained sand layer in the vicinity of VMW-9 and DSI-5-40.

The highest concentrations of TCE were detected in saturated fine-grained sand layer samples collected 10 feet to 60 feet west of well VMW-9. The highest concentrations of TCE in groundwater are detected in VMW-9.

6.2.6 Treatment and Sampling Results

The details of the treatment events and verification sampling are included in the Final Groundwater Interim Action Report (Parametrix 2004b). A summary of the treatment and verification sampling results, and the analytical results for groundwater samples collected from verification wells in February 2007, is presented below.

The groundwater TCE isoconcentrations in the source area based on the baseline sampling event are shown on Figure 6-4. This represents initial conditions in the source area prior to any treatment. Baseline data were used to define two areas with TCE concentrations exceeding 10,000 µg/l:

- A small area centered around VMW-2
- An area defined by DSI-6-40, VMW-8, SSI-9-40 and SSI-10-40

After seven rounds of treatment, the water quality data indicated that the majority of the source area had TCE concentrations less than 10,000 µg/l. The exception is the area defined by DSI-6-40, VMW-8 and VMW-9. The groundwater TCE isoconcentrations for the March 2002, March 2003, and February 2005 sampling events are shown on Figures 6-5 through 6-7. TCE concentrations remained above 10,000 µg/l near DSI-6-40 and VMW-9, even after several of the treatment events were focused on that area.

Groundwater samples were collected from specific source area treatment wells in February 2007 to evaluate VOC concentrations. Groundwater TCE isoconcentrations in the source area are shown on Figure 6-8. The data indicate that TCE concentrations have decreased in most wells located near VMW-9 since the last treatment event in October 2004. Only one small area remains with TCE concentrations in groundwater greater than 10,000 µg/l.

The groundwater interim action has met the RAO and has treated groundwater in the source area to the extent feasible by direct injection technology. Additional remedial actions in the source area will be evaluated in the FS.

7. GEOLOGIC/HYDROGEOLOGIC CONDITIONS

Information regarding geologic and hydrogeologic conditions in the project area has been obtained primarily through the completion of borings and monitoring wells during the SMC, Cadet, and ST Services investigations, described in Section 5, and data collected to further refine the Port's groundwater model, described in Section 8.

Information collected in the project area since completion of the 2002 RI Report has led to refinement of the interpretation of geologic and hydrogeologic conditions in the project area, including:

- Definition of hydrogeologic units based on geologic conditions
- Refinement of spatial relationship of hydrogeologic units
- Redefinition of groundwater zones

In the 2002 RI Report, hydrogeologic conditions were discussed primarily in terms of groundwater quality zones.

This section describes regional geologic and hydrogeologic conditions to provide a context for local conditions in the project area. Figure 7-1 presents a comparison of the regional and project area geologic and hydrogeologic units. As shown on Figure 7-1, two regional hydrogeologic units are identified in the project area, the unconsolidated sedimentary aquifer (USA) and the Troutdale gravel aquifer (TGA). Three groundwater zones (shallow, intermediate, and deep) were established during the early phase of the RI to describe the distribution of contaminants in the project area. Wells identified as deep are screened either in the USA or the TGA. While the use of groundwater zones is still useful for discussing contaminant distribution in the project area, they are now only applied to the USA. These zones have been modified to reflect different depositional units and are now based on mean sea level (MSL) rather than feet below ground surface reference. The use of MSL data for evaluation of the hydrogeologic zones corrects for surface elevation differences. The surface elevations in the project area range from approximately 25 to 80 feet MSL. The surface elevation in the vicinity of the SMC site is approximately 30 feet MSL.

It should be noted that a "TGA and Deep USA White Paper, SMC and Cadet Sites" (Parametrix 2008) discussing both geologic and hydrogeologic conditions as it relates to TCE contamination in the deep USA and TGA was prepared at the request of Ecology to support the conclusions in this Final RI Report. An electronic copy of TGA and Deep USA White Paper is included on the compact disk in Appendix K.

7.1 REGIONAL CONDITIONS

The 2002 RI Report included a detailed description of the geologic and hydrogeologic conditions in the site area. Regional geologic and hydrogeologic conditions were further examined to develop a conceptual model for the project area. United States Geologic Survey (USGS), City of Vancouver, Clark County, and City of Portland water supply-related reports were used to develop the regional conceptual model. The model's regional geologic framework and groundwater system are based on the geologic setting described and the nomenclature used in the USGS water resources investigation report, Description of the Hydrogeologic Units in the Portland Basin (Swanson et. al. 1993). The Groundwater Model Summary Report (Parametrix 2004d) describes the regional conceptual model and presents a detailed discussion of geologic and hydrogeologic units in the region and their presence in the project area.

7.1.1 Geologic Units

Three geologic units have been encountered in investigative borings completed in the project area (Figure 7-1). From shallow to deep, these depositional units are Quaternary alluvium deposits, Pleistocene catastrophic flood deposits, and the Pleistocene Troutdale Formation. A description of these units, as used in the regional conceptual model, is presented below.

Quaternary alluvial deposits of very poorly consolidated silt, sand, and clay have been deposited in the floodplains of the Columbia River. These deposits are present from ground surface to depths typically ranging from 30 to 60 feet bgs. In the Vancouver Lake lowland area the alluvial deposits include two subunits, an upper subunit consisting of silt and a lower subunit consisting of fine sand. These subunits are regionally extensive but may be locally absent in some areas of the lowland (Pacific Groundwater Group 2002a).

Catastrophic floods, caused by repeated periodic failures of ice dams impounding huge lakes in Montana and Idaho during the Pleistocene age, led to the deposition of large quantities of Pleistocene-aged sediments. Sediments associated with these catastrophic floods were deposited on an erosional surface of the Pleistocene-aged Troutdale Formation sediments. In southern Clark County, these episodes of flooding deposited basaltic sand and gravel with varied amounts of cobbles and boulders.

The Pleistocene-aged Troutdale Formation sediments are, in turn, deposited on top of an erosional surface of Tertiary-aged Sandy River Mudstone and the Troutdale Formation. The Pleistocene section of the Troutdale Formation generally consists of cemented basaltic gravel, with quartzite pebbles in a micaceous silty sand matrix and some silt or clay lenses.

7.1.2 Hydrogeologic Units

There are two regional hydrogeologic units in the project area; the unconsolidated sedimentary aquifer (USA) and the underlying Troutdale Gravel Aquifer (TGA). As shown on Figure 7-1, the USA occurs in material associated with the saturated portions of the Quaternary alluvium deposits and the Pleistocene-aged catastrophic flood deposits. The TGA occurs in the Pleistocene-aged Troutdale Formation. These two aquifers are part of the Portland Basin upper sedimentary subsystem described in the regional conceptual model (Parametrix 2004d). A description of these hydrogeologic units, as used in the regional conceptual model, is presented below.

The TGA and overlying USA consist of coarse-grained materials, predominantly sands and gravels that can be difficult to differentiate. The method of differentiation is commonly based on drilling conditions, groundwater production, and/or the presence of cementation or a silty sandy matrix. The Troutdale Formation was exposed to a period of erosion prior to deposition of unconsolidated sediments through catastrophic flooding events. Due to this erosion, the top of the Troutdale Formation has an uneven and undulating surface. The base of the USA is most commonly identified by the transition to the underlying conglomerate or consolidated/semi-consolidated silty sandy gravel of the Pleistocene-aged Troutdale Formation. For the Port’s regional conceptual model, the top of the TGA was interpreted where harder drilling conditions were encountered and/or the presence of cementation or a silty sandy matrix was encountered. The contact between the TGA and the overlying USA is also marked by a permeability contrast. Although both aquifers are permeable and productive, the USA is considerably more productive due to its higher permeability. Due to consolidation and the higher percentage of fine-grained material, the permeability of the underlying TGA is lower than that of the USA by at least one order of magnitude (McFarland and Morgan 1996). A decrease in water production is usually observed when the TGA is encountered.

The Quaternary alluvium deposits, which overlie the catastrophic flood deposits, consist of very poorly consolidated silt and sand. The alluvium deposits are partially saturated and have a lower permeability than the underling catastrophic flood deposits. The saturated portion of the alluvium deposits is considered to be part of the USA.

7.2 LOCAL CONDITIONS

The 2002 RI Report included a detailed description on the geologic and hydrogeologic conditions in the project area. Since the 2002 RI Report, additional borings and monitoring wells have been completed at the SMC site and the nearby Cadet and ST Services sites. Information obtained from borings and wells completed as part of the investigation of these three sites has been used to further define the geologic and hydrogeologic conditions in the project area. Figure 7-1 shows the relationship of lithologic units identified in the project area with respect to the regional geologic units. The presence, distribution and permeability of these lithologic units can differ significantly throughout the project area and can influence the distribution of contaminants in the area (Section 10). The relationship of project area lithologic units to project area groundwater zones is described in this section.

7.2.1 Geologic Conditions

The distribution of lithologic units in the project area was defined using information from boring logs for investigative borings and monitoring wells drilled as part of the investigations completed at the SMC, Cadet, and ST Services sites. A series of cross sections was constructed to further evaluate the distribution of lithologic units in the project area. Figure 7-2 shows the orientation of three cross sections that have been completed for the project area. Cross sections D-D’, E-E’, and E’-E” are shown on Figures 7-3, 7-4, and 7-5, respectively.

Consistent with regional conditions, three geologic units have been identified in the project area, including Quaternary alluvium, catastrophic flood deposits, and the Troutdale Formation. Investigative borings completed as part of the SMC, Cadet, and ST Services investigations have fully penetrated the alluvium and catastrophic flood deposits, but not the Troutdale Formation. Additional details for these three geologic units are provided in this section.

7.2.1.1 Alluvium

This unit is the uppermost geologic unit in the project area and includes fill material and Quaternary alluvial deposits. The unit consists of very fine sand with variable amounts of silt, and can range from fairly clean sand to silty clay. The alluvium deposits do not contain gravel, and generally range in thickness from 10 to 55 feet in the project area. Table 7-1 summarizes the thickness of the alluvium encountered in borings completed as part of the SMC, Cadet, and ST Services investigations.

The Quaternary alluvial deposits in the project area primarily consist of two main subunits; a lower sand subunit and an upper silt subunit. In the area adjacent to the Columbia River, two localized subunits have been identified; these represent overbank flood deposits and dredge fill. The variability in fines present in the Quaternary alluvial deposits influences the rate at which groundwater passes through the material, as well as the transfer and movement of soil gas. These four subunits, from youngest to oldest, are described below.

Sand 2 (dredge fill) – Sand 2 is assumed to be primary dredge fill deposits. It is present in the southern portion of the project area, adjacent to the Columbia River, as shown on Figures 7-4 and 7-6. Sand 2 overlies Silt 2 and is generally better sorted than Sand 1, but in places contains variable amounts of silt.

Silt 2 (overbank deposits) – This alluvial subunit is present along the Columbia River, generally in the same area as Sand 2 (Figure 7-6). Silt 2 is considered to represent river overbank flood deposits, which are thicker, interbedded, and can contain more clayey material than the Silt 1 subunit observed further away from the Columbia River.

Silt 1 (lowland area upper subunit) – Silt 1 is the same as the upper alluvium subunit referred to in Section 7.1.1. As summarized in Table 7-1, Silt 1 is generally present throughout the project area. However, Silt 1 does not appear to be present in the vicinity of the ST Services site (Figure 7-4). Silt 1 is stratigraphically similar to Silt 2, is generally described as brownish silt, and appears to have been deposited throughout most of the Vancouver Lake lowlands area. Silt 2 is generally denser and was deposited adjacent to the Columbia River by seasonal flood events.

Sand 1 (lowland area lower subunit) – This alluvium sand subunit is present throughout the project area and is same as the lower alluvium subunit referred to in Section 7.1.1 (Figures 7-3 and 7-5). Sand 1 contains variable amounts of fines and is described in places as silty sand. This subunit overlies the catastrophic flood deposits and can be differentiated from those deposits by its lack of gravel.

7.2.1.2 Catastrophic Flood Deposits

This unit consists predominantly of medium- to coarse-grained sand with gravel. The gravel can be coarse, ranging up to cobbles 6 inches or greater in diameter. These deposits are associated with the Late Pleistocene catastrophic floods of the Columbia River. This material was deposited throughout the project area and underlies the Quaternary alluvium. Due to the generally coarse nature of these deposits and the general lack of fines, these deposits are highly transmissive.

As shown on Figure 7-1, three catastrophic flood deposit subunits units have been identified in the project area; these subunits are described below.

Sand and Gravel – This subunit consists of sand with gravel to gravel with sand that consists of basaltic material. It underlies the alluvium deposits and is present throughout the project area (Figures 7-3 and 7-5). The sand and gravel subunit is not cemented and is usually loose. Little to no fines are present in the unit.

Channel Fill – This subunit consists of sand with only trace amounts of gravel. When present, it underlies the sand and gravel subunit. Sand in the channel fill subunit ranges from fine to coarse grain in size. Channel fill deposits are usually well graded, but can also be poorly graded with silt zones, and include small lenses of gravel. The channel fill subunit has been deposited in an erosional trough in the Troutdale Formation located beneath the SMC and Cadet sites (Figures 7-3 and 7-5). The approximate extent and thickness of the channel fill deposits are shown on Figure 7-7.

Re-Worked Troutdale Formation Material – The sandy gravel subunit overlies the Troutdale Formation and is interpreted to be re-worked Troutdale Formation material. It is usually described as gravel with sand or sand with gravel. The type and range of material in this subunit is fairly variable. The size of clasts can range from small gravels up to cobbles; its matrix can range from sand to silt, and it is generally described as poorly sorted. It consists mostly of basalt clasts and sand, but in places contains quartzite clasts and/or a micaceous matrix. The sandy gravel subunit is generally not cemented, but indications of cementation can be observed prior to encountering the underlying Troutdale Formation. The sandy gravel subunit is not consolidated like the Troutdale Formation. Re-worked Troutdale Formation material appears to be less prevalent or not present in the area of the ST Services site and east of Kotobuki way (Figures 7-3, 7-4, and 7-5).

7.2.1.3 Troutdale Formation

The Troutdale Formation encountered at the site consists of well graded, cemented to semi-consolidated sandy gravel with varying amounts of sand, silt, and clay. The gravel clasts can range up to 8 inches in diameter and generally consist of basalt and quartzite. The matrix usually consists of brown to green fine-grained silty sand with varying amounts of silt and clay, and is usually abundant with mica. The Troutdale Formation underlies the catastrophic flood deposits throughout the project area. It is distinguished from the catastrophic flood deposits by the presence of cementation, consolidation, quartzite clasts, and a silty matrix containing mica. In places it can be difficult to distinguish the Troutdale Formation from the re-worked Troutdale Formation material subunit. A noticeable reduction in water production is another characteristic that can be used to distinguish the Troutdale Formation from the overlying catastrophic flood deposits.

As shown on Figure 7-8, the elevation of the top of the Troutdale Formation varies substantially in the project area. Table 7-2 identifies the elevations where the Troutdale Formation was encountered in deep monitoring well borings. Mapping the top of the Troutdale Formation in the project area defines the erosional trough or low area beneath the SMC and Cadet sites. The presence of an erosional feature incised into the Troutdale Formation was identified in the 2002 RI Report. The deepest portion of the erosional trough appears to occur beneath the SMC and Cadet sites. The lowest elevation of the top of the Troutdale Formation has been encountered at SMC well MW-13d, northwest of the SMC site (Figure 7-3). The top of the Troutdale Formation was not encountered at deep borings CM-MW-1d, CM-MW-2d, and possibly at CM-MW-3d, which were completed adjacent to the Cadet site. It is therefore possible that the top of the Troutdale Formation may be present at greater depths beneath the Cadet site. The top of the Troutdale Formation rises very steeply directly east of the SMC site (Figures 7-3 and 7-8), and rises relatively steeply to the southwest of the SMC site (Figure 7-8). The highest elevation of the Troutdale Formation in the project area occurs just east of Kotobuki Way at well MW-16d. As shown on Figures 7-3 and 7-8, the erosional trough located beneath the SMC and Cadet sites was filled by the channel fill deposits, which pinch out in the areas where the elevation of the top of the Troutdale Formation is higher. The top of the Troutdale Formation appears to be present beneath the southern portion of the ST Services site at approximately -80 feet MSL (Figure 7-8).

The elevation of the Troutdale Formation rises slightly north of the ST Services site, where it is present at an elevation of approximately -65 feet MSL. Descriptions of sedimentary deposits encountered at deep borings ST-CMT-1, MW-32i and MW-31i, completed north of the ST Services site, provide conclusive information regarding the presence of the Troutdale Formation. The boring logs for deep borings ST-MGMS-1, ST-MGMS-2 and ST-MGMS-3 completed at the ST Services site, however, do not provide sufficient detail to allow conclusive determination of the presence or absence of the Troutdale Formation beneath the ST Services site.

Upriver of the ST Services site, in the area of the GWM/Port wellfield, the top of the Troutdale Formation is encountered at an elevation of approximately -100 feet MSL. It is possible that the Troutdale Formation beneath the ST Services site was eroded as part of an ancestral river channel and then backfilled with a sand and gravel deposit.

7.2.2 Hydrogeologic Conditions

Two regional hydrogeologic units, the USA and the TGA, have been identified in the project area. The uppermost aquifer in the project area is the USA (Figure 7-1). It occurs in the alluvial and catastrophic flood deposits present in the Vancouver Lake lowlands area. Based on a review of geologic information obtained during the SMC, Cadet, and ST Services investigations, three groundwater zones have been established for the USA. Underlying the USA is the TGA. The TGA occurs in the consolidated to semi-consolidated Troutdale Formation. A confining layer or *aquitard* separating the two hydrogeologic units has not been observed during the RI or reported in documents reviewed during the investigation.

The distinction between the USA and the TGA is based on differences in the geologic units; specifically, the overall permeability of the USA is at least one order of magnitude greater than the permeability of the TGA (McFarland and Morgan 1996). Consequently, groundwater flow conditions in the USA differ from conditions in the TGA. In addition, groundwater flow conditions within the three zones of the USA differ due to permeability contrasts between the alluvium and the catastrophic flood deposits.

The following sections describe the hydrogeologic conditions of the three USA groundwater zones and the TGA in the project area.

7.2.2.1 Unconsolidated Sedimentary Aquifer

Regionally, the USA receives recharge primarily from precipitation. In the project area, the USA also receives recharge from the Columbia River or discharges to the river, depending upon relative river stage conditions. In the project area, the flow of groundwater in the USA is dominated by pumping at the GWM site. Water levels in the USA respond quickly to changes in the Columbia River stage, indicating that the river is in direct hydraulic connection with the USA. This rapid response is attributed to the proximity of the river and the high hydraulic conductivity of the USA. These dynamic conditions make it difficult to define groundwater flow direction based on water level measurements.

As previously discussed, three groundwater zones have been established for the USA based on observed geologic conditions (Figure 7-1). During the course of the RI, groundwater zones were adopted to evaluate and describe groundwater quality and groundwater flow trends. These zones were used to facilitate understanding of the hydrogeologic system and were originally defined by groundwater quality conditions observed during early phases of the RI. The installation of monitoring wells at the SMC site applied a nomenclature to identify the zone being monitored. Wells designated with an “i” are intermediate wells, while wells designated with a “d” are deep wells. The designation “s” or no designation indicates a shallow well. This designation method has also been applied at the nearby Cadet site and, to a lesser extent, at the ST Services site.

Based on the presence and distribution of the alluvial and catastrophic flood deposits in the project area, the groundwater zone classification system has been retained but modified, and is now applied only to the USA. As shown on Figure 7-1, the groundwater zones for the USA are as follows:

- Shallow USA groundwater zone: This zone extends from the ground surface to -10 feet MSL. The shallow groundwater zone of the USA primarily corresponds to the alluvial deposits.
- Intermediate USA groundwater zone: This zone extends from -10 feet MSL to -100 feet MSL. The intermediate groundwater zone of the USA primarily corresponds with the catastrophic flood sand and gravel deposits. This zone can also include a portion of the channel fill deposits and re-worked Troutdale Formation material.
- Deep USA groundwater zone: This zone extends below -100 feet MSL. The deep groundwater zone of the USA primarily corresponds with the channel fill deposits and re-worked Troutdale Formation material.

Characteristics of the three groundwater flow zones within the USA are discussed in more detail below.

Shallow USA Zone

The shallow USA zone extends to a depth of -10 feet MSL and consists of the alluvial deposits. In areas where it is thinner, the shallow USA zone can extend into the upper part of the sand and gravel subunit of the catastrophic flood deposits. Table 7-3 presents a completion summary of the SMC site monitoring well network, including the aquifer and groundwater zone monitored by each well. As indicated in Table 7-3, 30 of the 38 shallow monitoring wells at the SMC site are screened in alluvial deposits. The remaining eight shallow wells are screened in catastrophic fill deposits.

The alluvial deposits contain greater amounts of finer material than the underlying catastrophic flood deposits. Consequently, the transmissivity of the alluvial deposits is notably lower than underlying sand and gravel deposits. Due to the overall presence of finer material with notably lower permeability, the distribution of contaminants in the shallow USA zone can differ from the distribution of contaminants in the underlying catastrophic flood deposits. The distribution of contaminants is discussed in Section 10.

Groundwater flow in the shallow USA zone at the SMC site is toward the southeast. Contaminant distribution shows high concentrations of solvents in groundwater at the SMC source area, decreasing with distance southeast (i.e., downgradient) of the source area (Section 10). Potentiometric contour maps based on water level measurements from shallow monitoring wells also indicate a southeastern flow direction in the shallow USA zone in the project area. Groundwater flow model results indicate that flow in the shallow USA zone is primarily influenced by pumping occurring at the GWM site. The flow direction at the Cadet site is similar, based on the distribution of contaminants, potentiometric contour maps and modeling.

Recharge of the shallow USA zone is from precipitation and the river. Groundwater flow in the shallow USA zone in the area of the ST Services site has been observed to fluctuate toward or away from the river in response to river stage changes (Ash Creek 2006a). A groundwater divide appears to exist much of the time within the shallow USA zone beneath the ST Services site. North of the groundwater divide, flow is generally toward the north/northeast, but the flow direction south of the groundwater divide appears to be toward the river (Ash Creek 2006a). Due to the presence of overbank deposits (Silt 2) and dredge fill deposits (Sand 2) at the ST Services site, the influence of pumping at GWM is less than at the SMC and Cadet sites. As a result of these conditions at the ST Services site, groundwater flow in the shallow USA zone can also be toward the river (Ash Creek 2006a).

Intermediate USA Zone

The intermediate USA zone extends from -10 feet to -100 feet MSL and corresponds to the catastrophic flood deposits. As indicated in Table 7-3, there are 19 intermediate USA zone monitoring wells at the SMC site. Nine are screened in the sand and gravel subunit; seven are screened in the channel fill subunit; and two are screened in re-worked Troutdale Formation material.

The catastrophic flood deposits are more permeable than the overlying alluvial deposits or the underlying TGA. Based on well log descriptions, the sand and gravel subunit is the most permeable sedimentary unit in the USA (Mundorff 1964). Consequently, the rate of groundwater movement is greatest in the intermediate USA zone. Water supply wells located at GWM produce from the intermediate USA zone. Due to the combination of highly transmissive deposits and extraction of groundwater from the same zone, the rate of groundwater flow is notably higher in the intermediate USA zone than in the zones above and below.

Based on the distribution of contaminants in the vicinity of the SMC source area, groundwater flow in the intermediate USA zone at the SMC site is initially toward the southeast, and then becomes southerly approximately 1,500 feet east of the site. Based on contaminant distribution, the overall flow direction at the Cadet site appears to be similar. Potentiometric contour maps based on water level measurements collected from intermediate monitoring wells also indicate a southeastern and southern flow direction toward the GWM production wells. Groundwater flow model results also indicate that flow in the intermediate USA zone is highly influenced by pumping occurring at the GWM site and that flow is toward these production wells (Figure 7-9). As discussed in Section 7.3, recharge of the intermediate USA zone is primarily from the river. Consequently, groundwater flow in the intermediate zone in the area of the ST Services site is toward the north and northeast.

Evidence of this groundwater flow is supported by stable hydrogen and oxygen isotope data (Tables 9-1, 9-2, and 9-3). Recharge of the intermediate USA zone from the Columbia River is clearly seen in stable isotope vertical profiles from the three multi-port wells adjacent to the shoreline at ST Services (ST-MGMS-1, -2, and -3). Sample ports screened at elevations lower than 6 feet MSL have significantly lower stable oxygen and hydrogen isotope ratios than local precipitation. The lowest ratios (generally occurring between -26 and -76 feet MSL) fall within the range observed locally for the Columbia River. In the intermediate USA, river-like isotope signatures are observed at upland locations up to several hundred feet from the shoreline (e.g., ST-MW-18i, MW-29i). Further inland, isotope ratios gradually increase to values representative of local precipitation, reflecting increasing dilution of the river-derived groundwater by precipitation recharge. Thus, the stable oxygen and hydrogen data support the northerly flow of groundwater from the ST Services site. A more detailed discussion of the isotope data is presented in Section 9.

Deep USA Zone

The deep zone of the USA extends below -100 feet MSL. Based on the top of the Troutdale Formation as shown on Figure 7-8, the deep USA zone in the project area is primarily present in the Troutdale Formation erosional trough. The deep USA zone corresponds to channel fill deposits and re-worked Troutdale Formation material. However, as indicated in Table 7-3, all seven SMC site deep USA zone monitoring wells are screened in re-worked Troutdale Formation material.

Based on well log descriptions, the channel fill deposit and the re-worked Troutdale Formation material are permeable, but do not appear to be as permeable as the sand and gravel subunit of the intermediate USA zone. Both the channel fill deposits and the re-worked Troutdale Formation material are more permeable than the underlying consolidated to semi-consolidated Troutdale Formation that makes up the TGA. The rate of groundwater movement is anticipated to be lower in the deep USA zone due to the zone's location primarily in the erosional trough, the lower influence of pumping stresses from the GWM production wells, and the lower overall permeability of the material that makes up the deep USA zone.

The direction of groundwater flow in the deep USA zone is toward the GWM production wells, based on model results. However, potentiometric contour maps based on water level measurements from the deep wells do not indicate a clear or consistent groundwater flow direction. Rather, these maps suggest that groundwater in the deep USA zone flows in different directions at different times, and usually does not flow consistently at all measurement points.

Stable hydrogen and oxygen isotope data for the deep zone show a bimodal distribution. The two data populations are characterized by isotope values indicative of (1) local precipitation and (2) a mixture of local precipitation and Columbia River water. Groundwater samples collected from wells screened in the TGA generally have isotope values indicative of local precipitation. Groundwater samples collected from wells screened in the deep USA zone generally have isotope values indicative of a mixture of local precipitation and river. These results suggest that groundwater flow in the deep USA zone is away from the river, consistent with the flow direction for the intermediate USA zone. A more detailed discussion of the isotope data is presented in Section 9.

7.2.2.2 Troutdale Gravel Aquifer

The TGA is associated with the Troutdale Formation, which underlies the catastrophic flood deposits and alluvial deposits that make up the USA in the project area. The top of the Troutdale Formation varies noticeably, and the presence of an erosional trough has been identified. There are three SMC monitoring wells that are screened in the TGA (Table 7-3). These three wells are all located in the eastern portion of the project area in a north/south orientation between the SMC site and GWM. As indicated in Table 7-2, there are seven additional wells in the project area that are screened or have a monitoring port that is screened in the TGA.

The permeability of the TGA is a least one order of magnitude lower than the USA (McFarland and Morgan 1996). This is due to the presence of more fines in the Troutdale Formation and the extent of its lithification/cementation, which ranges from consolidated to semi-consolidated. The combination of lower permeability and lack of groundwater extraction from the TGA in the project area produces much lower flow rates in the aquifer than those in the overlying USA. There is hydraulic connection with the USA due to a lack of a confining layer. Water level measurements collected from TGA and deep zone USA wells do not indicate a noticeable difference, which suggests that the two aquifers are hydraulically connected. It is anticipated that the TGA would exhibit similar river response behavior as the USA, but would be more attenuated due to its lower permeability and the fact that it appears not to be in direct contact with the river (i.e., the USA is situated between the river and the TGA).

Based on water level measurements, the flow pattern in the TGA is variable. However, the groundwater flow model results indicate that the flow pattern in the TGA is similar to the flow pattern observed in the USA, toward GWM production wells. The rate of groundwater flow is lower in the TGA due to its lower permeability and its relationship to withdrawal points (i.e., production wells).

7.2.2.3 SMC Site Monitoring Well Network

Table 7-3 presents a completion summary of the SMC site monitoring well network, including the aquifer and groundwater zone monitored by each well. The SMC monitoring well network consists of:

- Thirty-eight shallow zone USA wells. Four of these wells function as piezometers (P-1 through P-4) and one has been decommissioned (MW-22).
- Nineteen intermediate zone USA wells.
- Seven deep zone USA wells.
- Three TGA wells. One well is designated an "i" well (MW-15i).

In addition to the three SMC wells screened in the TGA, there are four Cadet site wells screened in the TGA, and two wells with monitoring ports at the ST Services site that appear to be screened in the TGA (Table 7-2).

7.2.2.4 Potentiometric Mapping

The potentiometric surfaces of the USA and the TGA are flat in the project area. These flat potentiometric surfaces are caused by a combination of setting (the project area is situated in a topographically flat floodplain adjacent to a large river) and geologic conditions (presence of permeable unconsolidated and consolidated sedimentary deposits). Water levels from monitoring wells in the project area show an efficient response to river stage changes. Columbia River stage is influenced by tidal fluctuations, dam releases, and seasonal changes. Water levels in the wells quickly rise and fall in response to corresponding changes in river stage. Consequently, the development of potentiometric maps based on manual water level measurements has the potential for error, which becomes greater as the time between measurements becomes greater. Therefore, during the fall of 2006, groundwater flow analysis was completed in the project area. The analysis findings are summarized in Section 7.3.

7.3 GROUNDWATER FLOW ANALYSIS

Data collected during the RI indicates that determination of groundwater flow in the project area based on single sets of water-level measurements (particularly manually collected) may not be accurate and may potentially result in misinterpretation due to fluctuations of the Columbia River. Stage levels of the Columbia River change throughout the day in response to tidal fluctuations, dam releases, and regional precipitation. A transducer study was completed in the fall of 2006 to evaluate groundwater flow conditions in the Columbia River Lowlands with a focus on the project area. This data were used to calibrate the transmissivity of the groundwater flow model and to evaluate groundwater flow in the project area. The findings of the 2006 transducer study, groundwater flow conditions based on the transducer data, and use of the transducer data to refine the groundwater flow model are discussed below.

7.3.1 Transducer Study

A transducer study was completed from October to December 2006 in coordination with CPU to further define groundwater gradients in the Columbia River Lowlands, with a focus on the project area. The objective of the study was to obtain water-level data that could be used to calibrate the transmissivity of the intermediate USA zone in the POV groundwater flow model (Parametrix 2006e). The intermediate USA was selected because it is the highly permeable portion of the USA and includes most of the transmissivity in the Columbia River lowlands. The overall transmissivity of the Columbia River Lowlands includes the transmissivity of the shallow sand and silt deposits and the TGA. However, the shallow deposits, and the TGA contribute considerably less transmissivity than the gravel and sand deposits of the intermediate USA.

7.3.1.1 Data Collection and Analysis

The transducer study included collecting water level data from transducers installed in wells and surface water gages. Specific field tasks included:

- Installation of water-level transducers in 12 intermediate SMC/Cadet monitoring wells.
- Continued operation of four intermediate CPU monitoring wells instrumented with water-level transducers.
- Installation of transducers by CPU in four non-operating supply wells located to the west, north, and east of the SMC/Cadet project area to increase aerial coverage.
- Continued operation of the CPU gage and transducer on Vancouver Lake (Sailing Club gage and transducer).
- Collection of Columbia River stage levels at the I-5 bridge gaging station owned and maintained by the National Weather Service. The Corps of Engineers funds the USGS to collect and archive data from this gage station (USGS station 1414700).
- A survey of all wells and gage locations used in the transducer study. This surveying effort was arranged through CPU and completed by Hagedorn, Inc. using Clark County-certified benchmarks. All locations were surveyed using the NGVD 29 datum elevation with the 1947 adjustment.

The locations of instrumented wells and gages included in the transducer study are shown on Figure 7-10. The transducer study period was October 19, 2006, to December 7, 2006. Water level measurements were collected from all locations at 15-minute intervals. Manual water level measurements were collected weekly at transducer locations to evaluate instrument drift or error.

Pumping rates for production wells in the model area that were operational during the study were obtained for the City of Vancouver water station wells, the CPU generator plant well, COV's Westside Wastewater Treatment Facility well, Great Western Malting (GWM) production wells, and Port of Vancouver production wells.

Analysis of the transducer data consisted of the following steps:

- Correct data for observed drift, if necessary.
- Correct data for barometric pressure.
- Compute water level from surveyed measuring point elevation.

The data was plotted to identify the presence of outlier wells, spikes in data, errors in recording, or other anomalous readings. Columbia River stage data obtained from USGS station 1414700 (I-5 bridge) was obtained for the study period. The datum of this gage as indicated by the USGS station is the Columbia River Datum. The USGS gage data was adjusted +1.82 feet, as indicated by the USGS station description, to correct to the NGVD 29 with the 1947 adjustment datum. However, Hagedorn's survey of the station's gage datum, indicates that an additional correction of +0.079 feet was required to make the datum consistent with the transducer survey datum. It was also determined that the Corps of Engineers reports river stage data from the I-5 bridge site 0.05 feet higher than the USGS. The USGS recorded stage was used during the data review and analysis discussed below. These corrections constitute data validation of the transducer data. Appendix F includes a technical memorandum presenting a summary of the transducer data to be used for model transmissivity calibration.

7.3.1.2 Data Review

Figure 7-11 is a time series plot of water levels for all groundwater and surface water level locations monitored as part of the transducer study. As shown on the figure, the river is at a base level from the start of the study period to October 31, 2006. During this period the river stage is responding primarily to tidal effects. Beginning on November 1, 2006, an extensive precipitation event occurred which continued until November 12, 2006. In response to this precipitation event, river stage rose and then declined, but maintained an overall higher stage level for the remaining period of the transducer study. Most of the wells used in the study show a direct response to the precipitation event. Higher river stage conditions were observed following the precipitation event to the end of the study period. Figure 7-12 shows the precipitation record for the Portland-Vancouver area during the transducer study period. The high river stage corresponds to the precipitation event.

Tidal efficiencies were computed for each instrumented well. Water level data collected from October 19, 2006, at 16:30 to October 27, 2006, at 20:15 were used. This period begins and ends at high tides of similar river stage elevation. Table 7-4 shows the average water levels and tidal efficiencies. Tidal efficiency was not computed from COV water station 1 (WS-1) Well 8 because water level fluctuations at this well are due to pumping at COV WS-1 and not due to tidal effects. Figure 7-12 shows the average water level elevations and tidal efficiency.

As shown on Figure 7-11, data from wells CM-MW-21i and the Fort Vancouver Historic Park well appear to be anomalous. Water level data collected from CM-MW-21i had the lowest average water level elevation for all wells. Water levels at CM-MW-21i appear to be less responsive to water level changes in the system even though its tidal efficiency is similar to nearby study wells. Manual water level measurements collected at CM-MW-21i were similar to transducer measurements.

Water levels from the Fort Vancouver Historic Park well had the highest water levels recorded and the lowest tidal efficiency. The water level at this well is higher than the river stage and higher than the water level at COV Water Station #1 well #8 (COV WS-1 well 8). As discussed in the Vancouver Lake Lowlands Groundwater Model Summary Report (Parametrix et al 2008), based on physical (topographic) features and water levels for the USA (McFarland and Morgan 1996), COV WS-1 and the Fort Vancouver well were determined to be located near a higher recharge zone of the northern USA recharge boundary.

7.3.2 Mean Hydraulic Gradients

Hydraulic gradients and apparent groundwater flow in the project area were evaluated by examining 72-hour periods of the transducer data. Animation of the transducer data using visualization software indicates that river stage fluctuations propagate pressure waves that travel inland at the project area. These pressure waves tend to dissipate within the project area. In an unconfined aquifer, such as the USA, the pressure wave is mostly generated from changes in storage due to dewatering and re-saturation of pores (Serfes 1991). Due to these conditions, the apparent direction of groundwater flow and its gradient are difficult to characterize because, at best, they define a point in time, not the net, or mean effect of these fluctuations. In an unconfined aquifer, groundwater fluctuations in wells only tens of feet from each other can be out of phase and rise and fall with different amplitudes (Serfes 1991). In an effort to evaluate the mean gradient in the aquifer, 72-hour periods of data were averaged using the method described by Serfes (1991). Five 72-hour periods were selected from the transducer data set. An attempt was made to select periods that were fairly evenly spaced across the data set record but also represent periods when river stage was fairly stable and generally responding primarily to tidal fluctuations (no notable rising or declining trend). The data in each of the five 72-hour periods was then filtered using the moving average method described by Serfes (1991).

Table 7-5 summarizes rolling averages calculated for each water level location for each of the five 72-hour event periods. A description of each event period is also included on Table 7-5. Straight (or standard) averages were also calculated and compared to rolling averages as shown on Table 7-5. The difference between the two averaging methods is generally within 0.1 feet, but due to the presence of a flat gradient in the project area and the Columbia Lowlands region, this difference has the potential to influence the interpretation of the direction of groundwater flow.

For each of the five 72-hour events, the calculated rolling average was placed on a regional map that included all measurement locations and on a project area map that includes only the SMC and Cadet site monitoring locations. Groundwater flow directions were identified by contouring the water level elevations and placing an arrow perpendicular to the contours. These groundwater flow direction maps are included in Appendix G.

The flow direction maps generated for the five events all indicate that the mean groundwater flow direction in the project area is toward the GWM site. The mean groundwater flow direction was from the north, northwest, and northeast toward GWM. During the transducer study period, the median pump rate at GWM was 4,016 gpm, with pumping relatively equally divided between productions wells #4 and #5. The average total pump rate of 3,796 gpm is slightly lower due to a lower pumping rate at production well #5 that occurred from October 21 to October 26, 2006. This lower pump rate occurred between 72-hour Event periods 1 and 2. GWM pump rate data during the study period are included in Appendix H.

The regional flow direction for each event was consistent with the mean groundwater flow direction observed on the project area maps. Northerly CPU well TW-4, located north of the project area, consistently had the highest mean water level elevation measured in the Columbia Lowlands area. The mean water level elevations observed at wells CPU TW-2s and Firestone South, which are located between northern Cadet monitoring locations CM-MW-18i and CM-MW-19i and CPU TW-4, are consistent with the observation that higher mean water level elevations are present north and northwest of the project area. An exception is Event 4, when the mean water level elevation at CPU TW-2s was lower than adjacent monitoring locations.

Southern well MW-19i had the lowest mean water level elevation in the Columbia Lowlands. Exceptions are CM-MW-21i and MW-26i during Event 4. Well MW-19i is located near GWM production wells #4 and #5. As indicated in the transducer data review, water levels measured at CM-MW-21i were anomalously low. The data recorded for MW-CM-21i ended on November 27th due to transducer malfunction. Of the five event periods examined, the highest mean river elevation occurred during Event 4.

During each of the five 72-hour events, the calculated rolling average of the river was higher than the calculated average water level elevation of the project area monitoring locations. Exceptions are Event 2 when the water level elevations at northerly wells CM-MW-18i and CM-MW-19i and eastern well MW-26i were higher, and Event 6 when northern well CM-MW-18i was again higher. With exception of Event 4, the only Columbia Lowland well to have a water level elevation consistently higher than the river mean water level elevation was northerly well CPU TW-4.

Groundwater flow in the intermediate USA zone in the vicinity of the SMC, Cadet, and ST Services source areas is summarized below:

- At the SMC site, the mean groundwater flow direction is to the east-southeast. East of the SMC site, the mean flow direction is predominantly to the south.
- At the Cadet site, the mean groundwater flow direction is toward the east/southeast.
- At the ST Services site, the mean flow direction appears to be generally toward the northeast. With the exception of Event 4, there is not a notable mean gradient toward the north; rather the mean groundwater gradient north of ST Services tends to be flat or slightly higher further to the north of the ST Services site. The mean river elevation is consistently higher than the mean water level elevation at MW-32i located north of the ST Services site.

Mean water level measurements for the periods evaluated are consistent with the flow direction predicted by the groundwater flow model. The mean direction of groundwater flow in the intermediate USA zone in the project area is toward the GWM production wells. Mean river level elevation compared to mean groundwater levels in the project area indicates that the river functions as a recharge boundary. The mean groundwater flow direction can change during high precipitation or runoff events that cause the Columbia River stage to rise notably, as observed during the period of November 6 through November 9. However, these high stage events represent short-period events, and the influence these events have on contaminant transport are dependent upon the length of the event and pumping conditions that are occurring at GWM during the event.

As discussed in Section 8.3, the findings of the groundwater flow analysis are being used to refine the groundwater model.

8. GROUNDWATER MODELING SUMMARY

The complete groundwater model for the SMC project area consists of a *groundwater flow model* and a *contaminant transport model*. The three-dimensional groundwater flow model was constructed as part of the RI. Output from this flow model was then applied to a contaminant transport model to predict contaminant migration from known source areas. Development of the flow and transport models was based on site-specific and regional geologic and hydrogeologic data. Model construction, calibration, and results were originally presented as part of the 2002 RI Report (Parametrix 2002a), and were more recently described in the Groundwater Model Summary Report (Parametrix 2004d).

Following completion and submittal of the March 30, 2007 Final RI Report, the Vancouver Lake Lowlands Groundwater Model Summary Report (Parametrix et. al. 2008) was completed in February 2008. This report describes additional model refinements and further calibration and validation of the model. These additional model refinements are identified in Section 8.3 below and detailed in the 2008 model report.

The groundwater flow model uses the USGS three-dimensional, finite difference MODFLOW code (McDonald and Harbaugh, 1988). The contaminant transport model uses the three-dimensional MT3D-99 code (S.S.P.A. 1999). MODFLOW and MT3D are the most widely used codes for groundwater modeling and are essentially the industry standard for simulation of groundwater flow and contaminant transport in groundwater.

The model computes groundwater flow and contaminant transport over an area defined by the model grid. The model area for the SMC model covers the entire Columbia River Lowlands, from McLoughlin Boulevard on the east to the mouth of Salmon Creek on the west. From north to south, the model extends from the south shore of the Columbia River to the top of the bluffs north of Burnt Bridge Creek. The entire model grid covers 74 square miles. The active flow model area covers approximately 42 square miles, and the active transport model area covers approximately 25 square miles. The transport model can be smaller than the flow model area to save computation time, as long as the active transport model area includes the contaminant plumes.

The hydrogeologic units within the model area are represented by layers within the numerical model. The model includes recent alluvium, the USA, and the TGA. The bottom of the model is Confining Unit 1, so the model includes the entire thickness of the Upper Sedimentary Subsystem (Section 7.2). To more accurately simulate the vertical distribution of contaminants, the USA was divided into 4 layers. Hydrogeologic units associated with each layer are presented in the following table. Some layers are split between units to account for thickness or absence of a unit. For instance, the silty alluvium in layer 1 is missing in the area of the SMC and Cadet sites.

Model Layer	Hydrogeologic Unit	
	On Site	Off Site
1	Coarse Alluvium, possibly USA	Silty Alluvium
2	Coarse Alluvium, possibly USA	Sandy Alluvium
3	USA	USA to west of site, Sandy Alluvium to east of site
4-6	USA with some Channel Sand Deposits	USA
7-9	TGA with some Channel Sand Deposits	TGA
10-17	TGA	TGA

The number of model layers was chosen to allow for a gradually increasing thickness of model layers through the TGA. Because of the thickness of the TGA, this resulted in more layers in the TGA than in the USA.

Flow model boundary conditions for the model were selected to coincide with physical (hydrologic) boundaries of the groundwater flow system wherever possible. The following boundary conditions were assigned to the regional model area:

- Specified head
- Drain
- No flow
- Specified flux

Specified head boundary cells were applied to represent Vancouver Lake, the Columbia River, and the upgradient boundary condition north of Burnt Bridge Creek. A MODFLOW drain boundary with a specified head boundary was used to represent Burnt Bridge Creek. No flow boundaries were assumed on the south and west model boundaries (south and west of the Columbia River) or for the bottom of the model. Specified flux boundaries were used to represent aerial recharge and pumping wells in the model area.

The model extends to approximately the limits of the USA in the Columbia River Lowlands to the east and northwest and to the Columbia River on the west and south. Where the model could not be extended to hydrologic boundaries to the east and northwest, the model was extended sufficiently far in both directions to provide reasonable assurance that model predictions of contaminant migration at the SMC site are not affected by these boundaries due to the distance from the boundary to the site or the limited extent of the USA in these directions. The only place that the model does not extend to a water body is to the north, where it instead reaches the northern extent of the USA in the Columbia River Lowlands.

Transport model boundary conditions consist of zero mass flux and constant concentration boundaries. Zero mass flux boundaries were defined along the edge of the active transport model area. Constant concentration cells were used to define the SMC, Cadet, and the ST Services source areas.

The model has been modified and refined several times since its original presentation in the 2002 RI Report. There have been two major modification events. The first event was in response to comments associated with modeling completed by Clark Public Utilities (CPU). The second event was to simulate historical groundwater flow conditions during the period when known source area releases occurred. These model modification events are described below and are also discussed in the Groundwater Model Summary Report (Parametrix 2004d). In addition to the major modification events, the results of the transducer study completed in October through December 2006 (discussed in Section 7.3) were used to refine the model. These refinements are discussed in Section 8.3.

Following submittal of the 2002 RI Report to Ecology, CPU identified the Columbia River Lowlands around Vancouver Lake as a potential water supply source. As part of their review of Ecology files, CPU reviewed the 2002 RI Report and initial model and made several comments regarding the construction and application of the model. The review effort by CPU and its consultant, Pacific Groundwater Group (PGG), represents a peer review of the model (PGG 2002b). The following is a summary of model refinements completed in response to CPU's comments and the impact of these changes on model calibration and prediction.

- The original model extended from the confluence of the Willamette and Columbia Rivers to upstream of Hayden Island. The model domain was expanded to reflect CPU's model domain (from the confluence of Salmon Creek and Lake River to approximately 2 miles upstream of Hayden Island). Result - No significant change in the calibration or results from the model.
- To evaluate the significance of a potential gradient from the river to the lake, the lake level was simulated as lower than the river level. The water level gradients between the lake and river were based on the water level elevation results in Table B-1, Appendix B of the Evaluation of Clark Public Utilities Proposed South Lake Wellfield report (PGG 2002a). Result - No significant change in the calibration or results from the model.
- In conjunction with the extension of the model domain, a surface water gradient along the Columbia River was incorporated into the model. The water level gradient was based on the water level elevation results in Table B-1, Appendix B of the Evaluation of Clark Public Utilities Proposed South Lake Wellfield report (PGG 2002a). Result - No significant change in the calibration or results from the model.
- Pumping wells at Vanalco, Boise Cascade, and City of Vancouver Water Station 4 were added in the model update. Result – No significant change in the calibration or results from the model.
- The drawdown at the Westside Wastewater Reclamation Facility (WWRF) was addressed through model refinement completed after the 2002 RI Report was issued. In the updated model, the model-to-data residual was reduced from the original value of 2.60 feet to 0.89 feet. Result - No significant change in the model.

After refining the model, no significant changes were observed between predictions made prior to and after the revisions.

To develop a more detailed representation of the groundwater flow system that could then be used to examine the migration of contaminants in the SMC site area, the following additional model refinements were completed:

- Historical water supply well use in the model area and chlorinated solvent use/release dates were used to develop an understanding of the relationship between pumping stresses and solvent releases.
- Operation of the model was changed from steady state to non-steady state (or transient) conditions to incorporate the time-dependent pumping stresses.
- The resolution of the SMC, Cadet, and ST Services site source areas was further refined using site-specific data and recently obtained off-site, depth-specific data.

8.1 HISTORICAL MODEL SIMULATION RESULTS

The groundwater flow model was used to simulate the period from 1956 to 2003. The transient simulation was made using 32 stress periods, selected based on historical pump rate information. When new wells were put into production (or ceased production) or when there were other significant changes in well production, stress periods were added to incorporate the changes in production rate. One-year stress periods were chosen beginning in 1977, when the City of Vancouver began keeping record of annual production rates at water stations. Stress periods were also chosen to correspond with the time that each of the source area facilities (SMC, Cadet, and ST Services) began operation.

Flows within the aquifer are dominated by inflows and outflows from constant head boundaries and outflows at wells. Constant head inflow and outflow boundaries include the upland boundary at Burnt Bridge Creek, Vancouver Lake, and the Columbia River. Recharge from precipitation to the model area is a relatively small input, amounting to approximately 25 percent of the total inflow.

Under natural conditions, groundwater flows in a roughly uniform pattern from the upland boundary north of Burnt Bridge Creek to the Columbia River. However, extensive groundwater pumping in the Columbia River Lowlands has significantly affected groundwater flow patterns. Inflow from the northern boundary only reaches the Columbia River to the west and north of Vancouver Lake. South of the lake, virtually all groundwater entering from the northern boundary is captured by wells, and a significant volume of the flow at wells is pulled from the Columbia River in a reversal of natural flow patterns.

The transport model was used to simulate the historical migration of chlorinated solvents from 1956 to 2003. Groundwater flow over this period was provided from the flow model simulation for the same period. The start of the simulation corresponds to the start of operations at the SMC site in 1956. The Cadet and ST Services sources began in 1964. The solvents migrated to the east and south in response to groundwater withdrawal at the GWM/Port wellfield. By 1967, three separate plumes are shown originating from the source areas at the SMC, Cadet, and ST Services sites, and the plumes originating from the SMC and Cadet sites begin to commingle south of Fourth Plain Boulevard. By 1977, the plume originating from the ST Services site is commingling with the plumes originating from the SMC and Cadet sites to the south and east of the SMC and Cadet sites. Also by this time, the plume has reached the GWM wells. Following 1977, the Cadet plume and the commingled plume broaden in response to changes in pumping at COV Water Station 1, particularly during the period from 1989 to 1999 when operation of Water Station 1 was expanded due to reduced pumping at Water Station 4. Figures 8-1, 8-2, and 8-3 show the model runs for 1967 through 2003 using the model changes discussed in the following sections.

8.2 MODEL CHANGES SINCE THE GROUNDWATER MODEL SUMMARY REPORT

The groundwater transport model was refined following publication of the Groundwater Model Summary Report (Parametrix 2004d) to address comments from Cadet concerning delineation of and concentrations associated with the Cadet, SMC, and ST Services source areas. This resulted in three changes to the transport model:

- Delineation of source areas
- Concentration in source areas
- Soil/water partitioning coefficient in the silty recent alluvium and the sandy recent alluvium

8.2.1 Source Area Delineation

The exact location of the source area(s) at each site is not known with certainty. The Cadet source area is partially located under the Cadet building. Additional investigation is currently being completed to further define the ST Services source area (Ash Creek 2006a). The SMC source area is the best defined due to its limited size and the removal of the building formerly located at the site.

To better define the source area at each site, historical soil data were used. The concentrations of PCE and TCE in the soil were interpolated over an area that encompassed the likely extent of the source area. The interpolated soil concentration data were then tabulated in descending order, and the soil concentrations were converted to a mass of TCE and PCE in soil for each interpolation point. The interpolated data were then summed to produce a running total of the mass of TCE and PCE in soil over the data set. The soil source area was defined by the area that encompassed 95% of the soil mass.

A similar approach was used to identify the groundwater source area. TCE and PCE concentrations in groundwater were interpolated over the same area as for the soil interpolation. The data were tabulated in descending order, and the same number of interpolation points that defined the soil area was used to define the groundwater source area. This yields two source area footprints for each site, one for soil and one for groundwater. The results of this analysis produced the source area delineations shown on Figures 8-4, 8-5, and 8-6.

A comparison of the soil and groundwater source area footprints indicate that the SMC site shows the strongest correlation between soil and groundwater source areas, while the ST Services site shows the weakest correlation. Ideally, the soil and groundwater source areas would match.

Lastly, the groundwater source area was mapped onto the model grid. This provides a delineation of the source area for the fate and transport model.

8.2.2 Concentration in the Source Areas

The source area concentrations in the transport model were changed in two ways:

- The concentrations were changed to represent the sum of PCE and TCE.
- The concentrations in the source areas were recomputed based on recent site data.

The model was originally constructed to simulate groundwater transport of TCE because it is the dominant VOC at the Cadet and SMC sites. There are detectable levels of PCE and very low levels of PCE/TCE daughter products on the Cadet site, but for the most part it is dominated by TCE. The ST Services site contains a mix of PCE and TCE. To account for PCE at the Cadet and ST Services sites, the source area concentration was changed to represent the sum of PCE and TCE concentrations.

The volumes and concentrations of VOCs at the time of the original releases at each site are unknown. Consequently, the initial source area concentrations input into the model were varied to produce the observed contaminant distribution. The calibration produced source area concentrations of 5,000 to 10,000 µg/l at each site. However, to make better predictions of a cleanup time frame, the historical source concentrations was modified to account for source area cleanup actions at each site. The best estimate of the source concentration for each site was taken from the interpolated source area data used to define the groundwater source area. The PCE and TCE concentrations interpolated over the groundwater source area footprint were averaged to produce an average source area concentration of PCE plus TCE. This analysis produced source area concentrations (PCE plus TCE) of 1,000, 3,600, and 8,700 µg/l for the Cadet, SMC, and ST Services sites, respectively. The computed source area concentrations reflect the level of source removal effort at the three sites. The source area concentrations at the Cadet and SMC sites, where significant source removal has occurred, are substantially less than the concentration at the ST Services site, where limited source removal has occurred.

Groundwater source area concentrations developed above were used in the model in a two-step process. First, the calibrated source area concentrations of 5,000 to 10,000 µg/l were used in the simulation of the period from 1957 to 2003. This simulation produced a representation of the historic plumes extending from the source areas to the GWM wells. In the second step, the historic plume was used as the initial concentration, but the source concentrations were changed to 1,000, 3,600, and 8,700 µg/l for the Cadet, SMC, and ST Services sites, respectively, to reflect the source area actions at each site. These initial concentrations, combinations of the historic plumes, and revised source area concentrations were used for simulation of remedial action alternatives.

8.2.3 Soil/Water Partitioning Coefficient

The soil/water partitioning coefficient, K_d, (also known as the distribution coefficient or equilibrium partitioning coefficient) is used in the model to relate the dissolved-phase concentration in groundwater to an equilibrium sorbed-phase concentration in soil. Higher K_d values indicate that higher concentrations will be found sorbed to the soil matrix than dissolved in groundwater. Implications of higher K_d values for site cleanup are twofold:

- More contaminant is sorbed to soil, which means there is more contaminant mass to clean up. For instance, if groundwater in two areas has the same concentration, but one area has a higher K_d value than the other, there will be a greater total contaminant mass in the area with the higher K_d value, even though the groundwater concentrations are the same.
- Dissolved contaminants move more slowly through the aquifer due to a greater tendency to sorb to the soil matrix, which means a longer time frame will be required to reach cleanup levels.

The K_d value used in the model was developed during model calibration. A range of K_d values was used to test which value resulted in the plume reaching the GWM wells by the early 1990s, when TCE was first detected at these wells. The calibration produced a K_d value of 0.2 l/kg for the catastrophic flood deposits. This is a reasonably low value, consistent with the low total organic carbon (TOC) concentration in the USA.

However, the silty and sandy recent alluvium is expected to have a higher TOC and consequently would have a high K_d value. The source area concentrations were used to develop an estimate for the K_d value of the silty and sandy alluvium (discussed in Section 8.2.2). The source area analysis produced soil and groundwater source area concentrations. Theoretically, if these concentrations represent soil and groundwater concentrations in equilibrium, then the ratio of the soil concentration to the groundwater concentration produces a valid K_d value. Using this approach for the groundwater source area footprint at each site, the computed K_d values range from 1.16 to 1.28. A K_d value of 1.2 was used in the model for the silty recent alluvium and the sandy recent alluvium.

8.3 ADDITIONAL MODEL CHANGES

Additional model refinements were completed during the development of this Final RI Report. These refinements were designed to incorporate recent data collection and interpretation including:

- Re-interpretation of the top of the TGA, which affects the thickness of the TGA and USA.
- Results of the tidal and river stage transducer study (Section 7.3).

Model refinements from these changes include redefinition of the number of model layers and distribution of hydrogeologic units among the layers. In addition, the transducer data was used to recalibrate model parameters using a combination of steady-state and transient calibrations.

As discussed in Section 7.3, the transducer study was designed to produce water level data at short time intervals to allow simulation of tidal influences, as well as over a longer period of time to show the effect of large changes in river stage on the aquifer. To accomplish these objectives, the study was initiated during in October 2006 when river stage was relatively stable and was dominated by tidal fluctuations. The transducer study was continued into December 2006 after recording a large increase in river stage in November 2006. The transducer study was terminated after river stage stabilized again, in early December 2006.

The results of the transducer study was used to recalibrate the POV groundwater flow model in a three-step process:

- Steady-state calibration of hydraulic conductivity and boundary conditions to average water levels prior to the rise in river stage.
- Transient calibration of storage coefficients to tidal fluctuations (and possible refinement of hydraulic conductivity and boundary conditions) during the same period used for the steady-state calibration.
- Transient validation to period of rising river stage during November.

This three-part calibration/validation process involving both steady-state and transient calibrations provides for a very robust calibration. The refinements to the model are included in the Febraury 2008 Vancouver Lake Lowlands Groundwater Model Summary Report (Parametrix, et al. 2008). The model will be used for evaluation of groundwater remediation alternatives in the Feasibility Study.

9. STABLE ISOTOPE EVALUATION

Stable isotope data can provide useful information that can be used to support or refine the site conceptual model. Compound-specific isotope analyses (CSIAs) of carbon in chlorinated VOCs in groundwater were used to further characterize and define source areas for the groundwater contamination in the project area. Stable hydrogen and oxygen isotope ratios of water were also used to evaluate sources of recharge and groundwater flow, and to provide an independent line of evidence supporting the groundwater flow model. The stable isotope data collected during various phases of the RI are summarized in Tables 9-1 through 9-3. As detailed in the following sections, the stable isotope analytical results support the conclusion that three distinct sources of contaminants (SMC, Cadet, and ST Services sites) are present in the project area.

9.1 COMPOUND-SPECIFIC ISOTOPE SIGNATURES OF CHLORINATED SOLVENTS

TCE and PCE are the prevalent groundwater contaminants in the project area. Compound-specific stable carbon isotope signatures[1] of TCE and PCE indicate that the sources of these compounds are distinguishable. Specifically, TCE from the Cadet and SMC sites is isotopically distinguishable because the ranges of carbon isotope ratios of TCE from the Cadet and SMC source areas do not overlap. Similarly, PCE from the Cadet and ST Services sites is also isotopically distinguishable because the ranges of PCE carbon isotope ratios from these sites do not overlap.

Samples were collected for CSIA of chlorinated VOCs during several groundwater monitoring events between 2002 and 2005. Sampling for CSIA took place in parallel with groundwater sampling for VOCs using low-flow purge and sample techniques, with the collection of additional sample volume for CSIA (typically 3 additional 40-mL VOA vials were collected). During 2004 and 2005, split samples were also collected by Cadet. Samples were analyzed using gas chromatography-isotope ratio mass spectrometry (GC-IRMS) at the Center for Isotope Geochemistry, Lawrence Berkeley National Laboratory (Port) and The University of Oklahoma (Cadet).

In 2002, selected Cadet and SMC wells were sampled by Cadet for CSIA for PCE, TCE, and 1,1,1-TCA (Table 9-1 and Philp 2005). The isotope data for TCE indicated distinct signatures in the Cadet and SMC source areas. Downgradient shallow and intermediate depth wells with isotope values intermediate between the two source area signatures were consistent with the existence of a commingled plume.

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[1] Stable isotope ratios for carbon are defined as:

$$\delta^{13}\mathrm{C} = \frac{R_S - R_{PDB}}{R_{PDB}} \times 1000$$

Where R denotes the ratio of the heavy to light isotope ($^{13}C/^{12}C$), and R_S and R_{PDB} are the ratios in the sample and standard, respectively. The reference standard for carbon (PDB) is calcite ($CaCO_3$), which by definition has a $\delta^{13}C$ value of 0. A positive δ value means that the isotopic ratio of the sample is higher (more of the heavy isotope) than that of the standard; a negative δ value means that the isotopic ratio of the sample is lower (less of the heavy isotope) than that of the standard. For example, a $\delta^{13}C$ value of -25 per mil means that the $^{13}C/^{12}C$ ratio of the sample is 25 parts per thousand or 2.5 % lower than that of the PDB standard.

In 2004 and 2005, additional samples were collected for CSIA from SMC, Cadet, and ST Services wells by both Cadet and the Port (Philp 2005; Vlassopoulos 2005). The data are summarized in Table 9-1. In most cases, results for split samples analyzed by both labs were within 1 per mil, although in a few cases (MW-36i, MW-37i, and MW-38i), interlaboratory differences for TCE were greater than 2 per mil. For consistency, the ensuing discussion is based on the Port's CSIA dataset. The 2004-2005 data confirmed the earlier noted difference in the isotopic signatures of TCE at the SMC and Cadet source areas. The $\delta^{13}C$ of TCE in SMC source area wells (MW-02, MW-05) ranges from -22.2 to -23.4 per mil, whereas for the Cadet source, the $\delta^{13}C$ of TCE ranges from -25.8 to -27.7 per mil (CM-MW-01d-040, CM-MW-05s, CM-MW-08s, CM-DPW-01, and CM-DPW-16). The $\delta^{13}C$ of TCE derived from the ST Services source ranges from -25.6 to 26.2 per mil (ST-MW-01, ST-MW-16, and ST-MW-18i) and overlaps with the Cadet signature (Figure 9-1). The CSIA data for PCE, on the other hand, distinguish the ST Services and Cadet sources. The $\delta^{13}C$ of PCE from the ST Services source areas range from -29.1 to -32.8 per mil, while that of PCE from the Cadet source area ranges from -23.8 to -26.0 per mil (Figure 9-2). As discussed by Slater (2003), to be able to distinguish two or more sources of chlorinated VOCs in the field, their compound-specific carbon isotope ratios must differ by at least 1.0 per mil. It is therefore possible to discriminate among all three sources by using both PCE and TCE isotope signatures (Figure 9-3).

Using these ranges for the $\delta^{13}C$ of TCE and PCE, contaminants found at a given monitoring location can be attributed to one or more of the three sources. For example, the isotope signatures of TCE in wells MW-7i ($\delta^{13}C$ = -22.3 per mil), MW-10 ($\delta^{13}C$ = -22.3 per mil), MW-16 ($\delta^{13}C$ = -23.1 per mil), and MW-21 ($\delta^{13}C$ = -22.8 per mil) are within the observed range for the SMC source, indicating that most of the TCE in these wells originated from SMC. The isotope signature of PCE in well MW-20 ($\delta^{13}C$ = -24.9 per mil) is within the range observed for the Cadet source, indicating that the PCE in this well is derived from Cadet. The TCE isotope signature in MW-20 ($\delta^{13}C$ = -24.9 to -25.3 per mil) is intermediate between the Cadet and SMC signatures, indicating a contribution from both sources. Similarly, PCE signatures in wells MW-30i ($\delta^{13}C$ = -30.8 per mil), MW-31i ($\delta^{13}C$ = -29.0 per mil), MW-32i ($\delta^{13}C$ = -29.4 per mil), and MW-33i ($\delta^{13}C$ = -29.2 per mil) fall within the observed range for ST Services. The isotope signature of PCE in well MW-28i ($\delta^{13}C$ = -28.2 per mil) indicates that it is derived from both Cadet and ST Services.

9.2 STABLE OXYGEN AND HYDROGEN ISOTOPES

The stable isotope ratios of oxygen and hydrogen in water are natural tracers that can be used to study the interaction between groundwater and surface water. This technique provides an independent means for evaluating hypotheses based on more traditional hydrologic investigations of groundwater-surface water interactions, and has been successfully applied to alluvial aquifers in the lower Columbia and Willamette River basins (MacCarthy et al. 1992; Hinkle et al. 2001).

Similar to carbon, stable isotope ratios of hydrogen and oxygen are reported as δ (delta) values in units of "per mil" (parts per thousand) relative to a standard of known composition. For oxygen, $\delta^{18}O$ refers to the $^{18}O/^{16}O$ ratio; for hydrogen, δD refers to the D/H or $^{2}H/^{1}H$ stable isotope ratio. For natural water samples, $\delta^{18}O$ and δD values are routinely determined with a precision of ±0.1 and ±3 per mil, respectively.

Selected monitoring wells at the Cadet and SMC sites and the Columbia River were sampled for oxygen and hydrogen isotopes in 2004 and 2005, and an extensive sampling of wells in the vicinity of the ST Services site was conducted in November 2005 to supplement the existing data and to fill spatial data gaps. For the 2005 event, a total of 53 well locations were sampled from both Port and ST Services groundwater monitoring networks, including 22 shallow wells, 16 intermediate wells, 4 deep wells, and 11 samples from 3 multilevel monitoring wells. The oxygen and hydrogen stable isotope data are summarized in Tables 9-2 and 9-3. Selected wells sampled in 2002 were re-sampled in 2005 to assess variability in isotope signatures over time. Oxygen and hydrogen isotope ratios between the two sampling events were found to be very similar, indicating that the groundwater system has reached a steady state under long-term pumping at GWM.

Stable isotopes are most useful in studies of groundwater-surface water interaction when there is a significant contrast between isotopic composition of surface water and local precipitation recharge. As shown on Figure 9-4, surface water in the Columbia River is more depleted in $\delta^{18}O$ and δD (-16 per mil) than precipitation runoff in the Vancouver area (-9 to -11 per mil). Stable isotope data used for Figure 9-4 are included in Table 9-2. This is due to the fact that most of the Columbia River water flowing past the Port originates from precipitation occurring further inland. Figure 9-5 illustrates the spatial variation of the isotopic composition of precipitation across Washington. In general, precipitation becomes isotopically lighter (δ values more negative) further inland. This gradient within the Columbia River basin is largely responsible for the distinct isotopic signature of the Columbia River at Vancouver as compared with groundwater recharged by local precipitation, and was a key factor in the successful application of the technique. As Figure 9-4 shows, there is a difference of more than 6 per mil in $\delta^{18}O$ between local precipitation and Columbia River water. Groundwater recharged by varying mixtures of precipitation and Columbia River water plots along a linear mixing line between the two end member waters. Both end members are derived from precipitation; therefore, they plot on the global precipitation line (GPL), as would their mixtures. A mixing trend is apparent for intermediate and most deep wells, as well as for the GWM production wells. For shallow groundwater, two groups are apparent. One group falls close to the GPL and is tightly clustered around the range of local precipitation. The second group shows a wider range of values but is generally enriched in $\delta^{18}O$ relative to the GPL (i.e., these wells plot to the right of the GPL). This trend is characteristic of water that has experienced evaporation, and could be indicative of recharge from ponded surface water.

Figure 9-6 shows the distribution of $\delta^{18}O$ in shallow wells across the project area. Stable isotope data used for Figure 9-6 are included in Table 9-2. Most of the shallow groundwater at the ST Services site and other areas is recharged by precipitation infiltration (characterized by $\delta^{18}O > -11$ per mil). A number of locations, however, are noted with relatively low $\delta^{18}O$ (< -11 per mil). For example, an irregular lobe of low $\delta^{18}O$ groundwater extends from the Cadet site eastward (CM-MW-2s, -4s, -5s, -6s, and -7s; MW-2, -7, -8, and -10). The isotopic composition in these wells cannot be explained by recharge from precipitation alone, and requires a significant component of recharge from an isotopically lighter water source, such as Columbia River water. Stable oxygen (and hydrogen) isotope ratios in most of the shallow groundwater wells to the south of these wells have signatures in the range of local precipitation (> - 11 per mil), and indicate that the isotopically light shallow groundwater areas are not due to direct river recharge.

The distribution of $\delta^{18}O$ values in the intermediate groundwater zone is shown on Figure 9-7. It is evident from the plot that intermediate depth groundwater beneath ST Services is recharged by the Columbia River. Further inland, increasing recharge from precipitation results in dilution of the river water signature, as evidenced by the gradually increasing groundwater $\delta^{18}O$ values. Also superimposed on Figure 9-7 are particle tracks representing modeled groundwater flow path lines. Wells with $\delta^{18}O$ values less than -11 per mil are located on path lines that extend upgradient to the Columbia River, indicating that a portion of the groundwater at these locations was derived from the river. Wells with $\delta^{18}O$ values between -9 and -11 per mil are located on longer path lines that often do not extend back to the river, indicating that local precipitation is the dominant source of groundwater recharge at these locations. The correlation between stable isotope data and groundwater flow modeling indicates that induced river recharge is occurring in the project area and provides conclusive evidence that the USA and river are hydraulically connected.

Stable hydrogen and oxygen isotope data for samples collected from deep wells (i.e., screened in the USA deep zone or the TGA) show a bimodal distribution (Figure 9-8). Stable isotope data used for Figure 9-8 are included in Table 9-2. Two populations of wells are apparent. One group has isotope ratios similar to local precipitation ($\delta^{18}O$ in the -10 to -11 per mil range); this group includes MW-2d, MW-13d, MW-16d, MW-17d, CM-28TGA, and CM-MW-10d. With the exception of MW-2d and MW-13d, these wells are screened in the TGA (Table 9-2). The other group has lighter isotope ratios, indicating a significant component of Columbia River water ($\delta^{18}O$ in the -14 to -15 per mil range); this group includes MW-1d, MW-5d, MW-12d, MW-14d, CMW-1d, CM-MW-5d, and CM-MW-18d. These wells are all screened in the deep zone of the USA (Table 9-2). Based on these results, it appears that river recharge is more significant in the USA than the TGA, consistent with the more permeable nature of the USA. These results also indicate that groundwater flow in the USA deep zone is away from the river, consistent with the flow direction inferred for the USA intermediate zone.

10. NATURE AND EXTENT OF CONTAMINATION

The nature and extent of contamination in the project area were determined based on the following:

- Data collected during the RI completed for the SMC site
- Geologic and hydrogeologic understanding for the project area
- Interim action findings completed for the SMC site
- Data collected during RI and interim actions completed at the Cadet and ST Services sites
- Groundwater flow and transport models

10.1 ANALYTICAL DATA

Analytical data collected during the SMC RI are summarized in Tables 5-2 through 5-21. Analytical data for depth-specific samples collected from the SMC and Cadet sites during the drilling of monitoring wells are summarized in Table 10-1. Laboratory data reports and data quality assurance review (QA/QC) information for all samples collected during the SMC RI are included in Appendix A.

The data collected during the RI, and RI activities completed for Cadet and ST Services sites, are sufficient to define the nature and extent of contamination at the SMC site and in the project area. Therefore, the RI activities are considered complete and sufficient for a Feasibility Study and selection of a site remedy.

10.2 SMC SITE SOURCE AREA

The SMC source area was identified through evaluation of soil and groundwater data and other site-specific information, such as former SMC employee descriptions of facility operations. As discussed in Section 2.3.2.1, several activities associated with degreasing operations at the SMC facility could have released TCE to the environment. The source area for the contamination was identified immediately south of former SMC building and north of former Building 2220 (Figure 2-2), where the highest soil and groundwater TCE concentrations were detected. The two primary source areas identified include:

- A vadose zone soil source found from the surface of the SMC site to the water table
- A residual TCE source located below the water table

These source areas contributed to the continued release of dissolved TCE to the groundwater prior to completing the interim actions. If left unmitigated, these sources would have continued to degrade groundwater in the project area. Therefore, two interim actions where conducted to eliminate these sources of TCE in the environment.

The interim action for vadose zone soil included excavating, stockpiling and treating the TCE-impacted soil using enhanced soil vapor extraction, as described in Section 4.0. The interim action for groundwater included in-situ oxidation treatment (Fenton's Reagent and potassium permanganate), as described in Section 6, and detailed in the Final Groundwater Interim Action Report (Parametrix 2004b). Interim actions completed at the SMC site have significantly reduced contaminant concentrations and the potential for continued degradation of groundwater. As discussed in Section 6.2, limited residual TCE remains in the source area, primarily within a relatively shallow and thin fine-grained sand layer.

10.3 CHEMICAL MARKERS

As discussed previously, the Cadet and the ST Services sites are also sources for the identified groundwater contamination. VOCs, primarily PCE and TCE, are associated with all three sites. Groundwater data, including geochemistry and stable isotope analyses, have been used to differentiate contaminants from the three source areas in the project area (Sections 8 and 9).

The chemical signatures of the three source areas are distinct. The SMC source signature is dominated by TCE. The Cadet facility source area is characterized by a mixture of TCE and PCE in approximately a 4:1 ratio. The ST Services facility source shows the greatest variability due to the effects of degradation, but is generally characterized by a mixture of PCE, TCE and cis-1,2-DCE, and in most cases is dominated by PCE and cis-1,2-DCE.

Subsurface conditions at the SMC and Cadet sites are generally aerobic, while conditions at the ST Services site are generally anaerobic and favorable for reductive dechlorination (Vlassopoulos 2005). PCE was reportedly handled in bulk at the ST Services site and is likely a constituent of the original degreasing product handled or used at the Cadet site. Cis-1,2-DCE and 1,1-DCE are degradation products of PCE and TCE.

1,1,1-TCA and its degradation products 1,1-dichloroethane (1,1-DCA) and 1,1-dichloroethene (1,1-DCE) are also present in groundwater in the project area. 1,1,1-TCA is not a degradation product of either PCE or TCE. 1,1,1-TCA appears to be associated only with the VOC plumes originating from the ST Services and Cadet sites. 1,1,1-TCA was handled in bulk at the ST Services facility. If 1,1,1-TCA were associated with the release from the SMC site, it should be detected in shallow groundwater samples at the SMC site source area. 1,1,1-TCA has not been detected at significant concentrations in shallow groundwater at the SMC site. Therefore, 1,1,1-TCA is used as chemical marker to evaluate the extent of the TCE plumes released from the ST Services and Cadet facilities.

10.4 DISTRIBUTION OF CONTAMINATION IN SOIL

TCE-impacted soil (maximum concentration of 17,000 µg/kg in the vadose zone) was detected in the vicinity of the SMC site. The TCE-impacted soil was the primary source material for impacting groundwater. Therefore, the Port completed an interim action in 1998 to remove the source material. As discussed in Section 4, approximately 13,800 yd^3 of TCE-impacted soil were excavated from the area and treated using enhanced soil vapor extraction. The treated soil was used as fill material under bridge abutments for a new Port entrance overpass that crosses the railroad tracks southwest of the SMC site or as fill material at Parcel 1A, located at Terminal 4.

Interim actions have successfully treated VOC-contaminated soil in the unsaturated zone beneath the SMC site. Analytical results for groundwater samples collected from wells in the SMC site source area suggest that residual TCE may be present in two relatively small areas of the fine-grained sand layer located in the saturated zone beneath the SMC site.

10.5 DISTRIBUTION OF CONTAMINATION IN GROUNDWATER

The analytical data collected as part of the RI are sufficient to define the extent of the chlorinated solvent plume in groundwater in the project area. Since TCE is the most prevalent contaminant in the project area, a discussion of the distribution of TCE provides an understanding of the extent of groundwater contamination. This discussion focuses on the TCE plume originating from the SMC site. However, the Cadet-sourced and ST Services-sourced plumes have commingled with the SMC site plume and reached GWM production wells, where air strippers treat the groundwater prior to use at the GWM facility. Therefore, it is necessary to discuss data collected as part of the RI activities completed at the Cadet and ST Services sites to provide a complete understanding of distribution of groundwater contamination in the project area.

10.5.1 Migration of TCE

Based on groundwater data, groundwater flow and transport models, and stable isotope data, the extent of contamination in the project area is in relative equilibrium. The configuration of the contaminant plume is not changing and the concentrations of contaminants are decreasing over time. This equilibrium in the configuration of the contaminant plume is due to historic and current operation of production wells at the GWM facility that are located in the southeastern corner of the project area.

As described in the Section 8, dissolved TCE from the SMC source area has migrated to the east and south under the influence of the WWRF, GWM and Port wells. This has resulted in a TCE plume with an east-southeast orientation that is pulled to the south primarily by pumping at the GWM wells. The majority of the TCE plume is captured by GWM wells #5 and #4. Due to pumping at GWM, TCE from the SMC and Cadet sites does not reach the Columbia River. Figures 10-1 and 10-2 show groundwater TCE isoconcentrations in the project area. These figures also show the distribution of TCE contamination from the SMC, Cadet and ST Services sites. The following sections provide further information regarding the migration and distribution of TCE in the project area.

10.5.1.1 Contaminants in the USA

The distribution of contaminants in the USA is influenced by hydrogeologic conditions in the project area (Section 7). The presence of an erosional trough containing channel sands and re-worked Troutdale Formation material, the heterogeneous nature of the USA, the interconnectivity of the USA and the Columbia River, and the influence of various pumping wells in the area create a complex flow path from the source areas to the GWM wellfield. This has resulted in a three-dimensional contaminant distribution across the project area. As discussed in Section 7.2.2.1, three groundwater zones in the USA have been defined to evaluate and describe groundwater quality in the project area:

- Shallow USA zone – from ground surface to -10 feet MSL
- Intermediate USA zone – from -10 feet MSL to -100 feet MSL
- Deep USA zone – below -100 feet MSL

The shallow zone of the USA corresponds primarily to the alluvial deposits, while the intermediate and deep zones of the USA correspond to catastrophic flood deposits.

The deep USA zone is primarily present in the area of the erosional trough, but it does extend to the river east of the ST Service site and south and east of the GWM site (Figure 10-6). However, in this part of the project area, the deep USA zone is generally less than 15 feet thick.

The distributions of contaminants detected in the shallow and intermediate USA zones are similar and are therefore discussed together. The specific sources and migration pathways of the contaminants detected in the deep USA zone are not completely understood and are therefore discussed separately.

Shallow and Intermediate USA Zones

The distribution of TCE in the shallow and intermediate USA zones is shown on Figures 10-1 and 10-2, respectively. The shallow zone of the USA corresponds to the alluvial deposits, while the intermediate zone corresponds to the catastrophic flood deposits. Figure 10-3 shows the orientations for cross sections F-F’ and G-G’, shown on Figures 10-4 and 10-5, respectively.

Dissolved TCE plumes originating from the SMC, Cadet, and ST Services sites have migrated to the GWM production wells. TCE released to groundwater at the SMC and Cadet source areas has migrated to the east and south in response to groundwater withdrawal, primarily at the GWM wellfield. TCE released to groundwater at the ST Services site has migrated to the north and northeast and eventually to the southeast in response to these same pumping stresses. The groundwater flow model indicates that pumping stresses created by City of Vancouver (COV) water stations #1 and #3, located several miles to the east and northeast of the SMC site, also have influenced the migration of contaminants in the USA.

Due to the differences in the hydrogeologic conditions (e.g., hydraulic conductivity) between the shallow and intermediate groundwater zones of the USA (Section 7.2.2.1), there is some difference in the distribution of contaminants between the two zones. This difference is due in part because the rate of groundwater movement in the intermediate USA zone is greater than in the shallow USA zone. The higher rate of groundwater movement in the intermediate zone is due to a combination of the intermediate zone’s higher transmissivity along with the withdrawal of groundwater from the intermediate zone at GWM. These conditions and the proximity of the shallow USA zone to the source areas result in higher contaminant concentrations in the shallow USA zone. In addition, the contaminant distribution is slightly less extensive in the shallow USA zone.

As shown on Figures 10-1 and 10-2, the TCE plume sourced from the SMC site has migrated in the shallow USA zone, while at the same time it has been drawn down into the more transmissive intermediate USA zone due pumping at the GWM wellfield. The resulting plume from the SMC site is relatively long and narrow in the shallow zone, with a centerline trending approximately 20 degrees south of east. A few hundred feet east of the SMC site source area, there is a “bend” in the plume, which is more defined in the intermediate zone, where it turns to the south. Contaminants migrating toward the GWM wellfield are generally not present in the shallow USA zone south of NE 20th Street, because the greatest groundwater movement occurs in the intermediate USA zone due to its higher transmissivity and pumping from the zone at the GWM wellfield. This diving behavior of the plume as it migrates away from the SMC source is shown on Figure 10-4. Figure 10-5 shows the vertical distribution of contaminants migrating away from the ST Services site. As contaminants migrate to the north away from the ST Services source area, they become more vertically dispersed as they encounter a thicker portion of the USA. As shown on Figures 10-4 and

10-5, the vertical migration of contaminants is limited by the underlying lower permeability of the Troutdale Formation.

The maximum southern extent of the plume in the USA is GWM well #4, where the plume is captured by operation of the GWM production wells. GWM production wells # 2 and #3 went off line in October 2003 when operation of the drum house germinator ceased (Figure 10-2). Figure 10-4 shows how contaminants are captured by GWM production wells #4 and #5. These two wells are equipped with air stripping towers to treat groundwater prior to use. GWM well #5, the most northerly GWM production well, has captured the majority of the commingled plume originating from the SMC, Cadet, and ST Services sites.

All production wells in the GWM/Port wellfield, including the WWRF production well, are screened in the intermediate zone of the USA. TCE concentrations less than 5 µg/l have been detected in Port and WWRF wells. As shown on Figures 10-1 and 10-2, the contamination from the ST Services site has migrated to the north and northeast, where it has commingled with contamination sourced from the SMC site and the Cadet facility. The groundwater model and geochemistry data, discussed in Sections 8.0 and 9.0, support the belief that ST Services-sourced contaminants have reached GWM wells #4 and #5.

Deep USA Zone

The extent of the deep USA zone is shown on Figure 10-6. The deep USA zone is thickest in the Troutdale Formation erosional trough located beneath the SMC and Cadet sites (Figure 7-8). Deep USA zone monitoring wells in the project area and the distribution of TCE in this zone are shown on Figure 10-7. The deep USA zone contamination includes low concentrations of TCE, with lesser amounts of PCE, cis-1,2-DCE, 1,1,1-TCA, 1,1-DCE, 1,1-DCA, and traces of trichlorofluoromethane (TCFM). VOC contamination in the deep USA zone is limited to the erosional trough area (Figure 7-8).

Based on the hydrogeologic information and the -100 feet MSL criteria used to define the deep USA zone, the zone extends from the north to the river in the area between ST Services site and the former Fort Vancouver Plywood site, and to the area east of Northwest Packing (Figure 10-6). However, as shown on Figure 10-6, the thickness of the deep USA near the river is less than 15 feet.

Concentrations of TCE detected in deep USA zone wells are generally less than 15 µg/l. As shown on Figure 10-7, the deep USA zone underlying the SMC and Cadet site source areas has TCE at concentrations slightly higher (maximum conctration of 36.5 µg/l). TCE concentration trends in deep USA wells are shown on Figure 10-8.

As discussed in Section 5.6.8, MW-5d was determined to be compromised, and therefore was decommissioned and replaced by MW-5dR in November 2006. Analytical data previously collected from MW-5d were determined not be representative of groundwater conditions and thus, not used to evaluate the contaminant distribution in the deep USA zone. TCE was detected at a concentration of 14 µg/l in the groundwater sample collected in February 2006 from MW-5dR. This TCE concentration is similar to concentrations detected in groundwater samples collected from MW-5d after it was initially installed.

Stable isotope data suggest the contamination in the deep USA zone could have been derived from the SMC, Cadet and/or ST Services sites. Compound-specific carbon isotope ratios of 1,1,1-TCA, TCE, and PCE for a number of deep wells were presented in Philp (2005). Similar to chemical signatures in these wells, the isotope ratios for specific compounds are also very uniform. The carbon isotope signature for 1,1,1-TCA ranges from -19 to -21 per mil, and is within the ranges observed by Philp (2005) for Cadet (-20 to -30 per mil) and ST

Services (-15 to -23 per mil). For TCE, the range in deep USA wells is from -26 to -27 per mil; this range overlaps with the ranges observed for Cadet (-24 to -27 per mil) and ST Services (-25 to -28 per mil), but not SMC (-21 to -24 per mil). PCE in the deep USA ranges from -31 to -32 per mil; this does not overlap with Cadet (-24 to -26 per mil), but it does appear to be within the range for ST Services PCE (-27 to -33 per mil). It should be noted that the isotope range for PCE in shallow groundwater at the SMC site and PCE in the underlying deep USA overlap suggesting a similar source.

Samples from the deep USA zone wells also contain low concentrations of trichlorofluoromethane (Table 10-3). This compound was detected at low concentrations in several shallow probe borings completed north of the Cadet facility and on three occasions in shallow well samples collected from the ST Services facility. Potential transport mechanisms for producing the relatively low TCFM concentration distribution in the USA deep groundwater zone are not clear.

10.5.1.2 Contaminants in the TGA

As described in Section 7.2 and shown on Figure 7-8, the Troutdale Formation has an undulating surface in the project area. The elevation of the top of the TGA in the project area ranges from -59 feet MSL to more than -229 feet MSL. Figure 10-9 shows the location of monitoring wells that are screened in the TGA. With a couple of exceptions, VOCs are not detected in wells screened in the TGA and were generally not detected in depth-specific groundwater samples collected from the TGA. The only SMC monitoring well screened in the TGA where TCE (and cis-1,2-DCE) was detected is intermediate well MW-15i, with a TCE concentration of approximately 2 µg/l. VOCs were also detected at deep sample ports of ST Services wells MGMS-2 and MGMS-3, which appear to be screened in the TGA (Figures 7-4, 10-5, and 10-9). Low concentrations of TCE and PCE were also found in Cadet well MW-29TGA, in the northeast part of the North Fruit Valley Neighborhood.

TCE and related compounds have been detected in several depth-specific groundwater samples collected from borings that were advanced into the TGA during the course of the RI activities completed at the SMC and Cadet sites. Table 10-1 includes the results of depth-specific samples collected during drilling and installation of monitoring wells at the SMC and Cadet sites. The hydrogeologic unit sampled is identified on Table 10-1, along with the depth at which the Troutdale Formation was encountered. Depth-specific samples collected during drilling of MW-5dR in November 2006 are also shown on Table 10-1. Depth-specific samples from the TGA have been collected at 27 different locations in the project area. At 11 locations, TCE was not detected in the TGA. Of the 16 remaining locations where depth-specific TGA samples were collected, there were four locations (MW-7i, MW-12d, MW-35i, and MW-37i) where TCE was detected at a depth representing more than 20 feet of penetration into the Troutdale Formation. The highest TCE concentration detected in these samples was 2.66 µg/l. Figures 10-4 and 10-5 show the reduction in TCE concentrations that occurs when the TGA is encountered. The lower permeability of the TGA along with pumping occurring above the Troutdale Formation serves to limit the extent that TCE and related compounds migrate into the TGA.

10.5.2 Commingling of Plumes

The two plumes originating separately from the SMC and Cadet site source areas migrate to the east and south (i.e., down-gradient) in response to pumping at the WWRF well and the GWM/Port wellfield. As the plumes migrate laterally near the surface of the water table, they also migrate vertically through the USA (Figure 10-4). The downward migration of the plumes is primarily in response to pumping at the GWM pumping wells, which have intake screens set between 80 and 120 feet bgs. The extent of downward migration is limited by the less permeable Troutdale Formation and the depth of the GWM well screens. The SMC and Cadet plumes merge (commingle) on Port property near Kotobuki Way, and can be characterized as a single plume to the east of the SMC site source area (Figures 10-1 and 10-2).

Evidence for the commingling of the SMC site and Cadet plumes is provided by data from the quarterly groundwater monitoring events. For example, the SMC site well MW-8, which is approximately 500 feet east of the SMC site, has consistently contained TCE concentrations in the tens of micrograms per liter. To the east of MW-8 is SMC well MW-20, which generally contains TCE at concentrations in the hundreds of micrograms per liter. The higher TCE concentrations detected at well MW-20, located east of the SMC site source area (compared to MW-8), are the result of the Cadet-sourced plume "bending" south in this area and migrating to the south of Fourth Plain Boulevard (Figures 10-1 and 10-2).

Contaminants in groundwater at the ST Services site are also migrating off-site in response to pumping at the GWM pumping wells. These pumping stresses are pulling the plume northward from the ST Services site, where the plume is commingled with the contaminants sourced from the SMC and Cadet sites. Flow model results indicate that the Columbia River functions as a recharge boundary for the USA in response to GWM pumping stresses. Pumping at GWM produces flow paths that originate perpendicularly from the river, initially flow away from the river, and then bend toward the GWM production wells (Figure 9-7). The distance at which the flow path begins to bend increases and the degree of the bend decreases with distance from the GWM production wells. At the ST Services site, the pump-induced flow path in the USA is toward the northeast and bends more to the east further north of the ST Services site. Groundwater does not flow parallel to the river because the river functions as a recharge or discharge boundary, depending upon groundwater pumping activities and river stage conditions. As shown on Figure 10-5, the vertical extent of the plume from the ST Services site increases in the USA as it migrates north. This occurs because the depth to the top of the Troutdale Formation increases to the north of the ST Services site, with the deepest location in the erosional trough located under the SMC and Cadet sites. As described in Section 9.0, geochemical analysis of groundwater data collected from GWM wells #4 and #5 indicate that contaminants sourced from the ST Services site have reached these two production wells.

10.5.3 Capture of Chlorinated Solvents by GWM

In the project area, the dominant influence on the groundwater flow systems in the USA, and to a lesser extent in the TGA, is groundwater withdrawal by GWM production wells. This is primarily due to the screen interval of the GWM production wells, which are located in the USA between 80 and 120 feet bgs. As a result, groundwater flow directions and gradients in the USA vary with location because flow is radial towards the GWM wellfield. The understanding that groundwater flow in the TGA is also influenced by the GWM wellfield is based primary on groundwater flow model results. Although the GWM wells obtain a significant percentage of their yield from the nearby Columbia River, the flat horizontal hydraulic gradient in the aquifers enables these wells to exert an influence over a large area (i.e., a relatively great distance from the wells).

10.5.4 Groundwater Quality Trends

Linear regression analysis has been used to evaluate TCE concentration data trends (i.e., increasing or decreasing). Linear regression is a common statistical method of assessing linear trends in a data set containing pairs of observations (for example, concentrations as a function of time). The method is described in more detail in the 2005 Annual Groundwater Monitoring Report for the Former Building 2220/SMC Site (Parametrix 2006d). The concentrations of VOCs detected in monitoring wells have declined over time in response to interim actions completed at the SMC and Cadet sites. Trend analysis provides a statistical means to determine if concentrations are increasing or decreasing, but has the potential to lack the robustness to capture rapid data quality changes that have occurred at site. Consequently, examination of linear regression results should consider the time-period analyzed, along with inspection of time series plots of TCE concentrations at the well.

Table 10-2 shows the correlation coefficients (r) and coefficients of determination (r^2) calculated for groundwater data collected between 2002 and the first quarter of 2007 from monitoring wells in the shallow, intermediate, and deep USA zones. The table only includes monitoring wells where TCE was detected in groundwater samples during at least two monitoring events. The data set for wells MW-30i and MW-31i starts after the wells were installed in 2003; the data set for wells MW-32i through MW-38i starts after the wells were installed in 2004. The following observations are based on linear regression analysis and an examination of time series plots for TCE and PCE included in Appendix J:

- TCE concentrations in a majority of the shallow USA zone monitoring wells have been decreasing, with a few wells showing no discernable trend correlation. There are notable decreases in TCE concentrations in shallow zone wells MW-2, MW-5, and MW-7, located at or down-gradient of the SMC source area. The soil source removal action conducted by the Port in 1998 and the groundwater treatment interim action initiated in 2002 and completed in 2004 have improved groundwater quality in the shallow USA zone down-gradient from the SMC source area. Notable decreasing TCE concentration trends are also observed at wells MW-16, MW-20, and MW-21, which are located downgradient of the Cadet site source area. Interim actions completed at the Cadet site have improved groundwater quality conditions in these wells.

- Overall increasing TCE concentration trends are calculated for shallow USA zone monitoring wells MW-6, MW-8, MW-10, and MW-G. The time series plot for MW-8 indicates that TCE was detected at a maximum concentration in 2005. TCE concentrations in MW-8 have since rapidly declined to pre-2005 levels. Time series plots indicate that the increasing trends calculated at wells MW-6 and MW-G are subtle and represent small concentration changes. The only shallow USA zone well showing a notable increasing trend is MW-10. However, TCE concentrations in MW-10 have declined since early 2006.

- TCE concentrations are decreasing or show no discernable trend in all but two of the intermediate USA zone wells. At several wells, the concentration decrease is notable and/or sustained. The overall decreasing TCE trend in intermediate USA zone wells is related to the soil source removal and groundwater source area treatment actions completed at the SMC and Cadet sites.

- Increasing TCE concentration trends are identified at intermediate USA zone wells MW-5i and MW-38i. The increasing trend in MW-5i is due to two recent detections. TCE is typically not detected at MW-5i. The groundwater quality data set for well

MW-38i starts after the well was installed in 2004. TCE concentrations in MW-38i increased until early 2006 and have since steadily decreased.

- TCE concentration trends at the four deep USA zone wells vary. An increasing concentration trend is identified at well MW-5d. However, as discussed in Section 5.6.8, samples collected from well MW-5d were determined not to be representative of formation conditions screened by the well. MW-5d was decommissioned and replaced by MW-5dR in November 2006. An increasing concentration trend is also identified at well MW-14d. The time series plot for TCE at MW-14d indicates that while there is an overall upward trend, TCE concentrations vary over time in the well. A slow and subtle declining TCE trend is observed at MW-12d, while no discernable trend is identified at MW-1d.

Figures 10-10, 10-11, 10-12, and 10-13 show the extent of the commingled Cadet and SMC plume in the shallow USA zone in 2002, 2004, 2005 and 2006. As shown on these figures, the concentrations of TCE in the shallow USA zone have decreased significantly since 2002. The most significant TCE concentration reductions have occurred in the shallow USA zone east of the Cadet facility, in the NFVN. The decrease in TCE concentrations occurred after interim actions were initiated at the SMC and Cadet sites.

10.6 DISTRIBUTION OF CONTAMINATION IN SOIL GAS

Evaluation of the distribution of soil gas is based on soil gas sampling from probe borings during Phase III of the RI and from soil gas wells during Phase IV of the RI (Section 5). TCE and other VOCs are expected to be present in soil gas as a result of volatilization of contaminants from groundwater. In general, it is expected that TCE in soil gas would be higher closer to the groundwater, and at lower concentrations as it moves upward through the vadose zone to the surface. In addition, the distribution of soil gas across the site is expected to correlate with the lateral extent of the groundwater plume. The understanding of soil gas distribution throughout the project area is important because it can be an indicator of potential indoor air contamination through vapor intrusion.

Figure 10-14 presents the distribution of TCE in soil gas samples collected from the soil gas wells. Also included on Figure 10-14 is TCE data for the most recent groundwater sampling events. In general, the lateral distribution of soil gas is correlated with the lateral distribution of the groundwater plume; that is, areas of higher or lower TCE concentrations in groundwater tend to have higher or lower soil gas concentrations, respectively. However, there is some variability due to the nature of soil gas movement in the subsurface.

The highest concentrations of TCE in soil gas were detected in soil gas well POV-SG-04, immediately adjacent to monitoring wells MW-7s and MW-7i. As shown on Figure 10-14, monitoring wells MW-7s and MW-7i have relatively high TCE concentrations in groundwater.

Between July 2005 and November 2006, TCE was detected at 10 feet bgs in soil gas well POV-SG-04 at concentrations between 16,000 $\mu g/m^3$ and 23,000 $\mu g/m^3$. Concentrations of TCE were higher in the soil gas samples collected from 15 feet bgs (maximum concentration of 33,000 $\mu g/m^3$) and 20 feet bgs (maximum concentration of 46,000 $\mu g/m^3$). The vertical profile of TCE in soil gas in this area is consistent with a groundwater source (i.e., shallow soil contamination would be expected to result in higher soil gas concentrations in shallower soil and less in deeper soil). The distribution of impacted soil gas in the remaining wells is also consistent with a groundwater source.

Currently, there are no MTCA cleanup levels for soil gas. The primary consideration for evaluating soil gas is potential vapor intrusion to overlying structures or volatilization to outdoor air, both of which can create a complete exposure pathway. The results of the Port tenant property and SFVN soil gas investigations were used to select buildings and/or houses for indoor air sampling (Sections 5.6.4 and 5.6.5). In addition, an evaluation of the soil gas results and the relationship to potential indoor air conditions in overlying properties was completed in the CAMP submitted to Ecology in January 2007.

10.7 DISTRIBUTION OF CONTAMINATION IN INDOOR AIR

Indoor air investigations were completed for residential houses in the SFVN and Port tenant buildings.

10.7.1 South Fruit Valley Neighborhood

As part of the Phase IV activities, indoor air sampling was completed in 19 homes in the SFVN. Sampling was completed in March 2006 and September 2006, which represents seasonal variances. The results of the investigation indicate that indoor air in these homes contains concentrations of VOCs. The CAMP (Parametrix 2009) was prepared to evaluate indoor air conditions in the SFVN and provide recommendations for cleanup levels and future monitoring. In addition, the indoor air results obtained during 2006 from the SFVN were used in the risk assessment included as Appendix I.

MTCA ambient air cleanup levels (levels below which no further action is required) for all COPCs are included on Table 5-15. Several houses in the SFVN had concentrations exceeding the MTCA ambient air cleanup levels. A monitoring program was developed for indoor air in both the SFVN and NFVN and is included in the CAMP (Parametrix 2009). The monitoring program has not yet been approved by Ecology.

10.7.2 Port Tenant Buildings

Two Port tenant buildings, 2400 and 2401, were selected for preliminary indoor air sampling. Buildings 2400 and 2401 contain large open area warehouse space, with no closed office space in either building. Building 2400 was selected for indoor air sampling because it was near (less than 70 feet from) soil gas well POV-SG-04, which had soil gas concentrations of TCE detected at up to 23,000 $\mu g/m^3$ in the 10-foot level. Building 2401 was selected to provide an additional sampling point and context for indoor air in the Port buildings.

PCE and TCE were detected in Building 2400 at maximum concentrations of 0.26 $\mu g/m^3$ and 1.2 $\mu g/m^3$, respectively. PCE and TCE were detected in Building 2401 at maximum concentrations of 0.13 $\mu g/m^3$ and 0.07 $\mu g/m^3$, respectively.

The results of the indoor air sampling at the Port buildings should not be measured against standard residential criteria. Exposure of workers to any indoor air contamination is limited to working hours, and the typical work-life span at a particular building is generally much less than the assumptions used to generate residential criteria. The indoor air sampling in the Port buildings was intended to be preliminary in nature. For comparison purposes only, OSHA standards for an 8-hour permissible exposure limit (PEL) for TCE is 537,000 $\mu g/m^3$, the NIOSH Recommended Exposure Limit (REL; 10-hour time-weighted average) is 134,000 $\mu g/m^3$, and the American Conference of Governmental Industrial Hygienists (ACGIH; 8-hour time-weighted average) is 269,000 $\mu g/m^3$. Indoor air contamination resulting from vapor intrusion is evaluated using the MTCA indoor air cleanup levels. The risk associated with these occupational exposures is included in the risk assessment in Section 11. Based on the sample results, significant concentrations of VOCs are not present in Buildings 2400 and 2401.

10.8 DISTRIBUTION OF CONTAMINATION IN OUTDOOR AIR

As part of the Phase IV activities, outdoor air sampling was completed in several areas around the Port and the SFVN. The results of the investigation indicate that outdoor air contains concentrations of VOCs. The results of the ambient air sampling were used to evaluate background concentrations and potential impact on indoor air quality. The evaluation is presented in the CAMP (Parametrix 2009).

11. RISK ASSESSMENT SUMMARY

A risk assessment (RA) was conducted as part of the RI to evaluate the potential risk associated with the SMC site; it is included as Appendix I. The RA is intended to summarize the current potential risk at the site (after interim remedial actions) and provide a basis for completion of a Feasibility Study (FS) and selection of a site remedy. The potential human health risks from the release of VOCs at the SMC site were examined by evaluating soil, soil gas, groundwater and indoor air data collected within the project area. An exposure assessment, toxicity assessment, and risk characterization was completed for all of the identified potential exposure pathways. A brief summary of the RA is included in the following sections.

At the request of Ecology and DOH, the Port also prepared a Comprehensive Vapor Intrusion and Indoor Air Evaluation Plan (CAMP) (Parametrix 2009), which includes a discussion of the indoor air data collected at the site and provides recommendations for evaluating indoor air results. The purpose of the CAMP was to provide context for the indoor air results, including how background concentrations may potentially impact indoor air quality. The CAMP also includes cleanup levels and provides a basis for further indoor air monitoring. The CAMP should be utilized as a companion document to the RA, specifically for evaluating the potential risks from indoor air.

11.1 EXPOSURE ASSESSMENT

An exposure assessment was conducted to estimate the magnitude, frequency, duration and route of exposure of a receptor to the contaminant source. Information about waste sources, exposure pathways, and receptors at the SMC site were used to develop a conceptual understanding of the SMC site to evaluate potential risks to human health. The conceptual site model includes known and suspected sources of VOCs, affected media, potential routes of migration to human receptors, and potential exposure pathways (see Appendix I).

Receptors are defined as persons who may come into contact with site chemicals. Human receptors in this analysis represent individuals who work or live within the project area. “Workers” include individuals who work regularly at Port facilities or other non-Port owned property downgradient of the SMC site. Two receptors were evaluated for Port workers; one near the SMC source area (source area workers) and one at the terminus of the commingled plume, near the Great Western Malting facility (project area workers). This was completed to provide a comparison of risks across the relatively large project area. Temporary workers were also evaluated, such as an excavation worker on the Port property. Residents include people who live east of the SMC site in the SFVN where groundwater containing VOCs may have migrated. The NFVN residents were not evaluated in this risk assessment because this Final RI Report is for the SMC site and downgradient extent. NFVN residents will be included in the risk assessment completed for the Cadet RI Report.

11.2 TOXICITY ASSESSMENT

The toxicity assessment was conducted to evaluate which potential adverse health effects are associated with specific contaminants of potential concern, and identifies regulatory toxicity values used to evaluate the significance of predicted exposures estimated in the Exposure Assessment. Toxicity values are identified for both non-carcinogenic and carcinogenic health effects (Appendix I).

11.3 RISK CHARACTERIZATION

Risk characterization was conducted to provide a quantitative estimate of the potential for health risk. For each exposure pathway and receptor, risk was predicted for a reasonable upper bound (95% upper confidence limit) and/or maximum exposure. The risk assessment was conducted following standard risk assessment guidance, including the State of Washington's MTCA guidance. Risks from exposure to contaminants in soil, indoor air, and outdoor air and potable use of groundwater were examined (Appendix I). According to MTCA, non-cancer risks should not exceed a hazard quotient (HQ) of 1 for individual chemicals or a hazard index (HI) of 1 for multiple chemicals (i.e., the sum of the HQ values). Cancer risks should not exceed an excess lifetime cancer risk (ELCR) of $1x10^{-6}$ (i.e., one additional chance of contracting cancer per one million) for exposures to individual chemicals and $1x10^{-5}$ for multiple chemicals.

11.4 RA CONCLUSIONS

The goals of the RA were to identify potential risks to on-site and off-site Port workers, excavation/construction workers, and off-site residents from chemicals found in soil, soil gas, groundwater, and indoor air. Based on the results of the risk assessment, Parametrix reached the following conclusions for each of the media at the site.

1. **Groundwater**: The potential risk associated with groundwater was evaluated for source area and project area workers, an excavation worker, and an SFVN resident. While previous remedial actions have significantly reduced groundwater concentrations, current concentrations are still at a level that suggests potential elevated risks to human health for all receptors and exposure pathways evaluated. The results indicate that remedial actions are necessary to reduce groundwater concentrations to levels that are protective of potential future receptors and should be evaluated in a feasibility study. Use of groundwater within the project area, in areas of contamination at levels evaluated in the RA, should continue to be restricted until contaminant concentrations do not exceed cleanup goals.

   The Port currently has three wellheads located near and within the confines of the project area. The wells are used to supply fire suppression, irrigation, and drinking water to selected Port properties. Based on quarterly sampling reports, the Port wells currently meet the Safe Drinking Water Act MCLs for VOCs and are acceptable for continued use. The GWM facility utilizes pumping wells to obtain groundwater for use in its production process. Air strippers, paid for by the Port and installed and operated by GWM, treat the groundwater pumped from these wells prior to use at the GWM facility.

2. **Soil**: The potential risk associated with soil was evaluated for a source area worker and an excavation worker. Based on the human health risk assessment, the current risk associated with COPCs in soil in the source area is within the acceptable risk range. Further remediation of soil is not warranted based on the potential receptor scenarios evaluated. However, reduction of COPCs in source material may be evaluated in the feasibility study to supplement the groundwater remedial efforts.

3. **Indoor Air**: The potential risk associated with indoor air was evaluated for source area workers and SFVN residents. Current measured concentrations of VOCs at all SFVN residences indicate elevated cancer risks (i.e., above $1x10^{-6}$) from chronic exposure to indoor air (Excess Lifetime Cancer Risks [ELCRs] ranging from $2x10^{-6}$ to $8x10^{-5}$). However, background air conditions should be considered when

evaluating the indoor air results. The conservative nature of the risk assessment indicates that there is potential for long-term health risks associated with the current levels of TCE in indoor air. However, the presence of TCE in background concentrations (which are similar to national levels and could be sourced from the groundwater plume, local facility emissions, and/or other sources) in outdoor air suggests that the residents in the SFVN are not at significantly greater risks than residents in typical urban settings. It should be noted that remedial efforts to mitigate indoor air concentrations may still be required and are likely to include the reduction of TCE in groundwater, which will reduce volatilization to indoor air. Based on the indoor air results, additional indoor air monitoring may be warranted and was recommended in the CAMP.

Exposure and risk estimates for source area workers suggests that VOC contaminants in indoor air (Port buildings) pose a slightly elevated risk if workers are chronically exposed (maximum ELCR $2x10^{-6}$). However, the concentrations of COPCs in indoor air are significantly lower than OSHA or NIOSH levels for occupational workers.

4. **Outdoor Air**: The risk from outdoor air was evaluated for a source area worker and an SFVN resident (child and adult). Based on the human health risk assessment, the current risk associated with COPCs in outdoor air is within the acceptable risk range. Outdoor air was evaluated because it is a complete exposure pathway at the site. However, it should be noted that the source of the outdoor air concentrations is unknown and could be sourced from the groundwater plume, local facility emissions, and/or other sources.

5. **Ecological Receptors:** In accordance with WAC 173-340-7490, a simplified terrestrial ecological evaluation was conducted for the SMC site. The SMC site has a confined area with exposed soil contamination and minimal adjacent areas of undeveloped land that suggest that this site does not have a substantial potential for posing a threat of significant adverse effects to terrestrial ecological receptors. Contaminant concentrations in exposed soil at the SMC site do not pose a significant threat to terrestrial ecological receptors. Based on the size of the contaminated area, the land use at the site, and the relatively low contaminant concentrations (compared to ecological indicator soil concentrations), this site may be excluded from further ecological assessment per WAC 173-340-7492.

12. CONCLUSIONS

The following conclusions can be made based on an evaluation of field and analytical data collected during the SMC site RI, and RI activities completed at the Cadet and ST Services sites:

1. With the exception of a small area located to the south of the remedial excavation, all soil associated with the SMC site that contained TCE at concentrations greater than 500 μg/kg was excavated and stockpiled for treatment. TCE was detected in two soil samples at concentrations greater than 500 μg/kg to the south of the SMC remedial excavation.
2. Interim actions have successfully treated VOC-contaminated soil located in the unsaturated and saturated zones beneath the SMC site. Analytical results for groundwater samples collected from wells located in the SMC site source area suggest that residual TCE may be present in one relatively small area of the fine-grained sand layer located in the saturated zone beneath the SMC site.
3. The extent of VOC groundwater contamination originating from the SMC site has been defined to the method reporting limit of 0.5 µg/l and is stable. The horizontal extent of contaminated groundwater is limited to the project area. The vertical extent of contaminated groundwater is generally limited to the USA. However, low concentrations of VOCs have been detected at the top of the underlying TGA.
4. The observed distribution of VOCs in the TGA is consistent with the understood characteristics of the aquifer. The presence of VOCs in the TGA appears to have occurred at locations where the Troutdale Formation has allowed contaminant migration via percolation from the USA consistent with the regional model. There is no VOC plume in the TGA. There are only locations where top-of-Troutdale Formation conditions have allowed for intrusion-type migration to occur due to percolation from the overlying USA. With limited exceptions noted, depth-specific data indicate that the extent of this type of VOC migration is limited to the upper 10 feet of the Troutdale Formation.
5. In addition to contamination originating from the SMC site, the Cadet and ST Services sites are sources for the VOC contamination present in groundwater in the project area. The VOC contamination originating from each of the source areas on the three sites (SMC, Cadet, and ST Services) is geochemically distinct.
6. Plumes of VOC-contaminated groundwater originating from the SMC, Cadet, and ST Services sites are commingled in the project area. The commingled plumes are captured by the pumping wells located at GWM. Air strippers installed and operated by GWM treat the groundwater pumped from these wells prior to use of the water at the GWM facility.
7. The GWM pumping wells effectively capture the commingled plume and prevent the contamination from the SMC and Cadet sites from reaching the Columbia River.
8. The risk assessment indicates that the concentrations of VOCs in the plume of contaminated groundwater originating from the SMC site exceed acceptable drinking water criteria. In addition, the risk assessment model suggests a potential risk associated with indoor air. However, the allocation between the subsurface contribution and background source contribution of VOCs to indoor air is unknown. The residual soil contamination at the SMC site does not pose an unacceptable risk to potential receptors.

The results of the risk assessment indicate that additional remedial actions are necessary at the site to protect human health and/or the environment, which should be evaluated in an FS.

9. The RI is complete. As part of the RI, the Port installed 326 borings and 110 monitoring wells, and collected and analyzed 355 soil samples, 2,465 water samples, 270 soil gas samples, 80 indoor air samples, and 21 outdoor air samples. Sufficient information has been collected to prepare an FS for the SMC site.

13. RECOMMENDATIONS

The following recommendations are based on the conclusions of the RI:

1. An FS should be prepared to evaluate alternatives for further reducing the concentrations of VOCs in groundwater impacted by the SMC site.
2. Groundwater and soil gas monitoring should be continued to document the stability of the commingled plumes. In addition, results from the monitoring should be used to refine the FS, including further assessment of the potential risks associated with outdoor and indoor air.
3. Recommendations included in Draft CAMP (Parametrix 2009) after the document is finalized should be implemented.
4. The FS should include an analysis of alternatives for treating the residual TCE that may be present in one relatively small area of the fine-grained sand layer located in the saturated zone beneath the SMC site.
5. Pumping at the GWM wells should be continued until the final corrective action is implemented to maintain capture of the TCE plumes.
6. Operation of the air strippers associated with the GWM wells should be continued to remove TCE from groundwater prior to use.

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