Final Remedial Investigation Report
Cadet Manufacturing Company Site

Prepared for

Port of Vancouver
3103 NW Lower River Road
Vancouver, WA 98660

Prepared by

Parametrix
700 NE Multnomah, Suite 1000
Portland, OR 97232-4110
T. 503.233.2400 T. 360.694.5020 F. 503.233.4825
www.parametrix.com

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CERTIFICATION

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

Prepared by Rick Wadsworth

Approved by Richard Roché, LHG

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APPENDICES

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ACRONYMS

1,1,1-TCA	1,1,1-trichloroethane
1,1-DCA	1,1-dichloroethane
1,1-DCE	1,1-dichloroethene
AGRA	AGRA Earth & Environmental, Inc.
AMEC	AMEC Earth & Environmental, Inc.
AO	Agreed Order
AS	Air sparging
AS/SVE	Air sparging/soil vapor extraction
bgs	Below ground surface
BNSF	Burlington Northern Santa Fe Railroad
Cadet	Cadet Manufacturing Company
CAMP	Comprehensive Vapor Intrusion Evaluation and Indoor Air Monitoring Plan
CHSM	Conceptual hydrogeologic site model
cis-1,2-DCE	1,2-dichloroethane
COPC	Chemical of potential concern
COV	City of Vancouver
CPU	Clark Public Utilities
CSIA	Compound-specific isotope analysis
DNAPL	Dense non-aqueous phase liquid
DOH	Washington Department of Health
Ecology	Washington Department of Ecology
ELCR	Excess lifetime cancer risk
EPA	U.S. Environmental Protection Agency
ESA	Environmental Site Assessment
FS	Feasibility Study
FVN	Fruit Valley Neighborhood
g	Gram
GAC	Granular activated carbon
GPL	Global precipitation line
GWM	Great Western Malting
HEPA	High efficiency particulate air
HI	Hazard index
HQ	Hazard quotient

ACRONYMS (CONTINUED)

HVOC	Halogenated volatile organic compound
IRAM	Interim Remedial Action Measure
K	Hydraulic conductivity
K_d	Soil/water partitioning coefficient, equilibrium partitioning coefficient, distribution coefficient
kg	Kilogram
L	Liter
m	Milli- (prefix); 10^{-3}
m	Meter
MGMS	Multi-level groundwater monitoring wells
MSL	Mean sea level
MTCA	Model Toxics Control Act (Washington)
MW	Monitoring well
NFVN	North Fruit Valley Neighborhood
NGVD	National Geodetic Vertical Datum
NIOSH	National Institute for Occupational Safety and Health
O&M	Operation and maintenance
OSHA	Occupational Safety and Health Administration
PCE	Tetrachloroethene
PID	Photoionization detector
Port	Port of Vancouver, U.S.A.
QA/QC	Data quality assurance review
RA	Risk assessment
RCRA	Resource Conservation and Recovery Act
RGRW	Recirculating groundwater remediation well
RI	Remedial Investigation
RI/FS	Remedial Investigation/Feasibility Study
SFVN	South Fruit Valley Neighborhood
SMC	Swan Manufacturing Company
SOP	Standard operating procedure
ST Services	Support Terminal Services
SVE	Soil vapor extraction
SVV	Soil vapor vacuum

ACRONYMS (CONTINUED)

TCE	Trichloroethylene
TCFM	Trichlorofluoromethane
TGA	Troutdale Gravel Aquifer
TOC	Total organic carbon
UCL	Upper confidence limit
USA	Unconsolidated sedimentary aquifer
USGS	U.S. Geological Survey
UV	Ultraviolet
VOC	Volatile organic compound
WAC	Washington Administrative Code
WWRF	Westside Wastewater Reclamation Facility
µ	Micro- (prefix); 10^{-6}
µg/L	Micrograms per liter
µg/m3	Micrograms per cubic meter

EXECUTIVE SUMMARY

On behalf of the Port of Vancouver, U.S.A. (the Port), Parametrix has prepared this Final Remedial Investigation (RI) Report for the Cadet Manufacturing Company (Cadet) site, located at 2500 Lower River Road in Vancouver, Washington. This Final RI Report has been prepared to provide a comprehensive summary of Cadet site-related investigations and interim remedial actions completed from 1999 through March 2009. 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 Department of Ecology (Ecology) requirements included in Washington Administrative Code (WAC) 173-340-710.

Trichloroethylene (TCE) and/or other solvents were used at the Cadet site as degreasers from prior to the 1970s until approximately 2006. Several areas of the facility including the vapor degreaser, TCE dip tank, and paint room are likely areas of past spills or releases. In the early 1990s to mid-1990s, breaks were identified in a sanitary sewer line at the site, which received wastewater from the parts cleaning equipment. The specific date of the first break is unknown, but it was discovered and repaired in the early 1990s. In the mid-1990s a second break in the sanitary sewer line at approximately the same location as the first break was discovered during construction of a 20,000 square foot addition to the original building. Contaminated wastewater was believed to have been released to the subsurface as a result of the pipeline breaks. These areas, as well as those directly beneath the solvent use areas of the Cadet building, are considered the primary source areas for TCE contamination in soil and groundwater.

Two other sources of VOCs in groundwater have been identified near the Cadet site: the Swan Manufacturing Company (SMC) site and the ST Services site (note that in 2005, ST Services was purchased by Valero and currently operates as NuStar Energy, LP; the site is referred to as the NuStar site throughout this document). Plumes of VOC-contaminated groundwater originating from the Cadet, SMC and NuStar sites are commingled in the project area. The commingled plume has been historically captured by the pumping wells located at Great Western Malting (GWM). The GWM pumping wells effectively captured the commingled plume and prevented the contamination from the Cadet and SMC sites from reaching the Columbia River. The Port's recently installed groundwater pump and treatment system at the SMC site has been designed to hydraulically capture the entire VOC commingled plume and treat contaminated groundwater. The treatment system began operation in June 2009 at an approximate rate of 2,500 gpm. It is expected that the groundwater flow regime in the project area will change, resulting in a capture zone centered at the SMC site and encompassing the entire Cadet-sourced plume.

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, the commingled plume from the Cadet and SMC source areas has migrated to the east and south in response to groundwater withdrawal, primarily at the GWM wellfield. The deep USA zone is mostly contained in an erosional trough located beneath the Cadet and SMC sites. Contamination in this zone includes low concentrations of TCE.

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.

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 eight 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.

The concentrations of TCE in the shallow USA zone have decreased significantly since 1999. 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 Cadet site. 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 Cadet 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 indoor air sourced contribution of VOCs is unknown. The residual soil contamination at the Cadet 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. A total of 76 soil samples, 2,879 groundwater samples, 452 soil gas samples, 716 indoor air samples, and 131 outdoor air samples have been collected in connection with Cadet site investigations. Sufficient information has been collected to prepare an FS for the Cadet site.

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

1. Pumping at the Port's groundwater pump and treatment system at SMC should be continued to maintain capture of the SMC and Cadet TCE plumes.
2. After evaluating the effectiveness of the Port's groundwater pump and treatment system at SMC, an FS should be prepared to evaluate alternatives for further reducing the concentrations of VOCs in groundwater impacted by the Cadet site. The FS will be combined with the SMC site to fully evaluate alternatives for both Cadet and SMC.
3. Groundwater and limited soil gas monitoring should be continued to document the stability of the commingled plume. In addition, results from the monitoring should be used to refine the FS, including further assessment of the potential risks associated with indoor and outdoor air.
4. Once the Final Comprehensive Vapor Intrusion and Indoor Air Evaluation (CAMP) is approved, recommendations in that document should be implemented to monitor indoor air.

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 Cadet Manufacturing Company (Cadet) site, located at 2500 Lower River Road in Vancouver, Washington. The Cadet site and surrounding area are shown on Figures 1-1 and 1-2.

Remedial investigation activities were initiated at the Cadet site in 1999. In January 2000, Cadet entered into Agreed Order (AO) No. 00TCPVA-847 with the Washington Department of Ecology (Ecology). The AO directed Cadet to conduct an RI, a Feasibility Study (FS), and an interim remedial action for halogenated volatile organic compounds (HVOCs) in soil and groundwater at and near the Cadet property.

AMEC prepared a Draft Remedial Investigation Report for RI activities conducted from 1999 through October 2002 and submitted it to Ecology in February 2003 (AMEC 2003a). In August 2005, AMEC submitted a Draft Remedial Investigation Update Report (AMEC 2005) to Ecology and the Washington Department of Health (DOH) to document RI activities conducted from May 2003 through January 2005. DOH provided comments on these 2003 and 2005 RI reports in letters dated June 16, 2003, (DOH 2003a) and May 5, 2006 (DOH 2006). Ecology did not provide formal comments on the Draft RI Report or Draft RI Update Report. The intent of this current report is to provide a comprehensive summary of all RI activities at the Cadet site from 1999 through March 2009.

Information included in this RI Report meets Ecology requirements included in Washington Administrative Code (WAC) 173-340-710 (Ecology 2007). Ecology approval of this report will complete the RI phase of the Cadet project. Based on the recommendations of the RI, a Feasibility Study (FS) will be prepared for the Cadet site. In May 2006, the Port assumed ownership of the Cadet property and responsibility for cleanup of the Cadet site. As the Port is also responsible for cleanup and remediation of the adjacent Swan Manufacturing Company (SMC) site, an FS will be prepared to include an evaluation of remedial alternatives for both the Cadet and SMC sites.

1.1 PURPOSE

This Final RI Report has been prepared to:

1. Provide a comprehensive summary of Cadet site-related investigations and interim remedial actions completed from 1999 through March 2009. A majority of the information included in this Draft RI Report was previously submitted to Ecology in other reports and/or technical memorandums, but has not previously been included in one comprehensive document.
2. Provide a basis for completion of a Feasibility Study and selection of a site remedy.

Activities completed since the submittal of the 2005 RI Update Report include groundwater monitoring, soil gas monitoring, indoor and outdoor air monitoring, and ongoing operation of several interim remedial actions. The interim remedial actions include soil vapor vacuum (SVV) systems installed in six homes in the Fruit Valley Neighborhood (FVN), recirculating groundwater remediation wells (RGRWs) on the Cadet site and in the Fruit Valley Neighborhood, and an air sparging/soil vapor extraction (AS/SVE) system at the Cadet building. In addition, in June 2009, a groundwater pump and treat interim action was started by the Port at the SMC site to address dissolved-phase volatile organic compounds (VOCs) in groundwater at both the SMC and Cadet sites.

In addition to the 2003 RI Report and 2005 RI Update Report, detailed background information and data used to support the conclusions presented in this Final RI Report are included in the following reports:

- Final Remedial Investigation Report, Former Building 2220 Site (Swan Manufacturing Company Site) (Parametrix 2009c)
- Vancouver Lake Lowlands Groundwater Model Summary Report (Parametrix, et al. 2008)
- TGA and Deep USA White Paper – SMC and Cadet Site Area (Parametrix 2008c).
- RGRW Operations Plan, Cadet Facility (Parametrix 2007b)
- AS/SVE Performance Evaluation Report (Parametrix 2009b)
- Final Comprehensive Vapor Intrusion Evaluation and Indoor Air Monitoring Plan (CAMP) (Parametrix 2009d)

1.2 REPORT ORGANIZATION

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

Section 2	Site Background – Describes the Cadet site and discusses the regulatory framework of the remedial investigation.
Section 3	Remedial Investigation Summary – Includes a summary of previous RI activities and a chronology of activities and events conducted at the Cadet site.
Section 4	Geologic/Hydrogeologic Conditions – Summarizes the geologic and hydrogeologic conditions at the Cadet site.
Section 5	Interim Actions – Summarizes interim actions completed at the Cadet site.
Section 6	Groundwater Modeling Summary – Summarizes the groundwater model prepared for the site, and results of groundwater modeling.
Section 7	Stable Isotope Evaluation – Summarizes the investigations of stable isotopes in the project area.
Section 8	Nature and Extent of Contamination – Summarizes the current understanding of the nature and extent of contamination at the Cadet site.
Section 9	Risk Assessment Summary – Summarizes the risk assessment process and conclusions.
Section 10	Conclusions – Draws conclusions about the sources of TCE in groundwater, groundwater flow direction, and the extent of TCE impacts connected with the Cadet site.
Section 11	Recommendations.
Section 12	References – Lists the references cited in this report.

2. SITE BACKGROUND

This section briefly describes the Cadet site location, historical use of the site, and the regulatory framework for remedial activities conducted at the site.

2.1 SITE LOCATION AND DESCRIPTION

The Cadet site is a rectangular parcel located at 2500 Lower River Road in Vancouver, Washington (Figure 1-1). The site is located in the southwest quarter of Section 21, Township 2 North, Range 1 East of the Vancouver U.S. Geological Survey (USGS) Quadrangle. The property is occupied by a single building with associated asphalt and gravel parking areas, and landscaping. The building is primarily a single-story manufacturing building approximately 15,750 square feet in size. A partial second floor mezzanine at the southern end of the building contains offices. The building was constructed in the mid-1960s, with a 20,000 square foot addition in the mid-1990s. Two paved access roads enter the south side of the Cadet site from Lower River Road (Figure 1-2). Detailed features of the Cadet building are shown on Figure 1-3. The monitoring well network in the project area is shown on Figure 2-1. Cadet monitoring wells are shown on Figure 2-2.

The Cadet site is surrounded predominantly by residential and industrial properties. Vancouver Lake is located approximately 0.75 mile northwest of the Cadet site. The property between the Cadet site and Vancouver Lake is currently undeveloped. The Cadet site includes the property with the Cadet building and an adjacent undeveloped "L-Shaped Parcel" which is located to the north and west of the building (Figure 1-2). The North Fruit Valley Neighborhood (NFVN), which is defined here as the area of single-family residences located north and east of the Cadet site, is also considered part of the project area. The NFVN is bounded on the east by the Burlington Northern Santa Fe Railroad (BNSF), on the south by West Fourth Plain Boulevard, on the west by Yeoman Avenue, and on the north by West 39th Street and La Frambois Road (Figure 1-2).

2.1.1 Site Setting

The site lies on the relatively flat floor of the Columbia River Valley within the Vancouver Lake Lowlands. The Columbia River is located approximately 0.5 mile southwest of the site (Figure 1-2). Vancouver Lake, located approximately 0.75 mile northwest of the site, is connected to the Columbia River via a flushing channel and Lake River.

The elevation at the site is approximately 25 feet above mean sea level (MSL). Approximately 0.5 mile east of the site, the flat topography is bordered by a ridge that runs north-northwest and rises to an elevation of approximately 100 feet above MSL.

2.1.2 Climate

The site has a modified marine climate with mean annual precipitation of 41.5 inches, as measured at the Vancouver 4 NNE Station and reported by the National Climatic Data Center. Over 70 percent of the precipitation falls as rain between October and May. The average temperature in January, the coldest month, is 39°F, and the average temperature in July, the hottest month, is 69°F. Based on Portland airport data, winds average 7.86 knots, most commonly from the northwest.

2.2 HISTORICAL USE OF THE CADET SITE

The following sections summarize the ownership and previous use of the Cadet site.

2.2.1 Ownership

Prior to the mid-1960s, the site was an undeveloped field, sometimes cultivated, with an orchard present in the northwest portion for an unknown length of time. In 1964, a single building was constructed in the same location as the present-day building. Swan Manufacturing occupied the building from 1964 until 1972, at which time Cadet assumed ownership of the property. Cadet continues to operate at the site, but in May 2006, ownership of the property was transferred to the Port as part of a settlement agreement.

2.2.2 Previous Industrial Use of Cadet Site

At the time Cadet took over the property in 1972, Swan Manufacturing reportedly used trichloroethylene (TCE) as a degreaser in their parts cleaning process. This process involved a large dip tank or vault into which parts would be lowered on a rack. Parts were lowered to just above the liquid TCE level, the lid of the tank was closed, and the tank was heated to produce TCE vapor. Once cleaning was complete, the temperature of the tank was lowered so the TCE would return to a liquid phase. Excess TCE was shaken off the parts inside the tank. The TCE tank was approximately 10 feet long by 5 feet wide by 12 feet deep, with 8 feet of the tank set below surface level inside a concrete containment bunker. No drains were present in the base of the containment bunker. Spent TCE from the tank was removed by pumping the product into drums placed next to the tank, which were subsequently placed outside for recycling pick-up. Fresh TCE was pumped into the tank from new drums of TCE. No remote pumping of TCE was performed (such as from outside the building), and no underground piping was in place for the remote delivery or removal of TCE (AMEC 2003a).

Once clean, the parts were ready for painting. The parts were hung on racks in the painting area, where two waterfall structures were located. Each waterfall structure consisted of a 10-foot wide by 8-foot tall backdrop structure, over which water would cascade into a concrete trough that surrounded the backdrop structure and contained the water. Hence, the term “waterfall.” Paint was sprayed onto the parts in front of the waterfall, which collected paint over-spray. A small hood covered the top of the backdrop structure to prevent discharge outside the waterfall structure. Water passed through filters and then flowed out of the trough through one of two drains. One drain was located in the bottom of the concrete trough, and allowed the trough to be completely emptied of water when the waterfall was not in use. The second drain was located near the top rim of the trough, and allowed water to drain from the trough while the waterfall was in use. During operation, a small amount of fresh water was continually added, so a small amount of water was always flowing out of the system. This type of system was referred to as an “overflow” system. Both drains were connected to piping that transported water via gravity flow to the sanitary sewer line (AMEC 2003a).

Cadet continued to use TCE and the vapor degreasing process until approximately 1976, when they changed to a water soak cleaning process that used hot water and an alkaline cleaner. The waterfall painting system remained in use, and wastewater continued to be discharged to the City’s sanitary sewer system. In 1987, Cadet switched to a powder-coating system for painting metal that includes a three-stage cleaning system. Rinse water from the cleaning system is continuously discharged to the sanitary sewer. The waterfall structures have been removed, and the powder-coating system continues to be used.

2.3 DISCOVERY OF RELEASE

In the early 1990s and mid-1990s, breaks were identified in the sanitary sewer line at the site. As discussed in Section 2.2.2, wastewater from the parts cleaning equipment was discharged to the sanitary sewer line. The specific date of the first break is unknown, but it was discovered and repaired in the early 1990s. A small section of the line was replaced under the Cadet parking lot, approximately 30 feet east of the Cadet building. In the mid-1990s a second break in the sanitary sewer line was discovered during construction of a 20,000 square foot addition to the original building. The second break, at approximately the same location as the first break, was discovered during installation of water and sewer line extensions to the north end of the building. Contaminated wastewater was believed to have been released to the subsurface as a result of the pipeline breaks.

2.4 REGULATORY FRAMEWORK

In January 2000, Cadet entered into Agreed Order (AO) No. 00TCPVA-847 with Ecology. The AO directed Cadet to conduct investigations and interim remedial actions for HVOCs in the subsurface at the Cadet site. Soil, soil gas, groundwater, and indoor and outdoor air investigations were conducted in response to the AO. In addition, three interim remedial actions were implemented in the course of conducting the RI: installation and operation of the AS/SVE system, the RGRWs, and the SVVs in six NFVN residences.

Based on a May 2006 settlement agreement, the Port assumed responsibility for cleanup of the Cadet site, and subsequently entered into Agreed Order 07-TC-S DE-5189 with Ecology. Effective May 1, 2008, this Agreed Order replaced separate Agreed Orders that Ecology had in place with the Port and Cadet:

- Swan Manufacturing Company (SMC) Agreed Orders 98-TC-S337 and 01-TCPVA-3257
- Cadet Agreed Order 00-TCPVA-847

Agreed Order 07-TC-S DE-5189 names the Port as the responsible party for both SMC and Cadet sites and requires the Port to complete a Remedial Investigation, implement interim action cleanup at the SMC and Cadet sites, and conduct a Feasibility Study in accordance with the project schedule stipulated.

As required by Ecology, the Port is continuing to conduct multi-media sampling and remedial activities at the SMC and Cadet sites. These activities include groundwater, soil gas, and indoor and outdoor air monitoring; operation of six SVV systems in homes in the NFVN; operation of the AS/SVE system; and operation of the RGRWs.

The Port also implemented an interim action consisting of a groundwater pump and treat system at the SMC site. The groundwater pump and treat system provides hydraulic containment of groundwater in the project area (including the Cadet site), and treats dissolved-phase VOCs in extracted groundwater through the use of an air stripping process. The treated water is discharged to the Columbia River, south of the SMC site. The groundwater treatment system was constructed from fall 2008 through spring 2009. The system was started in June 2009. Initial pumping rates are approximately 2,500 gallons per minute.

2.5 OTHER SOURCES

Two other sources of TCE (and other VOCs) in groundwater have been identified near the Cadet site: the Swan Manufacturing Company (SMC) site, and the Former Support Terminals Services (ST Services) site (Figure 1-2). Note that in 2005, ST Services was purchased by Valero and currently operates as NuStar Energy, LP. It will be referred to as the NuStar site throughout the remainder of this document. While the focus of this Final RI Report is on the Cadet site, it should be noted that these two other source areas impact the interpretation of Cadet site data and the nature and extent of contamination in the project area. Remedial investigations were completed at the SMC site and are ongoing at the NuStar site; resulting documentation can be found in Ecology files. The SMC and NuStar sites are discussed *passim* throughout this Final RI Report.

The following brief description of the SMC and NuStar sites establishes their relationship with the Cadet site. Additional, detailed information on these sites can be found in the Final Remedial Investigation Report prepared for the SMC site (Parametrix 2009c).

2.5.1 Swan Manufacturing Company Site

VOC contamination was first discovered near the former Building 2220 site (a.k.a. the SMC site) by the City of Vancouver in 1997, in conjunction with the City's 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. 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.

In 1998, the Port initiated a remedial investigation and feasibility study (RI/FS) at the SMC site to address TCE and other related VOCs in soil and groundwater in the project area. VOC contamination has impacted the groundwater aquifer beneath the site. Figure 2-1 shows the groundwater monitoring well network in the project area, including wells associated with the SMC site.

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 NuStar-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 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).

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 cubic yards 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 2008, the Port initiated the construction of a groundwater pump and treat system at the SMC site. The groundwater pump and treat system provides hydraulic containment of groundwater in the project area (including both the SMC and Cadet sites) and treats dissolved-phase VOCs in extracted groundwater through the use of an air stripping process. The treated water is discharged to the Columbia River, south of the SMC site. The system was started in June 2009. Initial pumping rates are approximately 2,500 gallons per minute.

Additional information regarding the SMC site can be found in the Final Remedial Investigation Report dated May 7, 2009 (Parametrix 2009c).

2.5.2 NuStar

The NuStar site is located on Port property (Figure 1-2). The NuStar 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. In 2005, ST Services was purchased by Valero and currently operates as NuStar Energy, LP. The current Agreed Order (07-TC-S DE3938) was issued in November 2007 between Ecology and NuStar.

Several phases of investigation and remedial activities have been conducted at the site since 1991 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 2-1 shows the groundwater monitoring well network in the vicinity of the NuStar site.

Three source areas for the release of VOCs to the subsurface have been identified at the NuStar 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 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 tetrachloroethene (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 USA zone between 35 and 45 feet below ground surface (bgs); these concentrations are detected in groundwater monitoring wells located near the probable source area between Warehouses 13 and 15. 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 a maximum concentration of 5,000 µg/L in monitoring well MW-9. Monitoring wells MW-7 and MW-9 are located along the rail spur, in the northern portion of the site (Figure 2-1).

In 2000, an Interim Remedial Action Measure (IRAM) was implemented to reduce VOC concentrations in groundwater beneath the site. The IRAM consisted of the installation and operation 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 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 NuStar site in November 2006 (Ash Creek 2006b), enhanced bioremediation and soil vapor extraction were recommended as an interim action for the source area located between Warehouses 13 and 15. The subsequent interim action, initiated in 2008, focused on addressing the potential migration of vapors to breathing spaces and reducing the relatively high concentrations of VOCs that could migrate to the Columbia River (Ash Creek 2008b).

2.5.3 Other Potential Sources

As part of the SMC RI activities, 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 2005).

Other than the SMC and NuStar sites described above, the following sites were identified as potential sources of chlorinated solvents in the vicinity of the Cadet site:

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

However, these sites do not appear to have contributed to the chlorinated solvents captured by GWM pumping wells. Based on the findings of the Other Potential Sources Report (Parametrix 2005), none of these sites represent a significant impact to the design, implementation, and/or effectiveness of the final remedy for the Cadet or SMC sites.

3. SUMMARY OF REMEDIAL INVESTIGATIONS

Since 1998, approximately 20 investigations and/or phases of investigation have been conducted at or in the vicinity of the Cadet site to delineate the nature and extent of TCE and other VOCs. Most of the investigations were completed by AMEC, an environmental consultant hired by Cadet. In general, the investigations included sampling more than one media. Therefore, rather than presenting the remedial investigation summary by the sequence of events conducted (which alternate between media), this section of the Final RI Report includes a comprehensive summary of the investigations conducted for each media. This summary covers the period from 1998 through June 2009.

Investigations in the project area began after the Port began investigating environmental conditions at the SMC site. As part of those investigations, limited sampling was conducted in the Cadet area to assess whether the source of contamination was from Cadet. Based on that information, Cadet initiated a Phase II Environmental Site Assessment (ESA) in 1999. Since that time, a total of 76 soil samples, 2,879 groundwater samples, 452 soil gas samples, 716 indoor air samples, and 131 outdoor air samples have been collected in connection with Cadet site investigations. The following sections describe the remedial investigations conducted for:

- Soil
- Soil gas
- Groundwater
- Indoor air
- Outdoor air
- Hydrogeologic investigations

It should be noted that the naming scheme for samples has been modified. In order to differentiate Cadet site samples from the SMC samples, the Port has added the identifier "CM" to the beginning of the Cadet samples in this and other reports. For example, a groundwater sample collected by AMEC and labeled "MW-18" becomes "CM-MW-18". However, the analytical laboratory reports do not have the "CM" identifier, since the samples were collected by AMEC or others specifically for Cadet and independent of the Port's work at the SMC site. When the Port took over the Cadet investigation in 2006, all subsequent Cadet samples have included the "CM" identifier, including the analytical laboratory reports. Therefore, to avoid confusion as much as possible, all Cadet site samples referenced in this report include the "CM" identifier when referencing Cadet samples.

3.1 SOIL INVESTIGATIONS

Soil investigations completed at the Cadet site and in the NFVN are summarized in the following sections. Laboratory analytical reports and data validation are included in Appendix A. Boring logs are included in Appendix B. Detailed results for each investigation are included in the following sections. A summary of the overall soil conditions and the nature and extent of soil contamination is included in Section 8.2.

3.1.1 POV Off-Site Investigation

In early 1998, the Port began investigating impacted soil encountered adjacent to the SMC site during a road expansion project. Additional investigations were conducted by the Port in the area north of Fourth Plain Boulevard to assess whether VOCs extended north of the former SMC facility (Parametrix 1999).

During this investigation, soil samples were collected from seven borings (labeled Cadet-01 through Cadet-07) located on the eastern portion of the Cadet site, adjacent to the NFVN. These soil samples were collected because groundwater samples collected in the NFVN contained VOCs. The locations of these borings are shown on Figure 3-1.

Soil samples were collected from two depths in each boring: 3 feet below ground surface (bgs) and 15 to 18 feet bgs. The depths were selected to evaluate a shallow depth and the depth near groundwater. The soil samples were analyzed for VOCs by U.S. Environmental Protection Agency (EPA) Method 8021B. No VOCs were detected in the soil samples. Analytical results are summarized in Table 3-1.

3.1.2 Phase II Environmental Site Assessment

In March 1999, AMEC conducted a Phase II ESA for the Cadet property. The Phase II ESA included the collection of soil and groundwater samples from 16 borings (CM-GP-001 through CM-GP-016) completed on the site and adjacent parcel. The purpose of the investigation was to evaluate if VOCs were present in the subsurface of these two properties.

These borings were advanced to 16 to 20 feet bgs (AGRA 1999). Soil samples were collected at 10 feet bgs and 14 feet bgs in borings CM-GP-002 and CM-GP-003, respectively. The locations of the borings are shown on Figure 3-1.

PCE, TCE, and cis-1,2-DCE were detected in each soil sample at maximum concentrations of 0.21 mg/kg, 0.4 mg/kg, and 0.058 mg/kg, respectively. No other VOCs were detected in soil samples collected from the borings. Analytical results are presented in Table 3-1.

3.1.3 Preliminary Subsurface Investigation

During the fall of 1999, AMEC conducted additional soil sampling by completing four probe borings in the NFVN (CM-FV-05 through CM-FV-08) and three borings beneath the Cadet building (CM-C-01 through CM-C-03) (AGRA 2000a). The locations of the borings are shown on Figure 3-1.

Borings CM-FV-05 through CM-FV-08 were completed near the main sanitary sewer line that runs north/south under Weigel Avenue. Soil samples were collected near the sanitary sewer line to determine if solvents were present in soil from leaking sewer pipes that may have contained solvents in waste water and whether permeable backfill presumed to be present in the sewer trench was a preferential migration pathway for the movement of VOC-impacted groundwater from the site. Based on the investigation, it appears that native soil was used as pipe backfill material; no engineered fill was encountered as backfill. Soil samples were collected from 17 feet bgs in each boring and analyzed for VOCs by EPA Method 8260B.

TCE was detected in the soil sample collected from boring CM-FV-05 at a concentration of 0.031 mg/kg. Methylene chloride was detected in the soil samples collected from boring CM-FV-06 and CM-FV-07 at concentrations of 0.052 mg/kg and 0.047 mg/kg, respectively. No other VOCs were detected from the soil samples. Based on the lack of significant VOCs in soil (and groundwater; see Section 3.3), the sewer line backfill was judged not to be a preferential migration pathway.

Borings CM-C-01 through CM-C-03 were completed beneath the Cadet building to determine if the former locations of the TCE tank and waterfall structures were source areas for the subsurface VOC contamination. One soil sample was collected from each boring and analyzed for VOCs by EPA Method 8260B. The soil samples were collected at depths ranging from 5 to 13 feet bgs. Sample depths were selected based on the results of field screening using a photoionization detector (PID). PCE, TCE, and cis-1,2-DCE were detected in the soil samples at maximum concentrations of 0.15, 0.84, and 0.04 mg/kg, respectively (Table 3-1). Based on the analytical results, the former locations of the TCE tank and structures were suspected source areas for the subsurface VOC contamination.

3.1.4 Interim Action Source Investigation

In June and July 2000, AMEC sampled and tested soil gas (from the vadose zone), soil, and groundwater for VOCs to develop additional data delineating the source of VOCs in groundwater. The work was completed consistent with the Interim Action Source Investigation Work Plan (AGRA 2000b) and documented in the Interim Action Source Investigation Report (AMEC 2000).

As part of the investigation, soil samples were collected from six borings completed in the parking lot east of the Cadet building (CM-GP-017 through CM-GP-022), five borings along a sanitary sewer easement on private property in the NFVN (CM-FV-09 through CM-FV-13), and six borings in the paint department inside the Cadet building (CM-C-04 through CM-C-09). The locations of these borings are shown on Figure 3-1.

Field screening of soil samples from these borings using a PID, Sudan IV dye, and/or ultraviolet (UV) light did not detect evidence of VOCs at levels high enough to be regarded as a source material known as dense non-aqueous phase liquid (DNAPL). Section 3.3.10 discusses the potential presence of DNAPL at the site.

Soil samples were collected for field inspection from borings CM-GP-017 through CM-GP-022 at 4-foot vertical intervals between 0 and 20 feet bgs (Table 3-1). One or two soil samples from each boring were chosen for analysis based on field-screening results and the estimated depths of nearby underground utilities that potentially could have served as preferential pathways for the migration of dissolved phase VOCs in groundwater. PCE, TCE, and cis-1,2-DCE were detected in the chosen soil samples at maximum concentrations of 0.15 mg/kg, 0.22 mg/kg, and 0.087 mg/kg, respectively. No other VOCs were detected in the soil samples. The analytical results are included in Table 3-1.

Soil samples were collected for field inspection from borings CM-FV-09 through CM-FV-13, along the sewer line easement. The soil samples were collected at 4-foot vertical intervals to a total depth of 13 feet bgs at each boring. One or two soil samples from each boring were analyzed by EPA Method 8260B. Low levels of PCE (0.026 mg/kg) and TCE (0.024 mg/kg) were detected in soil sample CM-VF-09 at 13 feet bgs. No VOCs were detected in any of the other soil samples. The analytical results are included in Table 3-1.

Soil samples were collected from borings CM-C-04 through CM-C-09, located inside the paint department in the Cadet building. Soil samples were collected from 9 feet bgs in CM-C-04, from 5 and 13 feet bgs in borings CM-C-07, CM-C-08, and CM-C-09, and from 5, 9, 13, and 17 feet bgs in borings CM-C-05 and CM-C-06. PCE and TCE were detected in all soil samples at maximum concentrations of 1.7 mg/kg and 14 mg/kg, respectively. The analytical results are included in Table 3-1.

3.1.5 Interim Action Source Investigation Update

In November 2000, AMEC installed additional monitoring wells inside the Cadet building to further assess the distribution of VOCs in groundwater (AMEC 2001a). Soil samples were collected in each of the borings during the drilling of the monitoring wells. The locations of the borings (labeled CM-C-10 through CM-C-13) are shown on Figure 3-1.

Boring CM-C-10 was located north of the former waterfall structures; boring CM-C-12 was located in the paint department; and borings CM-C-11 and CM-C-13 were located west and south of the paint department area, respectively. Soil samples from 17 feet bgs were submitted for analysis based on field readings from a PID. The samples were analyzed for VOCs by EPA Method 8260B.

PCE and TCE were detected in the soil samples at maximum concentrations of 1.7 mg/kg and 0.2 mg/kg, respectively. No other VOCs were detected in the soil samples. The analytical results are shown in Table 3-1.

3.1.6 Spring 2001 Soil and Groundwater Sampling

In February and March 2001, soil and groundwater samples were collected from probe borings completed in systematic grid cells established across the site (both inside and outside the building) and the L-Shaped Parcel. Samples were collected for field screening from 56 of the cells to further delineate areas of elevated VOCs and to assess other potential areas of interest. Sample results were presented in the Semi-Annual Groundwater Monitoring Report 2001 (AMEC 2001b) and are summarized below.

In February 2001, 17 probe borings (CM-C-13A through CM-C-29) were completed inside the Cadet building. Soil samples were collected from 5 feet bgs and/or 13 feet bgs at borings CM-C-13A, CM-C-14, CM-C-16, CM-C-20, CM-C-21, CM-C-24, and CM-C-26. The locations of these seven borings are shown on Figure 3-1. These samples were analyzed for VOCs by EPA Method 8260B.

PCE and TCE were detected in the soil samples at maximum concentrations of 0.00547 mg/kg and 0.00588 mg/kg, respectively. The analytical results are included in Table 3-1.

In March 2001, the grid was extended outside the Cadet building and onto the adjacent L-Shaped Parcel. The grid spacing was 50 feet on the Cadet site, and 75 or 100 feet on the L-Shaped Parcel. Soil samples were collected from 56 borings (CM-GP-24 through CM-GP-80, excluding CM-GP-62 because it was inadvertently omitted from the numbering scheme), 35 in and near the Cadet building and 21 on the L-Shaped Parcel. The locations of the borings are shown on Figure 3-2.

Soil samples were collected from each boring at 1 to 5 feet bgs and screened in the field for VOCs using a PID. If elevated PID readings were measured, deeper soil samples were collected and screened. This procedure was followed until VOCs were not identified by the PID or until groundwater was encountered. The soil sample with the highest PID reading (CM-GP-72 at 16 feet bgs) was submitted for laboratory analysis. PCE was detected in this sample at a concentration of 0.15 mg/kg. No other VOCs were detected. Laboratory analytical results are included in Table 3-1 (note that PID readings are not available and are not included in Table 3-1).

3.1.7 Vapor Extraction Wells

In September 2001, AMEC installed a soil vapor extraction system at the site (see Section 5.1 for details). As part of the investigation, soil samples were collected from four borings (labeled CM-V-01 and CM-V-03 through CM-V-05). The locations of the borings are shown on Figure 3-1.

Soil samples were collected from the borings at depths ranging from 12 feet bgs to 20 feet bgs and analyzed for VOCs by EPA Method 8260B. PCE and TCE were detected in all soil samples, with maximum concentrations of 0.28 mg/kg and 0.476 mg/kg, respectively. No other VOCs were detected. Laboratory analytical results are included in Table 3-1.

3.1.8 Distribution of VOCs in Soil

Based on the soil investigations summarized in Sections 3.1.6 and 3.1.7, the distribution of VOCs in soil was determined to be limited in extent. No VOCs were detected in soil samples collected in the NFVN, and only very low concentrations of VOCs were detected in samples collected on the eastern portion of the Cadet site. This suggested the source material for the contamination was not a surface release in the east side of the Cadet property or the NFVN.

The highest concentrations of PCE and TCE were detected in soil samples collected beneath the Cadet building. Based on the data collected, the soil contamination was determined to be limited in extent to the area under the Cadet building. The source of VOCs in groundwater was determined to be the result of spills or releases in the Cadet building and in the subsurface along the sewer line breakage.

3.2 SOIL GAS INVESTIGATIONS

The following sections discuss soil gas investigations conducted at the Cadet site.

3.2.1 Preliminary Soil Gas Probes

In June and November 2000, six soil gas samples were collected at the site. The samples were collected inside the Cadet building in borings CM-C-08 through CM-C-13, in the vicinity of the paint department (Figure 3-3), at 4 feet bgs.

PCE concentrations detected in soil gas under the Cadet building ranged from 46,000 micrograms per cubic meter (µg/m^3) in boring CM-C-10 to 710,000 µg/m^3 in boring CM-C-09. TCE concentrations in soil gas ranged from 220,000 µg/m^3 in boring CM-C-08 to 1,800,000 µg/m^3 in boring CM-C-13. 1,1,1-TCA concentrations in soil gas ranged from non-detect in borings CM-C-08, CM-C-09, and CM-C-13 to 11,000 µg/m^3 in boring CM-C-11.

In June 2000, four soil gas samples were collected from temporary soil gas probes (labeled CM-FV-09, CM-FV-11 and CM-FV-13) installed in the NFVN (Figure 3-3). These borings were installed along the sanitary sewer easement east of the Cadet facility. One soil gas sample was collected from 8 to 10 feet bgs from each boring; one additional sample was collected from 4 to 6 feet bgs in CM-FV-11. The highest concentrations of TCE, PCE and 1,1,1-TCA were 1,500 µg/m^3, 2,300 µg/m^3 and 510 µg/m^3, respectively. These maximum concentrations were detected in soil gas collected from CM-FV-09. Table 3-2 presents the preliminary soil gas analytical results.

In August 2001, 22 temporary soil gas probes (labeled CM-FV-14 through CM-FV-35) were installed in the NFVN. Soil gas samples were collected at 3 to 4 feet bgs and were analyzed for PCE, TCE, cis-1,2-DCE, 1,1-DCE, and 1,1,1-TCA. Most of the soil gas samples were collected in the southwest portion of the NFVN, with a focus on existing sewer line locations (Figure 3-3).

The highest concentrations of VOCs were detected in the soil gas probes along the sewer line beneath W. 28th Street and Unander Avenue (Figure 3-3). PCE, TCE and 1,1,1-TCA were detected in soil gas collected from probe CM-FV-27 at concentrations of 3,200 µg/m^3, 4,300 µg/m^3, and 2,000 µg/m^3, respectively. Based on the preliminary soil gas investigation, it was determined that the potential to impact indoor air was present. DOH prepared a Health

Consultation (DOH 2002) and recommended indoor air sampling in the NFVN (see Section 3.4).

3.2.2 Soil Gas Monitoring Wells

Based on the preliminary soil gas results described above and initial indoor air sampling results obtained in January and September 2002 (Section 3.4), Ecology required additional soil gas sampling in the NFVN to further evaluate vapor intrusion issues. In January 2004, Cadet installed soil gas monitoring wells CM-SG-01 through CM-SG-12 in the NFVN (Figure 3-3) and initiated a soil gas monitoring program. The intent of the program was to try to establish a site-specific correlation between soil gas and indoor air, and to delineate the extent and distribution of VOCs in soil gas in the NFVN.

3.2.2.1 Design and Installation

In January 2004, soil gas monitoring wells CM-SG-01 through CM-SG-12 were drilled in the NFVN using the hollow-stem-auger method (Figure 3-3). The wells consist of up to three nested screen intervals in each of the borings, 1-foot long well screens installed at 10 feet bgs, 15 feet bgs, and 20 feet bgs. The screens are isolated from each other to prevent migration of soil gas and potential cross-contamination. At soil gas monitoring locations CM-SG-9 and CM-SG-10, an additional well screen was installed at a depth of 30 feet bgs, because depth to groundwater in these two areas is greater than 30 feet bgs during most of the year.

The locations of the soil gas wells were approved by Ecology and were intended to provide adequate coverage of the area where the majority of the indoor air samples were previously collected. The 12 soil gas monitoring wells were installed in the rights-of-way of W. 27th Street, W. 28th Street, W. 31st Street, Weigel Avenue, Van Allman Avenue, and Unander Avenue (Figure 3-3). To allow for comparison to groundwater concentrations, the soil gas monitoring wells were generally located within 100 feet of groundwater monitoring wells (AMEC 2005). Well construction data for the soil gas monitoring wells are summarized in Table 3-3. Boring logs are included in Appendix B.

Each soil gas well is equipped with a 1-foot Schedule 40 polyvinyl chloride (PVC) 0.020-inch slotted screen. The screen interval of each soil gas sampling well is positioned vertically in the center of a 2-foot long, 8/12 silica sand pack. Positioning the screen interval in the center of the sand pack improved the soil gas exchange with the native sediments, thereby allowing the collection of a representative soil gas sample. Bentonite casing seal material was used between the screen and sand pack intervals in each borehole. The installation and hydration of the bentonite prevents cross-contamination with other screen intervals within a single borehole. The topmost sand pack, placed in the annulus of the 10-foot depth soil gas sampling point, extends approximately 1.5 feet above the screen interval. A 6-inch layer of 10/20 silica sand pack was placed above the 8/12 silica sand pack. A one-inch schedule 40 PVC riser was used to extend each soil gas sampling point from the top of the screen interval to the ground surface.

The borehole around each sampling point was backfilled from the top of the sand pack to the ground surface with bentonite chips placed in 5-foot lifts and hydrated. This provides an air-tight seal and excludes the possibility of surface water migrating along the well annulus; such migration could potentially obstruct the screens. The air-tight seal also helps limit the potential for surface air from entering the well screen which may bias soil gas samples. The top of each soil gas sampling point was sealed using a permanent air-tight cap. Each soil gas monitoring location was finished with a flush-mount, traffic-rated monument and set in concrete to provide a water-tight seal. A schematic of a typical soil gas monitoring well is presented on Figure 3-4.

3.2.2.2 Soil Gas Sampling

Soil gas wells CM-SG-01 through CM-SG-12 were sampled during 17 sampling events, completed from January 2004 through March 2009. The frequency of soil gas monitoring has varied from quarterly in the initial years to annually in 2009. During some of the events, samples were only collected from the wells screened at 10 feet bgs. All of the sampling events were approved by Ecology prior to implementation.

All samples were collected in Summa canisters and analyzed for selected VOCs by EPA Method TO-15. Sampling procedures followed the Ecology-approved standard operating procedures (SOPs) included in Appendix C. The soil gas analytical results are included in Table 3-4. The following sections summarize the distribution of VOCs in soil gas observed at the site.

3.2.2.3 Vertical Distribution

A review of the soil gas data from each well and sampling depth indicates that, in general, VOC detected concentrations were highest in the deepest port sampled for a particular well (20 or 30 feet bgs). This was expected, as the compounds in the soil gas are derived from volatilization of contaminants in the underlying groundwater, and samples collected closer to the source material are expected to yield higher concentrations. As the contaminants migrate upward through the vadose zone, attenuation and degradation of the contaminants are expected to result in lower concentrations in the shallower zones. The concentration gradient from deeper soil gas (20 feet) to shallow soil gas (10 feet) varies greatly among the soil gas wells. However, in most of the wells, concentrations of TCE at the 10-foot level are 50% to 75% less than at the 20-foot or 30-foot level in each sampling event (Table 3-5).

Although this trend is generally true for all compounds, a number of anomalies in the data set were noted. For example, relatively high and consistent concentrations of TCE have been detected in soil gas well CM-SG-04 at 10 and 15 feet bgs (maximum concentrations of 5,500 $\mu g/m^3$ and 12,000 $\mu g/m^3$, respectively). However, there was a significant downward trend of TCE concentration in CM-SG-04 at the 20-foot depth (from 30,000 $\mu g/m^3$ in January 2004 to a low of 630 $\mu g/m^3$ in June 2005). The reason for this anomaly is unknown, but could be related to the groundwater level near the 20-foot zone, geologic conditions, and/or changing oxygen conditions (which can affect degradation). The March 2008 and March 2009 results do not exhibit this anomaly, suggesting that soil gas concentrations can be variable, but are equilibrating. Other anomalies occurred in the data collected, but do not appear to be significant and differ only slightly from the expectation that soil gas concentrations will be higher at increasing depths (Table 3-4).

3.2.2.4 Spatial Distribution

The distribution and concentrations of TCE and other VOCs in soil gas have generally decreased since soil gas sampling was initiated in 2004. This is attributed primarily to reduction of groundwater concentrations in the project area. In January 2004, the maximum concentrations of TCE in shallow groundwater near the source area (Cadet) exceeded 500 micrograms per liter (µg/L). As of March 2009, groundwater concentrations near the source area have been substantially reduced, with TCE in concentrations in most wells less than 50 µg/L.

With the exception of CM-SG-9 through CM-SG-12, relatively high concentrations of VOCs, particularly PCE and TCE, were detected in the soil gas wells across the site in 2004 (Table 3-4). In general, the distribution of VOCs in soil gas correlates with the location of the groundwater plume (Figure 3-5). Soil gas wells CM-SG-9, CM-SG-10, CM-SG-11 and CM-

SG-12 are located above the far east, northeast, and north portions of the groundwater plume, respectively, and exhibited much lower concentrations of contaminants in soil gas (although it should be noted that the concentration of TCE in CM-SG-10 at 30 feet bgs increased significantly in 2007).

The highest concentrations of TCE were detected in samples collected in 2004 from soil gas wells CM-SG-4, CM-SG-5 and CM-SG-8 (maximum concentrations of 33,000 $\mu g/m^3$, 49,000 $\mu g/m^3$ and 38,000 $\mu g/m^3$, respectively), all located above the portion of the groundwater plume with the historically elevated concentrations of VOCs. All of these maximum concentrations were detected in the 20-foot depth sample port. Analytical results for soil gas samples collected from these wells in March 2008 indicate TCE concentrations of 1,100 $\mu g/m^3$, 280 $\mu g/m^3$, and 470 $\mu g/m^3$, respectively. The significant declines in the spatial distribution of TCE concentrations in soil gas are attributed to the source area reduction of groundwater contaminants in the plume. This reduction is a result of the operation of the AS/SVE system, the installation and operation of recirculating groundwater remediation wells RGRW-1 through RGRW-7, and natural attenuation and degradation.

Historical time plots for TCE concentrations in soil gas wells in the NFVN are shown on Figure 3-5. In addition, the temporal distribution of TCE in soil gas is shown in Table 3-6. With few exceptions, TCE concentrations in all wells have decreased over time. Concentrations of TCE (and other contaminants) in soil gas samples from most depths in most of the wells have decreased more than 90% since 2004 (see Table 3-6).

3.2.3 Distribution of VOCs in Soil Gas

As described above, VOCs have been detected in soil gas near the Cadet site and across the NFVN. In general, the presence of VOCs in soil gas can be correlated with the occurrence of VOCs in groundwater. In most cases, concentrations of VOCs in soil gas increase with depth, which is expected due to volatilization of the groundwater source material into the overlying vadose zone. The concentrations of VOCs in soil gas have decreased significantly since initial soil gas wells were installed in 2004. The decrease in concentrations is due to the operation of the AS/SVE system at Cadet and the RGRWs at Cadet and in the NFVN. The presence of VOCs in soil gas is not evaluated in the risk assessment in Section 9 because exposure to soil gas is not a complete exposure pathway. However, VOCs in soil gas are the primary contributors to indoor air concentrations. Exposure to indoor air is evaluated in the risk assessment, summarized in Section 9.

3.3 GROUNDWATER INVESTIGATIONS

Groundwater investigations have been conducted at the Cadet site since 1998. The results of these investigations are discussed below.

3.3.1 POV Off-Site Investigation

In late 1997, the Port began investigating impacted soil encountered adjacent to the SMC site during a road expansion project. In 1998, and on behalf of the Port, Parametrix investigated the area north of Fourth Plain Boulevard as part of an assessment of the extent of HVOCs in groundwater north of the former SMC site (Parametrix 1999). Parametrix sampled groundwater in the NFVN from shallow (approximately 20 feet bgs) probe borings on Weigel Avenue, W. 27th Street, W. 28th Street, Unander Avenue, and W. 31st Street (Figure 3-6a). HVOCs were detected in groundwater samples collected from borings Weigel-01 through Weigel-05, W27th-01 through W27th-05, W28th-01, W28th-01A, W28th-02, and Unander-

01 through Unander-05. The maximum PCE and TCE concentrations detected were 245 µg/L and 2,490 µg/L, respectively. Analytical results are shown in Table 3-7.

Soil and groundwater samples also were collected by Parametrix from seven borings (labeled Cadet-01 through Cadet-07) located on the eastern portion of the site, adjacent to the NFVN (Figure 3-6a). These samples were collected because the NFVN groundwater samples contained HVOCs. HVOCs were detected in groundwater samples collected from first-encountered groundwater (at approximately 20 feet bgs) in six of the seven borings (labeled Cadet-01 and Cadet-03 through Cadet-07) (Figure 3-6a). PCE and TCE were detected at maximum concentrations of 58 µg/L and 201 µg/L, respectively. Analytical results are shown in Table 3-7.

3.3.2 Phase II Environmental Site Assessment

In March 1999, AMEC collected groundwater samples from sixteen borings (CM-GP-001 through CM-GP-016) at the Cadet site and adjacent L-Shaped Parcel. The borings were advanced to 16 to 20 feet bgs (AGRA 1999).

Twelve of the borings (labeled CM-GP-001 through CM-GP-012) were completed on the site, and four of the borings (labeled CM-GP-013 through CM-GP-016) were completed on the L-Shaped Parcel (Figure 3-6a). Elevated HVOCs were detected in groundwater samples collected from borings CM-GP-002 through CM-GP-005, on the east side of the Cadet building, and next to a former sewer line. PCE and TCE were detected at maximum concentrations of 930 µg/L and 3,000 µg/L in groundwater collected from CM-GP-003, located near the former paint room in the Cadet building. Analytical results are summarized in Table 3-7.

3.3.3 Preliminary Subsurface Characterization

During the fall of 1999, AMEC collected groundwater samples from eight probe borings (labeled CM-FV-01 through CM-FV-08) completed in the NFVN and three borings (labeled CM-C-01 through CM-C-03) completed beneath the Cadet building (AGRA 2000a). Boring locations are included on Figures 3-6b.

NFVN borings CM-FV-01 through CM-FV-04 were completed to depths of 40 feet bgs in the vicinity of borings completed by the Port in 1998 (borings W28th-02, Unander-04, W27th-04, and Weigel-03). Samples collected at the similar locations by the Port (at 20 feet bgs) and AMEC (at 40 feet bgs) contained TCE at concentrations greater than 1,000 micrograms per liter (µg/L). However, the TCE concentrations in samples from 40 feet bgs are mostly higher than those collected from 20 feet bgs.

NFVN borings CM-FV-05 through CM-FV-08 were completed near the main sanitary sewer line that runs north/south under Weigel Avenue. These borings were completed to evaluate whether permeable backfill presumed to be present in the sewer trench acted as a preferential migration pathway for the movement of HVOC-impacted groundwater from the site. Soil encountered in these borings at the depth of the sewer line was not coarser-grained than the native soil. Furthermore, testing of a groundwater sample (from a depth of 28 to 29 feet bgs) from each of these four borings indicated that HVOC levels along the sewer line were similar to those detected in adjacent native soil. Based on this information, it was determined that the sewer line backfill did not act as a preferential migration pathway.

Borings CM-C-01 through CM-C-03 were completed beneath the Cadet building to evaluate if the former TCE dip tank or former waterfall structures were sources for the HVOC contamination. One soil sample and one groundwater sample from each boring were analyzed for HVOCs. The groundwater samples were collected from first-occurring groundwater at approximately 22 feet bgs. HVOCs were detected in the groundwater samples (Table 3-7), with maximum PCE and TCE concentrations of 4,900 µg/L and 22,000 µg/L, respectively, from boring CM-C-03 (Figure 3-6b).

3.3.4 Interim Action Source Investigation

In June and July 2000, AMEC sampled groundwater to develop additional data delineating the source of HVOCs. The work was completed in a manner consistent with the Interim Action Source Investigation Work Plan (AGRA 2000b).

Seventeen shallow probe borings were completed: six in the parking lot east of the Cadet building (CM-GP-017 through CM-GP-022), five along a sanitary sewer easement on private property in the FVN (CM-FV-9 through CM-FV-13), and six in the paint department inside the Cadet building (CM-C-04 through CM-C-09). Boring locations are shown on Figure 3-6b. Groundwater samples were collected from 16 to 20 feet bgs in borings CM-GP-17 through CM-GP-22, from 18 to 22 feet bgs in borings CM-FV-09 through CM-FV-13, and from 18 to 22 feet bgs in borings CM-C-04 through CM-C-09. The maximum PCE and TCE concentrations detected were 70,000 µg/L (boring CM-C-09) and 41,000 µg/L (boring CM-C-06), respectively. Analytical results are summarized in Table 3-7.

3.3.5 Interim Action Source Investigation Update

In November 2000, AMEC conducted additional sampling to further assess the distribution of HVOCs in groundwater (AMEC 2001b). The samples were obtained from three of four probe borings (labeled CM-C-10 through CM-C-13) located inside the Cadet building (Figure 3-6b).

Boring CM-C-10 was located north of the former waterfall structures, and CM-C-12 was located in the paint department. Borings CM-C-11 and CM-C-13 were located west and south of the paint department area, respectively. Each boring was advanced to 22 feet bgs. Groundwater samples were collected in each boring at depths between 18 and 22 feet bgs, except for boring CM-C-11, which could not be sampled because the boring was dry after 30 minutes. The maximum PCE and TCE concentrations detected were 16,000 µg/L (boring CM-C-12) and 78,000 µg/L (boring CM-C-13), respectively. Analytical results are summarized in Table 3-7.

3.3.6 Spring 2001 Groundwater Sampling

In February and March 2001, soil and groundwater samples were collected from probe borings completed in systematic grid cells established across the site and the L-Shaped Parcel. The grid spacing was 50 feet inside and outside the Cadet building and 75 or 100 feet on the L-Shaped Parcel. The objective of this sampling was to further delineate known areas of elevated HVOCs and to screen for other potential areas of elevated HVOCs in soil and groundwater. The sample results were presented in the 2001 Semi-Annual Groundwater Monitoring Report (AMEC 2001b) and are summarized below.

In February 2001, 16 probe borings (CM-C-14 through CM-C-29) were completed inside the Cadet building. Groundwater samples were collected for HVOC analysis from each of the 16 borings between depths of 18 and 22 feet bgs. The groundwater samples collected from borings CM-C-17 and CM-C-29 were also analyzed for petroleum hydrocarbons because they were located near petroleum storage areas (hydraulic metal press and storage cabinet). The maximum PCE and TCE concentrations detected were 819 µg/L (boring CM-C-19) and 27,900 µg/L (boring CM-C-16), respectively (Figure 3-6b). Petroleum hydrocarbons were not detected.

In March 2001, the grid was extended outside the Cadet building and onto the adjacent L-Shaped Parcel. The grid spacing was 50 feet on the Cadet site, and 75 or 100 feet on the L-Shaped Parcel. Groundwater samples were collected from 56 probe borings (CM-GP-024 through CM-GP-080, excluding CM-GP-062 because it was inadvertently omitted from the numbering scheme), 35 of which were completed in and near the Cadet building and 21 of which were completed on the L-Shaped Parcel. Boring locations are shown on Figure 3-2.

Groundwater samples were collected from 18 to 24 feet bgs in each of the 56 borings. The maximum PCE and TCE concentrations detected were 6,800 µg/L and 21,500 µg/L, respectively, in boring CM-GP-072 (Figure 3-2). Deeper groundwater samples were also collected from 40 to 44 feet bgs in 12 of the 56 borings to attempt to delineate the vertical extent of HVOCs. The deeper groundwater samples were collected from a second probe boring completed next to the original shallow borings. This was done to minimize the possibility of cross contamination between shallow and deeper zones. The maximum PCE and TCE concentrations detected in the deeper borings were 233 µg/L and 1,330 µg/L, respectively. These concentrations were detected in the deeper sample collected from probe borings GP-070 and GP-057 (Figure 3-2). The groundwater analytical results are summarized in Table 3-7.

3.3.7 Probe Borings

The primary purpose of the probe investigation by AMEC was to further characterize the horizontal and vertical extent of HVOCs in shallow groundwater on and near the Cadet site. The secondary purpose was to evaluate a potential source of HVOCs near W. 28th Street and Unander Avenue in the FVN, adjacent to a former illegal drug laboratory. This work included completion of 31 additional borings in June and July 2002. Nineteen of the borings were located near the Cadet building (ten outdoors and nine indoors), six were located on the L-Shaped Parcel, and six were located in the FVN (Figure 3-6c).

The nine borings inside the Cadet building (CM-C-30 and CM-C-32 through CM-C-39) were completed to characterize groundwater quality at a greater depth than previously assessed beneath the building. Groundwater samples were collected from 40 and 60 feet bgs. The maximum PCE and TCE concentrations in the deeper borings were 128 µg/L and 880 µg/L, respectively, in boring CM-C-32 at 40 feet bgs (Figure 3-6c).

Of the ten site borings completed outdoors, five (CM-GP-081 through CM-GP-085) were located around the building perimeter where elevated HVOC levels had been detected in shallow groundwater at 20 feet bgs. Groundwater samples were collected from 40 and 60 feet bgs in these five borings. The maximum PCE and TCE concentrations detected were 79.6 µg/L and 111 µg/L, respectively, in boring CM-GP-082 at 60 feet bgs (Figure 3-6c).

Probe borings CM-GP-092 through CM-GP-096 were located along the eastern property boundary, between the Cadet building and the sewer easement in Weigel Avenue, both of which were previously identified as potential HVOC source areas. Groundwater samples were collected from 40 and 60 feet bgs to further define the extent of HVOCs in groundwater between these two areas. The maximum PCE and TCE concentrations detected were 128 µg/L (boring CM-GP-092 at 60 feet bgs) and 523 µg/L (boring CM-GP-094 at 60 feet bgs), respectively (Figure 3-6c).

Six borings (CM-GP-086 through CM-GP-091) were completed on the northern and western perimeters of the L-Shaped Parcel. Groundwater samples were collected at depths of 40 and 60 feet bgs to characterize groundwater quality at a greater depth than previously assessed and to evaluate groundwater quality beneath the L-Shaped Parcel. The maximum PCE and

TCE concentrations detected were 10.1 µg/L and 89.9 µg/L, respectively, in boring CM-GP-90 at 40 feet bgs (Figure 3-6c).

CM-GP-097 through CM-GP-102 were completed along W. 28th Street and Unander Avenue in the FVN, near a suspected former illegal drug laboratory at 2107 W. 28th Street. Groundwater samples were collected from each boring at three depths (20 or 25, 40, and 60 feet bgs). The groundwater samples were analyzed in the field using EPA Method 8535 (UV-induced fluorescence), which measures total HVOCs (note that the results of the field analysis are not available). The samples from all three depths from borings CM-GP-097 and CM-GP-101 were submitted for laboratory analysis of HVOCs. The maximum PCE and TCE concentrations detected were 200 µg/L and 1,240 µg/L, respectively, in boring CM-GP-101 at 40 feet bgs (Figure 3-6c).

3.3.8 Groundwater Monitoring Well Installation

The installation of groundwater monitoring wells associated the Cadet investigations is summarized in the following sections. The purpose of installing the wells was to characterize and delineate the extent of HVOCs associated with the Cadet site. Monitoring wells were nomenclated 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 SMC site.)

The groundwater installation events summarized below are grouped by the date of installation and hydrogeologic zone in which the wells were installed. Boring logs for all monitoring wells are included in Appendix B.

3.3.8.1 October and November 1999

In October and November 1999, seven groundwater monitoring wells were installed in the vicinity of the Cadet site, including five shallow and two intermediate wells. The wells were installed using the hollow stem auger drilling method. Groundwater monitoring well installation details are included in Table 3-8 and summarized below.

Shallow

The five shallow wells are:

Well ID	Location
CM-MW-01s	Near south end at east side of Cadet building parking lot.
CM-MW-02s	West of Cadet Building; 90 feet south and 70 feet west of NW corner of building.
CM-MW-03s	Cadet east side parking lot.
CM-MW-04s	Near SW corner of W. 27th St. and Unander Ave.
CM-MW-05s	East side of Weigel Ave. between 27th and 28th Sts.

These five shallow wells were screened at depths ranging from 10 feet to 30 feet bgs.

Intermediate

The two intermediate wells are CM-MW-01i (adjacent to east side of Cadet building near south end of east parking lot) and CM-MW-05i (near CM-MW-05s). These two wells were screened at depths of 81 feet to 91 feet bgs and 85 feet to 95 feet bgs, respectively.

3.3.8.2 June through August 2000

From June through August 2000, ten groundwater monitoring wells were installed in the vicinity of the Cadet site: eight shallow, one intermediate, and one deep well. Groundwater monitoring well installation details are included in Table 3-8 and summarized below.

Shallow

The shallow wells are:

Well ID	Location
CM-MW-06s	Adjacent to NW corner of West 28th St. and Unander Ave.
CM-MW-07s	Adjacent to NE corner of West 28th St. and Thompson Ave.
CM-MW-08s	Adjacent to NE corner at south intersection of Weigel and Allman Aves.
CM-MW-09s	Approximately 200 feet west of SW corner of Cadet building.
CM-MW-10s	West of Thompson Ave. near east end of West 31st St., near railroad tracks.
CM-DPW-01	Near east side of Cadet building in east parking lot, approximately 340 feet south of NE corner of building.
CM-DPW-06	Near east edge of east parking lot of Cadet building, approximately 260 feet south of NE corner of building.
CM-DPW-10	Near east side of Cadet building in east parking lot, approximately 230 feet south of NE corner of building.

Five of the shallow wells (CM-MW-06s through CM-MW-10s) were installed using hollow stem auger drilling and are screened at depths ranging from 7.5 feet to 59 feet bgs. The three remaining shallow wells were installed by the probe drilling method and are screened at depths ranging from 8 feet to 28 feet bgs.

Intermediate

The intermediate well is CM-MW-04i (near CM-MW-04s). This well was installed by the hollow stem auger drilling method and is screened from 85 feet to 95 feet bgs.

Deep

The deep well is CM-MW-05d (adjacent to northeast corner of West 27th Street and Weigel Avenue). This well was installed by the air rotary drilling method and is screened from 206.5 feet to 216.5 feet bgs.

3.3.8.3 November 2000

In November 2000, one deep groundwater monitoring well and one TGA groundwater monitoring well were installed in the vicinity of the Cadet site. Installation details are included in Table 3-8 and summarized below.

Deep

The deep well is CM-MW-02d (approximately 200 feet north of northwest corner of Cadet building). This well was installed by the air rotary drilling method and is screened from 220 feet to 230 feet bgs.

TGA

The TGA well is CM-MW-10d (near CM-MW-10s). This well was installed by the air rotary drilling method and is screened from 220 feet to 230 feet bgs.

3.3.8.4 February and May 2001

In February 2001 groundwater monitoring well CM-MW-06s was deepened from 26.5 feet to 34.5 feet bgs by the hollow stem auger drilling method. In May 2001, a multi-port well containing a cluster of five monitoring wells was installed at the site (adjacent to east side of Cadet building near south end of east parking lot). The cluster included one shallow, one intermediate, and three deep wells. Installation details are included in Table 3-8 and summarized below.

The shallow well is CM-MW-01d-040 and is screened from 39.75 feet to 40.25 feet bgs. The intermediate well is CM-MW-01d-121 and is screened from 120.25 feet to 120.75 feet bgs. The three deep wells are CM-MW-01d-161, -194, and -224, and are screened at depths ranging from 160.75 feet to 224.25 feet bgs. The multi-port well was installed by the sonic drilling method.

3.3.8.5 February through April 2002

From February through March 2002, six groundwater monitoring wells were installed in the vicinity of the Cadet site. The six monitoring wells (CM-MW-11 through CM-MW-14, CM-MW-15s, and CM-MW-16s) were installed as part of a pumping well network near extraction well CM-RW-1. In general, the purpose of these wells was to monitor aquifer pump testing which was used to provide information for the conceptual hydrogeologic model and numerical groundwater flow and constituent transport model that AMEC was completing for the Cadet site (additional information for aquifer testing can be found in Appendix I). The six monitoring wells are currently inactive. An additional well, CM-DPW-16 (near east edge of east parking lot of Cadet building, approximately 250 feet south of northeast corner of building) was installed in April 2002. This well is currently used as part of ongoing groundwater monitoring. Groundwater monitoring well installation details for the seven wells described above (and extraction well CM-RW-1) are included in Table 3-8.

Shallow

Shallow wells CM-MW-11 through CM-MW-14 and CM-MW-16s were installed by hollow stem auger and are screened at depths ranging from 23 feet to 54.5 feet bgs. Well CM-DPW-16 was installed using the probe drilling method and is screened from 17.5 feet to 27.5 feet bgs.

Intermediate

Intermediate well CM-MW-15s was installed by the hollow stem auger drilling method and is screened from 49.5 feet to 54.5 feet bgs. Based on its' location and geology, CM-MW-15s was later re-classified by Parametrix as an intermediate zone well (note that CM-MW-13 and CM-MW-14 are screened at similar depths and classified by AMEC as shallow wells; however, since those wells have been inactive and are not used in any interpretations, they have not been further examined to be re-classified by Parametrix). Extraction well CM-RW-1 is screened from 40 to 60 feet bgs (Table 3-8).

Interim Soil Vapor Extraction Wells

In May 2002, an interim soil vapor extraction (SVE) system was installed at the Cadet site, including 12 SVE wells (CM-VE-01 through CM-VE-12). Details of the SVE system and well installations are discussed in Section 5.1. Figure 5-2 shows the locations of the SVE wells. Four of the shallow SVE wells were added to the groundwater monitoring network: CM-VE-09 (inside Cadet building, approximately 200 feet south of north side of building and 60 feet west of east side of building), CM-VE-10 (inside Cadet building, approximately 260 feet south of north side of building and 70 feet west of east side of building), CM-VE-11 (inside Cadet building, approximately 340 feet south of north side of building and 60 feet west of east side of building), and CM-VE-12 (inside Cadet building, approximately 320 feet south of north side of building and 30 feet west of east side of building). The four wells were installed by the hollow stem auger drilling method and are screened from 5 feet to 30 feet bgs.

3.3.8.6 July through September 2002

From July through September 2002, eighteen groundwater monitoring wells were installed in the vicinity of the Cadet site, including four shallow, six intermediate, and three deep wells and a multi-port well containing a cluster of two intermediate and three deep screens. Groundwater monitoring well installation details are included in Table 3-8 and summarized below.

Shallow

The shallow wells are shown below:

Well ID	Location
CM-MW-18s	East side of Yeoman Ave., approximately 600 feet north of West 31st St., in front of house at 3211 Yeoman Ave.
CM-MW-19s	On Van Allman Ave. approximately 100 feet north of West 31st St.; near house at 3103 Van Allman Avenue.
CM-MW-20s	On median at intersection of Fourth Plain and Mill Plain Blvds.
CM-MW-21s	Approximately 100 feet east of railroad tracks and 420 feet north of Fourth Plain Blvd.

The four shallow wells were installed by the probe or hollow stem auger drilling methods and are screened at depths ranging from 14 feet to 64 feet bgs.

Intermediate

The intermediate wells are CM-MW-07i (near CM-MW-07s), CM-MW-17i (inside Cadet building, approximately 100 feet northeast of southwest corner of building), CM-MW-18i (near CM-MW-18s), CM-MW-19i (on Van Allman Avenue, approximately 120 feet north of West 31st Street; near house at 3102 Van Allman Avenue), CM-MW-20i (near CM-MW-20s), and CM-MW-21i (near CM-MW-21s).

Of the six intermediate wells, five (CM-MW-07i, CM-MW-18i, CM-MW-19i, CM-MW-20i, and CM-MW-21i) were installed by the probe or hollow stem auger drilling methods, and one (CM-MW-17i) was installed by the air rotary drilling method. The intermediate wells are screened at depths ranging from 84 feet to 120 feet bgs.

Deep

The deep wells are CM-MW-07d (near CM-MWs-07s and -07i), CM-MW-18d (near CM-MWs-18s and -18i), and CM-MW-19d (on Van Allman Avenue approximately 270 feet north of W. 31st Street, near house at 3109 Van Allman Avenue). The deep wells were installed by the air rotary drilling method and are screened at depths ranging from 168 feet to 225 feet bgs.

Multi-Port Well

The multi-port well is located approximately 60 feet south of the northeast corner of the Cadet building, and contains two intermediate screens (CM-MW-03d-060 and -100) and three deep screens (CM-MW-03d-141, -181, and -227). The multi-port well was installed by the air rotary drilling method. The intermediate screens are located at depths of 59.2 to 59.7 feet bgs and 99.7 feet to 100.2 feet bgs, respectively. The deep screens are located at depths of 140.2 feet to 140.7 feet bgs, 180.7 feet to 181.2 feet bgs, and 226.2 feet to 226.7 feet bgs, respectively (Table 3-8).

3.3.8.7 June 2003

In June 2003 one intermediate groundwater monitoring well was installed at the Cadet site: CM-MW-22s (adjacent to Cadet building in east parking lot, approximately 150 feet north of southeast corner of building). The well was installed by the hollow stem auger drilling method and is screened from 35 feet 40 feet bgs. Groundwater monitoring well installation details are included in Table 3-8.

3.3.8.8 November 2003

In November 2003 four groundwater monitoring wells were installed in the vicinity of the Cadet site, including two shallow and two intermediate wells. Groundwater monitoring well installation details are included in Table 3-8 and summarized below.

Shallow

The shallow wells are CM-MW-23s (on Unander Avenue approximately 220 feet south of West 31st Street, near house at 2913 Unander Avenue) and CM-MW-24s (on south side of West 31st Avenue, south of southeast corner at Xavier Avenue). The wells were installed by the hollow stem auger drilling method and are screened from 22 feet to 37 feet bgs and 20 feet to 35 feet bgs, respectively.

Intermediate

The intermediate wells are CM-MW-23i (on Unander Avenue approximately 260 feet south of West 31st Street, near house at 2912 Unander Avenue) and CM-MW-24i (on south side of West 31st Avenue approximately 50 feet east of southeast corner at Xavier Avenue). The wells were installed by the hollow stem auger drilling method and are screened from 92 feet to 102 feet bgs and 88 feet to 98 feet bgs, respectively.

3.3.8.9 January and March 2004

In January and March 2004 two shallow wells were installed in the vicinity of the Cadet site. Installation details are included in Table 3-8 and summarized below.

Shallow

The wells are CM-MW-25s (on West 28th Street, approximately 250 feet west of Unander Avenue, near house at 2109 West 28th Street) and CM-MW-26s (on north side of West 28th Street, approximately 50 feet east of Weigel Avenue). The wells were installed by the hollow stem auger drilling method and are screened from 15 feet to 30 feet bgs.

3.3.8.10 August through November 2004

From August through November 2004, twelve groundwater monitoring wells were installed in the vicinity of the Cadet site, including one shallow multi-port well with three screens, one intermediate multi-port well with two screens, one intermediate and deep multi-port well with two intermediate screens and one deep screen, and three TGA wells. Installation details are included in Table 3-8 and summarized below.

Shallow

CM-MW-27USA-49.5 is located in the park near the south corner of Fruit Valley and La Frambois Roads; it is the only well sampled in the three-well cluster. This well was installed by the sonic drilling method and is screened from 49 feet to 49.5 feet bgs. It should be noted that two other screens are located in this well; at 90 and 127.5 feet bgs, both of which would be an intermediate zone screen. However, neither of these screen intervals produce water and therefore, have not been sampled.

Intermediate

The first intermediate well includes two screens, CM-MW-28USA-050 and -120.5 (on Unander Avenue at intersection with Xavier Avenue, near house at 3416 Unander Avenue). The second intermediate well includes three screens, CM-MW-29USA-060.5, -100, and -140.5 (on south side of West 31st Street between Fruit Valley Road and Thompson Avenue, approximately 260 feet east of Fruit Valley Road). The wells were installed by the sonic drilling method. The CM-MW-28USA multi-port well is screened at 49.5 feet to 50 feet bgs and 120 feet to 120.5 feet bgs, respectively. The CM-MW-29USA multi-port well is screened at 60 feet to 60.5 feet bgs, 99.5 feet to 100 feet bgs, and 140 feet to 140.5 feet bgs, respectively.

Deep

The deep well screen is CM-MW-28USA-180 (at the CM-MW-28USA multi-port well). The well was installed by the sonic drilling method as part of the CM-MW-28USA multi-port well and is screened from 179.5 feet to 180 feet bgs.

TGA

The TGA wells are CM-MW-27TGA (in a park near south corner of Fruit Valley and La Frambois Roads), CM-MW-28TGA (on Unander Avenue at intersection with Xavier Avenue, near house at 3416 Unander Avenue), and CM-MW-29TGA (on south side of West 31st Street between Fruit Valley Road and Thompson Avenue, approximately 230 feet east of Fruit Valley Road). The TGA wells were installed by the sonic drilling method and are screened from 159.5 feet to 169.5 feet bgs, 200 feet to 210 feet bgs, and 150 feet to 160 feet bgs, respectively.

3.3.8.11 June 2005

In June 2005, two monitoring wells were installed on West 11th Ave west of Lincoln Street: one shallow well and one intermediate well. The wells were installed to assess the potential for other sources and were generally not used as part of the Cadet well network. Groundwater monitoring well installation details are included in Table 3-8 and summarized below.

Shallow

The shallow well is CM-MW-Us; it was installed using the sonic drilling method and is screened from 39.5 feet to 54.5 feet bgs. This well was sampled only once.

Intermediate

The intermediate well is CM-MW-Ui (just north of north side of West 11th Street, approximately 310 feet west of Lincoln Avenue); it was initially sampled only once. However, in 2008, well CM-MW-Ui was added to the active project area groundwater monitoring network. This well serves as an offsite monitoring point to monitor the SMC plume; VOCs previously detected in CM-MW-Ui were determined not to be from the SMC or Cadet sites. The well was installed using the sonic drilling method and is screened from 110 feet to 129.5 feet bgs.

3.3.9 Distribution of Contaminants in Groundwater

The project area includes an extensive monitoring well network to evaluate groundwater flow. Figure 2-2 shows the current groundwater monitoring well network in the project area. Specific monitoring wells associated with the Cadet site have been sampled on a quarterly basis since mid-1999 (Table 3-9). In February 2001, Ecology formally approved a quarterly groundwater quality monitoring schedule for monitoring wells associated with the Cadet site.

Table 3-8 includes the monitoring well construction details. Boring logs for the monitoring wells are included in Appendix B. Standard operating procedures for groundwater monitoring are included in Appendix C.

Groundwater quality data have been collected at the Cadet and SMC sites for more than 10 years. The analytical data collected as part of the Cadet and SMC RIs 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 Cadet site. However, the SMC-sourced and NuStar-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 SMC and NuStar sites to provide a complete understanding of the distribution of groundwater contamination in the project area.

Data collected during three monitoring events representative of historical and current conditions are used in the following sections to summarize the distribution of contaminants in groundwater. These events include the First Quarter 2002, Third Quarter 2006, and First Quarter 2009. These events were selected because they include comprehensive well sampling and show the differences in the temporal distribution of contaminants prior to and after remedial actions have been implemented. Analytical results for VOCs detected at least one time during these events are summarized in Table 3-9.

Isoconcentrations maps were developed for the project area, which includes the Cadet and SMC sites. These maps present snapshots of groundwater concentrations over the years. TCE and PCE isoconcentration maps for shallow USA zone wells are presented on Figures 3-7 and 3-8 (January through March 2002), Figures 3-9 and 3-10 (September 2006), and Figures 3-11 and 3-12 (March and April 2009). TCE and PCE isoconcentration maps for intermediate USA zone wells are presented on Figures 3-13 and 3-14 (September 2006) and Figures 3-15 and 3-16 (March and April 2009). TCE and PCE isoconcentration maps for deep USA zone wells are presented on Figures 3-17 and 3-18 (September 2006) and Figures 3-19 and 3-20 (March and April 2009). TCE and PCE concentrations in the TGA are presented on Figures 3-21 and 3-22 (September 2006) and Figures 3-23 and 3-24 (March and April 2009).

The following sections describe the distribution of contaminants for the three selected monitoring periods. Due to the commingling of the Cadet and SMC groundwater plumes, both sites are discussed to provide an overall description of groundwater quality in the project area.

3.3.9.1 January through March 2002

Groundwater samples collected from January through March 2002 included: 17 Cadet wells and 22 SMC wells in the shallow USA zone well network, 4 Cadet wells and 11 SMC wells in the intermediate USA zone well network, 5 Cadet wells and 7 SMC wells in the deep USA zone well network, one Cadet TGA well, and two SMC TGA wells. The monitoring wells sampled during the 2002 sampling event are summarized in the following table.

Cadet and SMC Monitoring Wells Sampled from January through March 2002

Monitoring Networks	Cadet	SMC
Shallow USA Zone Wells	CM-DPW-01, CM-DPW-06, CM-MW-01d-040, CM-MW-01s through CM-MW-10s, and CM-VE-09 through CM-VE-12	MW-01 through MW-13, MW-15 through MW-18, MW-20, MW-21, MW-23 through MW-25
Intermediate USA Zone Wells	CM-MW-01d-121, CM-MW-01i, CM-MW-04i, and CM-MW-05i	MW-04i, MW-05i, MW-07i, MW-08i, MW-15i, MW-18i, MW-19i, MW-24i, MW-26i, MW-28i, and MW-29i
Deep USA Zone Wells	Multi-port well screens CM-MW-01d-161, CM-MW-01d-194, and CM-MW-01d-224, and wells CM-MW-02d and CM-MW-05d	MW-01d, MW-02d, MW-04d, MW-05d, MW-12d, MW-13d, and MW-14d
TGA Wells	CM-MW-10d	MW-16d and MW-17d

Shallow USA Zone

Analytical results for shallow USA zone groundwater samples collected from January through March 2002 are summarized in Table 3-9. The concentration ranges of TCE in the shallow USA zone in the vicinity of the Cadet and SMC sites are summarized below.

Range of TCE Concentrations in Shallow USA Zone Wells

Monitoring Zone	Range of TCE Concentrations (µg/L)
Cadet	<0.5 – 20,300
SMC	<0.5 – 7,070

TCE, PCE, cis-1,2-DCE, 1,1,1-TCA, and 1,1-DCE were the most frequently detected VOCs among the shallow USA zone Cadet wells. TCE and PCE isoconcentration maps combining Cadet and SMC data are presented on Figures 3-7 and 3-8, respectively. The highest concentrations of TCE and PCE were detected beneath the north and east sides of the Cadet building and ranged from 2,080 µg/L and 234 µg/L (well CM-VE-09, north end), respectively, to 20,300 µg/L and 2,010 µg/L (well CM-VE-10, east side), respectively. The highest concentrations of TCE and PCE at the SMC site were detected in monitoring well MW-05, located at the SMC source area. As shown, the two TCE plumes appear to have commingled (Figure 3-7). The highest TCE concentrations in the Cadet plume are located beneath the Cadet building and extend approximately 1,800 feet to the east-southeast directly down gradient from the building. The highest TCE concentrations in the SMC plume are located at the former SMC building location and extend approximately 1,450 feet to the east-southeast.

Intermediate USA Zone

Analytical results for intermediate USA zone groundwater samples collected from January through March 2002 are summarized in Table 3-9. The concentration ranges of TCE in the intermediate USA zone in the vicinity of the Cadet and SMC sites are summarized below.

Range of TCE Concentrations in Intermediate USA Zone Wells

Monitoring Zone	Range of TCE Concentrations (µg/L)
Cadet	2.01 – 25.7
SMC	<0.5 – 769

TCE, PCE, cis-1,2-DCE, 1,1,1-TCA, 1,1-DCA, and 1,1-DCE were the most frequently detected VOCs among the intermediate USA zone Cadet wells. The highest concentration of TCE from the Cadet sampling (25.7 µg/L) was detected in well CM-MW-05i, located approximately 220 feet east of the Cadet building.

Deep USA Zone

Analytical results for deep USA zone groundwater samples collected from January through March 2002 are summarized in Table 3-9. The concentration ranges of TCE in the deep USA zone in the vicinity of the Cadet and SMC sites are summarized below.

Range of TCE Concentrations in Deep USA Zone Wells

Monitoring Zone	Range of TCE Concentrations (µg/L)
Cadet	11.1 – 35.8
SMC	<0.5 – 148

TCE, PCE, cis-1,2-DCE, 1,1,1-TCA, 1,1-DCA, and 1,1-DCE were the most frequently detected VOCs among the deep USA zone Cadet wells. The highest concentration of TCE from the Cadet sampling (35.8 µg/L) was detected in well CM-MW-05d, located approximately 220 feet east of the Cadet building.

TGA

From January through March 2002, groundwater samples were collected from one TGA well at the Cadet site. During the same period, groundwater samples were also collected from two TGA wells at the SMC site. No VOCs were detected in these samples.

3.3.9.2 September 2006

Groundwater samples collected in September 2006 included: 21 Cadet wells and 17 SMC wells in the shallow USA zone well network, 15 Cadet wells and 15 SMC wells in the intermediate USA zone well network, 11 Cadet wells and 4 SMC wells in the deep USA zone well network, and 3 Cadet TGA wells and one SMC TGA well. The monitoring wells sampled during the 2006 sampling event are summarized in the following table.

Cadet and SMC Monitoring Wells Sampled in September 2006

Monitoring Networks	Cadet	SMC
Shallow USA Zone Wells	CM-DPW-01, CM-DPW-06, CM-DPW-10, CM-DPW-16, CM-MW-01d-040, CM-MW-03s, CM-MW-04s, CM-MW-06s through CM-MW-09s, CM-MW-20s, CM-MW-23s through CM-MW-26s, CM-MW-27USA-049.5, and CM-VE-09 through CM-VE-12	MW-02, MW-05 through MW-11, MW-16, MW-17, MW-20, MW-21, MW-33, MW-36, MW-E, MW-F, and MW-G
Intermediate USA Zone Wells	CM-MW-01d-121, multi-port well screens CM-MW-03d-060 and CM-MW-03d-100, wells CM-MW-05i, CM-MW-07i, CM-MW-15s, CM-MW-19i, CM-MW-22s, CM-MW-23i, CM-MW-24i, multi-port well screens CM-MW-28USA-050 and CM-MW-28USA-120.5, and multi-port well screens CM-MW-29USA-060.5, CM-MW-29USA-100, and CM-MW-29USA-140.5	MW-05i, MW-07i, MW-08i, MW-18i, MW-19i, MW-28i, and MW-30i through MW-38i
Deep USA Zone Wells	Multi-port well screens CM-MW-01d-161, CM-MW-01d-194, and CM-MW-01d-224, well CM-MW-02d, multi-port well screens CM-MW-03d-141, CM-MW-03d-181, and CM-MW-03d-227, wells CM-MW-05d, CM-MW-18d, CM-MW-19d, and CM-MW-28USA-180	MW-01d, MW-05d, MW-12d, and MW-14d
TGA Wells	CM-MW-27TGA, CM-MW-28TGA, and CM-MW-29TGA	MW-15i

Shallow USA Zone

Analytical results for shallow USA zone groundwater samples collected in September 2006 are summarized in Table 3-9. The concentration ranges of TCE in the shallow USA zone in the vicinity of the Cadet and SMC sites are summarized below.

Range of TCE Concentrations in Shallow USA Zone Wells

Monitoring Zone	Range of TCE Concentrations (µg/L)
Cadet	<0.5 – 470
SMC	<0.5 – 2,920

Consistent with previous analytical results, TCE, PCE, cis-1,2-DCE, 1,1,1-TCA, and 1,1-DCA were the most frequently detected VOCs among the shallow USA zone Cadet wells. Whereas 1,1-DCE was detected in shallow SMC USA zone wells in 2006, it was not detected in shallow USA zone Cadet wells. TCE and PCE isoconcentration maps combining SMC and Cadet data are presented on Figures 3-9 and 3-10, respectively. As shown, the distribution of these compounds in the shallow USA zone remains consistent with past findings. However, notable concentration reductions are evident in shallow USA zone wells within the NFVN, resulting in a sizable region within the contaminant plume where concentrations are below 5 µg/L.

In addition, shallow USA zone Cadet wells with the historically highest concentrations of TCE and PCE have continued to decline to low levels (to less than 5 µg/L in some cases). Shallow USA zone Cadet wells with moderately elevated concentrations are also declining (e.g., CM-MW-08s) or remain within historical levels. Shallow USA zone wells with TCE concentrations less than 10 µg/L are generally declining.

Intermediate USA Zone

Analytical results for intermediate USA zone groundwater samples collected in September 2006 are summarized in Table 3-9. The concentration ranges of TCE in the intermediate USA zone in the vicinity of the Cadet and SMC sites are summarized below.

Range of TCE Concentrations in Intermediate USA Zone Wells

Monitoring Zone	Range of TCE Concentrations (µg/L)
Cadet	0.66 – 53.6
SMC	1 – 418

TCE, PCE, cis-1,2-DCE, 1,1,1-TCA, and 1,1-DCA were the most frequently detected VOCs among the intermediate USA zone Cadet wells, which is consistent with past findings. The highest concentration of TCE was 53.6 µg/L (detected in well CM-MW-15s). TCE and PCE isoconcentration maps combining SMC and Cadet data are presented on Figures 3-13 and 3-14, respectively. As shown, the distribution of these compounds in the intermediate USA zone is consistent with previous findings.

Cadet intermediate USA zone wells with historically elevated concentrations (CM-MW-05i, CM-MW-07i, and CM-MW-22s) remain stable at relatively low levels (<20 µg/L). PCE concentration trends for these wells appear similar to those of TCE; there does not appear to be a definable difference in trends between these two compounds.

TCE concentration trends remain variable at low levels (<30 µg/L), although most of the wells show a reduction in TCE.

Less frequently detected compounds include 1,1-DCE, chloroform, and toluene. The detection of 1,1-DCE, limited to CM-MW-23i at 0.65 µg/L, is consistent with past results. Chloroform was detected in CM-MW-15s at 1.45 µg/L, which is similar to historical results.

Toluene was detected in one intermediate USA zone well (CM-MW-29USA-140.5) during the September 2006 event at a concentration of 1.81 µg/L. Toluene has been detected in this well since 2005, but it should be noted that toluene was not historically included in the list of groundwater analytes. The majority of historical detections of toluene in the project area, except for CM-MW-20i, have been to the northeast of the Cadet site in the northern portion of the NFVN. The source of these toluene detections is unknown, but given that toluene only occurs at depth and does not appear to correlate with the delineated TCE plume, the source appears to be located to the north of the project area.

Deep USA Zone

Analytical results for deep USA zone groundwater samples collected in September 2006 are summarized in Table 3-9. The concentration ranges of TCE in the deep USA zone in the vicinity of the Cadet and SMC sites are summarized below.

Range of TCE Concentrations in Deep USA Zone Wells

Monitoring Zone	Range of TCE Concentrations (µg/L)
Cadet	1.71 – 30.3
SMC	11.5 – 34.6*

* A concentration of 8,770 µg/L TCE detected in MW-05d, but is not considered representative of Deep USA conditions; the anomaly is discussed below.

Consistent with past analytical results, the most frequently detected compounds in deep Cadet USA zone wells were TCE, PCE, cis-1,2-DCE, 1,1,1-TCA, 1,1-DCA, and 1,1-DCE; 1,1-DCE was not frequently detected in the shallow or intermediate USA zone Cadet wells. TCE was detected in all of the deep USA zone Cadet wells, with the highest concentration occurring in CM-MW-05d at 30.3 µg/L. PCE was detected in all but one (CM-MW-28USA-180) of the deep USA zone wells at concentrations of or less than 8.15 µg/L. TCE and PCE isoconcentration maps combining SMC and Cadet data are presented on Figures 3-17 and 3-18. As shown, the distribution of these compounds in the deep USA zone is consistent with past findings, except for SMC well MW-05d.

The concentration of TCE detected in the groundwater sample collected from MW-05d (8,770 µg/L) in 2006 had significantly increased since 2003. 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. This indicated that analytical results from SMC well MW-05d were not consistent with formation concentrations. This well was subsequently decommissioned and replaced with SMC well MW-05dR in November 2006. The concentrations of TCE subsequently detected in MW-05dR are significantly lower than detected in MW-05d and are consistent with the site model (Parametrix 2009c).

TCE and PCE concentrations in deep USA zone wells are relatively stable at moderately low concentrations (up to 45 µg/L). Although samples collected from well screens CM-MW-01d-161 and CM-MW-01d-224 have trended upward over the last 5 years, in both cases the net change has been less than 15 µg/L (Table 3-9).

Compounds less frequently detected in deep USA zone Cadet wells include toluene and trichlorofluoromethane. Toluene was detected in CM-MW-28USA-180 (9.29 µg/L). Trichlorofluoromethane (TCFM) was detected in five wells: CM-MW-01d-224, CM-MW-02d, CM-MW-03d-227, CM-MW-05d and CM-MW-19d. Trichlorofluoromethane detections were less than or equal to 0.95 µg/L.

Toluene had not been previously detected in CM-MW-28USA-180, but it was not historically included in the list of groundwater analytes. Sporadic detections of toluene at other wells date back to mid-2004. At the Cadet site, toluene was previously detected in shallow USA (CM-MW-23s, CM-MW-24s and CM-MW-25s), intermediate USA (CM-MW-20i, CM-MW-23i, CM-MW-24i and CM-MW-28USA-120.5, CM-MW-29USA-060.5, CM-MW-29USA-100, and CM-MW-29USA-140.5), and TGA (CM-MW-27TGA and CM-MW-28TGA) wells. Toluene had also been previously detected in SMC wells MW-23, MW-01d and MW-05d, but these detections were prior to 2002. All but one of the Cadet wells in which toluene had been detected are located to the east, northeast and north of the Cadet site, with the highest historical detections occurring in wells CM-MW-23i, CM-MW-24s, and CM-MW-24i (located approximately 700 feet from Cadet). The source of the toluene is unknown, but given that the distribution of toluene does not correlate with the delineated Cadet and SMC contaminant plumes, it does not appear to be sourced from the Cadet or SMC sites.

Trichlorofluoromethane, or Freon-11, has been consistently detected in deep wells located near the Cadet site and in the northernmost portion of NFVN. Trichlorofluoromethane has not been detected in any shallow or intermediate USA zone wells. The source of trichlorofluoromethane is unknown, and the fact that this compound has never been detected in shallow or intermediate USA zone wells suggests that the compound is not sourced from the Cadet or SMC sites.

TGA

Analytical results for TGA groundwater samples collected in September 2006 are summarized in Table 3-9. The concentration ranges of TCE in the TGA in the vicinity of the Cadet and SMC sites are summarized below.

Range of TCE Concentrations in TGA Wells

Monitoring Zone	Range of TCE Concentrations (µg/L)
Cadet	<0.5 – 13.9
SMC	<0.5

VOCs were detected in two of the three Cadet TGA wells sampled during the third quarter of 2006. The commonly detected VOCs (TCE, PCE, cis-1,2-DCE, 1,1,1-TCA, 1,1-DCA and 1,1-DCE) were detected in well CM-MW-29TGA. Toluene was the only compound detected in well CM-MW-27TGA. Concentrations of TCE and PCE are shown on Figures 3-21 and 3-22, respectively. As shown in Table 3-9, TCE and PCE concentrations in TGA wells remain within their historical ranges.

As discussed earlier, the source of toluene in the northern portion of the Cadet site is unknown, but given that the distribution of toluene does not correlate with the delineated Cadet and SMC contaminant plumes, the toluene does not appear to be sourced from the Cadet or SMC sites.

3.3.9.3 March and April 2009

Groundwater samples collected in March and April 2009 included: 28 Cadet wells and 32 SMC wells in the shallow USA zone well network, 20 Cadet wells and 20 SMC wells in the intermediate USA zone well network, 12 Cadet wells and 5 SMC wells in the deep USA zone well network, 4 Cadet TGA wells, and 4 SMC TGA wells. The monitoring wells sampled during the 2009 sampling event are summarized in the following table.

Shallow Cadet and SMC USA Zone Wells Sampled in February and March 2009

Monitoring Network	Cadet	SMC
Shallow USA Zone Wells	CM-DPW-01, CM-DPW-06, CM-DPW-10, CM-DPW-16, CM-MW-01s through CM-MW-10s, CM-MW-01d-040, CM-MW-18s through CM-MW-21s, CM-MW-23s through CM-MW-26s, CM-MW-27USA-049.5, and CM-VE-09 through CM-VE-12	IMW-05, MW-01, MW-02, MW-04, MW-05 through MW-12, MW-15 through MW-18, MW-19s, MW-20, MW-21, MW-23 through MW-25, MW-32s, MW-33s, MW-36s, MW-E, MW-F, MW-G, and VMW-8 through VMW-11

Monitoring Network	Cadet	SMC
Intermediate USA Zone Wells	CM-MW-01d-121, CM-MW-01i, multi-port well screen CM-MW-03d-100, wells CM-MW-04i, CM-MW-05i, CM-MW-07i, CM-MW-15s, CM-MW-17i, CM-MW-18i through CM-MW-21i, CM-MW-23i, CM-MW-24i, multi-port well screens CM-MW-28USA-050 and CM-MW-28USA-120.5, and multi-port well screens CM-MW-29USA-060.5, CM-MW-29USA-100, and wells CM-MW-29USA-140.5, and CM-MW-Ui	MW-04i, MW-05i, MW-07i, MW-08i, MW-15i, MW-18i, MW-19i, MW-24i, MW-26i, and MW-28i through MW-38i
Deep USA Zone Wells	Multi-port well screens CM-MW-01d-161, CM-MW-01d-194, and CM-MW-01d-224, well CM-MW-02d, multi-port well screens CM-MW-03d-141, CM-MW-03d-181, and CM-MW-03d-227, wells CM-MW-05d, CM-MW-07d, CM-MW-18d, CM-MW-19d, and CM-MW-28USA-180	MW-01d, MW-04d, MW-05dR, MW-12d, and MW-14d
TGA Wells	CM-MW-01d, CM-MW-27TGA, CM-MW-28TGA, and CM-MW-29TGA	MW-02d, MW-13d, MW-16d, and MW-17d

Shallow USA Zone

Analytical results for shallow USA zone well groundwater samples collected in March and April 2009 are summarized in Table 3-9. The concentration ranges of TCE in the shallow USA zone in the vicinity of the Cadet and SMC sites are summarized below.

Range of TCE Concentrations in Shallow USA Zone Wells

Monitoring Zone	Range of TCE Concentrations (µg/L)
Cadet	<0.5 – 260
SMC	<0.5 – 16,000

Consistent with previous analytical results, TCE, PCE, cis-1,2-DCE, 1,1,1-TCA, and 1,1-DCA were the most frequently detected VOCs among the shallow USA zone Cadet wells. TCE and PCE isoconcentration maps combining Cadet and SMC data are presented on Figures 3-11 and 3-12. As shown, the distribution of these compounds in the shallow USA zone remains consistent with past findings, and continues to show notable concentration reductions in shallow USA zone wells within the NFVN, resulting in a sizable region within the contaminant plume where concentrations remain below 5 µg/L.

Further evidence of substantial reductions in TCE and PCE concentrations is included in Table 3-9; shallow USA zone Cadet wells with the historically highest concentrations of TCE and PCE have continued to decline to low levels (to less than 5 µg/L in some cases). Shallow USA zone Cadet wells with moderately elevated concentrations are also declining (e.g., CM-MW-08s) or remain within historical levels. Shallow USA zone wells with TCE concentrations less than 10 µg/L are generally declining.

Intermediate USA Zone

Analytical results for intermediate USA zone well groundwater samples collected in March and April 2009 are summarized in Table 3-9. The concentration ranges of TCE in the intermediate USA zone in the vicinity of the Cadet and SMC sites are summarized below.

Range of TCE Concentrations in Intermediate USA Zone Wells

Monitoring Zone	Range of TCE Concentrations (µg/L)
Cadet	<0.5 – 110
SMC	<0.5 – 330

TCE, PCE, cis-1,2-DCE, 1,1,1-TCA, and 1,1-DCA were the most frequently detected VOCs in the intermediate USA zone Cadet wells, which is consistent with past findings. TCE and PCE isoconcentration maps combining Cadet and SMC data are presented on Figures 3-15 and 3-16, respectively. As shown on those figures, the distribution of these compounds in the intermediate USA zone is consistent with post-2002 through 2006 interim action findings.

TCE concentrations in intermediate USA zone wells with historically elevated concentrations (CM-MW-05i, CM-MW-07i) remain stable at relatively low levels (at or less than 20 µg/L). PCE concentrations in these wells also appear stable; there does not appear to be a definable difference in trends between these two compounds.

Declining or variable concentrations of TCE are shown in intermediate USA zone Cadet wells with moderately elevated concentrations of TCE (<60 µg/L) (Table 3-9). However, a notable increase in TCE concentration during the third quarter and fourth quarters of 2008 is evident in CM-MW-04i and is still apparent during the first quarter of 2009. Less notable TCE concentration increases were also observed at CM-MW-20i and CM-MW-23i. Slightly declining or variable concentrations of TCE are evident in CM-MW-03d-100 and CM-MW-01d-121, where concentrations remain within their historical ranges. PCE concentration trends generally appear similar to those of TCE.

Less frequently detected compounds include 1,1-DCE, chloroform, and toluene. The detection of 1,1-DCE continues to be limited to CM-MW-04i, CM-MW-20i, and CM-MW-23i, at a maximum concentration of 6.4 µg/L, which is consistent with past results. Chloroform was detected in CM-MW-15s at a concentration of 0.57 µg/L, which is also similar to historical results. Chloroform was also detected in CM-MW-Ui at a concentration of 0.73 µg/L. Toluene was detected in one intermediate well (CM-MW-29USA-140.5) at a concentration of 0.56 µg/L. As discussed earlier, the source of toluene in the northern portion of the Cadet site is unknown, but given that the distribution of toluene does not correlate with the delineated Cadet and SMC contaminant plumes, the toluene does not appear to be sourced from the Cadet or SMC site.

Deep USA zone

Analytical results for deep well groundwater samples collected in March and April 2009 are summarized in Table 3-9. The concentration ranges of TCE in the deep USA zone in the vicinity of the Cadet and SMC sites are summarized below.

Range of TCE Concentrations in Deep USA Wells

Monitoring Zone	Range of TCE Concentrations (µg/L)
Cadet	0.88 – 33
SMC	1 – 44

Consistent with past analytical results, the most frequently detected compounds in deep USA zone Cadet wells were TCE, PCE, cis-1,2-DCE, 1,1,1-TCA, 1,1-DCA, and 1,1-DCE. 1,1-DCE is not commonly detected in the shallow or intermediate Cadet wells. TCE was detected in all of the deep USA zone Cadet wells sampled during the 2009 first quarter sampling event, with the highest concentration occurring in CM-MW-05d at 33 µg/L. PCE was detected in all but two of the deep wells (CM-MW-07d and CM-MW-28USA-180) sampled during the 2009 first quarter sampling event, with concentrations at or less than 9.6 µg/L. In general, TCE and PCE concentrations in deep USA zone wells are relatively stable at moderately low concentrations (<45 µg/L). TCE and PCE isoconcentrations combining Cadet and SMC data are presented on Figures 3-19 and 3-20, respectively. As shown on the figures, the distribution of these compounds in the deep USA zone is consistent with past findings.

Compounds less frequently detected in deep USA zone Cadet wells include toluene and trichlorofluoromethane. Toluene was detected in CM-MW-05d, CM-MW-07d, and CM-MW-28USA-180 during the 2009 first quarter sampling event at concentrations of 0.77 µg/L, 1.9 µg/L, and 16 µg/L, respectively. The source of toluene in the northern portion of the Cadet site is unknown, but does not appear to be sourced from the Cadet or SMC site.

Trichlorofluoromethane was detected in six deep USA zone wells: CM-MW-01d-224, CM-MW-02d, CM-MW-03d-227, CM-MW-05d, CM-MW-18d, and CM-MW-19d. Trichlorofluoromethane detections were all less than or equal to 1.2 µg/L. Trichlorofluoromethane has consistently been detected in deep USA zone wells located near the Cadet site and in the northernmost portion of the NFVN. The source of the trichlorofluoromethane is unknown.

TGA

Analytical results for TGA well groundwater samples collected in March and April 2009 are summarized in Table 3-9. The concentration ranges of TCE in the TGA in the vicinity of the Cadet and SMC sites are summarized below.

Range of TCE Concentrations in TGA Wells

Monitoring Zone	Range of TCE Concentrations (µg/L)
Cadet	<0.5 - 20
SMC	<0.5 - 1.6

VOCs were detected in three of the four Cadet TGA wells sampled during the first quarter of 2009. The commonly detected VOCs (TCE, PCE, cis-1,2-DCE, 1,1,1-TCA, 1,1-DCA and 1,1-DCE) were detected in well CM-MW-29TGA, while toluene was the only compound detected in wells CM-MW-27TGA and CM-MW-28TGA. Concentrations of TCE and PCE are shown on Figures 3-23 and 3-24, respectively. As summarized in Table 3-9, TCE and PCE concentrations in TGA wells remain within their historical ranges.

The source of toluene in the northern portion of the Cadet site is unknown, but the toluene does not appear to be sourced from the Cadet or SMC site.

3.3.10 Potential for Occurrence of DNAPL

The depth to which potential DNAPL tends to sink in an aquifer and thus migrate within the subsurface is dependent upon the mass or volume of the release, the area of infiltration of the potential DNAPL, the duration of the release, the properties of both the DNAPL and the soil media, the subsurface lithology, and the absence/presence of preferential pathways (EPA 1992, 1993). At sites where DNAPL occurs, migration in both the saturated and unsaturated zones is primarily vertical, and is driven by gravity and capillary forces. As the DNAPL migrates downward through the soil column, small globules and/or fingers of DNAPL can remain trapped in the pores of the soil; this is known as residual saturation. Therefore, the DNAPL can exist as thin vertical stringers or as a vertical trail of globules in the unsaturated zone. If the DNAPL encounters a layer or unit of low hydraulic conductivity, it can collect on this surface and form a pool or lens.

DNAPL has not been directly observed in the samples taken from the site or project area. However, if groundwater samples contain HVOCs at concentrations exceeding 1% of chemical-specific solubility limits, DNAPL may be present. For TCE and PCE, aqueous solubilities are estimated at 1.1×10^6 µg/L and 1.5×10^5 µg/L, respectively (Wiedemeier et al. 1998); therefore, values for 1% of aqueous solubility are approximately 11,000 µg/L and 1,500 µg/L, respectively. The maximum TCE and PCE concentrations observed in the groundwater at the site (78,000 µg/L at C-13 and 70,000 µg/L at C-09, respectively; see Table 3-7) suggest indirectly that there may be small amounts of DNAPL at shallow depths in the saturated zone beneath the Cadet building. However, based on the density of sample locations and the fact that no DNAPL was found, any DNAPL potentially present would be of a minor amount. During numerous well installations, soil boring installations, and trenching, DNAPL was not observed in saturated or unsaturated soil samples using Sudan IV dye, ultraviolet (UV) light, Oil-n-Soil test kits, or visual screening (AMEC 2000, 2003a, 2005). In addition, current groundwater sampling indicates that TCE and PCE concentrations are on the decline and have not been detected at concentrations greater than the aqueous solubility stated above, suggesting that DNAPL is not present at the site.

3.4 INDOOR AIR INVESTIGATIONS

Based on groundwater investigations completed by Cadet, groundwater containing VOCs has migrated to the east of the Cadet site beneath the NFVN (Figures 3-7 through 3-24). Soil gas sampling was completed by Cadet in 2000 and 2001. From these results, DOH determined in a Health Consultation (DOH 2002) that the contaminated groundwater appeared to pose a low health risk for the indoor air pathway in the NFVN and recommended indoor air sampling at residences. In January 2002, an indoor air investigation was initiated in the NFVN. The investigation included the collection of indoor air samples in selected homes, primarily in the southern portion of the NFVN, where VOC levels in groundwater and soil gas were highest. The following sections present a summary of the Cadet and NFVN indoor air investigations.

3.4.1 Cadet Building Indoor Air Sampling

Limited indoor air sampling was conducted in the Cadet building between August 2000 and April 2005. Indoor air sampling results are summarized in Table 3-10. Laboratory reports and data validation reports are included in Appendix A.

Initial indoor air samples were collected in August 2000 in the paint department area (samples labeled CM-PaintDept and CM-PaintDept-Spray) to gain an understanding of the magnitude of VOCs within the building. PCE and TCE were detected in both samples at concentrations of 35 μg/m^3 and 110 μg/m^3, respectively. Two additional samples were collected in December 2000 (labeled CM-AS-01 and CM-AS-02). In these samples, PCE and TCE were detected at maximum concentrations of 8.7 μg/m^3 and 62 μg/m^3, respectively. Since PCE and TCE were reportedly used in the Cadet building at this time, the relatively high concentrations detected in the samples were expected, and differentiating between solvent use in the building and concentrations resulting from vapor intrusion could not be completed.

In May 2002, a soil vapor extraction system was installed at the site and later expanded into an air sparging and soil vapor extraction (AS/SVE) system beneath the Cadet building. The AS/SVE system was designed to mitigate concentrations of VOCs in soil and groundwater beneath the building and thus reduce potential vapor intrusion into the Cadet building (see Section 5.1 for details on the AS/SVE system). As part of the evaluation of the AS/SVE system, indoor air samples were collected from the building between September 2004 and April 2005. A total 26 indoor air samples were collected during six separate sampling events.

PCE and TCE were detected at maximum concentrations of 15 μg/m^3 and 44 μg/m^3, respectively, during these sampling events. The potential risk associated with building occupants and indoor air is summarized in Section 9.

3.4.2 Building Features and Water Use Survey

Building foundation surveys were completed by Cadet: a limited survey in the winter of 2002, and a more comprehensive survey in the fall of 2003. The initial survey included a water use survey to evaluate groundwater use in the NFVN. All residents surveyed reported that they use the municipal water supply, do not use groundwater, and have no groundwater wells on their property (AMEC 2003a). A subsequent survey requesting building foundation information was sent to the residents of the NFVN at the end of 2003 (note that this was after the two initial indoor air sampling events were conducted).

The primary purpose of the surveys was to identify the building ownership, along with the foundation type and other factors that might influence indoor air quality, such as possible sources of VOCs used or stored by the residents. Understanding building characteristics helped in selecting homes that might be at risk for vapor intrusion from contaminated groundwater. The surveys were completed through a series of mailings to residents, telephone interviews, and door-to-door visits. In addition, AMEC personnel completed visual assessments of the neighborhood properties to verify some of the information obtained. The results of the NFVN building features and water use survey are included in Appendix D.

The primary factors identified in the surveys that might affect indoor air were the type of foundation at each residence (see Figure 3-25) and the potential for cracks or other features which might make a home more susceptible to vapor intrusion. The majority of the houses, primarily west of Fruit Valley Road, include crawlspace construction. 16 houses were identified with basements or partial basements, and an additional 11 houses were identified with a basement and crawlspace combination. Slab-on-grade foundations were generally observed to the east of Fruit Valley Road (Figure 3-25).

The foundation types most susceptible to vapor intrusion are basement and slab-on-grade foundations. Basement foundations are generally closer to groundwater contamination, and vapors traveling upward through the vadose zone tend to collect in the first available space (i.e., the basement), then migrate to other living areas. For example, of the six residences in the NFVN which required SVV systems due to elevated concentrations of VOCs, four had basements or partial basements (Figure 3-25). (See Section 5.3 for details on SVV systems.)

Slab-on-grade foundations have the characteristic that no buffer zone (i.e., basement or crawlspace) exists between soil gas beneath the home and the living space, and thus are generally more susceptible to vapor intrusion. In addition, residences with crawlspaces that have blocked vents are also more susceptible to vapor intrusion. All of these conditions were classified as "unique foundation" types by Cadet and prioritized for indoor air sampling. The survey was used to guide indoor air sampling at the site. Results of the indoor air sampling completed in the NFVN are discussed in Section 3.4.3.

3.4.3 NFVN Indoor Air Sampling

Indoor air sampling within the NFVN has been conducted since January 2002. Air samples were collected from the living space and the basement and/or crawlspace of each sampled residence. In houses with both a basement and crawlspace, samples were generally collected from each area. Based on indoor air sampling results and foundation survey information, the following observations were used to indicate when vapor migration into a residence may be occurring (AMEC 2003c):

- There were cracks, gaps or openings to soil in the foundation walls and/or floor. Sometimes these gaps were evident in basements where water seeped in through foundation openings during rainy periods.
- There were elevated levels of VOCs in the crawlspace or basement and in living space air.
- The VOCs levels were higher in the basement and/or crawlspace than in the living space.
- When the above conditions were present, VOCs detected at the highest levels in indoor air were TCE, PCE and 1,1,1-trichloroethane (1,1,1-TCA).

At Ecology's request, following the initial indoor air sampling event (January 2002), DOH prepared a Health Consultation (DOH 2003b) to evaluate whether residents of the NFVN were being exposed to solvent vapors migrating from groundwater into indoor air. The Health Consultation indicated that the cancer risk from VOCs detected in samples from the initial sampling event at six NFVN buildings were approximately one to two orders of magnitude greater than would be expected in background air. DOH indicated that there was a perceived pathway between contaminated groundwater and indoor air at three of these residences, and that groundwater may be contributing contaminants to indoor air at three others. DOH recommended that action be taken to eliminate the exposure in the three residences where there appeared to be a complete pathway between groundwater and indoor air. Ecology also required that action be taken to eliminate exposure in the other three residences where VOC levels were greater than would be expected in background air.

Between 2002 and March 2009, 702 indoor air samples (living space, basement, and crawlspace) were collected from 121 homes in the NFVN. Table 3-11 includes the residence address, sample ID number, and date of samples collected for each indoor air sampling event. Figure 3-26 shows the residences in the NFVN which have had indoor air samples collected on at least one occasion. The laboratory analytical results are included in Table 3-12. Laboratory reports and data validation reports are included in Appendix A.

As part of the air sampling program, meteorological conditions such as outdoor and indoor temperature and barometric pressure were recorded before each sample was collected. Samples were collected using 6-liter capacity, stainless-steel Summa® canisters with mechanical flow controllers. The mechanical flow controllers were pre-set for a 24-hour air sampling duration. This duration was selected to allow air samples to be less influenced by hourly fluctuations in VOCs in indoor air that might be caused by meteorological conditions such as temperature, barometric pressure, or moisture level, and living conditions such as opening and closing of doors and windows, use of household chemicals, and turning heat on and off. At least one indoor air sample was collected in the living space and one from the basement or crawl space of each residence assessed. Living space air samples were collected near the center of the living room or living room/kitchen area. Air samples were obtained from the typical breathing zone at heights between 3 and 6 feet. Basement/crawl space samples were collected to assess the vertical distribution of VOCs. Sampling was conducted in accordance with the standard operating procedure (SOP) in Appendix C. The following sections summarize each of the sampling events.

3.4.3.1 January and September 2002

Initial indoor air sampling was conducted in accordance with the Fruit Valley Neighborhood Indoor Air Evaluation Work Plan (AMEC 2002a). A total of 31 houses were sampled in January 2002, primarily in the southern portion of the NFVN (Table 3-11 and Figure 3-26). The samples were analyzed for TCE, PCE, 1,1,1-TCA, cis-1,2-DCE, 1,1-DCE, and vinyl chloride. The results were submitted to Ecology in the Final Indoor Air Evaluation Analytical Results letter (AMEC 2002b).

Six houses were identified with elevated levels (i.e., significantly above the average) of VOCs in indoor air. Using information from Ecology, a TCE concentration of 3 $\mu g/m^3$ was used as an interim level for requiring remedial action, based on risk calculations provided by DOH. The residence addresses and the highest concentrations of TCE detected are shown below:

- 2809 Unander Avenue (31 $\mu g/m^3$ TCE)
- 2805 Unander Avenue (25 $\mu g/m^3$ TCE)
- 2206 West 28th Street (9.3 $\mu g/m^3$ TCE)
- 2202 West 28th Street (3.4 $\mu g/m^3$ TCE)
- 2105 West 28th Street (6 $\mu g/m^3$ TCE)
- 2103 West 28th Street (11 $\mu g/m^3$ TCE)

Other VOCs, including PCE and 1,1,1-TCA, were also generally detected at elevated concentrations in these homes. In September 2002, follow-up indoor air sampling was completed on all six homes that had exhibited elevated concentrations of VOCs (and from a home located at 2113 W. 27th with relatively low concentrations). With the exception of 2113 W. 27th, the laboratory results generally confirmed the presence of elevated concentrations of VOCs (AMEC 2002c). The analytical results are included in Table 3-12.

Ecology and Cadet concluded that remedial actions were necessary to reduce the concentrations of VOCs in the six homes with elevated concentrations. Therefore, SVV systems were installed in all of the homes. The installation of these SVV systems is documented in the Cadet RI Update Report (AMEC 2005) and summarized in Section 5.3 of this report.

3.4.3.2 October 2003 Through February 2004

Based on the initial sampling events, Ecology determined that vapor intrusion was a potential complete pathway at the site. Further indoor air sampling was necessary to define the extent and magnitude of indoor air contamination in the NFVN. The building survey conducted in September 2003 was used to identify additional homes to be sampled. Sampling priorities were based on a combination of factors, including (AMEC 2003a):

1. Proximity to areas where groundwater contamination was highest
2. Proximity to areas were VOCs had been confirmed in preliminary soil gas probes
3. Foundation type (a preference was given to structures with basements or slab-on-grade construction)
4. Buildings that may contain potentially sensitive populations (e.g., children)

A total of 75 additional homes were sampled (Table 3-11). The indoor air sampling was conducted in accordance with the Fruit Valley Neighborhood September 2003 and January 2004 Indoor Air Evaluation Work Plan (AMEC 2003c). The analytical results are included in Table 3-12.

In general, the analytical results were similar to results for samples collected previously in residences in the NFVN. TCE was detected in all homes above the (Washington) Model Toxics Control Act (MTCA) Method B cleanup level for ambient air of 0.022 $\mu g/m^3$ (note that the cleanup level has since been modified in October 2008 to 0.1 $\mu g/m^3$). PCE and 1,2-DCA were also detected in many homes above the MTCA cleanup levels of 0.42 $\mu g/m^3$ and 0.096 $\mu g/m^3$, respectively. The results of the investigation indicated that vapor intrusion appeared to be a completed pathway in many homes and that further evaluation was necessary.

3.4.3.3 May Through July 2004

Indoor air sampling was conducted in all six residences with SVV systems and at two additional residences. Indoor air data for the SVV systems are discussed in Section 5.3. The additional residences sampled during this event were:

- 2604 Weigel Avenue
- 2113 W. 28th Street

The analytical results of the indoor air sampling are included in Table 3-12. PCE was detected at a concentration of 73 $\mu g/m^3$ in the living space of the 2604 Weigel residence, and at 0.3 $\mu g/m^3$ in the crawlspace, in May 2004. The significant discrepancy between the living space and crawlspace concentrations suggested indoor air contamination at this residence may have been associated with product use and not due to vapor intrusion. TCE was detected in the living space and crawlspace at concentrations of 0.36 $\mu g/m^3$ and 0.12 $\mu g/m^3$, respectively, further suggesting that the PCE was from an in-home source. Re-sampling was conducted in June 2004. PCE was detected at a concentration of 25 $\mu g/m^3$ in the living space of the 2604 Weigel residence, and at 0.13 $\mu g/m^3$ in the crawlspace. However, the data from the crawlspace was rejected during data validation and therefore, the concentration in the crawlspace could not be verified (note that sampling conducted in September 2007 indicated significantly lower concentrations of PCE).

TCE and PCE were detected at the 2113 W. 28th Street residence at elevated concentrations. This home is discussed in detail in Section 5.4.

3.4.3.4 August/September/October 2004

At the request of Ecology, indoor air samples were collected from 22 residences located in the NFVN in August 2004. No work plan is associated with this sampling event. Sampling locations for August 2004 are presented in Table 3-11. The analytical results of the indoor air sampling are included in Table 3-12.

The focus of this additional investigation was to further define the extent of vapor intrusion in the NFVN. Houses added to this sampling event included selected locations within the 27th Street and 28th Street corridor, as well as houses farther to the north and east.

In September and October 2004, at the request of Ecology, indoor air samples were collected from five residences in the NFVN that had not previously been sampled. Sampling locations for September and October 2004 are shown in Table 3-11. The analytical results of the indoor air sampling are included in Table 3-12.

As with previous investigations, indoor air results were within a relatively small range (TCE at 0.0098 $\mu g/m^3$ to 3 $\mu g/m^3$). TCE was not detected above the interim remedial action level of 3 $\mu g/m^3$.

3.4.3.5 December 2004

At the request of Ecology, indoor air samples were collected from 12 additional residences in December 2004. No work plan is associated with this sampling event. Sampling locations for December 2004 are presented in Table 3-11. The analytical results of the indoor air sampling are included in Table 3-12.

The focus of this additional investigation was to further define the extent of vapor intrusion in the NFVN. Houses added to this sampling event included those within the 27th Street and 28th Street corridor, as well as houses further to the north and east. As with previous investigations and with the exception of 2113 W. 28th Street (14 $\mu g/m^3$), indoor air results were within a relatively small range (TCE at 0.11 $\mu g/m^3$ to 1.8 $\mu g/m^3$). TCE was not detected above the interim remedial action level of 3 $\mu g/m^3$.

3.4.3.6 February and March 2005

A relatively large indoor air sampling event was conducted between February and March 2005. The sampling event was completed: 1) to collect additional indoor air samples at homes previously sampled, and 2) to further expand the aerial extent within which indoor air samples have been collected in the NFVN. Indoor air sampling was completed on 26 homes in the NFVN during this event. Sampling locations are presented in Table 3-11. The analytical results of the indoor air sampling are included in Table 3-12. As with previous investigations, indoor air results were within a relatively small range. TCE was not detected above the interim remedial action level of 3 $\mu g/m^3$.

3.4.3.7 April Through June 2005

Indoor air sampling was conducted at the 2113 W. 28th Street residence in April and May 2005 to continue monitoring the elevated VOC levels found in this home. This home is discussed further in Section 5.4.

In June 2005, indoor air sampling was completed on 28 homes in the NFVN. Indoor air samples included homes with SVV systems installed, homes in which air samples had been collected previously, and new residences. Sampling locations are presented in Table 3-11. The analytical results of the indoor air sampling are included in Table 3-12. As with previous investigations, indoor air results were within a relatively small range. With the exception of the home located at 3107 Yeoman, TCE was not detected above the interim remedial action level of 3 μg/m^3.

TCE was detected at 3107 Yeoman at concentrations of 5.9 μg/m^3 and 7.5 μg/m^3 in the living space and basement, respectively. This home is located to the north of the Cadet facility (Figure 3-26) and is in an area of very low or non-detect concentrations of TCE in groundwater (see Figure 3-12). In addition, indoor air samples collected at the same time in a house across the street (3106 Yeoman) indicated concentrations of TCE at 0.07 μg/m^3 and 0.037 μg/m^3 in the living space and basement, respectively. The source of the elevated concentrations at 3107 Yeoman was not known, but based on the location of the home and other samples collected nearby, these concentrations were suspected to be the result of in-home activities (note that samples collected in March 2007 indicated TCE in the living space at 2.3 μg/m^3 and 0.13 μg/m^3 in the basement, which further supports this assertion).

3.4.3.8 November 2005

Indoor air samples were collected from all six residences with SVV systems installed and from the 2113 W. 28th Street residence. Data associated with these homes are discussed in Section 5.3.

3.4.3.9 June 2006 and Fall 2006

Indoor air samples were collected from all six residences with SVV systems installed and from the 2113 W. 28th Street residence. Data associated with these homes are discussed in Sections 5.3 and 5.4.

3.4.3.10 March Through June 2007

In January 2007, the Port submitted a Draft Comprehensive Vapor Intrusion Evaluation and Air Monitoring Plan (CAMP) to Ecology and DOH for review (Parametrix 2007a). The Draft CAMP recommended several houses in the NFVN for sampling. Ecology agreed with the selected houses and recommended sampling in March 2007 (Ecology 2007).

A Fruit Valley Neighborhood meeting was held on March 6, 2007, in which Ecology and DOH presented some preliminary findings of the remedial investigations for SMC and Cadet, as well as indoor air results. During the meeting, several residents of the NFVN requested indoor air sampling in their homes. The Port and Ecology agreed to add those homes to the sampling list.

The following homes were sampled in Spring 2007, based on recommendations in the Draft CAMP:

- 3107 Yeoman Avenue
- 2409 W. 31st Street
- 2203 W. 27th Street
- 2113 W. 28th Street

The following homes were sampled in March 2007, based on requests from residents during the March 2007 Fruit Valley Neighborhood meeting:

- 2910 Weigel Avenue
- 2109 W. 27th Street
- 2405 W. 31st Street

- 3117 Xavier Avenue
- 3302 Unander Avenue
- 3112 Yeoman Avenue

TCE and PCE were detected in all residences sampled. TCE was detected at concentrations ranging from 0.038 μg/m^3 to 2.3 μg/m^3. The highest concentration of TCE was detected in the home at 3107 Yeoman, which is discussed in Section 3.4.3.7. PCE was detected at concentrations ranging from 0.1 μg/m^3 to 12 μg/m^3. The highest concentration of PCE was detected at 2203 W. 27th Street. As shown in Table 3-12, this home has a history of elevated PCE in living space samples and relatively low PCE in the crawlspace samples. This suggests that the PCE detected in the living space was the result of in-home activities (e.g. cleaning products, etc.).

3.4.3.11 May/June 2007 Sampling Event

Two residences were sampled in May and June 2007, at the request of the residents (these were also recommended for sampling in the Draft CAMP):

- 2107 W 27th Street
- 2804 Weigel Avenue

Both residences are owned by new homeowners who were previously unfamiliar with indoor air sampling in the neighborhood.

TCE was not detected in samples collected from the 2107 W. 27th Street residence. PCE was detected at concentrations of 0.16 μg/m^3 and 0.2 μg/m^3 in the living space and basement, respectively.

TCE was detected in samples collected from 2804 Weigel Avenue at concentrations of 0.068μg/m^3 and 0.09 μg/m^3 in the living space and crawlspace, respectively. PCE was detected at 0.11 μg/m^3 and 0.15 μg/m^3 in the living space and crawlspace, respectively.

3.4.3.12 September 2007

In August 2007, Ecology and DOH indicated that additional indoor air sampling was necessary in the NFVN to satisfy potential data gaps. The Port, Ecology, and DOH identified homes for potential inclusion in the September 2007 indoor air sampling event. These homes were selected based on previous individual results for indoor air and the season in which they were collected, information obtained as part of the building foundation survey, analytical results for soil gas samples, and resident requests.

In accordance with an agreement with Ecology and DOH, 55 homes were selected for indoor sampling in September 2007. By the conclusion of the indoor air sampling event, 30 homes had been sampled. The remaining homes could not be sampled because residents declined sampling or were unresponsive. The 30 homes that were sampled are listed below:

- 1927 W 27th Street
- 2102 W 27th Street
- 2115 W 27th Street
- 2708 Unander Ave.
- 2811 Unander Ave.
- 2903 Unander Ave.
- 2914 Unander Ave.
- 2907 Van Allman Ave.

- 2206 W. 27th Street
- 2102 W 28th Street
- 2104 W 28th Street
- 2113 W 28th Street
- 2203 W 28th Street
- 2210 W 28th Street
- 2214 W 28th Street
- 2611 Unander Ave.
- 2703 Unander Ave.
- 2711 Unander Ave.
- 2810 Unander Ave.
- 2604 Weigel Ave.
- 2608 Weigel Ave.
- 2710 Weigel Ave.
- 2802 Weigel Ave.
- 2804 Weigel Ave.
- 2806 Weigel Ave.
- 2902 Weigel Ave.
- 2903 Weigel Ave.
- 3112 Weigel Ave.
- 3209 Weigel Ave.
- 2203 W. 27th Street

PCE was detected in all residences sampled, at concentrations ranging from 0.063 $\mu g/m^3$ to 16 $\mu g/m^3$. The highest concentration of PCE detected was in the 2203 W. 27th Street home, which has a history of elevated PCE in the living space samples and relatively low PCE in the crawlspace samples (Table 3-12). This suggests that the PCE detected in the living space was the result of in-home activities.

TCE was detected in all but six residences, at concentrations ranging from 0.037 $\mu g/m^3$ to 2.5 $\mu g/m^3$. The highest concentration of TCE was detected at the 2113 W. 28th Street residence, which is discussed in detail in Section 5.4. The remainder of the sample results indicated that PCE, TCE, and other compounds were detected at relatively low levels which are consistent with previous sampling events conducted in the NFVN. The analytical results of the indoor air sampling are included in Table 3-12.

3.4.3.13 December 2007

The December 2007 indoor air sampling event was a continuation of the September 2007 sampling event designed to gather data gap information. The homes included in the December sampling were selected based on previous individual results for indoor air in these homes and adjacent homes, the season in which samples were collected, information obtained as part of the foundation study, and analytical results for soil gas samples. Additional homes were added to or removed from the December sampling list based on the September indoor air results.

Twenty-seven homes were selected for indoor sampling in December 2007. By the conclusion of this indoor air sampling event, 21 of these homes had been sampled. The remaining homes could not be sampled because residents declined sampling or were unresponsive. The 21 homes that were sampled are listed below:

- 2102 W 27th Street
- 2104 W 28th Street
- 2109 W 28th Street
- 2804 Weigel Avenue
- 2806 Weigel Avenue
- 2810 Unander Avenue

- 2110 W 28th Street
- 2113 W 28th Street
- 2203 W 27th Street
- 2205 W 28th Street
- 2211 W 28th Street
- 2608 Weigel Avenue
- 2710 Weigel Avenue
- 2802 Weigel Avenue
- 2903 Van Allman Avenue
- 2904 Unander Avenue
- 2907 Unander Avenue
- 2910 Unander Avenue
- 2912 Weigel Avenue
- 2914 Unander Avenue
- 3110 Yeoman Avenue

PCE was detected in all residences sampled, at concentrations ranging from 0.082 $\mu g/m^3$ to 14 $\mu g/m^3$. The highest concentration of PCE detected was again detected in the 2203 W. 27th Street home, which has a history of elevated PCE in the living space samples and relatively low PCE in the crawlspace samples (Table 3-12). This suggests that the PCE detected in the living space was the result of in-home activities.

TCE was detected in all but two residences, at concentrations ranging from 0.039 $\mu g/m^3$ to 1.5 $\mu g/m^3$. The highest concentration of TCE was detected at the 2113 W. 28th Street residence; this residence is discussed in detail in Section 5.4. The remainder of the sample results indicated that PCE, TCE, and other compounds were detected at relatively low levels which are consistent with previous sampling events conducted in the NFVN. The analytical results of the indoor air sampling are included in Table 3-12.

3.4.4 Distribution of Contaminants in Indoor Air

The focus of indoor air sampling in the NFVN was to establish the nature and extent of indoor air contamination in the NFVN and to determine whether the concentrations detected pose a risk to residents. As part of the investigation, building survey information was evaluated against the sampling data set to evaluate whether houses deemed susceptible to contamination had been sufficiently sampled.

Between 2002 and March 2009, a total of 702 indoor air samples (living space, crawlspace, or basement) were collected from 121 homes in the NFVN. As shown on Figure 3-26, the area covered by indoor air sampling is extensive. Intensive indoor air sampling was conducted along West 27th and West 28th Streets, directly east of the Cadet facility and along the approximate axis of the TCE plume, which extends from Cadet to the east and south.

The building survey database included in Appendix D indicates homes in which at least one indoor air sample has been collected. Homes deemed susceptible to contamination (i.e., as indicated by slab-on-grade construction, presence of basements, foundation cracks, closed vents in the crawlspace, etc.) are also noted. As shown on Figure 3-25, the majority of homes with slab-on-grade construction are located east of Fruit Valley Road. Only one home with slab-on-grade construction is located west of Fruit Valley Road (3508 Yeoman Avenue). This home is located along the northern perimeter of the neighborhood.

Based on the available information, a total of 28 homes in the NFVN have basements or partial basements. Indoor air samples have been collected from 24 of these 28 homes on at least one occasion. As noted in Appendix D, many other homes with survey information indicating cracks, closed vents, or other conditions of vapor intrusion susceptibility have been sampled for indoor air on at least one occasion.

It should be noted that it is not possible or necessary to sample all homes in the NFVN to understand the extent and magnitude of potential contamination in indoor air. A number of homes included in the survey are located in the northern portion of the NFVN and have a low probability of being impacted by vapor intrusion due to its location away from the main portion of the underlying contaminant plume. In addition, some of the homeowners were unresponsive or not interested in being included in the indoor air sampling events. During scoping of the September and December 2007 sampling events, Ecology and DOH agreed on which houses would be sampled to complete the data gap investigation. The Port made every reasonable attempt to contact residents for sampling through letters, phone calls, and door-to-door canvassing of the neighborhood.

Based on the number of homes in the NFVN, the number of susceptible homes sampled, and the agreement with Ecology and DOH for the data gap sampling (September and December 2007), the number of homes sampled in the NFVN is sufficient to determine the associated risk related to indoor air quality. No further investigation of indoor air in homes that have not been previously sampled is warranted.

The ranges of concentrations detected in the homes in the NFVN are shown in the following table.

Summary of Indoor Air Samples Collected in the NFVN

Analyte	Total Samples	Total Detects	MTCA Cleanup Level (μg/m^3)	Minimum Concentration (μg/m^3)	Maximum Concentration[1] (μg/m^3)
1,1,1-Trichloroethane	702	693	4,800	0.04 U	68
1,1-Dichloroethane	642	105	320	0.0024	0.44
1,1-Dichloroethene	702	471	91	0.0035	2.7
1,2-Dichloroethane	642	597	0.096	0.015	8.5
Chloroethane	642	355	3	0.012 U	0.47
Cis-1,2-Dichloroethene	701	67	16	0.0023	0.4
Tetrachloroethene	702	696	0.42	0.031	73
Trans-1,2-Dichloroethene	642	43	32	0.0023 U	0.037
Trichloroethene	702	641	0.1	0.0075	95
Vinyl Chloride	702	207	0.28	0.002 N	0.14

U = Not detected above method detection limit.

N = Indicates the analyte has been tentatively identified but not all laboratory criteria have been met.

NE = Not established.

[1] = Excludes non-detects at significantly elevated detection limits due to laboratory dilution.

As summarized in the table, concentrations of TCE, PCE, and 1,2-DCA have been detected in one or more homes at concentrations above the MTCA ambient air cleanup levels. 1,1,1-TCA, 1,1-DCA, 1,1-DCE, cis-1,2-DCE, vinyl chloride, chloroethane, and trans-1,1-DCE have not been detected in any homes above the MTCA ambient air cleanup level.

In order to evaluate the overall impact of indoor air quality, the 95% upper confidence limit (UCL) was calculated for all indoor air samples collected in the NFVN. The following table summarizes the results.

Statistical Summary of Indoor Air Samples Collected in the NFVN

	MTCA Cleanup Level (μg/m^3)	Living Space 95% UCL (μg/m^3)	Crawlspace 95% UCL (μg/m^3)	Basement 95% UCL (μg/m^3)	All Data Combined 95% UCL (μg/m^3)
1,1,1-Trichloroethane	4,800	1.68	0.38	2.65	1.26
1,1-Dichloroethane	320	0.06	0.04	0.50	0.12
1,1-Dichloroethene	91	0.14	0.04	0.17	0.10
1,2-Dichloroethane	0.096	0.38	0.05	0.55	0.27
Chloroethane	3	0.07	0.03	0.5	0.12
Cis-1,2-Dichloroethene	16	0.09	0.11	0.49	0.14
Tetrachloroethene	0.42	1.76	0.66	2.13	1.31
Trans-1,2-Dichloroethene	32	0.06	0.05	0.5	0.11
Trichloroethene	0.1	1.03	0.59	5.42	1.4
Vinyl Chloride	0.28	0.03	0.03	0.18	0.05

UCL = Upper confidence limit.

As shown in the above table, the 95% UCL for all data combined exceeded the MTCA cleanup level for TCE, PCE, and 1,2-DCA (indicated by shaded cells). Although relatively low, there are observable differences in concentrations between living spaces and crawlspaces. This could be the result of: 1) use of chemicals in the home, or 2) venting of the crawlspace to the atmosphere. The contribution of chemicals from home use has not been quantified. However, the data do support the assertion that in-home activities (i.e., use of chemicals, dry cleaning, glues, etc.) have, at least in part, some effect on indoor air quality.

The data also support the assertion that homes with basements are more susceptible to vapor intrusion than homes with crawlspaces. The 95% UCL for all indoor air samples collected from the basement is significantly higher than crawlspace samples and is moderately higher than living space samples.

Indoor air data collected since 2002 in the NFVN were reviewed to determine if VOC concentrations in indoor air have changed over time. Indoor air data between 2002 and 2008 for TCE and PCE are shown in the following table (note that only limited indoor air data have been collected in 2009).

Statistical Summary of TCE and PCE Indoor Air Data Between 2002 and 2008

		TCE			PCE		
Year	Number of Samples Collected	BS 95% UCL (µg/m³)	CS 95% UCL (µg/m³)	LS 95% UCL (µg/m³)	BS 95% UCL (µg/m³)	CS 95% UCL (µg/m³)	LS 95% UCL (µg/m³)
2002	38	14.3	2.19	2.72	4.7	1.7	1.17
2003	18	4.62	1.94	1.65	2.66	1.97	1.19
2004	106	6.15	0.89	1.38	4.3	0.8	3.47
2005	65	1.59	0.27	0.64	1.55	0.53	1.28
2006*	14	29.5	0.55	5.89	2.55	1.42	1.78
2007	83	0.57	0.11	0.32	0.34	0.33	1.44
2008	25	0.08	0.09	0.11	0.3	0.49	0.48

* Note that if the anomaly of 2113 W. 28th Street is removed from the 2006 data set, the TCE 95% UCL in BS and LS is 0.096 µg/m³ and 0.15 µg/m³, respectively and PCE 95% UCL in BS and LS is 0.4 µg/m³ and 0.26 µg/m³, respectively.

BS = Basement sample.

CS = Crawlspace sample.

LS = Living space sample.

As shown in the above table, concentrations of TCE and PCE in indoor air have steadily declined over time. It should be noted that the number of samples collected and the focus of the indoor air sampling may be different for each year of sampling. For example, early indoor air sampling focused on residences located in the W. 27th and W. 28th Street corridors, which would be expected to have higher VOC concentrations in indoor air than outlying areas due to higher VOC concentrations in area groundwater. However, the data sets are generally large enough and varied enough that some broad interpretations of indoor air quality over time can be made.

For both TCE and PCE, the data indicate indoor air quality has improved since 2002. (Note that the elevated 95% UCL for TCE for 2006 in basement and living space samples is due to very high data points for the 2113 W. 28th Street residence [see Section 5.4] and the relatively low number of samples collected during that year. If this data is removed, the 95% UCL for the basement and living space samples are significantly lower and fall within the expected trend; see note on table above). This may be due to the interim actions implemented at the Cadet site (AS/SVE system, RGRWs) to reduce groundwater concentrations. As discussed in Section 3.3 and illustrated on Figure 3-5, groundwater and soil gas concentrations in the NFVN have been reduced significantly since 2004 (1st year of soil gas testing in permanent wells), most likely due to the interim actions. The reduction of soil gas concentrations beneath the neighborhood limits the availability of soil gas to migrate into indoor air.

3.4.5 Utility Corridors and Potential Contribution to Indoor Air Migration

In 2005, DOH recommended that an evaluation be completed to assess the potential for utility corridors to act as preferential pathways for soil gas. Underground utilities in the FVN include sanitary sewer lines, stormwater lines, natural gas lines, and municipal water lines. The utility lines are generally located in street rights-of-way at depths of less than 10 feet. Lateral lines for all of the utilities are generally present and connected to each residential property. In some areas, other utility lines (e.g., telephone) may also exist.

Backfill material used for utility corridors typically ranges from re-used soil that was excavated during the utility installation to engineered materials, including crushed rock and controlled density fill. If the permeability of the utility corridor backfill material is higher than the adjacent undisturbed soil, the corridor can become a preferential pathway for soil gas movement.

A review of City of Vancouver building codes and records was completed to determine if there are requirements for materials used to backfill utility corridors in the FVN. Of specific interest were backfill requirements for utility connections to the homes in the FVN. No backfill requirements were identified at the City of Vancouver. Typically, utility lines connecting homes to utilities in the street are backfilled with the soil excavated to install the utility. Utilities under streets are typically backfilled with engineered materials (crushed rock or controlled density fill). Although specific records could not be identified, it is expected that the utility lines to homes in the FVN were backfilled with soil that was excavated during installation of the utilities. Therefore, the permeability of the backfill material in the utility corridors to the homes should be similar to that of the surrounding, undisturbed material. Thus, the potential for preferential pathways for soil gas migration should be minimal. It should be noted that AMEC made some visual observations during soil boring work at the Cadet property and in the NFVN. The limited evaluation indicated that soil excavated for utility installation was used as backfill.

While the mechanisms involved in migration of soil gas through the NFVN are important to understand, there is no practical way to accurately determine the role of utility corridors on soil gas vapor migration. The NFVN includes thousands of feet of main line and lateral utility corridors. Visual and/or anecdotal information regarding the construction of the utility lines has not yielded any meaningful information. Field sampling techniques to quantify soil gas presence would have to be conducted through shallow probe borings. In order for a valid study to be conducted, not only would a large number of samples (one sample every 25 to 50 feet of corridor) need to be collected in the corridors, but numerous samples would have to be collected outside the utility corridors for comparison. Ideally, this would be done for each individual property, as conditions could vary widely from property to property. In addition, shallow soil gas probes (less than 5 feet) are subject to difficulties associated with eliminating influences from ambient air being drawn into the probes. For this reason, virtually all literature associated with soil gas investigations recommends that soil gas sampling be done at depths of 5 feet or greater. It is anticipated that the residential utilities are primarily located shallower than 5 feet.

Finally, more than 700 indoor air samples have been collected in the NFVN to evaluate potential impacts from vapor intrusion. The results of the sampling efforts indicate that indoor air concentrations are going down. Additional information regarding utility corridors is not necessary.

Based on this evaluation, further investigation of potential preferential pathways for soil gas migration is not necessary, as indoor air contaminant concentrations and the potential risks associated with the contaminants were determined using direct measurements from homes. In comments on the Draft CAMP, Ecology indicated that no additional utility corridor evaluations will be required (Ecology 2007).

3.5 OUTDOOR AIR INVESTIGATIONS

Outdoor air investigations have been conducted at the site to evaluate the occurrence of VOCs in outdoor air and the potential to impact indoor air results. A summary of the outdoor air investigations and evaluation of background concentrations is included in the following sections. It should be noted that much of the outdoor air evaluation was conducted for both the SMC and Cadet sites as one area.

3.5.1 Outdoor Air Sampling

Outdoor air sampling in the NFVN has been conducted since January 2002, primarily in conjunction with soil gas and/or indoor air sampling events. Based on discussions with Ecology and DOH, the Port initiated additional outdoor air sampling in selected locations in February 2007. The purpose of outdoor air sampling was to evaluate background conditions in the NFVN and how these conditions could affect indoor air quality. The outdoor air sampling locations are shown on Figure 3-27. The outdoor air analytical results are included in Table 3-13.

In general, VOCs have been detected in outdoor air during each event (Table 3-13). The distribution and magnitude of VOCs in outdoor air has been highly variable. However, a detailed evaluation of the outdoor air results was conducted as part of the indoor air evaluation and is summarized in the following section.

3.5.2 Background Evaluation

In order to establish site-specific indoor air cleanup goals, area background conditions should be considered. Throughout the U.S., TCE, as well as other VOCs, have historically been used and continue to be used in industrial and commercial facilities. The widespread use of these volatile chemicals has resulted in outdoor air concentrations in most developed areas throughout the country, which influence indoor air quality in residential structures. In cases where the MTCA Method A or B level is exceeded in the area background, a Method C cleanup level can be established at concentrations that are equal to area background concentrations [WAC 173-340-706(1)(i)].

Many indoor air samples collected in the NFVN and SFVN exceed the October 2008 revised MTCA Method B cleanup level for TCE of 0.1 µg/m^3. In addition, many outdoor air samples also exceed the MTCA Method B cleanup level for TCE, supporting the assertion that some contribution of TCE to indoor air is related to sources other than the groundwater plume beneath the site. The table below includes the MTCA Method B cleanup levels for all of the contaminants detected in indoor air at the site.

MTCA Method B Cleanup Level for Indoor Air

Compound	MTCA Method B Cleanup Level (µg/m^3)
1,1,1-TCA	4,800
1,1-DCA	320
1,1-DCE	91
1,2-DCA	0.096
Chloroethane	3
cis-1,2-DCE	16
PCE	0.42
Trans-1,2-DCE	32
TCE	0.1*
Vinyl Chloride	0.28

* Revised in October 2008 by Ecology to 0.1 µg/m^3 from previous value of 0.022 µg/m^3.

In order to establish area background conditions, sampling of hazardous substances in background areas may be conducted to distinguish site-related concentrations from non-site-related concentrations of hazardous substances [WAC 173-340-709(1)]. Therefore, in comments on the Draft CAMP, Ecology requested that background outdoor air concentrations be established in order to evaluate indoor air cleanup levels.

3.5.2.1 Area Background Data Selection

Outdoor air samples have been collected in the NFVN, SFVN, and other areas around the Port tenant properties since 2002. The purpose of this sampling was to establish local ambient air conditions which may contribute to indoor air concentrations detected within a residential structure. The primary focus of the CAMP background air data evaluation was to select outdoor air samples which are not impacted by the presence of the shallow TCE plume. There is the potential that volatilization of TCE (and other constituents) from groundwater into the atmosphere may be occurring and therefore influencing the outdoor air sample results.

Table 1 in Appendix H includes all outdoor air data collected to date (August 2009) in the project area. However, most of the samples collected prior to 2007 were collected within the NFVN within the known area of the TCE plume. In May 2007, Ecology indicated that a focused study of area background conditions should be completed. Five locations were selected to evaluate area background conditions. Three of the sample locations (labeled 1616-31-OA, CW-MW-9s-OA, and Fram-OA) were outside the footprint of the groundwater plume. One location (labeled RGRW-03-OA) was within the groundwater plume near RGRW-03, and one location was in the SFVN (labeled 2201-SI-OA). The outdoor air sampling locations are shown on Figure 1 in Appendix H.

3.5.2.2 Area Background Data Evaluation

Table 3 in Appendix H includes the data set for background calculations. Based on the evaluation process, 21 outdoor air samples are representative of area background conditions with no significant influence from the TCE plume (Parametrix 2008a). In August 2008, Ecology approved the data set included in Appendix H, Table 3 to be used for area background calculations (Ecology 2008c). This data set was used to calculate area background concentrations. A summary of the evaluation is presented below.

The MTCA Stat97 Background Module spreadsheet was obtained from Ecology and used to calculate area background concentrations for the known contaminants in outdoor air. The spreadsheet uses selected data to determine the distribution of the data set and the method for calculation of a statistically valid area background concentration.

The following table indicates the distribution of the data set (as determined by MTCA Stat97) and the 90% UCL for all constituents.

Calculated Area Background Level for COPCs[1]

Constituent	Data Points	Distribution	R-squared	90% UCL
1,1,1-TCA	20	Log normal	0.95	0.15
1,1-DCA	21	Non-parametric	0.68	0.13
1,1-DCE	21	Normal	0.88	0.03*
1,2-DCA	19	Log normal	0.94	0.05
Chloroethane	21	Non-parametric	0.83	0.04
Cis-1,2-DCE	20	Non-parametric	0.41	0.06
PCE	20	Non-parametric	0.82	0.18
Trans-1,2-DCE	21	Non-parametric	0.61	0.076
TCE	21	Log normal	0.92	0.12
Vinyl Chloride	21	Non-parametric	0.42	0.03

*80% UCL based on normal distribution [WAC 173-340-709(3)(c)].
[1] Chemicals of Potential Concern.

The calculated area background concentration for TCE is 0.12 µg/m^3, which is slightly above the October 2008 revised MTCA Method B cleanup level of 0.1 µg/m^3. All other calculated background concentrations for the remaining compounds are below the MTCA Method B cleanup levels for ambient air.

3.5.2.3 Cleanup Levels

This section presents the rationale for recommending cleanup levels and remediation levels for indoor air. Site-specific risk-based cleanup levels have not been previously developed for the site and have not been identified by Ecology or DOH. Therefore, the CAMP was developed to evaluate and recommend cleanup levels (Parametrix 2009a).

Based on outdoor air sampling conducted at the site and the MTCA Stat97 results, the calculated area background concentration for TCE is 0.12 µg/m^3, which is slightly above the October 2008 revised MTCA Method B cleanup level of 0.1 µg/m^3. All other background concentrations for the remaining compounds are below the MTCA Method B cleanup levels.

Area Background and MTCA Cleanup Level

Compound	Area Background Concentration (µg/m^3)	MTCA Method B Cleanup Level (µg/m^3)
1,1,1-TCA	0.15	**4,800**
1,1-DCA	0.076	**320**
1,1-DCE	0.03	**91**
1,2-DCA	0.05	**0.096**
Chloroethane	0.04	**3**
cis-1,2-DCE	0.06	**16**
PCE	0.18	**0.42**
Trans-1,2-DCE	0.076	**32**
TCE	**0.12**	0.1
Vinyl Chloride	0.03	**0.28**

NE = Not established.

In cases where background exceeds the MTCA cleanup level, WAC 173-340-706(1)(i) specifies that area background levels should be used as the appropriate cleanup level. However, since the calculated background level and the MTCA cleanup level for TCE are identical to the first decimal place, it was proposed that the MTCA Method B ambient air concentration be used as the indoor air cleanup level for TCE, as well as all other compounds. This is consistent with the August 2008 letter from Ecology approving cleanup levels for the site (Ecology 2008c).

3.6 HYDROGEOLOGIC INVESTIGATIONS

Several hydrogeologic investigations were conducted at the site and are summarized in the following sections.

3.6.1 Aquifer Pumping Test

At Ecology's request, AMEC conducted an aquifer pumping test at the site in March 2002. The test was performed to develop hydraulic conductivity estimates for use in evaluating possible interim remedial action measures (IRAMs) for the Cadet site and the NFVN. The procedures and results of the aquifer pumping test are presented in Appendix I.

Monitoring wells CM-MW-11 through CM-MW-16 were used in the pump test to estimate the horizontal hydraulic conductivity (K) of the USA. The K values for the shallow USA estimated from the pump test ranged from 140 to 14,260 feet per day (Appendix I). Slug testing of wells CM-MW-01i, CM-MW-02d, CM-MW-04i, CM-MW-05d, and CM-MW-10d completed in the intermediate and deep USA yielded K estimates of 140 feet per day for the intermediate USA and 170 feet per day for the deep USA (Appendix I). The results of the aquifer pumping test were incorporated into the understanding of hydrogeologic conditions described in Section 4.

3.6.2 Groundwater Tracer Tests

In August 2000 and April 2002, AMEC completed tracer tests to evaluate the local shallow groundwater gradient and velocity at the site. The procedures and results of the tracer tests are presented in Appendix J (includes relevant section of Remedial Investigation Work Plan [AMEC 2002e] and Appendix E of the Draft Remedial Investigation Report [2003a]).

The August 2000 tracer test indicated that groundwater flowed to the east at the time of the test. Groundwater velocities were calculated to range from 26.1 to 43.9 feet per day using the instantaneous slug injection method and 0.6 to 7.6 feet per day using a borehole dilution method (AMEC 2002e).

The April 2002 test was conducted in the vicinity of wells CM-DPW-2, CM-DPW-3, CM-DPW-4, CM-DPW-11, CM-DPW-13, and CM-DPW-16 during high water table conditions. The bromide tracer was detected in only one well, whose location relative to the injection point suggested that groundwater flowed to the south (AMEC 2003a). The results of the tracer tests were incorporated into the understanding of hydrogeologic conditions described in Section 4.

3.6.3 Tidal Evaluation

In April 2002, AMEC collected data to evaluate the effect of tides on groundwater levels in the project area. The data showed that tidal influences in the Columbia River influenced groundwater levels significantly, resulting in noticeable changes in the gradient over just a few hours. The procedures and results of the tidal evaluation are presented in Appendix K.

The study indicated that Columbia River tidal fluctuations apparently resulted in rapid changes in the horizontal groundwater flow direction in the shallow USA. For example, the apparent groundwater flow direction ranged from west to north-northwest to southwest over a period of 11 hours. This finding supports the assertion that groundwater flow direction varies with tidal stages. Based on the results of the tidal evaluation, it was unlikely that taking contemporaneous groundwater elevation measurements with other nearby parties (i.e., SMC, NuStar) would result in accurate groundwater gradient determinations, since these coordinate measurements typically take several hours to complete.

Using data obtained during the tidal influence investigation, the transmissivity of the shallow USA was estimated as approximately 170,000 gallons per day per foot. Dividing the transmissivity by the depth of the aquifer, yields a K estimate for the shallow USA of 800 feet per day (Appendix K).

3.6.4 Groundwater Geochemistry

Groundwater geochemistry data were collected during three groundwater monitoring events in November 1999, July 2000, and October 2002. These data were collected as part of the RI groundwater monitoring program for three purposes: 1) to obtain general groundwater data that may be useful in remedy design; 2) to evaluate whether conditions conducive to natural attenuation of chemicals of potential concern (COPCs) are present; and 3) to evaluate whether remedial activities underway at the SMC site have influenced groundwater chemistry in the project area. The groundwater geochemistry data and discussion are presented in Appendix L.

In general, there is some limited evidence for TCE transformation to cis-1,2-DCE based on the collection of groundwater from some of the wells. The evidence suggests that minor natural attenuation may be occurring under weak and transient anaerobic conditions (Appendix L). The results of the groundwater geochemistry evaluation were considered during development of the understanding of the nature and extent of contamination included in Section 8.

4. 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 Cadet investigations, described in Section 3, and other data collected for the SMC and NuStar investigations.

Information collected in the project area since completion of early investigations 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 2003 RI Report (AMEC 2003a), 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. The regional geologic and hydrogeologic conditions are also summarized in the Final Remedial Investigation Report for the SMC site (Parametrix 2009c) and the TGA and Deep USA White Paper, SMC and Cadet Sites (Parametrix 2008c) included here as Appendix N.

Figure 4-1 presents a comparison of the regional and project area geologic and hydrogeologic units. As shown on Figure 4-1, 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. 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 (bgs) 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 25 to 80 feet MSL. The surface elevation in the vicinity of the Cadet site is approximately 30 feet MSL.

4.1 REGIONAL CONDITIONS

The 2003 RI Report included a general overview 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 for the purpose of supporting both the SMC and Cadet remedial investigations. 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 Vancouver Lake Lowlands Groundwater Model Summary Report (Parametrix et al. 2008) 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.

4.1.1 Geologic Units

Three geologic units have been encountered in investigative borings completed in the project area (Figure 4-1). 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 (PGG 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.

4.1.2 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 4-1, 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 et al. 2008). 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 to lie 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.

4.2 LOCAL CONDITIONS

The 2003 Draft RI produced by AMEC included a description of the geologic and hydrogeologic conditions and their integration into a conceptual hydrogeologic site model (CHSM). Since AMEC produced the Draft RI in 2003, additional borings and wells have been installed at the Cadet and SMC sites, providing additional information on subsurface conditions and aiding in the definition of geologic and hydrogeologic conditions in the project area. Figure 4-1 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 8). The relationship of project area lithologic units to project area groundwater zones is described in this section.

4.2.1 Geologic Conditions

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

4.2.1.1 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 4-1 summarizes the thickness of the alluvium encountered in borings completed as part of the Cadet, SMC, and NuStar 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. These subunits are generally not present in the Cadet Site project area. The variability in fines 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 represent primary dredge fill deposits. It is present in the south of the project area, adjacent to the Columbia River, as shown on Figure 4-3. Sand 2 overlies Silt 2 and is generally better sorted than Sand 1, but in places it 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 4-3). 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 farther 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 4.1.1. As summarized in Table 4-1, Silt 1 is generally present throughout the project area. 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 4.1.1 (Figures 4-3 through 4-5). 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.

4.2.1.2 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, they are highly transmissive.

As shown on Figure 4-1, three catastrophic flood deposit subunits 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 4-3 through 4-5). 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 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 Cadet and SMC sites (Figures 4-3 through 4-5). The approximate extent and thickness of the channel fill deposits are shown on Figure 4-6.

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 present throughout the project area (Figures 4-3 through 4-5).

4.2.1.3 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 4-7, the elevation of the top of the Troutdale Formation varies substantially in the project area. Table 4-2 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 Cadet and SMC sites. The presence of an erosional feature incised into the Troutdale Formation was identified in the 2002 SMC RI Report (Parametrix 2002) and discussed further in the 2009 SMC Final RI Report (Parametrix 2009c). 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 4-5).

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 lie at greater depths beneath the Cadet site. The top of the Troutdale Formation rises very steeply directly east of the SMC site and rises relatively steeply to the southwest of the SMC site (Figure 4-7). The highest elevation of the Troutdale Formation in the project area occurs just east of Kotobuki Way at well MW-16d.

As shown on Figure 4-7, 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 NuStar site at approximately -80 feet MSL (Figure 4-7).

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

Upriver of the NuStar 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 NuStar site was eroded as part of an ancestral river channel and then backfilled with a sand and gravel deposit.

4.2.2 Hydrogeologic Conditions

Two regional hydrogeologic units, the unconsolidated sedimentary aquifer (USA) and the underlying Troutdale Gravel Aquifer (TGA), have been identified in the project area. The uppermost aquifer in the project area is the USA (Figure 4-1). 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 Cadet, SMC, and NuStar 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 was not 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.

4.2.2.1 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 4-1). During the course of the RI, groundwater zones were adopted to describe and evaluate 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 Cadet 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 SMC site and, to a lesser extent, at the NuStar 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 4-1, 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. It corresponds primarily 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 4-3 presents a completion summary of the Cadet site monitoring well network, including the aquifer and groundwater zone monitored by each well. As indicated in Table 4-3, 19 of the 34 shallow monitoring wells at the Cadet site are screened at least partially in alluvial deposits. The remaining 15 shallow wells are screened in catastrophic fill deposits.

The alluvial deposits contain greater amounts of fine material than the underlying catastrophic flood deposits. Consequently, the transmissivity of the alluvial deposits is notably lower than that of the 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 8.

Groundwater flow in the shallow USA zone at the Cadet site is generally toward the east. Contaminant distribution shows moderate concentrations of solvents in groundwater at the Cadet source area, decreasing with the distance east (i.e., downgradient) of the source area (Section 8). Potentiometric contour maps based on water level measurements from shallow monitoring wells also indicate an eastern or 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. With the startup of the Port's groundwater pump and treatment system at the SMC site in June 2009, coupled with the anticipated reduction in pumping rates at the GWM site, it is likely that a change in flow direction will occur at the site. However, these additional data have not yet been obtained or evaluated.

Recharge of the shallow USA zone is from precipitation and the Columbia River. Groundwater flow in the shallow USA zone in the area of the NuStar 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 NuStar 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), the influence of GWM pumping is less at the NuStar site than at the SMC and Cadet sites. As a result of these conditions at the NuStar 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 4-3, there are 22 intermediate USA zone monitoring wells at the Cadet site. Eighteen are screened in the sand and gravel subunit, and three are screened in the channel fill subunit.

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 Cadet source area, groundwater flow in the intermediate USA zone at the Cadet site is initially toward the east-southeast, and then becomes southerly approximately 1,500 feet east of the site. Potentiometric contour maps based on pressure transducer data 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. As in the shallow USA zone, groundwater flow in the intermediate USA is expected to change with the startup of the Port's groundwater pump and treatment system at the SMC site in June 2009 and the anticipated reduction in pumping rates at GWM (Figure 4-8). As discussed in Section 4.3, recharge of the intermediate USA zone is primarily from the Columbia River. Consequently, groundwater flow in the intermediate zone in the area of the NuStar site is toward the north and northeast.

Evidence of this groundwater flow is supported by an analysis of stable hydrogen and oxygen isotope data, primarily conducted as part of the SMC Final RI Report (Parametrix 2009c). 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 NuStar (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 the increasing dilution of river-derived groundwater by precipitation recharge. Thus, the stable oxygen and hydrogen data support the northerly flow of groundwater from the NuStar site. A more detailed discussion of the isotope data is presented in the SMC Final RI Report (Parametrix 2009c).

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 4-7, 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. As indicated in Table 4-3, all nine Cadet site deep USA zone monitoring wells are at least partially screened in re-worked Troutdale Formation material. The remaining three deep wells are screened in the channel fill subunit.

Based on well log descriptions, the channel fill deposits 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 currently 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 the SMC Final RI Report (Parametrix 2009c).

4.2.2.2 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 four Cadet site monitoring wells screened in the TGA (Table 4-3). These four wells are all located in the northeastern portion of the project area and oriented northwest/southeast along the northeastern edge of the project area (Figure 2-2).

The permeability of the TGA is a least one order of magnitude lower than that of 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 TGA than 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 in flow rates, 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, currently 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).

4.2.2.3 Cadet Site Monitoring Well Network

Table 4-3 presents a completion summary of the Cadet site monitoring well network, including the aquifer and groundwater zone monitored by each well. The Cadet monitoring well network consists of:

- Thirty-four shallow zone USA wells. Two of these wells are part of multiport systems.
- Twenty-two intermediate zone USA wells. Eight of these wells are part of multiport systems.
- Twelve deep zone USA wells. Seven of these wells are part of multiport systems.
- Four TGA wells.

4.2.2.4 Potentiometric Mapping

The potentiometric surfaces of the USA and the TGA are flat in the project area. This is 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 (Figure 4-9). 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. During the fall of 2006, groundwater flow analysis was completed in the project area. The analysis findings are summarized in Section 4.3.

4.3 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 those 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. These 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.

4.3.1 Transducer Study

A transducer study was completed from October to December 2006 in coordination with Clark Public Utilities (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 et al 2008). The intermediate USA was selected because it is the highly permeable portion of the USA and accounts for 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.

4.3.1.1 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 level data 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 National Geodetic Vertical Datum (NGVD) 29 datum elevation with the 1947 adjustment.

The locations of instrumented wells and gages included in the transducer study are shown on Figure 4-9. 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 (COV) water station wells, the CPU generator plant well, COV's Westside Wastewater Treatment Facility well, Great Western Malting (GWM) production wells, and Port production wells.

Analysis of the transducer data consisted of the following steps:

- Correct data for barometric pressure.
- Correct data for observed drift, if necessary.
- 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 as 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 M includes a technical memorandum that summarizes the transducer data used for model transmissivity calibration.

4.3.1.2 Data Review

Figure 4-10 is a time series plot of water levels for all groundwater and surface water 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 responded 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, the river stage rose and then declined, but maintained an overall higher 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 4-11 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 4-4 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 that station and not to tidal effects. Figure 4-10 shows the average water level elevations and tidal efficiency.

As shown on Figure 4-10, 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 level 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.

4.3.2 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 to the project area and that 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 that 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 4-5 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 in Table 4-5. Straight (or standard) averages were also calculated and compared to rolling averages as shown in Table 4-5. 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 Cadet and SMC 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 M.

The flow direction maps generated for the five events all indicate that the mean groundwater flow directions in the project area are toward the GWM site, from the north, northwest, and northeast. During the transducer study period, the median pump rate at GWM was 4,016 gallons per minute (gpm), with pumping relatively equally divided between production 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 M.

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, 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 at adjacent monitoring locations.

Southern well POV-MW-19i had the lowest mean water level elevation in the Columbia Lowlands. Exceptions are CM-MW-21i and POV-MW-26i during Event 4. Well POV-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 27 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 POV-MW-26i were higher, and Event 6 when northern well CM-MW-18i was again higher. With the 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 Cadet, SMC, and NuStar source areas is summarized below:

- At the Cadet site, the mean groundwater flow direction is toward the east/southeast.
- 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 NuStar 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 NuStar tends to be flat or slightly higher further to the north of the NuStar site. The mean river elevation is consistently higher than the mean water level elevation at MW-32i, located north of the NuStar site.

Mean water level measurements for the periods evaluated are consistent with the flow directions 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. Compared to mean groundwater levels in the project area, the mean river level elevation indicates that the Columbia River functions as a recharge boundary. The mean groundwater flow direction can change during high precipitation or runoff events that cause the river stage to rise noticeably, as observed during the period of November 6 through November 9. However, these high stage events are short-period events, and their influence on contaminant transport is dependent upon the length of the event and pumping conditions at GWM during the event.

5. INTERIM ACTIONS

Several interim actions have been implemented at the Cadet site and in the NFVN to reduce or mitigate the presence of VOCs in particular media. The interim actions include:

- Installation of a initial soil vapor extraction (SVE) system in the eastern side of the Cadet property
- Installation of an air sparging and soil vapor extraction (AS/SVE) system at the Cadet facility, primarily beneath the Cadet building
- Installation of recirculating groundwater remediation wells (RGRWs) in the NFVN
- Installation of soil vapor vacuum (SVV) systems at six residences in the NFVN

These interim actions are summarized in the following sections.

5.1 AIR SPARGING/SOIL VAPOR EXTRACTION SYSTEM

An air sparging (AS) and two SVE systems were installed at the Cadet site to address VOCs in source area soil and groundwater and to prevent further migration of VOCs to the east towards the NFVN. The first SVE system installation is documented in the Soil Vapor Extraction System Installation and Start-Up Report (AMEC 2002d) and the AS/SVE installation and startup is described in the Air Sparging and Soil Vapor Extraction Remediation System Installation and Startup Report (AMEC 2004d). A schematic of a typical AS/SVE system is shown on Figure 5-1. A summary of the AS/SVE system design, installation, operation, and performance is presented in the following sections.

5.1.1 Design and Installation

In May 2002, AMEC installed the original SVE system at the Cadet site to extract VOC vapors from soil and mitigate VOC levels in indoor air in the Cadet building. The original SVE system consisted of thirteen SVE wells, including eight vertical SVE wells (VE-01 to VE-04, and VE-08 to VE-12), three angled SVE wells (VE-05 to VE-07), and two horizontal SVE wells (HVE-01 and HVE-02). Six of the SVE wells (VE-09 to VE-12, HVE-01 and HVE-02) were installed inside the site building near the paint room. The remaining seven SVE wells (VE-01 and VE-03 to VE-08) were installed in the parking area along the eastern boundary of the site (Figure 5-2). Subsurface piping connected each well to the SVE equipment compound (except VE-02). Granular activated carbon (GAC) vessels were used to treat extracted soil vapors before being discharged to the atmosphere. SVE well completion details are included in Table 5-1.

The installation of the original SVE system is described in the Soil Vapor Extraction System Installation and Startup Report (AMEC 2002d). The original SVE system reportedly removed approximately 445 pounds of VOCs from the subsurface during the period of operation between May 2002 and June 2003 (AMEC 2004d). In June 2003, the original SVE system was shut down so that it could be expanded and incorporated into the larger AS/SVE remediation system (Figure 5-2).

The completed AS/SVE remediation system began operation in October 2003 as an interim groundwater source control measure. The influence of the AS/SVE system includes the area beneath the Cadet site building and the areas of the property to the north and east of the building. Two AS blowers and one AS compressor are used to deliver compressed ambient air through the AS wells into the groundwater aquifer. Four SVE blowers are used to extract soil gas and volatilized organic vapors from the SVE wells. The SVE air stream is treated with GAC before being discharged to the atmosphere. The following sections describe the specifications of the AS/SVE system. As-built drawings and supporting information are included in Appendix E.

5.1.1.1 AS System Components

The AS portion of the system includes 73 air sparging wells, of which:

- 30 are vertical wells within the building (AS-41 through AS-57, AS-59 through AS-64, and AS-67 through AS-73).
- 27 are vertical wells outside the building footprint (AS-01, AS-03, AS-04, AS-06, AS-07, AS-09, AS-10, AS-12, AS-15, AS-16, AS-18, AS-19, AS-21, AS-22, AS-24, AS-25, AS-27, AS-28, AS-30, AS-31, AS-33 through AS-38, and AS-40). Of these 27 wells, four are deep wells (AS-04, AS-06, AS-07, and AS-64).
- 3 are angled wells within the building (AS-58, AS-65, and AS-66).
- 13 are angled wells installed along the perimeter of the building (AS-02, AS-05, AS-08, AS-11, AS-13, AS-14, AS-17, AS-20, AS-23, AS-26, AS-29, AS-32, and AS-39).

Most of the AS wells are screened from 35 to 40 feet bgs. The AS wells extend about 15 to 20 feet into the groundwater, except in areas where VOCs were detected at deeper intervals; in these areas, the wells are screened from 55 to 60 feet bgs (AMEC 2005). The well completion details are included in Table 5-1.

Flow is diverted and balanced using manifolds into two functional groups, AS well Group 1 and AS well Group 2 (Figure 5-3). The AS system includes two rotary, 6-horsepower, positive-displacement blowers and one compressor. The blowers provide the optimum air flow to at least half of the 69 shallow AS wells, and the compressor provides optimum air flow to two of the four deeper AS wells, for a total system flow rate of 370 standard cubic feet per minute (scfm) (AMEC 2004d).

5.1.1.2 SVE System Components

The SVE portion of the system includes 41 vapor extraction wells, of which:

- 5 are vertical wells within the footprint of the building (VE-09 through VE-12, and VE-34). Wells VE-09 through VE-12 are currently equipped with dual-valve pumps, and do not function as vapor extraction points.
- 11 are horizontal wells within the footprint of the building (VE-30 [a,b], VE-31 [a,b,c], VE-32 [a,b,c], and VE-33 [a,b,c]).
- 22 are vertical wells outside the building footprint (VE-01 through VE-04, VE-08, and VE-13 through VE-29).
- 3 are angled wells installed along the perimeter of the building (VE-05, VE-06, and VE-07).

The SVE wells include both vertical and horizontal wells. A typical vertical SVE well includes a 4-inch PVC well casing that extends from ground surface to 5 feet bgs, and a 4-inch PVC well screen extending from 5 to 20 feet bgs (5 to 25 feet bgs in wells along the eastern site boundary). The horizontal SVE wells were installed inside trenches approximately 2 feet below the Cadet building foundation slab to prevent migration of VOC vapors into the building. These horizontal SVE wells were constructed of sections of 2-inch screened PVC pipe approximately 10 feet in length (AMEC 2004d). The well completion details are included in Table 5-1.

The SVE system includes four blowers capable of approximately 300 scfm at a vacuum level of 20 inches of water column, or a total of 750 scfm at a vacuum level of 60 inches of water column. This operational rate exceeds the designed flow rate of 740 scfm. Additional flow rate is available for back pressure caused by the GAC air treatment.

5.1.1.3 Air Discharge Treatment

Extracted air is treated using a GAC treatment system. The system consists of four 500-pound units and two 1,000-pound units installed in parallel and downstream of the blowers. Moisture is removed between the GAC treatment system and blowers by moisture separators.

5.1.1.4 AS/SVE Control System

System controls include on/off/auto switches, alarms, timers, data logging units, and an auto-dialer, all of which are contained in a mounted control panel. System controls and interlocks will shut down the AS system if the SVE system ceases to operate. Interlocks include an SVE Failure Alarm, an SVE Drain Alarm, and an AS High-pressure Alarm. A dedicated Portland General Electric meter is used to record AS/SVE system electrical consumption.

Further details regarding the configuration of the AS/SVE remediation system are presented in the Air Sparging and Soil Vapor Extraction Remediation System Installation and Startup Report (AMEC 2004d), which also contains the complete AS/SVE System As-Built Drawings and the Operation and Maintenance Manual for the system.

5.1.2 Operational History

The AS/SVE system has operated for approximately 7 years. The general chronology of AS/SVE system operation is as follows:

- Start-up of the interim SVE system began in May 2002. The original system consisted of 13 SVE wells.
- Shutdown of the interim SVE system occurred in June 2003 so that the system could be expanded and incorporated into a larger AS/SVE system. The expanded system consists of 73 AS wells and 41 SVE wells.
- Start-up of the AS/SVE system began in October 2003 as an interim source control measure. Operations data from October 2003 to February 2004 are included in the Air Sparging and Soil Vapor Extraction Remedial System Installation and Start-up Report (AMEC 2004d). Operations data for the AS/SVE system from March 2004 to January 2005 are documented in the Remedial Investigation (RI) Update Report (AMEC 2005).
- Operations of the AS/SVE system were modified in December 2004 to focus on remediation in the areas with the highest remaining TCE concentrations. Half of the AS wells—those closest to the area of concern (i.e., in the vicinity of VE-11)—were left operational, while the remaining half of the wells were shut down. The Updated RI Report does not identify which wells remained operational. Air delivery was changed to 2-week pulse cycles. These AS pulse cycles were operated in conjunction with the maximum SVE flow rates.
- In March 2004, AS/SVE operations were changed back to two operational groups (AMEC 2005), and operations of Group 1 and Group 2 were alternated, typically on

monthly cycles. The system was operating in this configuration until the start of the rebound test in August 2007.

- Rebound testing occurred between August 2007 and April 2008. The results of this testing are the focus of this current report. Only Group 1 AS wells were operated throughout the baseline and re-startup testing.
- April 2008 – March 2009: After rebound testing completion, the AS/SVE system was returned to operational status. Currently all 41 SVE wells and 23 of the AS wells are operating on a 24-hour basis. The SVE wells are served by two operating blowers. The AS wells are served by one operating compressor that maintains a minimum flow of 5 scfm. Bi-monthly maintenance is conducted by Parametrix

Operations data from October 2003 to February 2004 are summarized in the Air Sparging and Soil Vapor Extraction Remedial System Installation and Startup Report (AMEC 2004d). Operations data for the AS/SVE system from March 2004 to January 2005 are documented in the Cadet RI Update Report (AMEC 2005). Additional operational data are included in the Air Sparging/Soil Vapor Extraction Performance Evaluation Report (Parametrix 2009b).

5.1.3 AS/SVE System Historical Performance

This section presents a brief summary of the AS/SVE system performance from its implementation in May 2002 up to the start of the rebound test in August 2007. Additional detailed information can be found in the AS/SVE Performance Evaluation Report (Parametrix 2009b).

5.1.3.1 Distribution of TCE in Groundwater

A group of monitoring wells at the Cadet site was selected to evaluate the performance of the AS/SVE system (Figure 5-2). Isoconcentration maps were developed to evaluate the spatial distribution of TCE in shallow groundwater over the period of AS/SVE operation (Figures 5-4 through 5-6). The maps show TCE concentrations and isoconcentration lines for each of the sampling events selected (August 2003, February 2007, and March 2008).

Isoconcentration lines were constructed by contouring lines of equal concentration for 5 µg/L, 25 µg/L, 50 µg/L, 100 µg/L, 1000 µg/L and 5000 µg/L. These contour intervals were selected for purposes of comparison, and represent 1, 5, 10, 20, 200, and 1000 times, respectively, the EPA drinking water maximum contaminant level (MCL) for TCE of 5 µg/L. Contouring assumes that concentrations represent a two-dimensional surface. However, the monitoring network consists of monitoring wells, mini-wells (1-inch casing diameter), vapor wells and air sparge wells which have different screen depths (see Table 5-1). Review of well construction details indicates that well screen mid-points have an average depth of approximately 18 feet bgs. Data from these monitoring points are considered to be acceptable for the purposes of this evaluation since the majority of the screen intervals overlap. Analytical data are summarized in Table 5-2.

Figure 5-4 (August 2003) shows TCE concentrations just prior to the full-scale AS/SVE system startup. The highest TCE concentrations (exceeding 5,000 µg/L) were observed in wells CM-VE-10 through CM-VE-12. TCE concentrations ranging from 50 µg/L to 1,000 µg/L were detected in a portion of the adjacent NFVN, east of the site.

Figure 5-5 (February 2007) shows TCE concentrations 40 months after startup. A decrease in the TCE source area concentrations was observed. TCE was detected at concentrations at or below 10.5 µg/L in samples collected from wells CM-VE-10 through CM-VE-12. The highest TCE concentration was 516 µg/L, at CM-MW-01d-040.

Figure 5-6 (March 2008) shows TCE concentrations 53 months after startup and one month before the end of the rebound test (see Section 5.1.4). The plume had shifted to the northeast and southeast. A decrease in the TCE source area concentrations was observed. TCE was generally detected at concentrations at or below 25 µg/L in samples within the plume. The highest TCE concentration was 414 µg/L, at CM-MW-01d-040.

A review of the other VOCs analyzed, including PCE, indicated that, in general, the relative concentrations (i.e., concentrations relative to each well) are similar to those for TCE, as described above (Table 5-2). The data indicate that operation of the AS/SVE system has significantly reduced VOC concentrations in groundwater beneath the Cadet building and has removed a majority of the primary source material. Based on the performance evaluation summarized in Section 5.1.4, most of the mass removal occurred in the initial year of AS/SVE operation, with decreasing efficiency in later years. This is typical of remedial systems such as AS/SVE, and continued operation of the AS/SVE system is not expected to have much effect on the overall groundwater plume.

5.1.3.2 Soil Vapor Extraction

Soil vapor is extracted using the SVE wells and routed through a manifold system which directs the vapor into the GAC treatment system. Prior to entering the GAC system, influent soil vapor samples are collected for analysis from a dedicated sampling port. Influent air from the SVE system is routinely monitored to evaluate VOC concentration trends and to calculate the total mass of VOCs removed and removal rates.

Table 5-3 provides a summary of VOC concentrations in influent soil vapor prior to the start of the rebound test (data from October 2003 to May 2007). The data show decreasing concentrations of TCE and PCE in influent air. Concentrations of TCE and PCE in influent air remained at approximately 400 µg/m^3 and 250 µg/m^3, respectively, for close to 2.5 years prior to the rebound test. TCE and PCE concentrations decreased over the 43 months of operation, from initial start up in October 2003 (2,400 µg/m^3 and 1,600 µg/m^3, respectively) to May 2007 (150 µg/m^3 and 69 µg/m^3, respectively).

Figure 5-7 shows a time-trend plot for total VOC mass removal from May 2002 to February 2008. Based on the data, approximately 517 pounds of VOCs have been removed by the system. It should be noted that the mass calculated is only a gross estimate and is based on the best available data. The figure also shows that the rate of mass removal has dramatically decreased since May 2004. The estimated mass removal rate prior to the initiation of the rebound test was 0.016 pounds per day (Parametrix 2009b).

5.1.4 PERFORMANCE EVALUATION

When active remediation is ceased, residual contamination adsorbed to soil will re-equilibrate to the changed conditions and partition to the aqueous or vapor phase. Therefore, contaminant concentrations in groundwater (aqueous phase) and soil vapor (vapor phase) have a tendency to increase or rebound. The magnitude of rebound is dependent on the nature and extent of residual contamination, subsurface conditions, and time. It is assumed that given enough time, contamination will re-equilibrate to semi-steady state conditions. This semi-steady state condition is of interest because it allows for the evaluation of how much contaminant mass is available for removal. The performance of the AS/SVE system can be evaluated by observing how effective it is in reducing contaminant concentrations and mass when it is re-started, and how long it takes for these reductions to occur.

A performance evaluation of the AS/SVE system was conducted between August 2007 and April 2008. The evaluation consisted of a rebound test (also known as pulsing), which was conducted in a manner consistent with the AS/SVE Performance Evaluation Plan, dated November 20, 2007 (Parametrix 2007c) and approved by Ecology on June 19, 2008 (Ecology 2008d).

The objectives of the rebound test were to:

1. Evaluate the effectiveness of the AS/SVE system in reducing VOC concentrations and mass in groundwater and soil gas;
2. Assess residual contamination in the subsurface; and
3. Help determine an operations strategy for future use of the AS/SVE system.

The rebound test was conducted in three steps:

Step 1 Baseline Conditions: Assess operating conditions of the AS/SVE system as a result of long-term active remediation.

Step 2 Dormancy Period: Assess the level and distribution of residual contamination after a temporary shutdown of the AS/SVE system.

Step 3 Restart-up of System: Assess whether the AS/SVE system is effective in removing contaminant mass and reducing concentrations during a period of active remediation. Restart-up brought the system to the same operational rates as under baseline conditions.

Multiple sampling events were conducted for each step to help establish trends in groundwater, soil vapor, indoor air, and outdoor air for each step. Details of the evaluation are included in the Draft AS/SVE Performance Evaluation Report (Parametrix 2009b) and are summarized below.

5.1.4.1 Sampling and Analysis

Sampling locations in the immediate vicinity of the Cadet facility are shown on Figure 5-2. The sampling regime conducted as part of the evaluation included:

- Groundwater samples were collected for analysis from 17 locations, including monitoring wells, probe wells, air sparge wells, and vapor extraction wells.
- Soil vapor samples were collected for analysis from 9 locations, including vapor extraction wells and horizontal extraction trenches.
- Soil vapor was collected for quantification using a PID from 38 VE wells.
- Influent and effluent soil vapor samples were collected from the GAC treatment system.
- Indoor air samples were collected for analysis from 5 residences located adjacent to the eastern boundary of the site. Samples were collected from living spaces, basements, and/or crawl spaces of each residence to monitor contaminant levels over the course of the test and to ensure that these levels did not dramatically rise during the dormancy period.
- Outdoor air samples were collected from two locations.
- Weather station information was obtained from the Pearson Air Field, Vancouver, Washington.

5.1.4.2 Data Evaluation and Conclusions

Various analytical data (groundwater, soil gas, indoor and outdoor air) were obtained during the performance evaluation. A detailed discussion of the data is included in the Draft AS/SVE Performance Evaluation Report (Parametrix 2009b). Tables 5-2 and 5-3 include analytical data for the AS/SVE evaluation. The following are the main conclusions of the data evaluation.

In the following, responsiveness refers to the influence of the AS/SVE system on an individual well; i.e. if the well is responsive, then VOC concentrations in the well have a tendency to decrease when the system is "on" and increase when the system is "off."

Groundwater

- 17 wells were evaluated during the rebound test. Based on the data collected, 11 of the wells were considered responsive, 5 of the wells were considered non-responsive, and results from 1 well were inconclusive.
- An evaluation of the 11 responsive wells indicated that the maximum TCE and PCE concentrations during the dormancy period were 56.3 µg/L (at AS-55) and 208 µg/L (at DPW-01), respectively. These wells displayed the greatest decline in TCE and PCE concentrations during the restart-up period, with TCE decreasing to 8.13 µg/L (a difference of 48.1 µg/L) and PCE decreasing to 26.1 µg/L (a difference of 181.9 µg/L). Declines in concentration for the remaining wells were more modest, ranging from 5 µg/L to 25 µg/L for TCE, and from 2 µg/L to 10 µg/L for PCE. TCE and PCE ending concentrations were typically above baseline conditions, suggesting that additional time is likely needed to re-attain baseline conditions.
- An evaluation of the 5 non-responsive wells indicated that CM-MW-01s and CM-MW-05s are likely outside the zone of influence of the AS/SVE system; VE-16 had no or limited detections of TCE and PCE, and AS-49 and CM-MW-01d-40 indicated a general decline in TCE and PCE concentrations throughout the test. Therefore, contaminant levels in groundwater at these locations are likely indirectly affected by system operations.

Soil Vapor

- Review of the time trend plots suggests that of the 6 vapor wells, 5 appear to be responsive to the rebound test, while test results were inconclusive for 1 well.
- An evaluation of the 5 responsive wells indicated that the maximum TCE and PCE concentrations during the dormancy period were 7,200 µg/m^3 and 1,300 µg/m^3, respectively, at VE-07. Well VE-07 also indicated the greatest decrease in TCE and PCE concentrations during the restart-up period, with TCE decreasing to 410 µg/m^3 (a difference of 6,790 µg/m^3) and PCE decreasing to 61 µg/m^3 (a difference of 1,239 µg/m^3). In addition, at the end of restart-up, TCE and PCE concentrations in all vapor wells were lower than their baseline concentrations, suggesting that pulsing of the system resulted in reducing soil vapor concentrations.

Indoor and Outdoor Air

- Indoor air concentrations from 5 residences located adjacent to the eastern boundary of the site were non-responsive to the rebound test. Indoor air quality was relatively consistent throughout the test period, with no obvious increases or spikes during AS/SVE system dormancy. This supports the assertion that the AS/SVE system can be turned off with no increase in risk to adjacent property owners.

Mass Removal

- The highest mass removal rate (0.018 pounds per day) was observed within 5 hours (0.2 days) of restart-up using vapor extraction wells. However, this rate was of short duration and dropped to approximately 0.01 pounds per day within 48 hours. It is expected that the mass removal rate would approach an asymptotic level (approximately 0.006 pounds per day) within 15 days of operation.
- The addition of air sparging wells in the restart-up period increased the mass removal rate back up to 0.015 pounds per day and likely extended higher mass removal rates for an additional 25 days of operation.
- Within 25 days of operation, mass removal rates approach an asymptotic rate of 0.006 pounds per day.
- Extrapolation of the data suggests that removal of less than 2 pounds per year of TCE and PCE is likely using the AS/SVE system. This is less than 1% of the estimated total VOCs removed with the AS/SVE system between 2002 and 2008. The data indicates the AS/SVE system has reached its limit of effectiveness after approximately 7 years of operation (Parametrix 2009b).

5.1.4.3 Proposed AS/SVE Operation Plan

Full-time operation of the AS/SVE system is not recommended. Based on the evaluation, periodic pulsing of the system may have some benefit to remove persistent contamination in soil gas and groundwater. This method provides the most cost-efficient way of operating the AS/SVE system in the interim and phasing out its operation in the long term. Recommendations include:

- Restart-up the AS/SVE system every 6 months for a period of 60 days. The AS and SVE wells would be started concurrently. All SVE wells would be operated for 60 days. Group 1 AS wells would be operated for a period of 30 days, and then Group 2 AS wells operated for a period of 30 days.
- Conduct groundwater, soil gas, and indoor air monitoring in accordance with the Multi-Media Sampling Plan to further evaluate the AS/SVE system.
- Operate the AS/SVE system on the semi-annual pulsing schedule for a period of 2 years to allow overlap of the system with the groundwater treatment interim action being implemented at SMC. Evaluation of data will be completed after the 2-year time frame, and based on results, operation could continue or be modified and another assessment period ensue or system operation be discontinued.

Ecology is currently reviewing the Draft AS/SVE Performance Evaluation Report (Parametrix 2009b), including the proposed pulsing and shutdown of the AS/SVE system.

5.2 RECIRCULATING GROUNDWATER REMEDIATION WELLS

The RGRWs were designed and installed by AMEC and are one of the remedial action measures implemented by Cadet to reduce concentrations of VOCs originating from a source area located under the Cadet building (AMEC 2003b). The RGRWs were installed in the NFVN to treat VOCs in groundwater, which are a primary source of VOCs detected in the indoor air of homes located in the NFVN. The locations of the RGRWs are shown on Figure 5-8.

In April 2006, as part of the settlement agreement with Cadet, the Port assumed responsibility for operation and maintenance of the RGRWs. Operation of the RGRWs has been significantly reduced and the RGRWs may be shut down completely after the Port's interim action (groundwater pump and treat system) has been evaluated in 2011. The following provides a summary of the RGRW interim action.

5.2.1 Design and Installation

Each of the RGRWs is constructed with an upper screen located in the shallow levels of the unconsolidated sedimentary aquifer (USA) and a deeper screen located in the intermediate levels of the USA. A typical schematic of an RGRW is shown on Figure 5-9. A review of the RGRW construction logs and historical water level information indicates that the upper screen was placed at 15 to 20 feet below the average water level in the upper USA. The screen interval was placed deep enough to lie below the water table at all times, even in periods of low water. The well construction details are included in Table 5-4.

Each RGRW includes a submersible pump at the bottom of the well and a packer located between the two well screens. In addition, the vault for each RGRW includes a 90-gallon chemical tank, a chemical feed pump, and a compressor. The compressor is used to keep the packer inflated. The RGRWs withdraw groundwater from the lower well screen, inject liquid sodium permanganate (a strong oxidant that facilitates the breakdown of VOCs into innocuous by-products), then discharge the treated water into the shallow USA through the upper well screen (see Figure 5-9).

Several safeguards were built into the RGRW system to prevent permanganate spillage or groundwater discharge into the vault. The permanganate tank includes an inner tank within a open top containment tank, both of which are constructed of high density polyethylene plastic. The inner tank includes a sonic sensor which measures the permanganate level. At a predetermined low level (in most cases it is set at a 4-inch depth), the permanganate feed pump is automatically shut down. The outer containment tank includes a float, which is used to detect the presence of water or permanganate. If the float is activated, an alarm is sounded and the system is automatically shut down. Each vault also has a detection float at the bottom. If the float is activated (in the case of a pipe rupture or similar problem which would fill the vault with water), the RGRW pump will shut down. In addition, a high water level sensor is located in the injection well. If this sensor is activated it means that water is being discharged too quickly and could fill up the well. The system will automatically shut down upon activation of the high water level sensor.

Detailed information regarding the design, installation, and operation of the RGRWs is included in the Work Plan and Specifications for a Feasibility Test of a Recirculating Groundwater Remediation Well System for the Fruit Valley Neighborhood (AMEC 2003b), Operation and Maintenance Plan for a Feasibility Test of a Recirculating Groundwater Well System for the Fruit Valley Neighborhood (AMEC 2004c), Work Plan and Specifications for Continued Feasibility Testing of a Recirculating Groundwater Remediation Well System for the Fruit Valley Neighborhood (AMEC 2004e), and Recirculating Groundwater Remediation Well Update Report (AMEC 2004f). As-built drawings and supporting information are included in Appendix F.

5.2.2 Operational History

Between February 2004 and July 2005, eight RGRWs (labeled RGRW-1A and RGRW-1 through RGRW-7) were installed by Cadet in the vicinity of the Cadet facility and the NFVN. As detailed in the April 2005 Remedial Investigation Update Report (AMEC 2005), RGRW-1 was installed in February 2004 as a pilot test well to evaluate the effectiveness of RGRW technology at the site.

A monitoring well network (MR-1 through MR-9) was installed by Cadet between November 2003 and April 2004 around RGRW-1 to monitor its performance. Based on the performance of RGRW-1, RGRW-2 through RGRW-7 were installed in several phases. A monitoring well network (MR-10 through MR-16) was installed around RGRW-2 and RGRW-3 in April and May 2004. Figure 5-8 shows the location of the RGRWs and MR-series wells. Table 5-4 provides a well completion summary for the RGRWs and associated monitoring wells.

RGRW-1, RGRW-2 and RGRW-3 were installed along NW 28th Street, and RGRW-5 and RGRW-7 were installed along NW 27th Street in the NFVN. RGRW-4 was installed on Cadet property directly east of the Cadet facility building. RGRW-6 was installed on Thompson Avenue, north of Fourth Plain Blvd. The casing on RGRW-1 filled with silt and fine sand to the water table and due to uncertainty associated with the integrity of the well casing and screens, RGRW-1 was abandoned and replaced by RGRW-1A in September 2004. RGRW-1A was installed adjacent to the former RGRW-1 location and started operating in October 2004. The locations and construction details for the RGRWs are summarized in Table 5-4. RGRW well logs are included in Appendix B. A schematic of the typical RGRW construction is shown on Figure 5-9.

The following table indicates the current status of the RGRWs.

Well ID	Current Status	O&M[1] Notes
RGRW-1	Abandoned	Abandoned in September 2004.
RGRW-1A	Off	Not operational since June 2008; water mounding triggers high-water alarm and well shutdown.
RGRW-2	Off	Operational; located in clean area; not operated since Nov. 2005.
RGRW-3	Off	Operational; located in clean area; not operated since Nov. 2005.
RGRW-4	Off	Operational, but has limited pumping rate due to aquifer characteristics; not operated since Sept. 2005.
RGRW-5	Off	Not operational since January 2008; well packer failure.
RGRW-6	Active	Functioning properly.
RGRW-7	Off	Not operational since May 2006; well packer needs replacement. Limited pumping rate due to aquifer characteristics.

[1] O&M = Operation and Maintenance.

The following provides detailed information about the current operational status for each of the RGRWs.

5.2.2.1 RGRW-1

RGRW-1 was installed in February 2004 as a pilot test well. Due to uncertainty associated with the integrity of the well casing and screens, RGRW-1 was abandoned and replaced by RGRW-1A in September 2004.

5.2.2.2 RGRW-1A

RGRW-1A was installed in September 2004 and started operating in October 2004. RGRW-1A operated through June 2008. However, during that time period, specifically in the winter months, the well had significant operational issues related to high water levels. The high water level triggers an alarm in the system, which causes the well to shut down until the water level returns to static conditions. The high water level in RGRW-1A was likely due to a combination of locally high groundwater and inefficiency of the upper well screen. In drier months with lower groundwater levels, the well turned on and off in approximately 60 to 90 minute intervals. It is suspected that manganese dioxide (a byproduct of the permanganate reaction which forms a sludge-like substance) plugged the well screen and/or geologic formation near the well. When the pump is on, the water cannot be forced through the screen fast enough, thus creating high water in the well casing and resulting in almost immediate shutdown. In late June 2008, RGRW-1A was shut down due to this ineffectiveness and potential to burn out the pump. RGRW-1A has a limited radius of influence due to its maximum pump rate of approximately 50 gpm. Ecology approved shutting down the well, but RGRW-1 has not yet been decommissioned (Ecology 2008e).

5.2.2.3 RGRW-2

RGRW-2 started operating in June 2004. RGRW-2 was shut down in November 2005 because treatment objectives in the well's zone of influence were met (creation of low or non-detect concentrations of VOCs). Currently, the well is not operational. An inspection of the well in March 2008 indicated that the regulator that controls air flow to the packer was not functional; therefore, the integrity of the packer could not be tested. Discussions with AMEC staff familiar with the well indicated that it is unlikely that the packer has maintained its integrity, as it was not constructed of stainless steel. The RGRW Operation Plan (Parametrix 2007b) indicated that this well had been effective in reducing TCE and PCE concentrations and would remain off unless rebound is observed in the vicinity of this well. Per an approval letter from Ecology, dated October 23, 2008 (Ecology 2008e), contaminant rebound analyses, if needed, will be conducted for this well after the Port's groundwater interim action is operational. The analyses will be completed on a case-by-case basis using available monitoring information. Ecology and the Port will determine if a rebound analysis is required.

5.2.2.4 RGRW-3

RGRW-3 started operating in July 2004. RGRW-3 was shut down in November 2005 because treatment objectives in the well's zone of influence were met (creation of low or non-detect concentrations of VOCs). Currently, the well is not operational. An inspection of the well in March 2008 indicated that the regulator that controls airflow to the packer is not functional and the 4-inch PVC influent and effluent pipes going into the well are cracked at the couplers; therefore, the integrity of the packer could not be tested. A conversation with AMEC staff familiar with the well indicated that it is unlikely that the packer has maintained its integrity, as it was not constructed of stainless steel. The RGRW Operation Plan (Parametrix 2007b) indicated that this well had been effective in reducing TCE and PCE concentrations and would remain off unless rebound is observed in the vicinity of this well. Per an approval letter from Ecology, dated October 23, 2008 (Ecology 2008e), contaminant rebound analyses, if needed, will be conducted for this well after the groundwater interim action is operational. The analyses will be completed on a case-by-case basis using available monitoring information. Ecology and the Port will determine if a rebound analysis is required.

5.2.2.5 RGRW-4

RGRW-4 started operating in May 2005. RGRW-4 was shut down in November 2005 because its effectiveness is limited due to restrictions of the geologic formation in the area near the upper screen. It is suspected that a lower permeability zone is located at or near the injection screen depth. Moderate groundwater injection rates have caused mounding of groundwater and numerous shutdowns due to high water detected in the RGRW casing. In addition, soil near the RGRW vault caved in on several occasions; this was attributed to high water levels. RGRW-4 is located directly adjacent to the Cadet facility, where the AS/SVE system continues to operate. The use of the two remedial systems has been considered to be redundant (Parametrix 2007b). Ecology approved shutting down the well, but RGRW-1 has not yet been decommissioned (Ecology 2008e).

5.2.2.6 RGRW-5

RGRW-5 started operating in July 2005. RGRW-5 was intermittently operational through December 2007. In January 2008, the well was shut down due to failure of the packer. Prior to that time, the well was experiencing pump failure issues related to the physical restriction of groundwater flow as a method of controlling high water in the well casing. The system was not in operation for much of the second half of 2007.

No significant rebounds in groundwater or soil gas concentrations have been noted in sampling locations associated with the area of influence of RGRW-5. The RGRW Operation Plan (Parametrix 2007b) proposed performance criteria for returning an RGRW to active status as a 25% increase in TCE concentrations in groundwater and/or a 30% increase in TCE concentrations in soil gas over the previous four-quarter average (note that this has not been approved by Ecology). The table below shows that no such increases were observed in the vicinity of RGRW-5.

Summary of Groundwater and Soil Gas Levels near RGRW-5

Sample Location	Average over 2007 Q1 to Q4	Q1 2008	Percent Increase	Trigger RGRW Evaluation
Soil Gas				
CM-SG-03-10	527	380	-27.89%	No
CM-SG-03-20	1,300	1,400	7.69%	No
CM-SG-05-10	27.7	14	-49.46%	No
CM-SG-05-20	595	280	-52.94%	No
Groundwater				
CM-MW-04s	2.57	2.28	-11.28%	No
CM-MW-20s	34.8	28.6	-17.82%	No

Note:
Units are micrograms per cubic meter (µg/m^3) for soil gas and micrograms per liter (µg/L) for groundwater.

TCE and PCE concentrations in soil gas and groundwater in the vicinity of RGRW-5 have shown overall downward or stable trends since the system was last fully operational, in June 2007. Groundwater and soil gas will continue to be monitored, and RGRW-5 will be evaluated on an ongoing basis. Per an approval letter from the Department of Ecology, dated October 23, 2008 (Ecology 2008e), contaminant rebound analyses, if needed, will be conducted for this well after the groundwater interim action is operational. The analyses will be completed on a case-by-case basis using available monitoring information. Ecology and the Port will determine if a rebound analysis is required.

5.2.2.7 RGRW-6

RGRW-6 started operating in July 2005. RGRW-6 is currently operating as intended. No significant issues with the operation of this well have been observed.

5.2.2.8 RGRW-7

RGRW-7 started operating in July 2005. RGRW-7 has not been fully operational since failure of the packer in May 2006. Prior to this date, the well operated at a below optimum 75 gpm. In August 2007, Parametrix redeveloped the well and replaced the packer in an attempt to increase the capacity of the well. Increased flow was not achieved and the replacement packer failed within one week of its installation. The well has been shut down since that time. Based on the testing completed on the well, the lack of groundwater flow, and the relatively low concentrations of HVOCs in groundwater in the vicinity of RGRW-7, it is not expected that RGRW-7 will be restarted. Ecology approved shutting down the well, but RGRW-1 has not yet been decommissioned (Ecology 2008e).

5.2.3 Permanganate Mass Loading

An evaluation of the total mass loading of permanganate to the shallow aquifer was completed and used to provide recommendations for future operation of the RGRWs. The main focus of the permanganate mass loading evaluation was to determine the optimum operating rate of permanganate usage. A detailed evaluation is included in the Final RGRW Operation Plan (Parametrix 2007b).

Permanganate is a strong oxidant that facilitates the breakdown of VOCs into innocuous byproducts. However, only chloroethenes are susceptible to the reaction, and chloroethanes are not impacted by permanganate. Therefore, the primary VOCs at the Cadet site that would be expected to be treated by permanganate are PCE, TCE, and DCE. The operational history of each RGRW and the groundwater extraction and permanganate injection rates are included in Final RGRW Operation Plan (Parametrix 2007b).

Assuming 4 grams of permanganate is required to breakdown each “mixed” gram of the constituents, approximately 10,000 kg of permanganate would be required for the estimated 2,500 kilograms of TCE, PCE, and DCE at the site. Even considering the additional VOCs present which might use up some sodium permanganate, potential soil oxidant demand, and losses associated with inefficiencies of the injection system, groundwater movement, and chemical breakdown of sodium permanganate over time, the quantity of sodium permanganate injected in the USA over the course of the 3 years of operation is estimated at approximately eight (8) times the total amount required (Parametrix 2007b).

Additional evidence of overloading permanganate into the aquifer system was observed during the January 2006 sampling event. At that time, the RGRWs had been shut down since November 2005. Parametrix accessed the RGRWs and nearby monitoring wells (primarily the “MR” wells, which have been used to evaluate the influence of RGRW-1 through RGRW-3) for the purpose of collecting samples to evaluate potential contaminant rebound. During the sampling event, a number of groundwater samples appeared tinted purple, an indication of unreacted sodium permanganate.

Based on the total amount of permanganate injected into the aquifer system, the injection rate of permanganate in each of the operating RGRWs was modified. As discussed above, only RGRW-6 is operating at this time.

5.2.4 RGRW Performance

A contaminant reduction analysis was completed to evaluate the effectiveness of the RGRWs in reducing concentrations of contaminants in various media at the Cadet site. The effects on groundwater and soil gas concentrations in the NFVN are discussed in greater detail in the Final RGRW Operation Plan (Parametrix 2007b). A summary is provided below. For the purposes of the analysis, TCE and PCE were selected as the primary indicator compounds, since they are the most prevalent constituents at the site and are widespread throughout both the Cadet and SMC areas.

5.2.4.1 Groundwater

Analytical results for groundwater samples collected from monitoring wells located in the NFVN indicate the RGRWs have been effective at reducing concentrations of VOCs in shallow groundwater. Table 5-5 shows the total percent reduction of VOC concentrations in each groundwater monitoring well from February 2004 (prior to RGRW startup) through March 2009. The magnitude of the reduction varies for each constituent (Table 5-6). Since TCE and PCE are the most prevalent compounds at the site and are the primary target of permanganate treatment, the TCE and PCE concentration trends were further evaluated. Note that not all of the wells included in Tables 5-5 and 5-6 are under direct influence of the RGRWs; however, the wells were selected to provide an overall understanding and comparison of groundwater monitoring well trends such that some conclusions can be drawn as to the impact of the RGRWs on groundwater quality.

The approximate extent of TCE and PCE in groundwater near the Cadet facility during 2002, prior to RGRW implementation, is shown on Figures 3-7 and 3-8. Figures 3-9 and 3-10 show the approximate extent of TCE and PCE in June 2006, after operation of the RGRWs for approximately 2 years. Figures 3-11 and 3-12 show the TCE and PCE isoconcentration map for the March 2009 sampling event. The data indicate that the RGRWs have been effective in significantly reducing groundwater concentrations in the NFVN, primarily along the NW 28th Street transect (the location of RGRW-1 through RGRW-3). In this area, groundwater samples collected from a number of shallow monitoring wells have contained TCE at less than 5 μg/L, indicating that a “clean zone” has been created in the center of the Cadet plume. In addition, the areal extent of TCE concentrations greater than 50 μg/L has been reduced significantly. Although shallow groundwater data are relatively limited away from the main source area, operation of the RGRWs has not significantly impacted the overall extent of the TCE plume greater than 5 μg/L; i.e. the overall contaminated shallow groundwater footprint has not changed significantly (Figures 3-7 and 3-11). The plume defined by the 50 μg/L isoconcentration contour has been significantly reduced along the east-west axis, but expanded slightly to the north and the south.

As with most remedial systems, potential rebound of contaminants may occur once the remedial system is shut down. RGRW-2, RGRW-3, and RGRW-4 have been shut down since late 2005, and RGRW-7 since mid-2006. As shown in Table 5-5, the general trend of VOCs in the groundwater monitoring wells near the RGRWs has been decreasing since startup of the RGRWs. Table 5-6 presents a summary of the PCE and TCE concentrations during the period of RGRW operation and after the RGRWs were shut down. As shown, most of the increases seen are the result of the very low starting basis (i.e. non-detect). The general trend has been decreasing.

5.2.4.2 Soil Gas

The primary purpose for installation of the RGRWs was to reduce groundwater concentrations beneath the NFVN in an effort to reduce soil gas concentrations and thus indoor air concentrations of TCE in the NFVN (AMEC 2004f).

Twelve soil gas monitoring wells (SG-01 through SG-12) were installed in the NFVN in February 2004 (Figure 3-3). These wells have been sampled since February 2004. In general, each of the soil gas wells includes three distinct monitoring depths (10 feet bgs, 15 feet bgs, and 20 feet bgs). Several of the soil gas well locations also have separate wells with screens at 30 or 40 feet bgs. Figure 3-5 provides time graphs of the soil gas data collected from NFVN wells from February 2004 through March 2009. Soil gas data tables are also included in Table 3-4.

Soil gas concentrations observed in the NFVN have steadily decreased since February 2004. In general, the decrease in TCE concentrations has been observed at all sampling depths. In addition, soil gas wells located in proximity to RGRWs show significantly more decrease in TCE concentrations than soil gas wells located in other areas. The concentrations of TCE observed in soil gas wells in the NFVN indicate the RGRW influence and the corresponding reduction of groundwater concentrations have significantly reduced soil gas concentrations.

5.2.5 Current Status/Approach for RGRWs

Based on the performance evaluation and ongoing groundwater monitoring, operation of the RGRWs was effective at reducing VOC concentrations in groundwater in the NFVN. A relatively large “clean” zone occurred in the vicinity of the RGRWs starting in 2006, indicating that a significant portion of the source material had been removed. However, as VOC concentrations are reduced, the effectiveness of the RGRWs is lessened due to the amount of groundwater needed to treat the lower concentrations. In addition, the radius of influence of the RGRWs was not designed to capture the entire dissolved-phase VOC plume. The area of influence of each well is approximately 150 to 300 feet in diameter (AMEC 2005). With the exception of RGRW-6, all of the RGRWs have experienced significant operation and maintenance difficulties and have been shut down over the past couple of years. The cost to maintain the RGRWs, given their declining efficiencies, has proven to be very high.

The Port’s groundwater pump and treatment system at the SMC site has been designed to hydraulically capture the entire VOC plume and treat contaminated groundwater. Thus, the usefulness of the RGRWs is likely reaching their limit. It is expected that once the SMC interim action pump and treat treatment system has been operating and evaluated, the only such well still operating, RGRW-6, will be shut down. Ecology has approved stopping operation of the RGRW’s (with the exception of RGRW-6). Ecology is reviewing a RGRW decommissioning plan for all RGRW wells when it is certain their operation would not be continued.

5.3 RESIDENTIAL SOIL VAPOR VACUUM SYSTEMS

As previously discussed, in 2002 Cadet initiated indoor air sampling in the NFVN. Based on the initial indoor air sample results (Table 3-12), several of the residences had elevated concentrations of TCE (i.e. significantly above the average) or other VOCs in indoor air. Based on information from Ecology, a TCE concentration of 3 $\mu g/m^3$ was used as an interim level for requiring remedial actions, based on risk calculations provided by DOH (DOH

2002). These six residences are shown on Figure 5-10. The residences with the highest detected concentrations of TCE were:

- 2809 Unander Avenue (31 μg/m^3 TCE)
- 2805 Unander Avenue (25 μg/m^3 TCE)
- 2206 West 28th Street (9.3 μg/m^3 TCE)
- 2202 West 28th Street (8.5 μg/m^3 TCE)
- 2105 West 28th Street (6 μg/m^3 TCE)
- 2103 West 28th Street (11 μg/m^3 TCE)

In addition to these residences, in samples collected at a later monitoring event from a residence located at 2113 W. 28th Street indicated elevated concentrations of TCE. An evaluation of that residence indicated that the concentrations were likely elevated due to chemical use/storage in the home. Further evaluation of this residence has been completed and is discussed in Section 5.4.

5.3.1 SVV System Design and Installation

Prior to design of the SVV system, AMEC personnel conducted initial inspections of the six residences during June 2003. Information about the configuration (building and foundation type) and condition of each residence was collected. AMEC also conducted interviews with each of the residents to collect their input regarding the installation of the SVV systems.

Between August and September 2003, Cadet installed and activated a single SVV system in each of five of the six residences. Also in August and September 2003, two systems were installed at the residence located at 2105 West 28th Street, one in the basement and one in the crawlspace. The sub-slab depressurization design included sawing through and removing that section of the concrete floor slab of each residence to install horizontal, slotted vacuum pipes. After screen installation, the concrete floor was replaced. A moderate vacuum is induced in the sub-slab, which recovers soil vapors. The vapors are vented to the atmosphere through an exhaust stack mounted to the house outside or through the roof of the residence. The crawlspace systems are similar to the sub-slab systems, except that the vacuum is induced in the crawlspace to sweep the air across the area to the blower. The scope of work for the SVV system installation is described in detail in the bid plans and specifications, as well as the Residential SVVS Installation and Start-Up Report (AMEC 2004a).

The equipment for each SVV system included a new electrical panel, an intrinsically safe blower (GAST model R2103) and soundproof enclosure, intake and discharge piping, electrical conduit and wiring, and gauges. Portions of bare foundation walls or openings in the foundation to the ground (cracks, drains, and sumps) were sealed with an industrial grade epoxy or cement/grout in three homes where SVVs were installed. As-built drawings are included in Appendix G. A schematic of the SVV system is shown on Figure 5-11.

AMEC conducted SVV system start-up tests in the six residences between August and September 2003. The general system start-up activities included the following:

- Evaluation of vacuum gauges to observe blower performance and to evaluate for leaks in piping;
- Monitoring noise levels of each SVV system with a dosimeter;
- Photoionization detector measurements to monitor potential presence of significant levels of organic vapors in the systems;

- Use of differential pressure gauges/air flow sensors in crawlspaces to evaluate for evidence of a pressure drop in the crawlspaces;
- Use of differential pressure gauges in basement influent lines to measure the vacuum in the sub-slab at the recovery screens; and
- Use of differential pressure gauges at up to three sub-slab monitoring boreholes to measure vacuum influence at various distances from the recovery screens.

Each of the start-up activities is described in more detail in the SVVS Installation and Start-Up Report (AMEC 2004a). The SVV systems were fully operational by the end of October 2003. In January 2004, Cadet upgraded each system to include system effluent filter units containing GAC. Additional upgrades have included installation of several valves, installation of observation and vapor ports, additional soundproofing, and replacement blowers.

5.3.2 System Maintenance and Monitoring

Cadet conducted routine maintenance activities on the SVV systems, including system monitoring and scheduled GAC replacement. Monitoring work consisted of visual inspections of the SVV systems and influent and effluent performance observations with field instruments. The Port has continued maintenance activities since acquiring the Cadet property on May 29, 2006, as part of a settlement agreement. The Port prepared and follows the SVV Operation and Maintenance Plan (included as an appendix to the CAMP; Parametrix 2009a).

After the systems were installed, AMEC calculated the GAC efficiency (by calculating conservative loading rates from influent concentrations) to determine the breakthrough period and, thus, a conservative frequency of change-out. The most conservative breakthrough period was determined to be 90 days for one of the basement sub-slab SVV systems. The rest of the basement sub-slab systems had projected breakthroughs from 120 to 220 days (AMEC 2005). The breakthrough periods for the crawlspaces were calculated to be several decades. To promote effective capture of VOCs by the SVV systems, Cadet conservatively scheduled the GAC vessels for all basement sub-slab systems to be changed out on a quarterly basis, and the GAC vessels for the crawlspace systems to be changed out on an annual basis. In 2008, the Port requested modification of the GAC change out schedule based on recent system influent levels (Parametrix 2008b). Ecology reviewed the memo and granted approval of the modified change out schedule from quarterly and annually to annually in a letter dated July 31, 2008 (Ecology 2008b).

Quarterly inspection and monitoring is conducted on the SVV systems; system and indoor air sampling is conducted twice a year. More detail is provided in the SVVS Evaluation letter (Parametrix 2008b), as well as in the SVV Operation and Maintenance (O&M) Plan (Parametrix 2009a).

Indoor air and system monitoring data collected from the six residences indicate that the SVV systems have been operating effectively. TCE and other VOCs have been reduced significantly in indoor air (Table 5-7). Table 5-8 shows historical results for influent and effluent system samples for each residence. Figure 5-12 shows the indoor air concentrations for TCE since operation of the SVV systems began. The analytical results indicate that all of the recent indoor air samples are near the MTCA Method B air cleanup levels. However, none of the homes have demonstrated indoor air TCE or other contaminant concentrations below cleanup levels for an extended period of time. Therefore, continued operation of the SVV systems and indoor air sampling is warranted.

5.3.2.1 Site Inspections

Since installation of the SVV systems in 2003, routine site inspections have been conducted to ensure that the SVV systems and components are operating properly. These site inspections are currently conducted on a quarterly basis (previous inspection schedule was monthly, but based on information collected, Ecology approved a reduced frequency in 2008 [Ecology 2008b]).

Quarterly monitoring activities generally consist of a visual inspection of the SVV system and performance monitoring using field instrumentation. Visual inspection of the SVV systems includes an assessment to identify any potential damage or service required by the system.

GAC is used in the SVV systems to capture VOCs in the air stream. Periodic replacement of the GAC is necessary in order to maintain efficiency of the capture and limit the potential for contaminant breakthrough and discharge directly to the atmosphere.

5.3.2.2 SVV System Monitoring

In order to monitor the effectiveness of each SVV system and to ensure that the GAC replacement schedule is adequate, influent and effluent air samples are collected from the SVV system on a semi-annual basis (typically in March and September). The system air sampling is generally conducted concurrently with the quarterly O&M event. The SOP for system monitoring is included in Appendix C. Influent and effluent analytical data are included in Table 5-8.

5.3.2.3 Indoor Air Sampling

Indoor air monitoring for each residence is conducted on a semi-annual basis (March and September) to ensure that the SVV systems are working effectively and have reduced indoor air concentrations. The indoor air sampling is generally conducted concurrently with the quarterly O&M event. The SOP for indoor air sampling is included in Appendix C. Indoor air data are shown on Figure 5-12.

5.4 2113 W. 28TH STREET

Initial indoor air sampling within the residence located at 2113 W. 28th Street was conducted in January 2004. Elevated concentrations of VOCs were detected in those samples. For example, TCE was detected at a concentration of 42 µg/m^3 in the basement and 30 µg/m^3 in the living space. These concentrations were significantly higher than the established preliminary levels requiring remedial systems. However, based on information from Ecology, a remedial system was not installed in this residence due to two factors:

1. The resident routinely stored and used oils and other chemicals containing VOCs for hobbies in the basement, which likely contributed to the high concentrations detected.
2. RGRW-2 was being installed directly in front of the residence, which was expected to reduce groundwater concentrations and thus reduce any contribution of compounds in the subsurface to indoor air.

Ecology and Parametrix are working closely with the resident to keep him apprised of the indoor air sampling results and options for evaluating VOC sources to indoor air.

5.4.1 Residence Foundation Sealing

In July 2004, AMEC installed two sub-slab vapor ports (labeled SGVP1 and SGVP2) in the eastern and western portion of the basement at 2113 W. 28th Street. The purpose of the sub-slab ports was to measure soil gas directly beneath the basement foundation in order to provide additional information on possible vapor intrusion and to measure the effects of RGRW-2.

As shown in Table 5-9, after RGRW-2 had been installed and operated, the concentrations of TCE in indoor air continually dropped through April 2005 (4.6 $\mu g/m^3$ in living space). However, because the concentrations were still above the 3 $\mu g/m^3$ threshold established by Ecology, Cadet and the resident elected to seal the basement to limit or prevent any vapor intrusion from the subsurface.

In May 2005, the basement at 2113 W. 28th Street was sealed. Based on information from representatives of AMEC and Ecology, the basement was sealed using a commercial grade epoxy, which was applied to the entire basement floor, as well as around the base of support columns and a sump, and on the wall up to just below the ceiling level. The sub-slab sampling ports were resealed in October 2006.

5.4.2 2113 W. 28th Street Residence Monitoring

Indoor air monitoring was continued for this residence to measure the effect of the basement sealing. In addition, sub-slab vapor ports were sampled to measure soil gas concentrations directly beneath the basement foundation. Table 5-9 shows the indoor air samples and sub-slab soil gas data for the 2113 W. 28th residence.

In May 2005, immediately after the basement had been sealed, indoor air samples were collected. These samples indicated a TCE concentration of 0.97 $\mu g/m^3$ and 1.1 $\mu g/m^3$ in the basement and living space, respectively. Following sealing of the basement, the TCE concentrations increased until June 2006, when TCE was detected at concentrations of 21 $\mu g/m^3$ and 13 $\mu g/m^3$ in the basement and living space, respectively.

Based on this information, Parametrix conducted a follow-up sampling event in September 2006. TCE was detected at concentrations of 95 $\mu g/m^3$ and 20 $\mu g/m^3$ in the basement and living space, respectively. This represented the highest concentrations detected in this residence or in any residence in the NFVN or SFVN. Because soil gas levels beneath the residence were relatively low compared to previous sampling events (Table 5-9), Parametrix requested that a site inspection be completed to ensure that chemicals in the basement were not the cause of the elevated levels (Parametrix 2009a).

On October 18, 2006, Parametrix and Ecology completed a site inspection. Numerous small bottles and cans of oils, cleaners, and other products were identified in the basement. Three containers—two aerosol cans and one small (1-quart) paint-can type—were identified which contained TCE as a main ingredient. According to the property owner, none of the three containers had been removed during the basement sealing (they were located on a covered shelf) and had not been used in years. All three of the containers were immediately removed from the basement.

Indoor air sampling was conducted immediately after the site inspection. As shown in Table 5-9, the TCE concentrations decreased to 4.6 $\mu g/m^3$ and 4.4 $\mu g/m^3$ in the basement and living space, respectively. Another round of sampling was conducted in November 2006, which indicated TCE at a concentration of 1.5 $\mu g/m^3$ in the basement and living space samples. Additional sampling in February and September 2007 indicated TCE in the basement and living space samples at maximum concentrations of 2.5 $\mu g/m^3$ and 2.1 $\mu g/m^3$, respectively.

Based on these results, it is assumed that the high concentrations of VOCs detected at this residence were related, at least in part, to chemical products stored in the basement. The heating system is located in the basement and draws air which is distributed to the living space upstairs. Changes in air temperature or pressure in the basement could have released small doses of TCE (specifically from the paint-can type container, which was not permanently sealed), affecting the indoor air results. While some contribution of VOCs is likely from the subsurface, the anomaly observed in the TCE results suggests that the chemicals stored in the basement are the primary contributors. It should be noted that numerous other oils, chemicals, and cleaners in small containers are still present in the basement. The chemical makeup of the contents in the remaining containers could not be determined from the labels.

5.4.3 Air Filter Installation

In December 2007, the resident at 2113 W. 28th Street inquired about the possibility of the Port installing an indoor air filter system in his residence. In January 2008, the Port agreed to the installation of the air filter based on the following conditions:

- Data for indoor air indicates that the concentrations of VOCs are below the December 2007 Health Consultation levels of concern for immediate action (further information on the EPA-derived health levels can be found in the Health Consultation [DOH 2007]. However, indoor air concentrations exceed MTCA cleanup levels. The house appears to be an anomaly for the area.
- It is apparent that there is or has been some contribution to VOCs in indoor air from in-home sources, likely from the basement (many unlabelled materials). However, soil gas samples from sub-slab ports in the basement do indicate that vapor intrusion is also possible.
- Purchase and installation of the indoor air filter was done strictly as a preventative measure and at the resident's request. The Port has maintained a proactive approach in responding to resident's concerns.
- A long-term monitoring plan for indoor air in the NFVN would be developed (included in the Final CAMP), and this home would be included in the plan. The installation of the filter should allow the Port to reduce the frequency of sampling and mitigate any concerns from the resident. It may also provide information as to the effectiveness of this type of simple indoor air filter system.

The indoor air filter system used in this residence is the HealthMate Plus, manufactured by Austin Air Systems. The system has a rated capacity of treatment for approximately 1,500 square feet. The home at 2113 W. 28th Street has a living area footage of approximately 750 square feet, with an additional 500 square feet of basement space.

The unit has three separate filters: a pre-filter for dust, a high efficiency particulate air (HEPA) filter for particulate removal, and a carbon/zeolite unit for removal of VOCs and other chemicals. The Port purchased the system and installed it in the home on February 29, 2008. The system is portable and can be moved from room to room, if needed. There are also four speed settings for air movement. The speed and frequency at which the air filter is operated is at the discretion of the resident.

No additional indoor air data have been collected from this residence since installation of the filter system. However, this residence is included in the long-term monitoring plan.

6. GROUNDWATER MODELING

Groundwater modeling has been conducted to evaluate the hydrogeologic conditions at the Cadet site and the migration of dissolved-phase VOCs in groundwater. Cadet completed a preliminary model, primarily focusing on data collected in the vicinity of the Cadet site. On behalf of the Port, Parametrix completed a more robust model for the entire project area, including the Cadet, SMC, and NuStar sites (note that the model report was co-authored by representatives of the Port and Clark Public Utilities). A summary of the groundwater modeling is described in the following sections.

6.1 CADET MODELING EFFORTS

Cadet employed a numerical computer model to evaluate groundwater flow and contaminant fate-and-transport and the influence on the extent of HVOCs in the project area. The modeling goals were to estimate groundwater flow patterns, demonstrate potential HVOC migration pathways, and estimate the possible time of arrival and concentration of HVOCs at potential receptors (human and/or ecological). Modeling results were to be used as a preliminary interpretive tool—to evaluate whether historical groundwater pumping in the model area has had an effect on the migration of HVOCs from the site over a 36-year period, through September 2002—and as a tool in the selection and implementation of a groundwater treatment technology for the site.

Groundwater flow was simulated using the Visual MODFLOW software package (Waterloo Hydrogeologic, Inc., Waterloo, Ontario) and MT3DMS, a three-dimensional transport module for multiple chemical species. The resulting model simulated groundwater flow and contaminant transport and solved for total head and contaminant concentrations in aquifers based on known or calculated input parameters. These parameters included boundary conditions, hydraulic conductivity, and aquifer stresses. The model produced maps containing visual representations of simulated water levels, groundwater flow patterns, and distribution of contaminant concentrations. Illustrative figures and a more detailed description of the modeling methodology, input parameters, and simulation diagrams are presented in Appendix J of the RI Report (AMEC 2003a).

Under non-pumping, pre-development conditions, modeling results indicated that the groundwater flow direction was generally to the southwest toward the Columbia River, as would be expected. However, under pumping conditions, simulated particle tracking in the Cadet model indicated the existence of a localized groundwater flow pattern that originates east of the Cadet facility and flows easterly to southerly toward the GWM site (consistent with the Port model described below).

Cadet used the groundwater transport model to estimate contaminant concentrations and the time for elevated concentrations of chlorinated solvents to reach a potential receptor. Cadet interpreted the predicted chlorinated solvent migration results to indicate that GWM was the primary potential receptor at the time (also consistent with the Parametrix model). Cadet used the model results to support their position that while dissolved phase chlorinated solvents reached GWM, they did not do so in significant concentrations.

Parametrix evaluated this model and concluded that a more robust model was necessary. Therefore, further evaluation of the Cadet model is not included here.

6.2 PORT OF VANCOUVER MODEL

The complete groundwater model for the SMC and Cadet project areas consists of a *groundwater flow model* and a *contaminant transport model*. The initial three-dimensional groundwater flow model was constructed as part of the development of the SMC RI, but included the Cadet project area as well as the NuStar site. Output from this flow model was 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 2002) and were more recently described in the Groundwater Model Summary Report (Parametrix 2004). An updated version of the model is presented in the Vancouver Lake Lowlands Groundwater Model Summary Report, which was co-authored by the Port and CPU (Parametrix et al. 2008).

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 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 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 4.2). 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	
	SMC Site	**Cadet 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 and Cadet sites 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 NuStar source areas.

The model has been modified and refined several times since its original presentation in the 2002 SMC RI Report. There have been two major modification events since that initial presentation, as well as two modification events after the publication of the Groundwater Model Summary Report. 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 were discussed in the Groundwater Model Summary Report (Parametrix 2004). In addition to the major modification events, changes resulting from comments made by AMEC and from the results of the transducer study performed from October through December 2006 were used to refine the model. These modifications are included in the Vancouver Lake Lowlands Groundwater Model Summary Report (Parametrix et al. 2008) and are discussed below.

6.2.1 CPU Comment Modifications

Following submittal of the 2002 SMC 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 SMC 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 refinements and updates completed by the Port in response to CPU's comments. The summary also includes a description of the impact of these changes on model calibration and prediction.

- The Port's original model extended from the confluence of the Willamette and Columbia Rivers to upstream of Hayden Island. The Port's model domain was expanded to match 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 of or results from the Port's model.
- To evaluate the significance of a potential gradient from the Columbia River to Vancouver 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 provided by CPU 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 of or results from the Port's 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 provided by CPU 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 of or results from the Port's model.
- Pumping wells at Vanalco, Boise Cascade, and City of Vancouver Water Station 4 were added in the Port's model update. Result – No significant change in the calibration of or results from the Port's model.
- The drawdown from a pumping well located at the Westside Wastewater Reclamation Facility (WWRF) was addressed through model refinement completed after the 2002 SMC 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 and Cadet site areas, 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 NuStar site source areas was further refined using site-specific data and recently obtained off-site, depth-specific data.

6.2.2 Historical Model Simulation Results

Modifications to the model were also made in order to simulate historical groundwater flow conditions during the period when known source area releases occurred.

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, when wells 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 (COV) began keeping records 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 NuStar) 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 NuStar 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 NuStar 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 NuStar 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 commingled 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 6-1, 6-2, and 6-3 show the model runs for 1967 through 2003 using the model changes discussed in the following sections.

6.2.3 Cadet Comment Modifications

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

- Improved delineation of source areas
- Updated concentrations in source areas
- Soil/water partitioning coefficient in the silty recent alluvium and the sandy recent alluvium

6.2.3.1 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. The NuStar source area has been determined to be primarily in the vicinity of the historical direct load area near the northwest corner of Warehouse 13 (Ash Creek 2008a). The SMC source area is the best defined area 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 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 number of interpolation points used to define the soil area was also used to define the groundwater source area. This yielded 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 6-4, 6-5, and 6-6.

A comparison of the soil and groundwater source area footprints indicates that the SMC site shows the strongest correlation between soil and groundwater source areas, while the NuStar 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.

6.2.3.2 Concentrations 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 NuStar site contains a mix of PCE and TCE. To account for PCE at the Cadet and NuStar 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 were 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 NuStar 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 NuStar 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 NuStar 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.

6.2.3.3 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 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 4.2.2). 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.

6.2.4 Additional Model Changes

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

- Re-interpretation of the location 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 4.3).

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 were used to recalibrate model parameters using a combination of steady-state and transient calibrations.

As discussed in Section 4.3, the transducer study was designed to produce water level data distributed over 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 in October 2006 when the river stage was relatively stable and 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 the river stage restabilized in early December 2006.

The results of the transducer study were 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 February 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.

7. STABLE ISOTOPE EVALUATION

A stable isotope evaluation was completed as part of the SMC Final RI report (Parametrix 2009c). However, the evaluation included data from the Cadet and NuStar sites and was used to assess separate source areas and to refine and confirm the assumptions in the groundwater flow model (Section 6). Therefore, much of the stable isotope discussion from the SMC RI Report is included here, but with an emphasis on the specific data collected for Cadet and conclusions related to the Cadet site.

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 SMC and Cadet RIs are summarized in Tables 7-1 through 7-3. As detailed in the following sections, the stable isotope analytical results support the conclusion that three distinct sources of contaminants (Cadet, SMC, and NuStar sites) are present in the project area.

7.1 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 NuStar sites is also isotopically distinguishable because the ranges of PCE carbon isotope ratios from these sites do not overlap.

Samples of chlorinated VOCs were collected for CSIA 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 volumes for CSIA (typically three 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-

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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.

IRMS) at the Center for Isotope Geochemistry, Lawrence Berkeley National Laboratory (Port of Vancouver), 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 7-1 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.

In 2004 and 2005, additional samples were collected for CSIA from SMC, Cadet, and NuStar wells by both Cadet and the Port (Philp 2005; Vlassopoulos 2005). The data are summarized in Table 7-1. 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), inter-laboratory 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 NuStar 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 7-1). The CSIA data for PCE, on the other hand, distinguish the NuStar and Cadet sources. The $\delta^{13}C$ of PCE from the NuStar source areas ranges 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 7-2). 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 7-3).

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 NuStar. 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 NuStar.

7.2 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 NuStar 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 NuStar 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 7-2 and 7-3. 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. Stable isotope data used for Figure 7-4 are included in Table 7-2. As shown on Figure 7-4, 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). This is because most of the Columbia River water flowing past the Port originates from precipitation occurring further inland. Figure 7-5 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 7-4 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 7-6 shows the distribution of $\delta^{18}O$ in shallow wells across the project area. Stable isotope data used for Figure 7-6 are included in Table 7-2. Most of the shallow groundwater at the NuStar 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 7-7. It is evident from the plot that intermediate depth groundwater beneath NuStar 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 7-7 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 7-8). Stable isotope data used for Figure 7-8 are included in Table 7-2. 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 4-3). 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, CM-MW-1d, CM-MW-5d, and CM-MW-18d. These wells are all screened in the deep zone of the USA (Table 4-3). 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.

8. 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 Cadet site
- Geologic and hydrogeologic understanding of the project area
- Interim action findings completed for the Cadet site
- Data collected during RI and interim actions completed for the SMC and NuStar sites
- Groundwater flow and transport models

Soil, groundwater, soil gas, and indoor and outdoor air at the site and the project area have been identified as containing VOCs. This section describes the occurrence and distribution of the VOCs, specifically those identified in a risk assessment as chemicals of potential concern (COPCs) in soil, groundwater, and indoor and outdoor air. A total of 76 soil samples, 2,879 groundwater samples, 452 soil gas samples, 716 indoor air samples, and 131 outdoor air samples have been collected in connection with Cadet site investigations.

8.1 DATA VERIFICATION

Analytical data collected during the Cadet RI are summarized in Tables 3-1 through 3-13. Laboratory data reports and data quality assurance review (QA/QC) information for all samples collected during the Cadet RI are included in Appendix A. Data verification was performed with reference to U.S. EPA guidelines and the Resource Conservation and Recovery Act (RCRA) Corrective Action Program Data Review Guidance Manual.

The data collected during the RI are sufficient to define the nature and extent of contamination at the Cadet 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.

8.2 SOIL

The following sections describe the on- and off-site occurrences of VOCs in soil. Summarized soil analytical data are presented in Table 3-1. A total of 76 soil samples were collected from a total of 53 borings at depths ranging from 3.0 to 20 feet bgs across the project area and analyzed for VOCs.

8.2.1 Cadet Site

A total of 68 soil samples were collected from 44 borings within the Cadet property. The VOCs identified in at least one soil sample were TCE, PCE, 1,1,1-TCA, cis-1,2-DCE, methylene chloride, chloroform, and bromomethane. On the basis of the results of the risk assessment presented in Section 9, the COPCs for soil are PCE, TCE, 1,1,1-TCA, cis-1,2-DCE, and methylene chloride. PCE and TCE are the dominant constituents detected in soil, with very minor contributions of the other COPCs.

The highest concentrations of PCE and TCE were detected in soil samples collected beneath the Cadet building. The highest concentration of PCE in soil (1.7 mg/kg) was found at 13 feet bgs in boring CM-C-5 and at 17 feet bgs in CM-C-12, both near the former dip tank. The highest concentration of TCE in soil (14 mg/kg) was detected at 13 feet bgs in boring CM-C-6, near the former waterfall structures. Based on the data collected, soil contamination was not widespread across the site. Soil contamination was concentrated around the former building structures (paint room, dip tank, and waterfalls) that utilized PCE or TCE and extended east along the sewer line (Figure 1-3). VOCs in groundwater are the result of spills or releases within the Cadet building and in the subsurface along the sewer line breakage.

All of the elevated concentrations of VOCs in soil were detected in June 2000 and are within the radius of influence of the AS/SVE system installed in 2002 and 2003. Based on the operation of the AS/SVE system for approximately 7 years and mass removal rates calculated from operational data, it is expected that current concentrations of VOCs in soil beneath and near the Cadet building are limited or non-existent. However, no current soil data have been collected to confirm this assumption.

8.2.2 NFVN

A total of 11 soil samples were collected from nine borings (CM-FV-05 through CM-FV-13) within the NFVN (Table 3-1 and Figure 3-2), primarily along the existing sewer line adjacent to Cadet. Very low concentrations of limited constituents were detected in the borings completed in the NFVN. Based on the soil investigations conducted, the residual soil concentrations of VOCs in the NFVN are limited or non-existent. This suggests that source material was not spilled or released from the surface in the eastern portion of the Cadet site or the NFVN.

8.3 SOIL GAS

Evaluation of the distribution of soil gas is based on soil gas sampling from probe borings during initial phases of the RI and from soil gas monitoring wells. TCE, PCE 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 VOCs in soil gas would be present at higher concentrations closer to the groundwater and at lower concentrations as one 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.

8.3.1 Cadet Site

Six soil gas samples were collected on the Cadet site, at 4 feet bgs in borings CM-C-08 through CM-C-13 (Table 3-2 and Figure 3-3). These samples were collected inside the Cadet building, in the vicinity of the paint department where the highest levels of VOCs in soil were found.

PCE concentrations detected in soil gas under the Cadet building ranged from 46,000 $\mu g/m^3$ in boring CM-C-10 to 710,000 $\mu g/m^3$ in boring CM-C-9. TCE concentrations in soil gas ranged from 220,000 $\mu g/m^3$ in boring CM-C-8 to 1,800,000 $\mu g/m^3$ in boring CM-C-13. These concentrations are two to three orders of magnitude higher than any concentrations detected in the NFVN. The high concentrations support the conclusion that source material was released in the Cadet building near the paint room, dip tank, and/or waterfall structures.

8.3.2 NFVN

Table 3-4 shows the soil gas data collected in the NFVN. Figure 3-5 presents the distribution of TCE in soil gas samples collected from the soil gas wells located primarily in the NFVN. Also included on Figure 3-5 are TCE data for a recent groundwater sampling event. In general, the lateral distribution of soil gas is correlated with the lateral distribution of the groundwater plume; that is, areas with 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 were detected in samples collected in 2004 from soil gas wells CM-SG-4, CM-SG-5 and CM-SG-8 (maximum concentrations of 33,000 μg/m^3, 49,000 μg/m^3 and 38,000 μg/m^3, respectively), all located above the main part of the underlying groundwater plume. All of these maximum concentrations were detected in the 20-foot depth sample port. The most recent analytical results from these soil gas wells indicate TCE concentrations of 1,100 μg/m^3, 280 μg/m^3, and 470 μg/m^3, respectively. The significant declines in the spatial distribution of soil gas concentrations are attributed to the source area reduction of groundwater contaminants beneath the Cadet facility as a result of the operation of the AS/SVE system, the installation and operation of recirculating groundwater remediation wells RGRW-1 through RGRW-7, and natural attenuation and degradation.

The presence of VOCs in soil gas is not evaluated in the risk assessment in Section 9 because exposure to soil gas is not a complete exposure pathway. However, VOCs in soil gas are the primary contributors to indoor air concentrations. Exposure to indoor air was evaluated in the risk assessment, summarized in Section 9.

8.4 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 Cadet site. However, the Cadet plume has commingled with the SMC-sourced and NuStar-sourced plumes 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 SMC and NuStar sites to provide a complete understanding of the distribution of groundwater contamination in the project area.

8.4.1.1 Migration of TCE

Based on groundwater data and groundwater flow and transport models, the extent of contamination in the project area is in relative equilibrium. The configuration of the contaminant plume is not changing (that is the horizontal extent or aereal footprint of the plume) and the concentrations of contaminants are decreasing over time (see Figures 3-7 through 3-24). 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. This equilibrium supports the conclusion that the plume is contained.

As described in the Section 6, dissolved TCE from the Cadet 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 Cadet and SMC sites does not reach the Columbia River. Groundwater TCE isoconcentrations in the project area from the 2009 first quarter sampling event are shown on Figures 3-11, 3-15, and 3-19. These figures also show the distribution of TCE contamination from the Cadet and SMC sites.

The Port's groundwater pump and treatment system at the SMC site was started in June 2009 and operates at an extraction rate of approximately 2,500 gallons per minute. It is expected that GWM will reduce groundwater production in their wells; however, GWM pumping rates could increase or decrease based on specific facility needs. These actions (i.e. changes at GWM and installation of the Port's system) are expected to change the groundwater flow in the project area, resulting in the development of a hydraulic capture zone centered at the SMC site. However, the first large-scale groundwater monitoring event occurred in September 2009 and data to confirm the groundwater flow change is not yet available at the time of this report.

The following sections provide further information regarding the migration and distribution of TCE in the project area.

Contaminants in the USA

The distribution of contaminants in the USA is influenced by hydrogeologic conditions in the project area (Section 4). 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 4.2.2, three groundwater zones in the USA have been defined to describe and evaluate 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. However, in this part of the project area, the deep USA zone is generally less than 15 feet thick (Figure 8-4).

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. A document titled TGA and Deep USA White Paper, SMC and Cadet Sites (Parametrix 2008c) discussing both geologic and hydrogeologic conditions as they relate to TCE contamination in the deep USA and TGA was prepared at the request of Ecology to support the conclusions in the SMC Final RI Report; this white paper is included as Appendix N.

Shallow and Intermediate USA Zones

The distribution of TCE in the shallow and intermediate USA zones is shown on Figures 3-11 and 3-15, respectively. The shallow zone of the USA corresponds to the alluvial deposits, while the intermediate zone corresponds to the catastrophic flood deposits. Figure 4-2 shows the orientations for cross sections X-X', and Y-Y', and Z-Z'; these cross-sections are shown on Figures 4-3, 4-4, and 4-5, respectively.

Dissolved TCE plumes originating from the Cadet, SMC, and NuStar sites have migrated to the GWM production wells. TCE released into groundwater at the Cadet and SMC 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 NuStar site has migrated to the north and northeast and eventually to the southeast in response to these same pumping stresses (note that this refers primarily to the intermediate zone contamination at Nustar; a shallow groundwater divide was identified at NuStar where some shallow groundwater flows towards the south to the Columbia River). 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 Cadet 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 4.2.2.1), there is some difference in the distribution of contaminants between the two zones. This difference is due in part to the higher rate of groundwater movement in the intermediate USA zone as compared to 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 and the withdrawal of groundwater from the intermediate zone at GWM. These conditions and the proximity of the shallow USA zone to the source areas have resulted 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 8-2 and 8-3, the TCE plume sourced from the Cadet site has migrated into the shallow USA zone, while at the same time it has been drawn down into the more transmissive intermediate USA zone due to pumping at the GWM wellfield. The resulting plume from the Cadet site extends to the southeast and commingles with the relatively long and narrow SMC plume in the shallow zone. The Cadet plume also extends to the north and northeast into the NFVN in the shallow zone. A few hundred feet east of the Cadet source area, there is a "bend" in the plume, which is more defined in the intermediate zone, where it turns to the south and commingles with the SMC site plume. The plume from the Cadet site also extends to the north-northwest into the NFVN in the intermediate zone. 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.

Deep USA Zone

The deep USA zone is thickest in the Troutdale Formation erosional trough located beneath the Cadet and SMC sites (Figure 4-7 and 8-4). Deep USA zone monitoring wells in the project area and the distribution of TCE in this zone are shown on Figure 3-19. 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, and 1,1-DCA, and traces of trichlorofluoromethane (TCFM). VOC contamination in the deep USA zone is limited to the erosional trough area (Figure 4-7).

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 the NuStar site and the former Fort Vancouver Plywood site, and to the area east of Northwest Packing. However, 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 3-19, the deep USA zone underlying the Cadet and SMC site source areas has slightly higher TCE concentrations (maximum Cadet well concentration of 33 µg/L; maximum SMC well concentration of 44 µg/L). TCE concentrations in deep Cadet and SMC USA wells are shown on Figure 3-19.

Samples from the deep USA zone wells (CM-MW-01d-194, CM-MW-01d-224, CM-MW-02d, CM-MW-03d-227, CM-MW-05d, CM-MW-18d, and CM-MW-19d) also contain low concentrations of trichlorofluoromethane (Table 3-9). 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 NuStar facility. The source of the relatively low concentration trichlorofluoromethane distribution in the USA deep groundwater zone is not known.

Contaminants in the TGA

As described in Section 4.2 and shown on Figure 4-7, 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. The locations of monitoring wells screened in the TGA are shown on Figures 3-23 and 3-24. With a couple of exceptions, VOCs are not detected in wells screened in the TGA. The only Cadet monitoring well screened in the TGA where TCE (and 1,1,1-TCA, 1,1-DCA, 1,1-DCE, cis-1,2-DCE, PCE, and toluene) was detected is TGA well CM-MW-29TGA, with TCE concentrations ranging from 13.6 µg/L to 20 µg/L.

As described in the SMC RI Report (Parametrix 2009c), 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.

Additional information on the distribution of TCE in the TGA can be found in the TGA and Deep USA White Paper, SMC and Cadet Sites (Parametrix 2008c), included as Appendix N.

8.4.1.2 Commingling of Plumes

The commingling of the SMC and Cadet plumes are supported by multiple lines of evidence, including the geologic and hydrogeologic conditions at the site (see Section 4), historic pumping scenarios and groundwater modeling (Section 6), isotope analysis (Section 7), and the collection of groundwater data at both the SMC and Cadet sites (Section 3).

The two plumes originating separately from the Cadet and SMC site source areas have migrated to the east and south (i.e., downgradient) 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. 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. In addition, solvent-related contaminants tend to dive vertically in a groundwater environment. The extent of downward migration is limited by the less permeable Troutdale Formation and the depth of the GWM well screens. The Cadet and SMC plumes merge (commingle) on Port property near Kotobuki Way, and can be characterized as a single plume to the east and south of the Cadet site source area (Figures 3-11 and 3-15).

Evidence for the commingling of the Cadet and SMC plumes is provided by data from the quarterly groundwater monitoring events. For example, SMC site well MW-8, located 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 are the result of the Cadet-sourced plume "bending" south in this area and migrating to the south of Fourth Plain Boulevard (Figures 3-11 and 3-15).

8.4.1.3 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 intervals 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 (Figure 4-8). The understanding that groundwater flow in the TGA is also influenced by the GWM wellfield is based primarily on groundwater flow analysis results (Section 4.3). 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., at a relatively great distance from the wells).

As described above, the Port's groundwater pump and treatment system at the SMC site was started in June 2009 and operates at an extraction rate of approximately 2,500 gallons per minute. In addition, it is expected that GWM will alter groundwater production in their wells after June 2009. These actions are expected to change the groundwater flow in the project area, resulting in the development of a hydraulic capture zone centered at the SMC site. However, data to confirm the groundwater flow change are not yet available at the time of this report.

8.4.2 Groundwater Quality Trends

An examination of time series plots that show TCE and PCE trends during quarterly groundwater sampling was completed from 2004 through the first quarter of 2009. The following observations are based on the examination of the time series plots for TCE and PCE included in Appendix O:

- TCE concentrations in a majority of the shallow USA zone monitoring wells have been decreasing. There are notable decreases in TCE concentrations in most of the shallow zone wells located at or downgradient of the Cadet source area. Cadet wells with the greatest historical concentrations of TCE and PCE continue to trend downward to low concentrations, <5 µg/L in some cases. Shallow Cadet wells that had moderately elevated TCE concentrations (e.g., CM-MW-06s, CM-MW-07s, and CM-MW-08s) have decreased to slightly above 5 µg/L or to below the method reporting limit. Shallow wells with low TCE concentrations (<10 µg/L) generally show stable or declining trends. The AS/SVE system initiated in October 2003 and RGRW systems initiated in 2004 and 2005 have improved groundwater quality in the shallow USA zone downgradient from the Cadet source area.
- Overall, an increasing TCE concentration trend is calculated for shallow USA zone monitoring well CM-MW-26s. The time series plot indicates that this trend is subtle and represents a small concentration change.
- TCE concentrations are decreasing or show no discernable trend in all but five of the intermediate USA zone Cadet 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 groundwater source treatment actions (operation of the AS/SVE and RGRW systems) completed at the Cadet site.

- Increasing TCE concentration trends are identified at intermediate USA zone wells CM-MW-04i, CM-MW-18i, CM-MW-20i, CM-MW-28USA-120.5, and CM-MW-29USA-140.5. In general, the trends for these five wells have been steadily increasing since 2005. The reasons for the slight increasing trend is not clear, but may be related to operation and shutdown of nearby RGRWs and/or influence from well fields to the north (CPU, City of Vancouver). However, the increases do not appear to be significant.
- TCE concentration trends at the 12 deep USA zone Cadet wells vary. Most of the trends are variable, except for those at two of the wells. A slight increasing concentration trend is identified at well CM-MW-28USA-180. A slow declining TCE trend is observed at CM-MW-07d, which declined to below the method reporting limit in 2006.

Figures 3-7, 3-9, and 3-11 show the extent of the commingled Cadet and SMC plume in the shallow USA zone in First Quarter 2002, Third Quarter 2006, and First Quarter 2009. 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 Cadet and SMC sites.

8.5 INDOOR AIR

Indoor air sampling has been conducted at the site and the NFVN to evaluate whether VOCs in groundwater have impacted overlying structures. While some indoor air evaluation was conducted within the Cadet building, the primary focus of the indoor air investigations was on residential structures in the NFVN. Indoor air sampling was also conducted for the SMC site (SFVN), and all indoor air sampling for the Cadet and SMC sites was evaluated in the Final Comprehensive Vapor Intrusion and Indoor Air Evaluation Plan (CAMP) (Parametrix 2009d). A long-term indoor air sampling plan was proposed in the CAMP, and approved by Ecology in July 2009 (Ecology 2009). The following describes the distribution of VOCs in indoor air at the Cadet site and in the NFVN.

8.5.1 Cadet Building

A total of 14 indoor air samples were obtained during three sampling events completed within the Cadet building. Initially, two indoor air samples were collected in August 2000. Follow-up air sampling was performed in December 2000.

VOCs were detected in all of the indoor air samples, with TCE detected most frequently and at the highest concentrations. The highest concentrations of TCE and PCE were 110 $\mu g/m^3$ and 35 $\mu g/m^3$, respectively, in a sample collected in the paint department. Follow-up air sampling in this area showed decreased TCE levels.

Indoor air sampling has not been conducted within the Cadet building since 2005, partially due to the fact that Cadet continued to use small amounts of TCE in their operations until approximately 2006. Operation of the AS/SVE system beneath the Cadet building significantly reduced subsurface concentrations of VOCs which could contribute to vapor intrusion.

8.5.2 NFVN

Significant investigation has been conducted in the NFVN to evaluate the impacts of indoor air contamination. Between 2002 and March 2009, a total of 702 indoor air samples (living space, crawlspace, or basement) were collected from 121 homes in the NFVN. Intensive indoor air sampling was conducted along West 27th and West 28th Streets, directly east of the Cadet facility and the approximate axis of the TCE plume, which extends from Cadet to the east and south (Figure 3-26). The results of these investigations suggest that there is some contribution of contaminated vapors from the subsurface into the indoor air of overlying structures.

Based on the risk assessment summarized in Section 9, COPCs for indoor air include TCE, PCE, 1,1,1-TCA, 1,1-DCA, 1,1-DCE, 1,2-DCA, cis-1,2-DCE, chloroethane, trans-1,1-DCE, and vinyl chloride. However, concentrations of only TCE, PCE, and 1,2-DCA have been detected in one or more homes above the MTCA ambient air cleanup level.

As discussed in Section 3.4, there are observable differences in concentrations between living spaces and crawlspaces. This could be the result of: 1) use of chemicals in the home, or 2) venting of the crawlspace to the atmosphere. The contribution of chemicals from home use has not been quantified. However, the data do support the assertion that in-home activities (i.e., use of chemicals, dry cleaning, glues, etc.) have, at least in part, some effect on indoor air quality.

The data also appear to support the assertion that homes with basements are more susceptible to vapor intrusion than homes with crawlspaces. The 95% UCL for all indoor air samples collected from the basement is significantly higher than for crawlspace samples, and is moderately higher than for living space samples.

The concentrations of TCE and PCE in indoor air appear to have steadily declined since 2002. This is likely due to the interim actions implemented at the Cadet site (AS/SVE system, RGRWs) to reduce groundwater concentrations. The reduction of groundwater concentrations beneath the neighborhood limits the availability of VOCs to migrate into indoor air.

Based on the indoor air sampling conducted to date, residents in the NFVN do not have any short-term or immediate health risk related to vapor intrusion. A 2007 Department of Health Consultation (DOH 2007) confirmed this assertion, stating that “solvents found in indoor air in the Fruit Valley Neighborhood are not expected to make people sick (i.e., no apparent health hazard)”.

8.6 DISTRIBUTION OF CONTAMINATION IN OUTDOOR AIR

As part of the RI activities, outdoor air sampling was completed in several areas around Cadet and the NFVN. The results of the investigation indicate that outdoor air contains detectable concentrations of VOCs. The distribution and magnitude of VOCs in outdoor air have been variable. The results of ambient air sampling were used to evaluate background concentrations and their potential impact on indoor air quality. The evaluation is presented in the Final CAMP (Parametrix 2009d). Outdoor air results were also used to evaluate potential risk to workers and NFVN residents (see Section 9).

9. RISK ASSESSMENT SUMMARY

A risk assessment (RA) was conducted as part of the RI to evaluate the potential risk associated with the Cadet site; it is included as Appendix P. 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 Cadet site were examined by evaluating soil, soil gas, groundwater, and indoor and outdoor air data collected within the project area. An exposure assessment, toxicity assessment, and risk characterization were completed for all of the identified potential exposure pathways. A brief summary of the RA is included in the following discussions.

At the request of Ecology and DOH, the Port also prepared a Final Comprehensive Vapor Intrusion and Indoor Air Evaluation Plan (CAMP) (Parametrix 2009d), which includes a discussion of the indoor air data collected at the site and provides recommendations for management of the indoor air issues. 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.

9.1 EXPOSURE ASSESSMENT

An exposure assessment is conducted to estimate the magnitude, frequency, duration and route of exposure of a receptor to a contaminant source. Information about waste sources, exposure pathways, and receptors at the Cadet site were used to develop a conceptual understanding of the Cadet site in order 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 P).

Receptors are defined as persons who may come into contact with site chemicals. Receptors in this analysis are individuals who work or live within the project area. “Workers” include individuals who work regularly at the Cadet facility or other non-Port owned property downgradient of the Cadet site. Temporary workers were also evaluated, such as excavation workers on the Cadet property. Residents include people who live east of the Cadet site in the NFVN, where groundwater containing VOCs has migrated. The SFVN residents were not evaluated in this risk assessment because this RI Report is for the Cadet site only and SFVN residents were included in the risk assessment completed for the SMC RI Report (Parametrix 2009c).

9.2 TOXICITY ASSESSMENT

The toxicity assessment was conducted to evaluate which potential adverse health effects are associated with specific COPCs, 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 P).

9.3 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 from potable use of groundwater were examined. 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 a $1x10^{-5}$ ELCR for multiple chemicals.

9.4 RA CONCLUSIONS

The goals of the RA were to identify potential risks to on-site workers, excavation/construction workers, and off-site residents from chemicals found in soil, soil gas, groundwater, and indoor and outdoor 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 a Cadet site worker, an Cadet site excavation worker, and an NFVN resident. While previous and ongoing remedial actions have significantly reduced groundwater concentrations, current concentrations are still at a level that suggests potentially elevated risks to human health for all receptors and exposure pathways evaluated. The results indicate continued 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 a groundwater pump and treatment system in place at the SMC site; this system has been operational since June 2009.

2. **Soil:** The potential risk associated with soil was evaluated for a Cadet site worker and a Cadet site 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.

3. **Indoor Air:** The potential risk associated with indoor air was evaluated for Cadet site workers and NFVN residents. Current concentrations of VOCs at all NFVN residences indicate elevated cancer risks (i.e., above $1x10^{-6}$) from chronic exposure to indoor air (ELCRs ranging from $7.2x10^{-7}$ to $2.7x10^{-4}$). However, background air conditions should be considered when evaluating the indoor air results. The presence of TCE in background concentrations in outdoor air (which are similar to national levels and could be sourced from the groundwater plume, local facility emissions, and/or other sources) suggests that the residents in the NFVN are not at significantly greater risk 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 Cadet site workers suggests that VOC contaminants in indoor air (Cadet building) pose an elevated risk if workers are chronically exposed (maximum ELCR $5.4x10^{-5}$).

4. **Outdoor Air:** The risk from outdoor air was evaluated for a Cadet site worker and an NFVN 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. 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 Cadet site. The Cadet site includes a confined area with exposed soil contamination and minimal adjacent areas of undeveloped land; this suggests 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 Cadet 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.

10. CONCLUSIONS

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

1. TCE and/or other solvents have been used at the Cadet site as degreasers from prior to the 1970s until sometime in the 1990s (note that de minimis amounts of TCE were used in spray bottles until approximately 2006; no TCE is currently used at the site). Several areas of the facility including the vapor degreaser, TCE dip tank, and/or paint room are likely areas of past spills or releases. In the early 1990s and mid-1990s, breaks were identified in a sanitary sewer line at the site, which received wastewater from the parts cleaning equipment. The specific date of the first break is unknown, but it was discovered and repaired in the early 1990s. In the mid-1990s a second break in the sanitary sewer line at approximately the same location as the first break was discovered during construction of a 20,000 square foot addition to the original building. Contaminated wastewater was believed to have been released to the subsurface through the pipeline breaks. These areas, as well as those directly beneath the solvent use areas of the Cadet building, are considered the primary source areas for TCE contamination in soil and groundwater.
2. The concentrations of VOCs in soil have been defined and are limited to the site, primarily beneath the former TCE use areas and near the sewer line. Impacts to soil are expected to have been largely mitigated through the installation and operation of an AS/SVE system beneath the Cadet building. The current concentrations of VOCs in soil are not known. However, the results of the risk assessment indicate that VOCs in soil (using the highest concentrations detected) do not pose a significant risk to site workers or nearby residents.
3. VOCs have been detected in soil gas samples collected at the site and within the NFVN. Based on current data, the soil gas concentrations have decreased significantly since 2002. The reduction appears to be associated with the operation of the AS/SVE and RGRW interim actions, which have reduced groundwater concentrations across the project area.
4. VOCs have been detected in indoor air in some homes in the NFVN. The indoor air investigations included the collection of samples from the living space, crawlspace, and/or basement from 121 homes. The results of these investigations suggest that there is some contribution of contaminated vapors from the subsurface into the indoor air of overlying structures. TCE, PCE, and 1,2-DCA have been detected in indoor air above MTCA cleanup levels, but appear to have steadily declined since 2002. This is likely due to the interim actions implemented at the Cadet site (AS/SVE system, RGRWs), which reduced groundwater concentrations and source material available for vapor intrusion.
5. The extent of VOC groundwater contamination originating from the Cadet site has been defined to the method reporting limit of 0.5 µg/l and is stable. Primary VOCs that have been detected above the MTCA Method B groundwater cleanup levels include, but are not limited to, PCE, TCE, and chloroform. The horizontal extent of contaminated groundwater includes commingling with the SMC plume to the south towards GWM. 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.

6. 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.
7. In addition to contamination originating from the Cadet site, the SMC and NuStar 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 NuStar) is geochemically distinct.
8. Plumes of VOC-contaminated groundwater originating from the Cadet, SMC and NuStar sites are commingled in the project area. The commingled plume has been historically captured by the pumping wells located at GWM. The GWM pumping wells effectively captured the commingled plume and prevented the contamination from the SMC and Cadet sites from reaching the Columbia River. The Port's recently installed groundwater pump and treatment system at the SMC site has been designed to hydraulically capture the entire VOC commingled plume and treat contaminated groundwater. The treatment system began operation in June 2009 at an approximate rate of 2,500 gpm. It is expected that the groundwater flow regime in the project area will change, resulting in a capture zone centered at the SMC site. Data confirming the new groundwater flow regime are not yet available.
9. An air sparging and soil vapor vacuum system was designed, installed, and operated as part of an interim action to reduce VOC concentrations in soil and groundwater beneath the Cadet building. The AS/SVE system has significantly reduced residual soil and groundwater concentrations near the Cadet building. Approximately 500 pounds of VOCs have been removed from the subsurface by the AS/SVE system. However, after seven years of operation, the AS/SVE system has reached its effective limit and currently achieves only limited mass removal. The Port has proposed to Ecology that the AS/SVE system be operated on a six-month pulsing cycle (60 days each) for two years and then re-evaluated for shut down or continued operation.
10. Eight recirculating groundwater remediation wells (RGRWs-1A, and 1 through 7) were designed, installed, and operated as part of an interim action to reduce VOCs in groundwater at the Cadet site and in the NFVN. The RGRWs have significantly reduced concentrations in groundwater in the NFVN. With the exception of RGRW-6, all of the RGRWs have experienced significant operation and maintenance difficulties and have been shut down over the past couple of years. The cost to maintain the RGRWs, given their declining efficiencies, has proven to be very high. The Port's groundwater pump and treatment system at the SMC site has been designed to hydraulically capture the entire VOC plume and treat contaminated groundwater. Thus, the usefulness of the RGRWs is reaching their limit. It is expected that once the SMC treatment system has been operating and fully evaluated, the only remaining operating RGRW (RGRW-6) will be shut down. Ecology has approved shutting down all of the RGRWs, with the exception of RGRW-6. Ecology reviewed the Decommissioning Plan and provided approval for decommissioning RGRWs-1, 1A, 2, 4, and 7. It is expected that RGRW- 3, 5, and 6 will also be decommissioned.
11. Soil vacuum vapor systems were designed, installed, and operated in six homes in the NFVN as part of an interim action to reduce elevated VOC concentrations in indoor air. Operation of the SVV systems has reduced indoor air concentrations in those homes to

levels nearing the MTCA indoor air cleanup levels. The SVV systems will continue to be operated until indoor air concentrations are below the MTCA cleanup levels or as otherwise approved by Ecology.

12. The risk assessment indicates that the concentrations of VOCs in the plume of contaminated groundwater originating from the Cadet 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 indoor air sourced contribution of VOCs is unknown. A 2007 Department of Health Consultation (DOH 2007) indicated that "solvents found in indoor air in the Fruit Valley Neighborhood are not expected to make people sick (i.e., no apparent health hazard)." The residual soil contamination at the Cadet 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 the environment, which should be evaluated in an FS.

13. The RI is complete. The nature and extent of contamination has been defined. As part of the RI, a total of 76 soil samples, 2,879 groundwater samples, 452 soil gas samples, 716 indoor air samples, and 131 outdoor air samples have been collected in connection with Cadet site investigations. Sufficient information has been collected to prepare an FS for the Cadet site.

11. RECOMMENDATIONS

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

1. Pumping at the Port's groundwater pump and treatment system at SMC should be continued to maintain capture of the SMC and Cadet TCE plumes.
2. After evaluating the effectiveness of the Port's groundwater pump and treatment system at SMC, an FS should be prepared to evaluate alternatives for further reducing the concentrations of VOCs in groundwater impacted by the Cadet site. One FS will be prepared for both the Cadet and SMC sites to fully evaluate alternatives that address both sites.
3. Groundwater and limited 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.
4. Recommendations included in the Final CAMP should be implemented to monitor indoor air.

12. REFERENCES

AGRA (AGRA Earth & Environmental, Inc.). 1999. Phase II Environmental Site Assessment. March 31, 1999.

______ 2000a. Preliminary Subsurface Characterization Report. January 11, 2000.

______ 2000b. Interim Action Source Investigation Work Plan: Cadet Manufacturing Site, 2500 W. Fourth Plain Boulevard, Vancouver, Washington. March 28, 2000.

AMEC (AMEC Earth & Environmental, Inc.). 2000. Interim Action Source Investigation Report. October 2, 2000.

______ 2001a. Interim Action Source Remediation Work Plan and Source Investigation Update. April 6, 2001.

______ 2001b. Semi-Annual Groundwater Monitoring Report 2001. November 13, 2001.

______ 2002a. Fruit Valley Neighborhood Indoor Air Evaluation Work Plan. Prepared for Cadet Manufacturing. January 2002.

______ 2002b. Fruit Valley Neighborhood Indoor Air Sampling Report. Prepared for Cadet Manufacturing. April 2002.

______ 2002c. Fruit Valley Neighborhood Follow-up Indoor Air Sampling Report. Prepared for Cadet Manufacturing. December 2002.

______ 2002d. Soil Vapor Extraction System Installation and Start-Up Report: Cadet Manufacturing Company, 2500 West Fourth Plain Boulevard, Vancouver, Washington. July 23, 2002.

______ 2002e. Remedial Investigation Work Plan: Cadet Manufacturing Company, 2500 West Fourth Plain Boulevard, Vancouver, Washington. April 10, 2002.

______ 2003a. Draft Remedial Investigation Report. Prepared for Cadet Manufacturing Company. February 2003.

______ 2003b. Work Plan and Specifications for a Feasibility Test of a Recirculating Groundwater Remediation Well System for the Fruit Valley Neighborhood, Cadet Manufacturing Company. August 2003.

______ 2003c. Fruit Valley Neighborhood September 2003 and January 2004 Indoor Air Evaluation Work Plan. Prepared for Cadet Manufacturing Company. September 2003.

______ 2003d. Air Sparing and Soil Vapor Extraction Remediation System Design Report, Cadet Manufacturing Company, 2500 West Fourth Plain Boulevard, Vancouver Washington. Prepared by AMEC Earth and Environmental, Portland, Oregon. October 2005.

______ 2004a. Residential Soil Vapor Vacuum Installation and Start-up Report. Prepared for Cadet Manufacturing Company.

______ 2004b. Groundwater Modeling Summary Report. Prepared for Cadet Manufacturing Company, Vancouver, Washington. February 2004.

______ 2004c. Operation and Maintenance Plan for a Feasibility Test of a Recirculating Groundwater Remediation Well System for the Fruit Valley Neighborhood, Cadet Manufacturing Company. March 2004.

______ 2004d. AS/SVE Remediation System Installation and Startup Report, Cadet Manufacturing Company, 2500 West Fourth Plain Boulevard, Vancouver Washington. Prepared by AMEC Earth and Environmental, Portland, Oregon. April 2004.

______ 2004e. Work Plan and Specifications for Continued Feasibility Testing of a Recirculating Groundwater Remediation Well Systems for the Fruit Valley Neighborhood, Cadet Manufacturing Company. April 2004.

______ 2004f. Recirculating Groundwater Remediation Well Update Report, Cadet Manufacturing Company. June 16, 2004.

______ 2005. Remedial Investigation Report Update Report, Cadet Manufacturing Company. Prepared for Cadet Manufacturing Company, Vancouver, Washington. August 2005.

Ash Creek (Ash Creek Associates). 2006a. Site Investigation Data Summary Report, Support Terminal Services Vancouver Facility, Vancouver Washington. Prepared for Support Terminal Services by Ash Creek Associates, Inc. October 18, 2006.

______ 2006b. Interim Action Analysis Support Terminal Services Vancouver Facility Vancouver Washington. Prepared for Support Terminal Services by Ash Creek Associates. November 28, 2006.

______ 2008a. Groundwater Investigation Results Report. Prepared for Support Terminal Services by Ash Creek Associates. January 7, 2008.

______ 2008b. Remedial Investigation Report, NuStar Terminals Services, Inc., Vancouver Main Terminal, Vancouver, Washington. September 5, 2008.

DOH (Washington Department of Health). 2002. Health Consultation. Cadet Manufacturing, Vancouver, Clark County, Washington. January 29, 2002.

______ 2003a. Technical Document Review, Draft Remedial Investigation Report, Cadet Manufacturing Company Site. June 16, 2003.

______ 2003b. Health Consultation. Indoor Air Quality Evaluation, Cadet Manufacturing Company Site. May 6, 2003.

______ 2006. Health Consultation. Technical Document Review, Remedial Investigation Update Report, Cadet Manufacturing. May 5, 2006.

______ 2007. Health Consultation. Fruit Valley Neighborhood, Residential Indoor Air Test Results, Cadet Manufacturing and Former Swan Manufacturing Sites, Vancouver, Clark County, Washington. December 4, 2007.

Ecology (Washington Department of Ecology). 2007. Model Toxics Control Act Cleanup Regulation Chapter 173-340 WAC. Prepared by the Washington State Department of Ecology, Toxics Cleanup Program. Revised November 2007.

______ 2007. Ecology Comments on the Port of Vancouver's Draft Comprehensive Vapor Intrusion Evaluation and Indoor Air Monitoring Plan. April 6, 2007.

______ 2008a. Ecology Comments on June 19, 2008 Proposed Cleanup Levels for Indoor Air, Technical Memorandum. August 18, 2008.

______ 2008b. Ecology Comments on the July 10, 2008 Technical Memorandum – Evaluation of SVV Systems in Residences in the North Fruit Valley Neighborhood. July 31, 2008.

______ 2008c. Ecology Comments on the June 19, 2008, Proposed Cleanup Levels for Indoor Air, Technical Memorandum. August 18, 2008.

______ 2008d. Comments on the August 8, 2008 Technical Memorandum No. 4, Air Sparging/Vapor Extraction Well (AS/SVE) System Rebound Test Results. Prepared by Ecology. September 26, 2008.

______ 2008e. Ecology's Approval of Recirculating Groundwater Remediation Wells Operations. October 23, 2008.

______ 2009. Written Approval of Indoor Air Sampling Program Proposed in the January 21, 2009 Revised Draft CAMP. July 27, 2009.

EPA (US Environmental Protection Agency. 1992. Estimating Potential for Occurrence of DNAPL at Superfund Sites. R.S. Kerr Environmental Research Laboratory, Office of Solid Waste and Emergency Response, U.S. Environmental Protection Agency, Publication 9355.4-07FS. January 1992.

______ 1993. DNAPL Site Evaluation. Office of Research and Development, United States Environmental Protection Agency, EPA/600/R-93/022. February 1993.

Hinkle, S.R. et al. 2001. Linking hyporheic flow and nitrogen cycling near the Willamette River – a large river in Oregon, USA. Journal of Hydrology, 244:157-180.

McCarthy, K.A., McFarland, W.D., Wilkinson, J.M., and White, L.D. 1992. The dynamic relationship between ground water and the Columbia River: using deuterium and oxygen-18 as tracers. Journal of Hydrology, 135:1-12.

McDonald, M.G. and Harbaugh, A.W. 1988. A Modular Three-Dimensional Finite-Difference Groundwater Flow Model. US Geological Survey of Techniques of Water Resources Investigations. Book 6.

McFarland and Morgan. 1996. Description of Ground-Water Flow System in the Portland Basin, Oregon and Washington. U.S. Geological Survey Water-Supply Paper 2470-A. William D. McFarland and David S. Morgan. 1996.

Mundorff, M.J. 1964. Geology and Ground-Water Conditions of Clark County, Washington, with a description of a major alluvial aquifer along the Columbia River. U. S. Geological Survey Paper 1600, Washington D. C. 1964.

PGG (Pacific Groundwater Group). 2002a. Evaluation of Clark Public Utilities Proposed South Lake Wellfield. Prepared for Clark Public Utilities by Pacific Groundwater Group. October 2002.

______ 2002b. Comments on Remedial Investigation Report for Swan Manufacturing Company Site. November 2002.

Parametrix. 1999. Off-Site Investigation, Cadet Manufacturing Co. Site. Letter prepared for Schwabe, Williamson, and Wyatt, Portland, Oregon. January 11, 1999.

______ 2002. Remedial Investigation Report, Former Building 2220 Site (a.k.a. Swan Manufacturing Company site). Prepared for the Port of Vancouver. August 2002.

______ 2004. Groundwater Model Summary Report, Former Building 2220 Site (a.k.a. Swan Manufacturing Co. Site), prepared for the Port of Vancouver by Parametrix, Inc., December 2004.

______ 2005. Other Potential Sources Report, Former Building 2220 Site, prepared for the Port of Vancouver by Parametrix, Inc., May 2005.

______ 2007a. Draft Comprehensive Vapor Intrusion Evaluation and Indoor Air Monitoring Plan (CAMP). Prepared for the Port of Vancouver SMC and Cadet Sites. January 12, 2007.

______ 2007b. RGRW Operations Plan, Cadet Facility. Prepared for the Port of Vancouver by Parametrix, Portland, Oregon. February 9, 2007.

______ 2007c. Air Sparging/Shallow Vapor Extraction Performance Evaluation Plan, Cadet Facility. Prepared for the Port of Vancouver by Parametrix. November 20, 2007.

______ 2008a. Technical Memorandum: Outdoor Air Data and Wind Direction Information. April 4, 2008.

______ 2008b. Evaluation of SVV Systems in Residences in the North Fruit Valley Neighborhood. July 10, 2008.

______ 2008c. TGA and Deep USA White Paper – SMC and Cadet Site Area. Prepared for the Port of Vancouver. December 10, 2008.

______ 2009a. Revised Draft Comprehensive Vapor Intrusion Evaluation and Indoor Air Monitoring Plan (CAMP). Prepared for the Port of Vancouver SMC and Cadet Sites. January 2009.

______ 2009b. Draft AS/SVE Performance Evaluation Report, Cadet Manufacturing Company Site. Prepared for the Port of Vancouver. March 2009.

______ 2009c. Final RI Report, Former Building 2220 Site (Swan Manufacturing Company Site). Prepared for the Port of Vancouver. May 7, 2009.

______ 2009d. Final Comprehensive Vapor Intrusion Evaluation and Indoor Air Monitoring Plan (CAMP). Prepared for the Port of Vancouver SMC and Cadet Sites. December 2009.

Parametrix, et al. 2008. Vancouver Lake Lowlands Groundwater Model Summary Report. Prepared by Parametrix, S.S. Padapodpulos and Associates, Pacific Groundwater Group, and Keta Waters, Inc. Prepared for the Port of Vancouver and Clark Public Utilities. February 15, 2008.

Philp, R.P. 2005. Expert Report of Prof. R. Paul Philp, Port of Vancouver v. Cadet Manufacturing Company. June 2005.

Serfes, M.E. 1991. Determining the Mean Hydraulic Gradient of Ground Water Affected by Tidal Fluctuations. Groundwater. Vol. 29, No. 4. Pages 549-555. July 1991.

Slater. 2003. Stable Isotope Forensics – When Isotopes Work. Environmental Forensics, 4:13-23.

S.S.P.A. (Papadopulos and Associates, Inc.). 1999. MT3D99: A Modular Three-Dimensional Transport Model for Simulations of Advection, Dispersion, and Chemical Reactions of Contaminants in Groundwater Systems. S.S. Papadopulos and Associates, Inc. Bethesda, MD.

Swanson, R.D., McFarland, W.D., Conthier, J.B., and Wilkinson, J.M. 1993. A Description of Hydrogeologic Units in the Portland Basin, Oregon and Washington. U. S. Geological Survey Water Resources Investigation Report 90-4196. Portland, Oregon.

Vlassopoulos, D. 2005. Expert Report of Dimitrios Vlassopoulos, Port of Vancouver v. Cadet Manufacturing Company. May 2005.

Wiedemeier, T.H., M.A. Swanson, D.E. Moutoux, E.K. Gordon, J.T. Wilson, B.H. Wilson, D.H. Kampbell, P.E. Haas, R.N. Miller, J.E. Hansen, and F.H. Chapelle. 1998. *Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Groundwater,* U.S. Environmental Protection Agency, Report No. EPA/600/R-98/128, Washington, D.C. September 1998.