Final Draft Report

Site Characterization Report
Groundwater and Sediment Remediation

Occidental Chemical Corporation
Tacoma, Washington

Prepared by:
Conestoga-Rovers
& Associates

285 Delaware Avenue
Suite 500
Buffalo, New York
14202

Office: (716) 856-2142
Fax: (716) 856-2160
web: http:\\www.CRAworld.com

SEPTEMBER 2015
REF. NO. 007843 (128)

Table of Contents

Table of Contents

Table of Contents

Page

Table of Contents

Table of Contents

Table of Contents

List of Figures
(Following Text)

List of Figures
(Following Text)

List of Figures
(Following Text)

List of Figures
(Following Text)

List of Figures
(Following Text)

List of Figures
(Following Text)

List of Figures
(Following Text)

List of Figures
(Following Text)

List of Figures
(Following Text)

List of Tables
(Following Text)

List of Tables
(Following Text)

List of Tables
(Following Text)

List of Appendices
(On USB Drive)

Appendix A	Historical Aerial Photographs
Appendix B	Summary of Information Regarding Occidental Site Chemistry Resulting from Past Shipyard Activities
Appendix C	Sample Collection and Analysis Tables
Appendix D	Bathymetric Plots
Appendix E	Regional Stratigraphic Logs
Appendix F	Site Stratigraphic Logs
Appendix G	Analytical Database e:Dat™
Appendix H	MVS/EVS Detailed and Simplified 3-D Stratigraphic Models
Appendix I	Simplified Stratigraphic Model Approach
Appendix J	Naturally Occurring Fresh Groundwater/Salt Water Distribution Evaluation
Appendix K	Groundwater Density Distribution
Appendix L	Evaluation of Site-Wide Hydraulic Data
Appendix M	Evaluation of 709-721 Alexander Avenue Hydraulic Data
Appendix N	Single-Well Response Tests Technical Memorandum
Appendix O	3-D Chemistry Visualization Models
Appendix P	List of Data Validation Reports
Appendix Q	Dioxin, Furan, and PCB Congener Data
Appendix R	Vapor Investigation Report
Appendix S	DNAPL Assessment
Appendix T	Weston Cross-Sections Drawings
Appendix U	Natural Attenuation Evaluation
Appendix V	Exposure Pathway Assessment Report
Appendix W	University of Washington Report on Site-Specific Partition Coefficients of Heavy Metals

List of Acronyms

ABS_d	absorption factor - dermal
ABS_o	absorption factor – oral
ABW	average body weight
ACGIH	American Conference of Governmental Industrial Hygienists
ADP	anthropogenic density plume
AET	apparent effects thresholds
AF	adherence factor
AFs	absolute absorption fraction of lead in soil
Ah	Aryl hydrocarbon
AOC	Administrative Order on Consent
ARARs	Applicable or Relevant and Appropriate Requirements
ARF	Army Reserve Facility
ASTM	American Society for Testing and Materials
ATc	average time – carcinogenic
ATnc	average time – non-carcinogenic
atm m3/mol	atmospheres cubic meters per mole
AVS	acid volatile sulfide
BEF	bioaccumulation equivalence factors
BERA	Baseline ERA
BKSF	biokinetic slope factor
BTEX	benzene, toluene, ethybenzene, and xylenes
bgs	below ground surface
BML	below mud line
Bluffs	Puget Sound Bluffs
BOD	biochemical oxygen demand
BTEX	benzene, toluene, ethyl benzene, and xylenes
BZ	benzene
CA	chloroethane
CAP	Corrective Action Plan
CAMP	Corrective Action Monitoring Plan
CAS No.	Chemical Abstracts Service number
CB/NT	Commencement Bay/Nearshore Tideflats
CDF	confined disposal facility
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CF	conversion factor
cis-1,2-DCE	cis-1,2-dichloroethene
CLARC	Cleanup Levels and Risk Calculation
CLP	Contract Laboratory Program
CMA	Coastal Monitoring Associates
CMT	continuous multi-channel
cm/s	centimeters per second
cm^3	cubic centimeters
cm^2	square centimeters

List of Acronyms

Co-SQG	co-occurrence sediment quality guidelines
COCs	constituents of concerns
COD	chemical oxygen demand
COPECs	constituents of potential ecological concern
CRA	Conestoga-Rovers & Associates
CSF	cancer slope factor
CSI	Comprehensive Supplemental Investigation
CSM	Conceptual Site Model
CT	carbon tetrachloride
CVOCs	chlorinated volatile organic compounds
cy	cubic yards
DA_{event}	dermal absorbed per event
1,2-DCA	1,2-dichloroethane
1,4-DCB	1,4-dichlorobenzene
1,1-DCE	1,1-dichloroethene
DCM	dichloromethane
4,4'-DDD or DDD	4,4'-dichlorodiphenyl dichloroethane
4,4'-DDE or DDE	4,4'-dichlorodiphenyl dichloroethylene
4,4'-DDT or DDT	4,4'-dichlorodiphenyl trichloroethane
°C	degrees Celsius
DEHP	bis(2-ethylhexyl)phthalate
DRO	diesel range organics
DNAPL	dense non-aqueous phase liquid
DO	dissolved oxygen
DOC	dissolved organic carbon
EB	ethylbenzene
Ecology or WDEC	Washington State Department of Ecology
ED	exposure duration
EEC	estimated exposure concentration
EEPA	ecological exposure pathway assessment
EF	exposure frequency (Exposure Pathway Assessment)
EF	exceedance factor
EF_{max}	maximum EF
ENVs	environmental heads
ESVs	ecological screening values or ecotoxicity screening values
ERAs	Ecological Risk Assessments
EV	event frequency
EVS/MVS	Environmental Visualization System/Mining Visualization System
EWPT	extraction well pilot test
FCVs	Final Chronic Values
FEHs	freshwater equivalent heads
FeSO4	ferrous sulfate

List of Acronyms

ft	feet
ft/d	feet per day
FT	fraction time exposed
foc	fraction of organic carbon content
g/cm^3	grams per cubic centimeter
GRO	gasoline range organics
GRS	global remote sensing
GSD	geometric standard deviation
GSH	Glenn Springs Holdings
HCB	hexachlorobenzene
HCBD	hexachlorobutadiene
HCC	Hylebos Cleanup Committee
HHEPA	human health exposure pathway assessment
Hooker	Hooker Chemical Corporation
IA	indoor air
IR	ingestion rate
IRIS	USEPA Integrated Risk Information System
J&E Model	Johnson & Ettinger Model
Kg/L	kilograms per litre
Kd	soil-water partitioning coefficient
Koc	soil organic carbon-water partitioning coefficient
Kow	octanol/water partition coefficient
lbs/ft^3	pounds per cubic feet
LC50	Lethal concentration at which 50 percent of the sample population dies
LOAEL	lowest-observed adverse effect level
M-3	Heavy Industrial district
Manke	Manke Lumber Yard area
MLEs	maximum likelihood estimates
mg/(kg-day)	milligram carcinogen per kilogram body weight per day
µg/dL	micrograms per deciliter
µg/L	micrograms per Litre
µg/kg	micrograms per milligrams
µg/m^3	micrograms per cubic meter
mg/kg	milligrams per kilogram
mg/L	milligrams per litre
mg/m^3	milligrams per cubic meter
mL/g	milliliters per gram
MLEs	maximum likelihood estimates
MLLW	mean lower low water
MPC	Maximum Permissible Concentration
MS/MSD	matrix spike and matrix spike duplicate
MTCA	Model Toxics Control Act
MWAC	Middle Waterway Action Committee

List of Acronyms

ng/kg	nanograms per kilogram
NaCl	sodium chloride
NAPLCALC	NAPL Calculator
NCD	nearshore confined disposal
NCP	National Contingency Plan
NGA	Northwest Geophysical Association, Inc.
NGVD	National Geodetic Vertical Datum
NOAA	National Oceanic and Atmospheric Administration
NOAA's ER-L	NOAA's sediment quality guidelines, effects range-low
NOAA's ER-M	NOAA's sediment quality guidelines, effects range-medium
NOAEL	No-Observed Adverse Effect Level
NOEC	No Observable Effect Concentration
NSAT	DNAPL saturation
OA	outdoor air
OCC	Occidental Chemical Corporation
OERR	Office of Emergency and Remedial Response
OELs	occupational exposure levels
ORP	oxidation-reduction potential
OSHA	U.S. Occupational Safety and Health Administration
OSWER	USEPA Office of Solid Waste and Emergency Response
PAHs	polyaromatic hydrocarbons
PbB	target blood lead
PbB_{95}	95th percentile target blood lead
$PbB_{adult,0}$	baseline blood lead concentration
PCA	tetrachloroethane
PCBs	polychlorinated biphenyls
PCDD	dioxins
PCDF	furans
PCE	tetrachloroethene (perchloroethylene)
PCPH or PCP	pentachlorophenol
PDT	Pacific Daylight Time
PEF	Particulate Emission Factor
PELs	permissible exposure limits
Permit	Joint Permit for the Storage of Dangerous Waste
PMI	Port Maritime Industrial
POT	Port of Tacoma
Properties	605 and 709 Alexander Avenue
ppm	parts per million
PQLs	practical quantitation limits
PRD	pre-remedial design
PRI	PRI Northwest, Inc.
PSDDA	Puget Sound Dredged Disposal Analysis
QAPP	Quality Assurance Project Plan

List of Acronyms

$R_{fetal/maternal}$	Mean ratio of fetal to maternal PbB
RAGS	USEPA Risk Assessment Guidance for Superfund
RBCs	risk-based concentrations
RBSs	risk-based standards
RCRA	Resource Conservation and Recovery Act
RD/RA	Remedial Design and Remedial Action
Redox	oxidation and reduction
RFA	RCRA Facility Assessment
RfC	reference concentration
RfD	reference dose
RFI-I	RCRA Facility Investigation I
RI	Remedial Investigation
RME	Reasonable Maximum Exposure
ROD	Record of Decision
RSL	Regional Screening Level
S-10	Port Industrial Shoreline district
SA	surface area exposed
SAP	sampling and analysis plan
SCR	Site Characterization Report
SEM	simultaneously extractable metals
SIR	soil ingestion rate
SLERA	Screening Level Ecological Risk Assessment
SMMP	Seepage Meter Monitoring Program
SMS	sediment management standard
SOW	Statement of Work
SQ	screening quotient
SQG	sediment quality guidelines
SQOs	sediment quality objectives
SQS	sediment quality standard
SPLP	Synthetic Precipitation Leaching Procedure
SS	sub-slab
su	standard units of pH
SVOCs	semi-volatile organic compounds
2,3,7,8-TCDD or TCDD	2,3,7,8-tetrachlorodibenzo-p-dioxin
TCE	trichloroethene
TCM	trichloromethane
TCVOCs	total chlorinated volatile organic compounds
1,1,2-TCA	1,1,2-trichloroethane
TDS	total dissolved solids
TEFs	Toxicity Equivalency Factors
TEQ	Toxicity Equivalents
TLV	Threshold Limit Value
1,2,4-TMB	1,2,4-trimethylbenzene

List of Acronyms

TEQ	Toxic Equivalency
TOC	total organic carbon
TPH	total petroleum hydrocarbon
TR	Target Cancer Risk
THQ	Target Hazard Quotient
HI	Hazard Index
trans-1,2-DCE	trans-1,2-dichloroethene
TRW	Technical Review Workgroup for Lead
TSS	total suspended solids
TWA	time-weighted average
UAOs	Unilateral Administrative Orders
UCL	Upper Confidence Level
URF	unit risk factor
USEPA or EPA	United States Environmental Protection Agency
USCS	Unified Soil Classification System
U.S. Navy	United States Navy
UW	University of Washington
VC	vinyl chloride
VDEQ	Virginia Department of Environmental Quality
VF	Volatization Factor
VFWAMB	groundwater to ambient air volatilization factor
VI	vapor Intrusion
VOCs	volatile organic compounds
WAC	Washington Administrative Code
WIR	water ingestion rate
WMUs	waste management units
Waterway	Hylebos Waterway
WHO	World Health Organization
WISHA	Washington Industrial Safety and Health Act
WQC	Washington State's water quality criterion
yr	year

Section 1.0 Introduction

Occidental Chemical Corporation (OCC) has been working with the Washington State Department of Ecology (Ecology) and the United States Environmental Protection Agency (USEPA) (together referred to as the "Agencies") to address remaining environmental issues at the "Occidental" Site associated in part with the former OCC facility located in Tacoma, Washington (Site) under an Administrative Order on Consent (AOC) (EPA, 2005a). The work activities required under the AOC are outlined in the "Statement of Work for the Administrative Order on Consent" (SOW) (CRA, 2005). OCC has completed field investigations required under all Tasks of the SOW. Results from these investigations are presented in this Site Characterization Report (SCR), as required under Task A6 of the SOW.

This SCR presents the Site characterization based upon the analytical and hydraulic data collected from various groundwater, soil, sediment, and vapor investigations performed at the Site. The presented data includes both "new" data collected during the most recent investigations (May 2005 through March 2014) and relevant "historical" data collected during previous investigations (1993 through 2004).

The data presented in this SCR was used to develop a conceptual Site Model (CSM), which was presented under separate cover (CRA, April 2014) and is summarized in Section 5.6 of this SCR. The CSM will form the basis for the development of a three-dimensional groundwater flow and contaminant transport model that will be used in the evaluation of remedial alternatives.

1.1 Purpose and Scope of Report

The purpose of this Site characterization is to evaluate the data collected from all investigations at the Site and to adequately characterize the contamination of soil, sediment, and groundwater underlying the Site; assess the exposure pathways; to allow development and evaluation of remedial design alternatives to address relevant exposure pathways. The scope of work for the Site characterization activities was based upon the following objectives:

i) Determine the three-dimensional extent of volatile organic compounds (VOC) and pH contamination in groundwater onshore and beneath the Hylebos Waterway (Waterway)
ii) Determine the depth of hydraulic capture required to prevent contaminated groundwater from discharging into the Waterway
iii) Determine the three-dimensional extent of source material onshore and beneath the Waterway

iv) Quantify the hydrogeological parameters that will allow the flux of potential contaminants into the Waterway to be determined, and provide data needed to refine the conceptual hydrogeological model for the Site

1.2 Site Description

The Site is located on the eastern-most[1] peninsula of the area of ownership and operations of the Port of Tacoma (POT) that extends into Commencement Bay at the mouth of the Puyallup River Valley. The Site is defined in the AOC[2]. A general location map showing the Site, including the formerly OCC-owned properties and that portion of Segment 5 of the Waterway contained within the Site, is presented on Figure 1.1.

A plan showing local property ownership is presented on Figure 1.2. The properties formerly owned and/or operated on by OCC or its predecessors include:

- 605 Alexander Avenue (former OCC Facility currently owned by Mariana Properties, Inc. [Mariana])
- 709 Alexander Avenue (currently owned by Mariana)

The properties are referred to as the 'Former OCC Facility (605) and Mariana Properties (709)' on Figure 1.2. The properties are bounded on the west, north, and south by former Navy property (now owned by the POT or U.S. Navy), and on the east by the Waterway.

The approximate extent of groundwater contamination at the Site is shown on Figure 1.1. The Site is within the 10- to 12-square mile area Commencement Bay Nearshore/Tideflats (CB/NT) Superfund Site which includes several waterway problem areas and adjoining uplands as described by the CB/NT Record of Decision (EPA, 1989). The Site includes part of Segment 5 of the Mouth of Hylebos Problem Area where contaminated sediments were dredged and disposed in 2003-2005 (CRA, 2014a), or excavated and capped 2007-2008 (Hart Crowser, 2014). This work was performed under the Mouth of Hylebos Consent Decree (EPA, 2005b). Sediment contaminants removed from the dredged areas of the Waterway included hexachlorobenzene (HCB), hexachlorobutadiene (HCBD), polychlorinated biphenyls (PCBs), various metals, and other organic chemicals. Remaining sediment contamination within the Site is to be addressed under the AOC (EPA, 2005a).

---

[1] Note that all directional references are relative to plant-north that points toward Commencement Bay, approximately aligned with the centerline of the Site peninsula.

[2] Note that the AOC definition of the Site is repeated in the RD/RA Consent Decree for the Mouth of Hylebos Problem Area of the Commencement Bay Nearshore/Tideflats Superfund Site, *U.S. v. Port of Tacoma, et al*., Civil Action No. C05-5103 FDB (Western District of Washington)(Mouth RD/RA Consent Decree).

The most recent aerial photograph of the Site (dated 2011) is presented on the USB drive attached as Appendix A. This aerial photograph reflects the removal of buildings and process equipment that occurred during the recent demolition of the former OCC Facility completed between 2006 and 2008. For reference, historical aerial photographs of the former OCC Facility are also included in Appendix A.

1.3 Property Ownership

Prior to 1920, the properties which comprise the Site were undeveloped tidal mudflats. Between 1920 and 1936, the area was filled with approximately 16 feet (ft) of dredge material, primarily sand, as part of an upland expansion project.

Mariana Properties, an affiliate of OCC, currently owns the property at 605 Alexander Avenue, having acquired it from Pioneer Americas, LLC in 2005. A predecessor of OCC began operations on the property in 1929 and acquired additional adjacent parcels over time. Other owners and/or operators of all or a portion of the property have included Hooker-Detrex Corporation, the United States Navy, Todd Shipyards, the United States Defense Plant Corporation, and Pioneer Americas.

OCC Tacoma, a wholly owned subsidiary of OCC, acquired the property at 709 Alexander Avenue from PRI Northwest, Inc. (PRI) in 1997. In 2001, OCC Tacoma merged back into OCC, and the property was conveyed to Mariana Properties. Previous owners of the property included Fletcher Oil, which acquired it in 1938 from Norton and Mary Clapp. Tesoro Petroleum, Inc. and United Independent Oil Company, Inc. also leased portions of the 709 Alexander Avenue property in the 1970s.

The property along the east side of the Waterway is held in trust for the Puyallup Tribe of Indians. Previous owners of this property include the POT. The United States Navy owns the eastern portion of the property at 721 Alexander Avenue. With the exception of Alexander Avenue itself, which is owned by the City of Tacoma, the remaining portions of the Site, including the Waterway, are owned by the POT.

1.4 Current Land Use

The Site is located in the industrial tideflats area of Tacoma, Washington. The zoning of the properties which comprise the Site is "S-10", Port Industrial Shoreline District, "M-3", Heavy Industrial District, and "PMI", Port Maritime Industrial. Restrictive covenants restricting land use on the properties to non-residential industrial use are contained and set forth in the Quit Claim Deed (Corrected) recorded on April 28, 1997, in the records of the Pierce County Auditor

(Recording No. 9704280734). Pertinent property owned by the POT is the subject of a restrictive covenant recorded on May 5, 2003, in the records of the Pierce County Auditor (Recording No. 200305050452). Those restrictive covenants prohibit groundwater extraction, supply or use for drinking or other human consumption or domestic use of any kind.

The nearest residential properties are approximately 1 mile to the east, on the bluff across the Waterway from the Facility, 3/4 of a mile across the Waterway to the northeast, and approximately 3 miles to the south.

Current land uses of the properties that encompass the Site include:

i) **Mariana Property**: The existing groundwater treatment plant is located on the northern portion of the 605 Alexander Avenue property. Portions of the existing groundwater extraction and injection systems, as well as groundwater monitoring wells, are located on the property. The two docks along the Waterway are in poor condition and are not in use.

ii) **Port of Tacoma:** The properties owned by the POT are used for various industrial and commercial activities. Portions of the existing extraction and injection systems, as well as groundwater monitoring wells, are located on the POT property. The Waterway and Piers 24/25 are used for commercial shipping purposes.

iii) **United States Navy:** There is no current land use of this property.

iv) **Puyallup Tribe of Indians:** This property includes two marinas used for the storage and berthing of private boats.

1.5 Historical OCC Operations

OCC's predecessor's manufacturing operations began at the Site in 1929 and continued by OCC and others until 2002. The operations undertaken on the former OCC Facility (605) and Mariana Properties (709) are described below.

605 Alexander Avenue

The chemical processes, products, and byproducts associated with the property are summarized below, based on information provided in Attachment 9 (Tacoma Groundwater Continuing Releases Program Groundwater Treatment Technology Assessment) of the RCRA Facility Investigation (CRA, 1989) and other sources.

Processes	***Products***	***Byproducts***	***Period of Operation***
Chlorine/Caustic soda production	Chlorine/Caustic soda	Calcium carbonate, magnesium hydroxide, sodium chloride (recycled into brine), chlorinated organic residue, dioxins/furans	1929 to 2002
Sodium hypochlorite production	Sodium hypochlorite	Sodium chloride (recycled into brine), water	1974 to 1992
Chlorinated solvent production	Trichloroethene/ Tetrachloroethene (TCE/PCE)	Calcium chloride, calcium hydroxide, chlorinated organic residue with VOC and SVOC compounds including HCB, HCBD, and other by-products	1947 to 1973
Ammonia production	Ammonia	None	1952 to 1992
Muriatic acid production	Muriatic Acid	None	1936 to 2002
Calcium chloride production	Calcium chloride	Carbon dioxide, water, magnesium and transition metal precipitate	1964 to 2002
Fish oils hydrogenation	Saturated (hydrogenated) oil	Used catalyst (e.g., nickel)	1939 to 1952
Aluminum chloride production	Aluminum chloride	None	1942 to 1945
Sodium aluminate production	Sodium aluminate	Water	1959 to 1960

TCE was produced at the facility from 1947 to 1973. PCE was produced from 1960 to 1973. Plant records indicate a fairly consistent production rate of 1,100,000 and 660,000 pounds per month of TCE and PCE, respectively. Over the period of solvent production (1947 – 1973), it is estimated that a total mass of 350 million pounds of TCE and 107 million pounds of PCE were produced. Thus, the total solvent production was on the order of 457 million pounds.

Wastes generated during the manufacturing processes were managed on this property. Waste management practices included: wastewater treatment (settling) ponds, settling barges, landfills, disposal pits, and waste piles. Available historical information does not indicate whether pits, ponds, landfills, piles, etc. were partly contained or, if so, how they were contained. Based on sampling data from the vicinity of these waste management units (WMUs), it is apparent that releases to the subsurface occurred.

The locations and descriptions of historical chemical activity areas are shown on Figure 1.3. Seventeen (17) WMUs were historically located on the property. The locations of the WMUs, and the chemicals associated with them, are shown on Figure 1.4.

From 1929 to 2002, chlorine was produced using electrolytic cells. Linseed and other oils were originally used to bind the graphite electrodes used for chlorine production, and were later replaced by phenolic resin binders. According to European Commission (2001)[3], spent graphite anodes are a potential source of dioxin/furan compounds. However, the lack of available oxygen in the process combined with the lack of a significant heat source would have made the production of dioxins and furans at the Site minimal. The change to phenolic resin binders increased the potential for dioxin/furan formation. Graphite waste was disposed in WMUs L, M, P, and Q, and has also been observed in the embankment area. Results for spent anodes analyzed during 1987[4] and 1988 showed that total 2,3,7,8-TCDD equivalent concentrations were all less than 1 microgram per kilogram (µg/kg), and as a result, anodes were disposed off Site as non-TCDD RCRA waste.

From 1947 to 1973, a chlorinated solvents process producing PCE and TCE was in operation on the northern section of the property proximate to Area 5106 (see Figure 1.3). The chlorinated solvent production process consisted of the chlorination of acetylene to produce tetrachloroethane (PCA). The PCA was heated to 100°C with lime to form TCE, which was then chlorinated to form pentachloroethylene. The pentachloroethylene was treated with lime to produce PCE. By-products in the residue from the process included (in approximate decreasing relative amounts):

- Calcium chloride and calcium hydroxide
- HCB and HCBD[5], as well as hexachloroethane, trichloroethane, dichloroethylenes
- Other chlorobutadienes

During the first year of production, effluent from the chlorinated solvents process (consisting of an aqueous slurry composed of byproduct calcium chloride [lime sludge], and chlorinated organic [solvent] residue) was discharged directly to the Waterway through a pipe labeled on historical drawings as '4" Lime'. The location of the direct discharge line is shown on Figure 1.3.

---

[3] European Commission, 2001. Integrated Pollution Prevention and Control (IPPC). Reference Document on Best Available Techniques in the Chlor-Alkali Manufacturing Industry. December. http://eippcb.jrc.ec.europa.eu/reference/BREF/cak_bref_1201.pdf.

[4] Results transmitted by OCC's September 16, 1987 letter to USEPA (Catherine Massimino) and Ecology (Steve Robb).

[5] "Chlorine, Its Manufacture, Properties, and Uses" Ed. Sconce. ACS Monograph Series No. 154, 1962.

From approximately 1949 to 1952, and again from 1972 to 1973, the process effluent was passed through one of a series of upland settling ponds where the solids settled out, and the supernatant was discharged to the Waterway. During the period from 1952 to 1972, the effluent was discharged to a settling barge berthed alongside the present northern walking pier (WMU F on Figure 1.4). The solids settled in the barge, and the supernatant was discharged to the Waterway. The solids in the barge were taken to a deep water disposal site. Between 1949 and 1971, a small landfill shown as WMU C on Figure 1.4 was used for the disposal of lime and calcium chloride from the chlorinated solvents process.

As discussed in the Embankment Area Characterization Report (CRA, 1999), the embankment area is defined as the area along the Waterway that extends from the northwest boundary of the 605 Alexander Avenue property to the southeast boundary of the adjacent property at 709 Alexander Avenue (otherwise identified as the former PRI property). Previous reports segregated the embankment area into the following sections, which are shown on Figure 1.5:

- Northern Section
- Central Section
- Southern Section
- PRI Section

The Northern Section is approximately 500 ft of embankment area extending southward from the facility's northern property boundary, and was acquired prior to OCC by Hooker Chemical Corporation (Hooker) from Todd Shipyards. Heavy industrial activities took place in this area both before and after Hooker's ownership, most notably war-related shipyard activities undertaken by the U.S. Navy and Todd Shipyards for both World War I and World War II. Historical information indicates that landfilling and incinerating operations (among other activities) took place along the shoreline and in the uplands during the World War II shipyard activities. Following acquisition of the property by Hooker, a landfill was developed, identified as WMU C. Additionally, settling ponds were installed in the Northern Section identified as WMU H.

The Central Section is approximately 600 ft of embankment area between the Northern Section and the Southern Section. Due to extensive development in this area for active industrial use, limited to no landfilling or disposal operations were performed, and therefore no documented WMUs exist in this area.

The Southern Section is approximately 400 ft of the embankment area between the Central Section and the PRI Section. Historical information indicates that this area was used for a landfill, and is identified as WMU N.

The PRI Section is approximately 200 ft of the embankment area extending southward from the south edge of the 605 Alexander Avenue property boundary, and is distinctly identified as part of the 709 Alexander Avenue property. Historical information indicates that an embankment fill area exists that extends south from the N Landfill (WMU N) on the 605 Alexander Avenue property.

As discussed in the Embankment Area Characterization Report (CRA, 1999), historical investigations were performed in each of the above-stated sections to identify physical properties of the embankment materials and collect samples of materials, groundwater, and seeps for analysis of various chemical parameters. The investigations identified several types of materials that were placed along the embankment area.

The primary embankment materials identified in each section are as follows:

- Northern Section – Sediment, waste sludge, slag, concrete, bricks, riprap, and shipyard incineration wastes
- Central Section – Sediment, concrete, bricks, and riprap
- Southern Section – Sediment, waste sludge, concrete, and riprap
- PRI Section – Sediment, waste sludge, anodes, and concrete

Contaminants associated with the waste sludge include VOCs and SVOCs. The shipyard incineration wastes and spent graphite anodes described above are potential sources of dioxin/furan compounds (European Commission, 2001).

The scope of the embankment investigations are discussed in Sections 2.1.7 through 2.1.9.

709 Alexander Avenue

OCC and its predecessors did not conduct any manufacturing operations on this property. However, fill materials that included wastes from the activities at the 605 Alexander Avenue property, and likely other potential sources, were placed on the 709 Alexander Avenue property along the embankment of the Waterway. This area of the embankment (PRI Section) is discussed above.

1.6 Other Historical Operations

Historical operations on 605 Alexander Avenue and the adjacent properties are provided in the following section, and are based on information provided in Appendix B.

Prior to the use of the 605 Alexander Avenue property by OCC and its predecessors for chemical manufacturing, a portion of the property (North 10 Acres) was used by the United States and Todd Shipyards Corporation for operations associated with ship building and dismantling activities, as well as for the gathering and incineration of shipyard wastes. In approximately 1945, these activities ceased and the facilities on the North 10 Acres were decommissioned. In 1945, shipyard wastes were dumped on uplands and on the shoreline and partially pushed into the Waterway. This area is now described as the "Navy Todd Dump" (shown on Figure 1.2).

The other historical operations of properties adjacent to 605 Alexander Avenue are summarized below:

401 Alexander Avenue

- Ship building and dismantling, and related activities, during World War I and World War II
- U.S. Naval Station Tacoma's ship storage, maintenance, and dismantling from World War II to 1960
- Port Industrial Yard (Early Business Center) and numerous tenant operations since 1960, including ship building and dismantling

Most of the Piers 24/25 Waterway embankment on this property was remediated with installation of a sediment cap, after excavating areas of more pronounced contamination, in 2007-2008 under the Mouth of Hylebos RD/RA Consent Decree (Hart Crowser, 2014). The southern 400 ft of sediment were not capped. EPA, POT, and OCC agreed that activities in this area will be incorporated with the sediment remediation activities to be accomplished under the AOC.

709 Alexander Avenue

i) Bulk petroleum fuel storage and distribution terminal between the 1930s and 1980s
ii) Tetraethyl lead plant, blending lead with gasoline in the late 1970s and early 1980s
iii) Topping plant for crude oil distillation in the 1970s and early 1980s

721 Alexander Avenue

i) Fuel distribution depot and bulk petroleum storage depot from 1936 through 1965
ii) Petroleum storage facility from 1966 through 1983
iii) Materials storage yard since 1983

Historical Site features on 709 and 721 Alexander Avenue are shown on Figure 1.6. These properties will be further investigated under Agreed Order No. DE 9835 among Ecology, Mariana, and the POT, effective on October 3, 2013.

1.7 Report Organization

This SCR is organized as follows:

i) **Section 1.0 – Introduction:** provides the general introduction, purpose, scope, and general background for the Site.

ii) **Section 2.0 – Summary of Investigations and Cleanup Actions:** includes a brief summary of the investigations and activities associated with the Site Characterization, along with previous cleanup actions.

iii) **Section 3.0 – Physical Characteristics:** presents the results of the field activities to determine physical characteristics of the Site.

iv) **Section 4.0 – Nature and Extent of Contamination:** presents the site-specific contaminants of concern, cleanup and screening levels, and results of the Site Characterization for each media including soil, groundwater, surface water, and sediment.

v) **Section 5.0 – Contaminant Fate and Transport:** presents the potential routes of migration, contaminant persistence and behavior, transport processes, and Conceptual Site Model.

vi) **Section 6.0 – Baseline Risk Assessment:** presents a summary of the Risk Assessment, including human health and ecological risk.

vii) **Section 7.0 – Summary and Conclusions.**

viii) **Section 8.0 – References**.

Section 2.0 Summary of Investigations and Cleanup Actions

2.1 Summary of Investigations[i]

These investigations have been accomplished by OCC and other parties under USEPA and Ecology oversight pursuant to several different regulatory mechanisms. As described in detail below, OCC's activities have been accomplished in accordance with permits issued pursuant to RCRA and Washington's Hazardous Waste Management Act, an agreed order on consent for Waterway pre-remedial design activities, a unilateral administrative order, and the AOC.

Numerous investigations of groundwater, soil, and sediment have been conducted at the Site, as described in the following sections. Over 8,200 groundwater, sediment, soil, seep, leachate, debris, indoor/outdoor air, and soil vapor samples were collected from approximately 1,300 locations and analyzed during the 25 investigations listed in the following sections. The locations of these samples are shown on Figure 2.1. The physical, chemical, and hydraulic data from these investigations have developed the current understanding of the Site and are incorporated in subsequent sections of this report.

Appendix C includes tables (on USB drive) that summarize the collection and analysis for each groundwater, soil, sediment, leachate/synthetic precipitation leaching procedure (SPLP), porewater, seep, debris, and geotechnical sample presented in this report. The tables can be sorted or queried by sample ID to locate particular samples of interest.

2.1.1 RCRA Facility Investigation (1988-1989)

The RCRA Facility Investigation I (RFI-I) was conducted pursuant to the requirements of the Joint Permit for the Storage of Dangerous Waste (Permit), WAD009242314, dated November 1988. USEPA and Ecology jointly administered the Permit. A RCRA Facility Assessment (RFA) was completed by USEPA and reported in February 1988 in a memorandum from C. Massimino (USEPA) to File and copied to S. Robb of Ecology. The RFA concluded that hazardous constituents were released from past WMUs and that an RFI-I was required to define the nature and extent of impacted groundwater for the development of a corrective action program.

The RFI-I included identification and investigation of WMUs, installation and development of monitoring wells, hydraulic conductivity testing, multiple rounds of groundwater sampling, surface runoff and seep sampling, and hydraulic monitoring. The data generated by the RFI-I became the basis for development of the existing corrective action measures (groundwater extraction and treatment) described in 2.2.3 and subsequent investigative activities.

2.1.2 Commencement Bay Nearshore/Tideflats Superfund Site (1993)

OCC and other parties comprising the Hylebos Cleanup Committee (HCC) undertook Hylebos Waterway Pre-Remedial Design activities pursuant to a 1993 AOC with USEPA (Docket No, 1093-07-03-104/122). In order to characterize sediment in the embankment, OCC conducted field activities in accordance with the requirements of the "Combined Sampling and Analysis Plan for the Commencement Bay Nearshore/Tideflats Superfund Site – Hylebos Waterway Problem Areas" (HCC, 1993). Field activities associated with this investigation were conducted in August 1993 and consisted of:

- Collection of 5 shallow (1 ft below ground surface [BGS]) soil samples from the top of the slope at the northeast portion of the Site embankment area
- Analysis of soil samples for TCLP-VOCs, TCLP-SVOCS, TCLP-Pesticides, TCLP-Herbicides, TCLP-Metals, corrosivity, cyanide reactivity, sulfide reactivity, and flash point

Data from the investigation were previously presented in Attachment E-3 of Appendix E of the "Work Plan; Characterization of the Embankment Along the Hylebos Waterway the OxyChem Tacoma Facility" (CRA, 1996) and in the "Summary of Previous Investigations" (CRA, 2004).

2.1.3 PRI Preliminary Site Investigation (1994)

In 1994, PRI Northwest, Inc. (PRI) conducted a preliminary investigation to characterize the Berm Area adjacent to the Waterway at 709 Alexander Avenue. Field activities associated with the investigation were conducted between December 1993 and January 1994 and consisted of:

- Collection of soil samples from 10 test pit excavations in the eastern portion of the property
- Installation of 5 monitoring wells in the eastern portion of the property
- Collection of 15 soil samples from test pits and soil borings completed during monitoring well installation
- Collection of groundwater samples from the 5 newly installed monitoring wells and from a low tide groundwater seep
- Analysis of soil samples for Volatile Organic Compounds (VOCs), Semi-volatile Organic Compounds (SVOCs), Total Petroleum Hydrocarbons (TPH), Polychlorinated Biphenyls (PCBs), metals, and Total Organic Carbon (TOC)
- Analysis of groundwater samples for VOCs, SVOCs, TPH, PCBs, metals (dissolved and total), TOC, pH, total suspended solids (TSS), conductivity, and chloride
- Completion of a 3-day monitoring program to assess groundwater flow

Data from the investigation were previously presented in the "Preliminary Site Investigation Report" (Hart Crowser, 1994), in the "Supplemental Monitoring Well Installation and Groundwater Sampling and Analysis Report" (Hart Crowser, 1994), and in the "Summary of Previous Investigations" (CRA, 2004).

2.1.4 Hylebos Waterway Pre-Remedial Design Program (1994)

In 1994, the HCC conducted an investigation that included the collection and analysis of sediment from the subtidal and intertidal portions of the Waterway adjacent to the Site and the collection of sediment samples from the embankment.

- Collection of 6 composite sediment/soil samples from the intertidal zone of the Waterway and embankment are adjacent to the Site
- Analysis of sediment/soil samples for VOCs, SVOCs, pesticides, and metals

Data from the investigation were previously presented in the "Hylebos Waterway Pre-Remedial Design Evaluation Report" (HCC, 1999).

2.1.5 PRI Source Identification Investigation (1994)

In 1993 and 1994, PRI conducted an investigation of subsurface soil and groundwater conditions at the former PRI bulk fuel facility located at 709 Alexander Avenue. This investigation was focused on the identification of the potential source(s) of VOCs detected in shallow groundwater beneath the PRI property. Field activities associated with this investigation were conducted between December 8, 1993, and an unknown date prior to October 1994 and included the following:

- Installation of 3 monitoring wells
- Collection of 3 soil samples from soil borings completed during monitoring well installation
- Collection of groundwater samples from the 5 existing and 3 newly installed monitoring wells and from a low tide groundwater seep
- Analysis of soil samples for VOCs, SVOCs, TPH, PCBs, and metals
- Analysis of groundwater samples for VOCs, SVOCs, TPH, PCBs, metals (dissolved and total), TOC, pH, TSS, conductivity, and chloride
- Assessment of groundwater flow directions

The results of the investigation were previously presented in the "Preliminary Site Investigation, Volume I" (Hart Crowser, 1994), in the "Supplemental Monitoring Well Installation and Groundwater Sampling and Analysis Report" (Hart Crowser, 1994), and the "PRI Source Identification Program Report" (CRA, 1996).

2.1.6 PRI Soil and Groundwater Investigation (1995)

In March and August 1995, PRI conducted a soil and groundwater investigation at 709 Alexander Avenue to further evaluate the extent and potential sources of groundwater contamination. The field activities included:

- Collection of soil samples from 11 test pit excavations

- Installation of 12 monitoring wells
- Collection of 28 soil samples from test pits and soil borings completed during monitoring well installation
- Collection of groundwater samples from the 8 existing and 12 newly installed monitoring wells
- Analysis of soil samples for VOCs, 4 test pit samples were additionally analyzed SVOCs and PCBs
- Analysis of groundwater samples for VOCs, ammonia as nitrogen, nitrate/nitrite as nitrogen, dissolved aluminum, pH, lead (dissolved and total), chloride, major and minor ions, and alkalinity
- Assessment of groundwater flow directions

Data from this investigation were previously presented in the "Soil and Groundwater Investigation (March and August 1995)" (Hart Crowser, 1995).

2.1.7 Embankment Investigation (1996)

In 1996, OCC conducted an investigation to define the extent of chemical presence in the embankment materials located within and above the intertidal zone. Field activities associated with this investigation were conducted between March 20 and April 5, 1996, and included:

- Installation of 15 borings within and above the intertidal zone of the embankment
- Collection of composite sediment/soil samples from the 15 borings within and above the intertidal zone of the embankment
- Collection of 20 surface composite samples of sediment, soil, and fill from 42 locations in the upland and embankment areas of the Site
- Collection of groundwater samples from 7 groundwater monitoring wells
- Analysis of soil/sediment and fill samples for VOCs, SVOCs, pesticides, PCBs, metals, and TPH

Bulk chemistry data from this investigation were previously presented in the "Embankment Area Characterization Report" (CRA, 1999).

2.1.8 Embankment Area Investigation (1998)

After initial review of the 1996 investigation data, OCC conducted an additional investigation to further characterize the embankment pursuant to the AOC, as originally executed by USEPA and OCC in 1997. Field sampling activities for the further characterization were performed as outlined in the "Sampling and Analysis Plan – Embankment Area Removal Action" (CRA, 1997). Field activities associated with the investigation were conducted between January 6 and April 1, 1998, and included:

- Installation of 12 soil borings in the embankment area of the Site
- Collection of 22 surface debris samples (anodes, red brick, concrete, and slag)
- Collection of 176 surface sediment and sludge samples from the embankment area of the Site
- Collection of seep samples during outgoing tides from 16 seep locations on the embankment area of the Site
- Collection of porewater samples and seep precipitant from 2 milky seep locations on the embankment area of the Site
- Analysis of soil samples from embankment area borings for grain size, moisture content and asbestos
- Analysis of milky seep porewater, and leachate prepared from surface debris, sediment, sludge, and milky seep precipitant for VOCs, SVOCs, pesticides, PCBs, and metals using the SPLP
- Analysis of seep samples for VOCs, SVOCs, pesticides, PCBs, and metals

Data from this investigation were previously presented in the "Embankment Area Characterization Report" (CRA, 1999).

2.1.9 Supplemental Embankment Investigation (1998)

In October 1998, OCC conducted supplemental investigation activities to obtain additional leachate data for the embankment. Field sampling activities for this supplemental investigation were performed as outlined in the "Work Plan – Supplemental Embankment Characterization" presented in Appendix F of the "Embankment Area Characterization Report" (CRA, 1999). Field activities associated with this supplemental investigation were conducted between October 8, 1998 and January 7, 1999, and included:

- Collection of seep samples from 3 embankment seeps
- Collection of interstitial water from 4 piezometer pairs installed in the embankment
- Analysis of seep and interstitial water samples for pesticides and dissolved metals

Data from this investigation were previously presented in the "Supplement A to the Embankment Area Characterization Report" (CRA, 1999).

2.1.10 Rapid pH Assessment (2002-2004)

OCC conducted a groundwater investigation focused in the Embankment Area, referred to as the Rapid pH Assessment, under Task A4 of the "Draft Work Plan, Groundwater Remediation, Embankment Area Removal Action and Area 5106 Capping" (CRA, 2004). The purpose of the Rapid pH Assessment was to further delineate the plume of elevated pH groundwater through sampling of groundwater from discrete intervals in borings advanced within the Embankment Area. Field activities associated with the Rapid pH Assessment were conducted in two phases between November 2002 and January 2003 (Phase I) and January 2004 and February 2004 (Phase II) and included:

- Installation of 89 soil borings within the embankment area
- Collection of 263 groundwater samples from discrete intervals in soil borings
- Collection of groundwater samples from 9 monitoring wells
- Collection of 87 seep samples from 43 seep locations along the embankment
- Analysis of groundwater samples from monitoring wells and soil boring for VOCs, alkalinity, chloride, sulfate, metals, silicon, total dissolved solids (TDS), specific gravity, and pH
- Analysis of samples from seep locations for VOCs, alkalinity, hydroxide, chloride, sulfate, metals, silicon, TDS, specific gravity, and pH

The results of the Rapid pH Assessment activities were previously presented in the "Draft Rapid pH Assessment Report (Revised July 1, 2004)" (CRA, 2004).

2.1.11 Area 5106 Post-Treatment Characterization (2003)

In March 2002, USEPA, OCC, and other parties agreed in order to maintain cleanup schedules, among other reasons, that USEPA should issue three unilateral administrative orders (UAOs) pertinent to the Waterway. Activities pertinent to Area 5106 were addressed by one such UAO (Docket No. CERCLA 10-2002-0066), which was eventually terminated by the AOC, as amended in 2005. OCC conducted an investigation to characterize the sediments within the relatively flat portion of Area 5106 following the completion of the dredging and treatment of Area 5106 sediment. Field activities associated with the investigation were conducted between July 21, 2003 to July 25, 2003, in accordance with the SAP and the QAPP approved by USEPA as Appendices A and B of the "Post-Treatment Work Plan" (CRA, 2003). Field activities included:

- Collection of 9 sediment cores to a minimum of 10 ft below the mudline from within the 5106 dredging area
- Collection of 98 discrete sediment samples from each core at 1-ft intervals

- Collection of 23 groundwater samples from 5 of the 9 sediment core locations at 2-ft intervals
- Physical characterization of sediment samples including: grain size, vane shear testing, and vertical hydraulic conductivity/site-specific seepage induced consolidation tests on recently deposited sediments
- Analysis of sediment samples for TOC, TCE, PCE, HCBD, and HCB
- Analysis of groundwater samples for TOC, TCE, and PCE

Data from this investigation were previously presented in the "Post-Treatment Characterization Report" (CRA, 2003).

2.1.12 Preliminary Investigation and Assessment of Techniques – Groundwater Discharge to the Hylebos Waterway (2004)

USEPA and Ecology conducted a joint investigation of groundwater discharge to the Waterway in 2004. The goals of the investigation were to gain a better understanding of the distribution and transport of contaminants in the subtidal zone of the Waterway, and to identify the most efficient and effective techniques for delineating and quantifying groundwater discharge during future comprehensive investigations.

Field activities associated with the investigation were conducted between April and August 2004. Field activities included:

- Diver inspection of the Waterway for evidence of discharging groundwater.
- Conductivity, temperature, and depth surveys to identify contrasts in surface water conductivity and temperature.
- Installation of 9 piezometers to collect groundwater samples and measure relative hydraulic heads in the groundwater and Waterway. Groundwater samples were analyzed for VOCs, SVOCs, and metals.
- Deployment of passive diffusion samplers to measure the quality of the ambient sediment porewater. Porewater samples were analyzed for VOCs.
- Installation of seepage meters to quantify groundwater discharge into the Waterway.

Conclusions drawn from this investigation were used by the Agencies and OCC to develop the scope of subsequent subtidal investigations.

2.1.13 Supplemental Investigation (2004)

OCC conducted this investigation under Task A3 of the SOW to further characterize the nature and extent of the groundwater, soil, and sediment contamination at the Site. The field activities associated with this investigation were conducted between January 2004 and July 2004 and included:

- Installation of 31 soil borings to further delineate the pH plume
- Installation of 5 groundwater monitoring wells to further delineate the pH plume
- Sampling of 3 seeps to further delineate the pH plume
- Installation of 16 soil boring to further delineate the northern extent of the groundwater COC plume
- Installation of 6 groundwater monitoring wells to further delineate the embankment area COC plume adjacent to Dock 2
- Sampling of 30 seeps to further delineate the embankment area COC plume adjacent to Dock 2
- Installation of 14 paired monitoring wells for hydraulic monitoring of existing E and F-Branch injection wells
- Sampling of 4 monitoring wells for Appendix IX Analytes
- Installation of 3 soil borings to further characterize COC presence in WMU H
- Installation of 2 soil borings to further characterize COC presence in WMU C
- Installation of 5 soil borings to further characterize COC presence in the former N Landfill area
- Installation of 10 soil borings to further characterize COC presence in WMU A
- Analysis of groundwater samples from soil borings, groundwater monitoring wells, and seeps from the Embankment Area pH plume for Alkalinity, Silica, and pH
- Analysis of groundwater samples from the northern extent soil borings for Upland Groundwater COCs (VOCs and pH)
- Analysis of groundwater samples from Dock 2 and E and F-Branch monitoring wells for Embankment Areas COCs (VOCs, SVOCs, PCBs, Metals, pH, and specific gravity)
- Analysis of soil samples from the WMU-H, WMU-C, and N-Landfill soil borings for Embankment Areas COCs (VOCs, SVOCs, PCBs, and Metals)
- Analysis of soil samples from WMU-A for target compound list VOCs and SVOCs

The data collected during this investigation was previously presented in the "Interim Data Report, Supplemental Field Investigation" (CRA, 2004).

2.1.14 Area 5106 Slope Investigation (2004)

The data collected from the borings installed for the Area 5106 Post-Treatment Characterization (2003) were not sufficient to fully define the extent of the residual chlorinated organic chemistry within the sediment and groundwater beneath and adjacent to Area 5106. Therefore, in order to further characterize the nature and extent of residual contamination in the area, additional borings were installed as part of the Supplemental Investigations (2004). Field activities related to these borings began on June 9, 2004, were completed on June 30, 2004, and included:

- Installation of 9 soil borings beneath and adjacent to area 5106
- Analysis of groundwater and sediment samples for VOCs (TCE and PCE) and SVOCs (HCB and HCBD)

2.1.15 709/721 Alexander Avenue Investigation (2004)

OCC conducted an investigation of the 709/721 Alexander Avenue properties in accordance with the SAP and the QAPP presented in Appendices G and H of the "Draft Work Plan (Revised 6/16/2004)," approved by USEPA and Ecology. Field activities associated with the investigation were conducted between March and July 2004 and included:

- Installation of 17 groundwater monitoring wells
- Collection of 50 groundwater samples from 18 monitoring wells and from discrete intervals in 10 direct push borings
- Completion of a hydraulic monitoring event
- Sampling of 8 seeps and 5 piezometers
- Analysis of groundwater samples for VOCs and pH

Chemistry data collected during this investigation were previously presented in the "Interim Groundwater Analytical Data Summary - 709/721 Alexander Avenue" (CRA, 2004). Hydraulic data collected during this investigation were previously presented in the memorandum "Interim Deliverable 4.6: Presentations of Hydraulic Data from 709/721 Alexander Investigation" (CRA, 2007).

2.1.16 Additional Supplemental Investigations (2005-2006)

The Sampling and Analysis Plan (SAP) and the Quality Assurance Project Plan (QAPP) for this investigation were conditionally approved by USEPA and Ecology on October 25, 2005 following a partial approval on May 23, 2005. Field activities for the investigation began on May 31, 2005, were completed on September 27, 2006, and included:

- Installation and collection of soil and groundwater samples from 3 soil borings within the subtidal area of the Site
- Installation and collection of soil and groundwater samples from 32 soil borings to further characterize COC presence in WMU A
- Installation and collection of soil and groundwater samples from 24 soil borings to further characterize COC presence in the N Landfill
- Installation and collection of soil and groundwater samples from 8 soil borings within and adjacent to the salt pad
- Installation and collection of soil and groundwater samples from 5 soil borings within and adjacent to the caustic house
- Installation and collection of groundwater samples from 2 soil borings adjacent to Dock 2
- Installation and collection of groundwater samples from 2 soil borings adjacent to the E-Branch injection wells
- Analysis of soil samples from the subtidal area for PCE, HCB, and HCBD
- Analysis of groundwater samples from the subtidal area for Embankment Area/Subtidal Groundwater VOCs, SVOCs, PCBs, metals, pH, and DOC
- Analysis of soil and groundwater samples from WMU A for Upland Groundwater VOCs, pH, and TOC
- Analysis of soil and groundwater samples from N Landfill for Embankment Area Subtidal COCs or Sediment/Porewater COCs including VOCs, SVOCs, pesticides/PCBs, metals, and pH
- Analysis of groundwater samples from the salt pad area for Embankment Area Subtidal VOCs, SVOCs, PCBs, metals, and pH, as well as, sodium, hydroxide, chloride, TDS, and specific gravity
- Analysis of soil samples from the salt pad area for Embankment Area Subtidal VOCs, SVOCs, PCBs, metals, and pH, as well as, sodium and chloride
- Analysis of groundwater samples from the E-Branch injection well area for Upland Groundwater VOCs and pH
- Analysis of groundwater samples from the caustic house area for Embankment Area Subtidal VOCs, metals, and pH, as well as, sodium, chloride, TDS, and specific gravity
- Analysis of soil samples from the caustic house area for Embankment Area Subtidal VOCs, metals, and pH, as well as, sodium and hydroxide
- Analysis of groundwater samples from the Dock 2 area for Upland Groundwater VOCs and pH

- Collection of groundwater samples for analysis of natural attenuation parameters as described in Section 2.18
- Collection of 309 soil samples from 29 locations within WMU A and N Landfill to archive for possible future PCDD/F and PCB congener analysis

2.1.17 Subtidal/Hydraulic Investigation (2005-2006)

The SAP and QAPP for this investigation were conditionally approved by USEPA and Ecology on May 20, 2005. Field activities for the investigation began on June 30, 2005, were completed on August 22, 2006, and included:

- Collection of groundwater and sediment/soil samples at discrete intervals from 99 subtidal borings
- Completion of 2 Site-wide groundwater sampling events (pre and post-extraction system shutdown) including groundwater monitoring wells, subtidal piezometers, and extraction wells
- Installation of 13 down-hole transducer groups at 10 subtidal locations and 3 upland locations on the east side of the Waterway
- Collection of sediment/soil and groundwater samples at discrete down-hole transducer elevations
- Collection of groundwater and sediment/soil samples at discrete intervals from 3 upland borings installed adjacent to the embankment area at Dock 1
- Completion of a seepage meter monitoring program, 26 seepage meters, to determine the nature and extent of groundwater to the Waterway during various phases of the tide cycle
- Analysis of groundwater, sediment, and soil samples from subtidal borings for Embankment Area/Subtidal Groundwater VOCs, SVOCs, PCBs, metals, and pH
- Analysis of pre-extraction system shutdown groundwater samples from the monitoring wells and extraction wells for Upland Groundwater VOCs, pH, DOC, specific gravity, sodium, TDS, chloride and natural attenuation parameters identified in Section 2.18
- Analysis of pre-extraction system shutdown groundwater samples from the subtidal piezometers for Embankment Area/Subtidal Groundwater VOCs, SVOCs, PCBs, metals, pH, DOC, specific gravity, sodium, TDS, chloride and natural attenuation parameters identified in Section 2.18
- Analysis of post-extraction system shutdown groundwater samples from the monitoring wells, extraction wells, and subtidal piezometers for DOC, specific gravity, sodium, TDS, and chloride

- Analysis of sediment/soil and groundwater samples from down-hole transducer locations for vertical hydraulic conductivity, grain size distribution, TOC, and moisture content (soil/sediment) and specific gravity, sodium, TDS, chloride, and, at select locations, natural attenuation parameters identified in Section 2.18 (groundwater)
- Analysis of groundwater, sediment, and soil samples from upland borings adjacent to Dock 1 for Embankment Area/Subtidal Groundwater VOCs, SVOCs, PCBs, metals, and pH
- Analysis of groundwater discharge samples from 19 seepage meter locations for Embankment Area/Subtidal Groundwater VOCs, SVOCs, PCBs, metals, and pH

2.1.18 Geophysical Survey (2006)

A comprehensive geophysical survey of the Waterway was conducted adjacent to the Site. The scope of work and objectives for the geophysical survey were developed by USEPA and Ecology and provided to OCC on March 27, 2006. Following minor revisions, the scope of work was finalized and approved by USEPA and Ecology on April 11, 2006. Field activities associated with the geophysical survey were conducted between April 10 and May 5, 2006, and included:

- Sidescan sonar and bathymetric surveys
- High-resolution conductivity survey
- Subbottom profile survey
- Marine electrical resistivity imaging survey

2.1.19 Focused Investigation of Dioxin/Furan and PCB Congeners (2006-2007)

The SAP and QAPP for this investigation were conditionally approved by USEPA and Ecology on January 8, 2007 following partial approval of the SAP on November 22, 2006. Field activities for the investigation began on November 28, 2006, were completed on February 2, 2007, and included:

- Analysis of 10 archived soil samples from WMU A for PCDD/F and PCB congeners
- Analysis of 1 archived soil sample from the N Landfill for PCDD/F and PCB congeners
- Installation of 6 subtidal and 1 upland boring east of the N Landfill
- Installation of 1 upland boring in the N Landfill
- Installation of 2 upland borings in the Navy-Todd Dump area
- Installation of 4 intertidal/subtidal borings under Pier 25
- Installation of 2 intertidal/subtidal borings under Dock 1

- Installation of 4 subtidal borings in the Waterway
- Collection of groundwater samples from 3 groundwater monitoring wells, each groundwater treatment plant extraction branch, and 1 seep location
- Analysis of soil and groundwater samples for from discrete intervals within each boring and groundwater and seep samples for PCDD/F and PCB congeners

2.1.20 Natural Attenuation Investigation (2006)[ii]

During the Subtidal/Hydraulic Investigation (2005-2006) and the Additional Supplemental Investigations (2005-2006), OCC collected groundwater samples for analysis of natural attenuation parameters. The groundwater samples were collected from beneath the Waterway and from upland portions of the Site. In total, 79 groundwater samples were collected from 8 background, 20 elevated VOC, 4 downgradient, and 3 beyond downgradient locations. Samples were analyzed for VOCs, metals (iron, manganese, and sodium), gases (ethane, ethene, and methane), alkalinity, ammonia, biochemical oxygen demand (BOD), chemical oxygen demand (COD), nitrate, nitrite, orthophosphate, sulfate, sulfide, and TOC.

2.1.21 pH Pilot Study (2006-2010)

The pH Pilot Study, performed under Task B4 of the SOW, was completed in three phases to assess the feasibility and effectiveness of treating groundwater and soil utilizing in-situ and ex-situ methodologies as a means to control sources of elevated groundwater pH. The study included:

Phase I pH Pilot Study

- Construction of a Ferrous Sulfate (FeSO4) mixing plant and mobile injection trailer
- Injection of FeSO4 and post-injection monitoring at 4 test locations (PS#1 to PS#4)

Pilot Test Area #1

- Installation of 4 temporary monitoring wells and an injection point
- Injection of 2,000 gallons of an 18 percent (%) FeSO4 solution at 8 gpm
- Monitoring of injection parameters in real-time (pressure, flow rate, and pump speed) during injection
- Collection of groundwater samples and real-time water quality parameter monitoring from 4 temporary monitoring wells
- Installation of 6 post-injection Geoprobe borings within the test area
- Collection of groundwater samples from Geoprobe borings to determine area influence

- Pre and post-injection hydraulic testing of temporary monitoring wells to determine injection impacts to aquifer hydraulic properties
- Analysis of pre and post-injection groundwater samples for field parameters (pH, conductivity, dissolved oxygen [DO], temperature, and oxidation-reduction potential [ORP])

Pilot Test Area #2

- Installation of 6 temporary monitoring wells and an injection point
- Injection of 2,000 gallons of an 18% FeSO4 solution at 4 gpm
- Monitoring of injection parameters in real-time (pressure, flow rate, and pump speed) during injection
- Collection of groundwater samples and real-time water quality parameter monitoring from 6 temporary monitoring wells
- Installation of 12 post-injection Geoprobe borings within the test area
- Collection of groundwater samples from Geoprobe borings to determine area influence
- Pre and post-injection hydraulic testing of temporary monitoring wells to determine injection impacts to aquifer hydraulic properties
- Analysis of pre and post-injection groundwater samples for field parameters (pH, conductivity, DO, temperature, and ORP) and laboratory analysis for iron, sulfate, and alkalinity
- Long-term monitoring of pH rebound and field parameters in temporary monitoring wells

Pilot Test Area #3

- Installation of 5 temporary monitoring wells and an injection point
- Injection of 2,000 gallons of an 9% FeSO4 solution at 4 gpm
- Monitoring of injection parameters in real-time (pressure, flow rate, and pump speed) during injection
- Collection of groundwater samples and real-time water quality parameter monitoring from 5 temporary monitoring wells
- Installation of 5 pre-injection and 15 post-injection Geoprobe borings within the test area
- Collection of groundwater samples from Geoprobe borings to determine area influence
- Pre and post-injection hydraulic testing of temporary monitoring wells to determine injection impacts to aquifer hydraulic properties

- Analysis of pre and post-injection groundwater samples for field parameters (pH, conductivity, DO, temperature, and ORP) and laboratory analysis for iron, sulfate, alkalinity, and metals
- Collection of 3 soil samples from monitoring well installations for initial soil alkalinity testing and 3 soil samples from post-treatment Geoprobe boring installations for residual soil alkalinity testing
- Long-term monitoring of pH rebound and field parameters in temporary monitoring wells

Pilot Test Area #4

- Installation of 5 temporary monitoring wells and an injection point
- Injection of 1,150 gallons of an 18% $FeSO_4$ solution at 12 to <1 gpm
- Monitoring of injection parameters in real-time (pressure, flow rate, and pump speed) during injection
- Collection of groundwater samples and real-time water quality parameter monitoring from 5 temporary monitoring wells
- Installation of 5 pre-injection and 13 post-injection Geoprobe borings within the test area
- Collection of groundwater samples from Geoprobe borings to determine area influence
- Pre and post-injection hydraulic testing of temporary monitoring wells to determine injection impacts to aquifer hydraulic properties
- Analysis of pre and post-injection groundwater samples for field parameters (pH, conductivity, DO, temperature, and ORP) and laboratory analysis for iron, sulfate, alkalinity, and metals
- Long-term monitoring of pH rebound and field parameters in temporary monitoring wells

Phase II pH Pilot Study

- Installation of an injection well with multiple screens and sand packs for use with packers to test a more controlled injection method
- Construction of a constant head reagent feed tank to provide a steady, low-pressure reagent injection
- Installation of 3 temporary standard groundwater monitoring wells
- Installation of 4 Continuous Multi-Channel (CMT) monitoring wells
- Injection of 3,700 gallons of an 18% $FeSO_4$ solution at <2 gpm
- Monitoring of injection parameters in real-time (pressure, flow rate, and pump speed) during injection

- Collection of groundwater samples and real-time water quality parameter monitoring from 3 temporary monitoring wells and 4 CMT wells
- Pre and post-injection hydraulic testing of temporary monitoring wells to determine injection impacts to aquifer hydraulic properties
- Analysis of pre and post-injection groundwater samples for field parameters (pH, conductivity, DO, temperature, and ORP) and laboratory analysis for iron, sulfate, alkalinity, and metals
- Long-term monitoring of pH rebound and field parameters in temporary monitoring wells and CMT wells

Phase III pH Pilot Study

- Collection of 9 bulk elevated pH and one bulk neutral pH groundwater samples for in-situ and ex-situ laboratory treatability testing
- Collection of 1 bulk seawater sample for ex-situ seawater reaction testing
- Collection of 1 bulk city water sample for ex-situ city water dilution testing
- Collection of 1 bulk Production Well groundwater sample for Production Well dilution sampling
- Installation of 3 groundwater monitoring wells
- Collection of 6 bulk soil samples for soil mixing testing
- Conducting in-situ groundwater treatability titration testing on filtered and unfiltered bulk groundwater samples using acetic acid, citric acid, hydrochloric acid, nitric acid, sulfuric acid, phosphoric acid, carbonic acid, ferrous sulfate, and sodium bisulfate recording pH changes, solids formation, dissolved silica concentration changes, viscosity changes, stability of solids formed, and other observations (i.e., gel/precipitant formation, color changes, temperature changes, etc.)
- Conducting ex-situ treatment tests on groundwater samples using city water for dilutions, Production Well water for dilutions, seawater for reactions/dilutions, and groundwater mixing (groundwater from varied on-Site potential sources) followed by testing similar to in-situ treatability titrations
- In-situ soil treatment (mixing) tests on bulk soil samples using acetic acid, citric acid, hydrochloric acid, nitric acid, sulfuric acid, phosphoric acid, ferrous sulfate, and sodium bisulfate, and recording pH measurements, volume/concentrations of reagent needed to neutralize pH, TDS, and dissolved silica in porewater, and other observations (i.e., drying, gelling, solidification, etc.)
- Geochemical modeling to determine whether laboratory results could be simulated with a model

2.1.22 Production Well Investigation (2009-2010)

Preliminary investigation activities to locate and assess the Former Production Well were performed between August 19, 2009 and December 2, 2009. Work Plans for this investigation were approved by USEPA and Ecology on March 16, 2010 (Phase I) and May 20, 2010 (Phase II). Field activities for the investigation began on March 15, 2010, were completed on August 23, 2010, and included:

- Installation of 4 groundwater monitoring wells in a cluster adjacent to the Production Well
- Collection of undisturbed soil samples and groundwater samples during the installation of the deepest monitoring well
- Conducting geophysical borehole logging of the deepest well in the cluster
- Collection of groundwater samples from the 4 newly installed monitoring wells, 4 existing monitoring wells, the Production Well, and the nearby Buffelen Production Well
- Completion of a hydraulic monitoring event to evaluate the potential influence of the deep artesian aquifer on shallow groundwater due to the Production Well
- Analysis of groundwater samples for isotopic ratios of 18O and 2H, major, minor, and trace ion geochemical parameters

2.1.23 Comprehensive Supplemental Investigation (CSI) (2012-2014)

USEPA and Ecology provided preliminary approval on January 26, 2012 for installation of 8 multichannel monitoring wells, conditional approval on April 16, 2012 for remaining field tasks, and final approval on July 26, 2012. Drilling activities began on February 14, 2012 and were completed on October 2, 2012, with remaining field activities completed in January 2014. Activities associated with the CSI included:

- Installation of 22 multi-channel monitoring wells (CMT wells) and permanent transducers to monitor groundwater and hydraulic properties in the 25-, 50-, 75-, 100-, 130-, and 160-ft zones
- Installation of permanent transducers within the geologic unit approximately 30 ft below the glacial contact to monitor hydraulic properties in glacial deposits
- Installation of 11 standard monitoring wells to supplement the existing monitoring network
- Installation of 46 soil borings in suspected potential source areas for VOCs and pH, and in WMUs L and M
- Collection of soil samples and groundwater grab samples from soil borings for chemical analysis, as well as collection of soil samples for geotechnical analysis

- Installation of 2 subtidal borings to obtain groundwater density data in the vicinity of subtidal piezometer WW-A1 and collection of groundwater and soil grab samples for chemical analysis
- Collection of groundwater samples from existing and newly installed monitoring wells
- Analysis of groundwater and soil samples for VOCs, SVOCs, PCBs, metals, dioxins/furans, polychlorinated naphthalenes, mineralogy, geochemistry, acetylene, field parameters, and/or specific gravity
- Expansion of the monitoring network on the 709/721 Alexander Avenue properties with 34 boreholes and 32 monitoring wells and analysis of soil and groundwater samples for petroleum-related compounds in addition to Site COCs
- Completion of the Event 3 Hydraulic Monitoring Program over the course of a 14-week period to update the groundwater flow models
- Collection of seawater samples from the Waterway, Blair Waterway, and Commencement Bay for geochemical analysis

2.1.24 Extraction Well Pilot Test Investigation (2013-2014)[iii]

USEPA and Ecology provided approval of the *Extraction Well Pilot Test Installation (EWPT) Work Plan* (CRA, 2013a) on June 18, 2013. The objectives of the EWPT Work Plan were to: partly fill recently identified data gaps concerning the spatial distribution and migration of dense non-aqueous phase liquid (DNAPL) and the pH, anthropogenic density plume (ADP), and chlorinated volatile organic compound (CVOC) plumes; aid in the assessment of VOC potential source zones; and, aid in the evaluation of treatment technologies in the FS. The field activities commenced on June 18, 2013~~ and were completed on January 21, 2014~~. Activities associated with the EWPT Work Plan included:

- The installation and development of two test extraction wells (EXT-7 and EXT-9) in areas of high CVOC concentrations
- The installation and development of three monitoring well nests (near EXT-9 and location F and G)
- The advancement and sampling of two soil borings for DNAPL screening at locations A and B
- Collection of soil samples for pH and selected CVOC analysis
- Collection of groundwater grab and monitoring well samples for pH, density, and selected CVOC analysis
- Performance of Geokon transducer field calibration checks at 11 locations in the 130-ft and 160-ft zones

The remaining activities to be completed under the EWPT Work Plan are the performance of step-drawdown and constant-rate pumping tests on EXT-7 and EXT-9.

2.1.25 Soil Vapor Intrusion Investigation (2013)

USEPA provided approval on February 22, 2013 for collection of 17 sub-slab vapor and 21 indoor air samples at nine buildings on and in the vicinity of the OCC Site, referred to as round one. The purpose of the investigation was to conduct a Tier II Assessment of the vapor intrusion pathway, as described in the Washington State Department of Ecology's (Ecology's) Review Draft *Guidance for Evaluating Soil Vapor Intrusion in Washington State: Investigation and Remedial Action* (Draft VI Guidance) (Ecology, 2009), and in accordance with the USEPA's interim final Vapor Intrusion Framework (USEPA, 2009). The Tier II Assessment involves characterizing vadose zone soil vapor and indoor air quality, and determining whether volatile organic compounds (VOCs) are present in soil vapor, and ultimately and more importantly, in indoor air at sufficient concentrations to potentially pose a risk to occupants. Installation activities for sub-slab soil probes began on March 26, 2013, and sample collection was completed April 26, 2013. Activities associated with the Soil Vapor Investigation round one included:

- Installation of 17 sub-slab soil probes in buildings throughout the Site with potential for vapor intrusion
- Collection of 17 sub-slab vapor samples using Summa canisters
- Collection of 17 indoor air samples using Summa canisters at each sub-slab sample location
- Collection of 3 additional indoor air samples at locations of potential VOC sources which could not be eliminated and at 1 location where no sub-slab sample could be collected
- Collection of 9 outdoor air samples using Summa canisters upwind from indoor air/sub-slab sample locations
- Analysis of sub-slab, indoor air, and outdoor air samples for VOCs

Round two sampling plan was approved by USEPA on June 11, 2013, which included collection of 9 sub-slab vapor and 17 indoor air samples at five building of the nine previously sampled buildings. The purpose of the investigation was to quantify potential variability of sample results over time and to compare with Round one data. Sample collection was completed July 9, 2013. Activities associated with the Soil Vapor Investigation round two included:

- Collection of 9 sub-slab vapor samples using Summa canisters
- Collection of 9 indoor air samples using passive samplers at each sub-slab sample location

- Collection of 8 additional indoor air samples using passive samplers at locations of potential VOC sources which could not be eliminated
- Collection of 4 outdoor air samples using passive samplers upwind from indoor air/sub-slab sample locations
- Analysis of sub-slab, indoor air, and outdoor air samples for VOCs

Round three sampling plan was approved by USEPA on March 12, 2014, which included collection of 18 sub-slab vapor and 33 indoor air samples at five building of the nine previously sampled buildings. The purpose of the investigation was to conduct sampling during the heating season (cold weather) to account for potential temporal variation of sub-slab vapor concentrations. Sample collection was completed March 21, 2014. Activities associated with the Soil Vapor Investigation round three included:

- Collection of 18 sub-slab vapor samples using Summa canisters
- Collection of 18 indoor air samples using Summa canisters at each sub-slab sample location
- Collection of 10 additional indoor air samples using Summa canisters at locations of potential VOC sources which could not be eliminated
- Collection of 5 additional indoor air samples using passive samplers at one indoor air sample location in each building
- Collection of 8 outdoor air samples using Summa canisters upwind from indoor air/sub-slab sample locations
- Collection of 6 additional outdoor air samples using passive samplers at selected outdoor air sample locations
- Analysis of sub-slab, indoor air, and outdoor air samples for VOCs

2.2 Previous Cleanup Actions

2.2.1 TCE/PCE Process Closure

The TCE/PCE process, which ceased operation in 1973, was dismantled in 1979. In 1980 and 1981, after the decommissioning of the TCE/PCE process, an extensive soil sampling and analytical program was conducted to delineate the extent of soil in the vadose zone containing chlorinated organics at concentrations greater than 150 milligrams per kilogram (mg/kg). These soils were excavated in 1981 and disposed of off Site. The analytical data from soil analyses in this area were previously submitted to USEPA/Ecology and were most recently summarized in the "Draft Work Plan, Focused Remedial Investigation/Feasibility Study," dated August 2002 and are also described in the "Compilation of Soils and Related Data" dated January 1999.

Approximately 1,850 cubic yards (cy) of soil were removed during this program. The excavation was backfilled with clean soil. The excavation project was conducted under the oversight of Ecology. Ecology field inspection reports are presented in the letter from J. Oberlander (Ecology) to L. Feller (OCC) dated June 16, 1981. Additional soils were removed from the TCE/PCE process area and disposed off Site in 1993/1994 during the construction of the groundwater treatment plant.

2.2.2 Waste Management Units

Seventeen WMUs were historically located on the Facility property. The locations of the WMUs, and the chemicals associated with them, are shown on Figure 1.4.

Prior to and subsequent to the Facility-wide RFI (referred to as RFI-I), OCC identified and characterized the WMUs at the facility. Where feasible to reduce their continued impact to Site groundwater, OCC implemented soil removal programs for closure of numerous WMUs. Descriptions and the activities or closures associated with the WMUs are as follows:

WMU A: WMU A was used as a settling pond for the effluent from the former TCE/PCE process. The effluent contained a slurry of lime, calcium chloride, and organics. A RCRA closure of WMU A was not conducted because the area predates the RCRA requirements; however, after the decommissioning of the TCE/PCE process, but prior to OCC's RCRA Application, the solids in the pond were removed and disposed of off Site.

In 1980, soil sampling and analyses were conducted within and surrounding the former WMU A on two occasions. The analytical data resulting from these soils analyses were previously submitted to USEPA/Ecology and were most recently summarized in the "Draft Work Plan, Focused Remedial Investigation/Feasibility Study" dated August 2002.

WMU B: WMU B, which was also known as Railcar Storage Area TC2, contained acid/organic waste from the chlorine plant stored in railroad tank car(s). USEPA and Ecology approved a clean closure of WMU B in 1995 without any soil removal activities. The certification of closure was presented in the letter from T. Vasko (OCC) to R. Smith (USEPA) and B. Warren (Ecology) dated March 9, 1995. A letter presenting "Verification of Closure for Rail Storage Area TC2" was sent from L. Wilhelm (Ecology) to M. Wassmann (OCC) April 19, 1995. The closure was based upon soils analytical data, which demonstrated that none of the chemicals being analyzed for were present in the soils at concentrations which exceeded the Model Toxic Control Act (MTCA) Method B values. These analytical data were previously submitted to USEPA/Ecology and were most recently summarized in the "Compilation of Soils and Related Data, Corrective Action Monitoring Program" dated January 1999.

WMU C: WMU C is a former landfill located at the north end of the Facility embankment along the Waterway. The landfill was used between 1949 and 1971 for disposal of unused lime and calcium chloride. Soil samples were collected and analyzed from WMU C in 1993, 1994, and 1996. The WMU C soils analytical data were previously submitted to USEPA/Ecology and were most recently summarized in the "Summary of Previous Investigations" dated March 2004.

WMU D: WMU D consisted of drainage ponds for the TCE/PCE manufacturing process. A RCRA closure of WMU D was not conducted. However, after the decommissioning of the TCE/PCE process, but prior to OCC's RCRA Application, the solids in the pond were removed and disposed of off Site. The excavation was conducted under the oversight of Ecology. Ecology field inspection reports are presented in the letter from J. Oberlander (Ecology) to L. Feller (OCC) dated June 16, 1981.

In 1980, soil sampling and analyses were conducted within and surrounding former WMU D in conjunction with the decommissioning of the TCE/PCE process. The analytical data resulting from these soils analyses were previously submitted to USEPA/Ecology and were most recently summarized in the "Draft Work Plan, Focused Remedial Investigation/Feasibility Study" dated August 2002.

WMU E: WMU E, located within the limits of WMU A, was used as a drum storage area and was closed in conjunction with WMU A. There are no records of soil sampling conducted within the limits of WMU E.

WMU F: WMU F was the location for barges used in the settling out of the slurry from the TCE/PCE manufacturing process (see description of WMU A above). WMU F is located within the limits of the Area 5106 Sediment remediation area.

WMU G: WMU G was used as a settling pond for the effluent from the TCE/PCE manufacturing process (see description of WMU A above). The contents of the pond were removed and disposed of off Site prior to OCC's RCRA Application. The salt pad, which has an asphalt base, was then constructed over the location of WMU G. There are no records of soil sampling conducted in this area prior to the recent investigations.

WMU H: WMU H consisted of a series of settling ponds for the effluent from the TCE/PCE manufacturing process (see description of WMU A above) and was used between 1949 and 1952. When the ponds were decommissioned, the contents were removed and disposed of off Site. Remaining soils above the water table were excavated during the TCE/PCE process closure to the depth of the water table surface and disposed of off Site. Analytical soil samples were collected from three locations within WMU H in 1996. The WMU H soils analytical data were previously submitted to USEPA/Ecology and were most recently summarized in the "Summary of Previous Investigations" dated March 2004.

WMUs I and J: WMU I and WMU J, also known as Railcar Storage Area TC3 and TC1, respectively, contained organic waste from the chlorine plant stored in railroad tank cars. A clean closure of WMU I and WMU J was approved by USEPA and Ecology in 1990 without any soil removal activities. The certification of closure was presented in the letter from B. Moore (OCC) to C. Findley (USEPA) and H. Steeley (Ecology) dated May 1, 1990. A provisional approval of the closures was provided in the letter from H. Steeley (Ecology) to B. Moore (OCC) dated August 20, 1990. The criterion for clean closure of these units was that analyte concentrations in all samples be lower than Site-specific background. The analytical data resulting from these soils analyses were previously submitted to USEPA/Ecology and were most recently summarized in the "Draft Work Plan, Focused Remedial Investigation/Feasibility Study" dated August 2002.

WMU K (Elementary Neutralization Unit): WMU K was used between approximately 1929 and 2002 for the neutralization of sulfuric acid with sodium hydroxide in the chlorine caustic process. Between 1929 and 1988, WMU K was located in the hot well trench west of injection well F-10. In 1988, an additional neutralization unit was added in the chlorine/caustic process area. (Both locations of WMU K are shown on Figure 1.4). No organic chemicals are associated with the unit. There are no records of soil sampling conducted in these areas.

WMU L: WMU L, also known as the Graphite Pile, was used from 1978 to 1980 to store graphite wastes generated by the breakdown of S-3 electrolytic cells. These wastes included halogenated hydrocarbons, lead, and carbon. There are no records of soil sampling conducted in this area.

WMU M: WMU M was used as an intermittent graphite pile from 1950 through 1978 to store graphite wastes generated by the breakdown of S-3 electrolytic cells. These wastes included halogenated hydrocarbons, lead, and carbon. There are no records of soil sampling conducted in this area.

N Landfill: The N Landfill was used from 1929 through 1971. This landfill received various plant process solid wastes, including corrosives, chlorinated organics, and lead. A characterization of the N Landfill was conducted in 1996 during the investigation referred to as the "PRI Source Identification Program." Soil samples were collected during the N Landfill characterization. The analytical data resulting from these soils analyses were previously submitted to USEPA/Ecology and were most recently summarized in the "Summary of Previous Investigations" dated March 2004.

WMU O: WMU O was used as a sodium aluminate pit from 1959 through 1960. Wastes stored within this pit included sodium hydroxide, sodium aluminate, and aluminum oxide. There are no records of soil sampling conducted in this area.

WMU P: WMU P, which was also known as the Waste Pile Area, was located adjacent to WMU Q. The waste pile was in a completely enclosed building authorized to store 40 cubic yards (cy) of solid regulated waste. Materials stored within the building originated from the renewal of the S-3 graphite anode electrolytic cells used in producing hydrogen and chlorine gases and sodium hydroxide solution from the electrolysis of a sodium chloride solution. The waste materials consisted of waste graphite (carbon) blades, butts, and stubs contaminated with lead and halogenated hydrocarbon residues, lead dross, and sealing mastic. The criterion for clean closure of WMU P was that analyte concentrations in all samples be lower than Site-specific background. Soils that did not meet the closure criteria were excavated and disposed of off Site. Confirmatory sampling was conducted following completion of the excavation. USEPA and Ecology approved a clean closure of WMU P in 1990. The certification of closure was presented in the letter from B. Moore (OCC) to C. Findley (USEPA) and H. Steeley (Ecology) dated May 1, 1990. A provisional approval of the closure was provided in the letter from H. Steeley (Ecology) to B. Moore (OCC) dated August 20, 1990. The analytical data resulting from these soils analyses were previously submitted to USEPA/Ecology and were most recently summarized in the "Draft Work Plan, Focused Remedial Investigation/Feasibility Study" dated August 2002.

WMU Q: WMU Q, which is also known as the Drum Storage Area, was used since the end of 1980 to store regulated wastes. Drums and other portable containers were stored in the designated container (drum) storage area located in the southwest portion of the Facility. Wastes potentially stored in the drum storage area could have included: chlorinated hydrocarbons, carbon tetrachloride, 1,1,1-trichloroethane, sodium hydroxide, sodium chloride, lab packs, contaminated clothing, spent graphite electrode blades, butts, mastic, lead dross, halogenated hydrocarbon contaminated residues, waste asbestos, electrostatic precipitator filter media, lead contaminated soils, corrosive solids, brine filter cake, and calcium chloride filter cake. Clean closure of WMU Q was certified by Ecology in the letter from L. Wilhelm (Ecology) to M. Wassmann (OCC) dated August 1, 1995 ("Verification of Closure for Drum Storage Area"). The closure was based upon soils analytical data, which demonstrated that none of the chemicals being analyzed for were present in the soils at concentrations which exceeded the MTCA method B values.

709 Alexander Avenue

WMUs are not known to have been present on the 709 Alexander Avenue property; however, storage tanks and transfer facilities related to petroleum handling operations were present.

Historical Site features on 709 and 721 Alexander Avenue are shown on Figure 1.6. Aboveground petroleum storage tanks were cleaned in 1989, and all tanks were removed from the property between 1989 and 1997. Structures associated with the topping plant were removed in 1985. Solid wastes associated with the former N Landfill extended into the berm area along the Waterway at the east end of the 709 Alexander Avenue property.

2.2.3 Groundwater Treatment and Containment System

The groundwater remedy selection for the Facility was conducted pursuant to the requirements of the Joint Permit for the Storage of Dangerous Waste (Permit), WAD009242314, dated November 1988. Based on the RFI-I, the Permit was modified to include the basic requirements for the groundwater remediation system. These requirements and the Permit condition in which they are contained included:

1. The type of system (V.D.1)
2. Performance criteria (V.D.1. i through iii)
3. Design parameters (V.D.2 through V.D.7)
4. Quality of injection water (V.D.10, modified August 26, 1996)
5. Groundwater cleanup standards (Tables 8 or 9 of the Permit)

Subsequently, OCC designed and constructed a groundwater remediation system consisting of groundwater extraction, treatment, and injection. Figure 2.2 presents the locations of the groundwater remediation system including treatment plant, extraction system, injection system, and the monitoring wells. OCC has operated the system in accordance with the Corrective Action Plan (CAP) since 1996. Potentiometric surface maps, drawn using monitoring data from monitoring wells as well as injection and extraction wells, have been used historically to evaluate the effectiveness of the hydraulic barrier to prevent upland contaminated groundwater from discharging into the Waterway. ~~OCC and the Agencies have agreed that certain requirements relating to the Corrective Action Plan (CAP) and Corrective Action Monitoring Plan (CAMP) shown in Section 3 of the Amendment to the Agreed Order on Consent for Removal Activities Embankment and Area 5106, are held in abeyance by Ecology until the RI/FS process has been completed. During this period, Occidental Chemical Corporation will continue to maintain and operate the groundwater treatment and extraction system at historical rates of extraction until a new extraction/treatment system has been designed and implemented under a new agreed order or consent decree.~~

2.2.4 Area 5106 Removal Action

On September 29, 1989, a Record of Decision (ROD) was issued by USEPA for the Commencement Bay Nearshore/Tideflats (CB/NT) Superfund Site, which includes the Waterway. As required by the ROD, the Hylebos Cleanup Committee (HCC) conducted Hylebos Waterway Pre-Remedial Design (PRD) activities to provide additional information for implementation of the ROD. The PRD activities included the collection and analysis of sediment samples from the Waterway in 1994, including one sample (described as very soft and gelatinous with a pH of 9.4) from a location identified as Station 5106. This location is downstream from the 11th Street Bridge, in the area known as the mouth of the Waterway, and about 100 ft into the Waterway from the bank of the former OCC Facility. The analytical results from the Station 5106 sample showed a mixture of chlorinated organic chemicals totaling about 0.65% with PCE at 0.32% and TCE at 0.16% as the principal constituents. Additional samples taken in the vicinity of Station 5106 confirmed the earlier sample results. The test results indicated that the sediments in the vicinity of Station 5106 were not appropriate for disposal with the remainder of the Waterway sediments under any of the disposal options being considered in the PRD Study and, therefore, needed to be addressed independently.

In November 1997, USEPA and OCC Tacoma entered into an AOC (Docket No. 10-97-0011-CERCLA) to address the sediments in the vicinity of Station 5106, hereafter referred to as Area 5106 Sediment, as a non-time-critical removal action under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) and the National Oil and Hazardous Substances Pollution Contingency Plan (NCP). The AOC also addressed the embankments of the properties at 605 and 709 Alexander Avenue, referred to as the Embankment Area. However, the embankment chemistry and concentrations, the recommended removal action, and its implementation schedule were substantially different from that outlined for the Area 5106 Removal Action. Therefore, the Embankment Area Removal Action was addressed separate from the Area 5106 Removal Action.

The scope of the Area 5106 Removal Action was to address sediment with different chemical constituents and concentration than those found in surrounding Waterway sediment and that, if removed, would require treatment prior to disposal. As such, the Sediment Quality Objectives (SQOs) specified under the ROD did not establish the criteria for the removal action. Sediment that remained following the Area 5106 Removal Action, which exceeded SQOs but did not require treatment, was to be addressed in accordance with the ROD as part of the Waterway remedial action.

Dredging, treatment, and dewatering of Area 5106 Sediment began on October 15, 2002 and continued until February 28, 2003. The treated, dewatered sediment was stockpiled at the treatment site until the construction of the Slip 1 Confined Disposal Facility (CDF) was completed. Placement of the treated sediment into the Slip 1 CDF began on January 23, 2003 and continued until March 28, 2003. Both the dredging and placement activities were extended beyond the planned February 15, 2003 completion date with the approval of USEPA and the resource agencies. In total, over 36,000 cy of Area 5106 Sediment and underlying native sediments were removed from the Waterway and treated prior to disposal in the Slip 1 CDF under USEPA oversight. The areal limits of the Area 5106 dredging are shown on Figures 1.4 and 2.1.

The entire Area 5106 dredging area was dredged to or below the design dredging elevations defined by the Area 5106 Sediment characterization pre-confirmatory sampling and analysis. All Area 5106 Sediment was therefore removed and treated prior to disposal into the Slip 1 CDF. Confirmation sampling, however, indicated that there was chlorinated organic contamination within the underlying native sediments. OCC presented a summary of the dredging compliance data in the Preliminary Completion Report for Area 5106 Dredging submitted to USEPA on March 10, 2003.

In a letter to OCC dated March 25, 2003, USEPA acknowledged the work completed and directed OCC to perform additional response actions pursuant to Sections X and XII of the Area 5106 UAO then in effect. In response, OCC submitted a Draft Post-Treatment Work Plan for Area 5106 Removal Action to USEPA on April 23, 2003. The Work Plan was revised based on USEPA comments and approved by USEPA on August 1, 2003. The approved Post-Treatment Work Plan included activities required to:

1. Characterize the sediment remaining within the areal limits of the Area 5106 dredging
2. Prepare an alternatives analysis report that will evaluate dredging or capping options based on the characterization and other pertinent factors
3. Recommend the appropriate alternatives and how those alternatives would be incorporated into the Segment 5 cleanup and/or the Embankment Area Removal Action

The Work Plan focused upon the relatively flat-bottom portion of Area 5106, where additional information was needed to make informed decisions about the Segment 5 Waterway dredge cuts within and around Area 5106. USEPA agreed that the additional data needed to adequately characterize sediment contamination within the steeply sloping portion of Area 5106 could be deferred and later incorporated into a Work Plan which would address both the steeply sloping portion of Area 5106 and the adjoining portion of the Embankment Area.

Subsequent to the approval of the Post-Treatment Work Plan, OCC and USEPA agreed to combine and integrate the Site's remedial activities/projects into the AOC, as amended to add

Ecology in 2005. Consequently, only the characterization activities within the relatively flat portion of the Area 5106 were performed. They are presented in Section 3.3 of this report.

2.2.5 Hylebos Waterway Cleanup Actions

The Waterway is a Class B Waterway, located within the POT, Washington. Flow from the Waterway is into Commencement Bay, located in the south Puget Sound. The Waterway was subdivided into five segments, and Waterway cleanup was completed in several phases. OCC and the POT jointly completed Segments 3, 4, and 5, as well as a portion of Segment 1, of the Hylebos Waterway Cleanup (described as the Mouth of the Hylebos).

The Mouth of the Hylebos Problem Area SOW included completing remedial design and remedial actions (RD/RA) in Segments 3, 4, and 5 and portions of Segment 1 of the Waterway (collectively referred to as the Mouth of the Hylebos Waterway Problem Area). The SOW also addressed all activities associated with the construction, filling, completion, operation and maintenance of the Nearshore Confined Disposal (NCD) Facility located at the Port of Tacoma's Slip 1. This SOW did not address activities in and/or adjacent to Segment 5 of the Waterway that are being performed under the Occidental Site AOC as amended February 2005.

The Mouth of the Hylebos Waterway Problem Area, located within the CB-N-T Superfund Site in Pierce County, Washington, is shown on Figure 1.1. Segment 5 included the area within the Waterway north of the East Eleventh Street Bridge. Segments 3 and 4, and a few parcels in Segment 1, are located within the Waterway south of the East Eleventh Street Bridge.

Segments 3, 4, and 5 were part of a comprehensive package of activities designed to remediate sediments from the Mouth of the Hylebos Waterway CERCLA area. The Waterway is part of the CB-N-T Site. The primary chemicals detected in the Waterway included hexachlorobenzene (HCB), hexachlorobutadiene (HCBD), polychlorinated biphenyls (PCBs), polyaromatic hydrocarbons (PAHs), and various metals and other organic chemicals.

Phase I of the Mouth of the Hylebos project was completed in February 2003, and consisted of construction of a Stage I containment berm for a Nearshore Confined Disposal Facility (NCD), on the Blair Waterway in the POT. Designated as Slip 1, Phase I NCD construction consisted of demolition and disposal of two existing piers, dredging of unsuitable foundation material at the mouth of the Slip, and construction of a containment berm up to an elevation of -5 ft mean lower low water (MLLW). Approximately 36,000 cy of treated sediments from the Area 5106 Removal Action were disposed of into the NCD through March 2003.

Phase II, initiated in July 2003, consisted of dredging sediments from Segment 5 of the Waterway, and placement via barge disposal into the Slip 1 NCD. Dredging of 254,000 cy of sediment was completed by February 2004.

The NCD facility had the capacity to allow for disposal of additional dredged sediments from areas not located within the Segments 3, 4, and 5 project areas. An additional 119,000 cy of sediment were received from other cleanup projects in the POT, including cleanup of the Middle Waterway, by the Middle Waterway Action Committee (MWAC), and cleanup of the Manke Lumber Yard area (Manke), located in Segment 1 of the Waterway.

Segment 5 also contained sediments that were approved for dredging and disposal at the Department of Natural Resources Disposal Site in Commencement Bay pursuant to the Puget Sound Dredged Disposal Analysis Program (PSDDA). Approximately 151,000 cy of dredged material were disposed of at the PSDDA open-water disposal site through February 2004.

As part of Phase III in 2004-2005, the Stage II berm was constructed from elevation -5 ft MLLW to +14 ft MLLW. This provided closure of the NCD from the Blair Waterway. To facilitate future placement of sediments into the NCD, a temporary transloading facility was constructed and operated to transfer sediments from barges on the Blair Waterway to a barge located within the NCD facility.

An additional 223,000 cy of sediments were dredged from Segments 3 and 4 of the Waterway and disposed of at the Slip 1 NCD. Work during this period included the disposal of sediments from other sources, with MWAC disposing of an additional 1,500 cy, and approximately 90,000 cy of sediment dredged by American Construction at their new facility, located at the former Taylor Way Properties, in Segment 4 of the Waterway. Work also included the demolition and disposal of miscellaneous pier and piling debris, slope reconstruction, collection of confirmation samples, and completion of the containment berm and Slip 1.

At the completion of disposal of all dredged sediments, additional capacity remained within the NCD, and a filling operation was completed to bring the elevation of fill in the Slip up to grade for the construction of the Primary Cap. Approximately 631,000 cy of dredged sediments were disposed at the Slip 1 NCD and approximately 270,000 tons of fill material were placed to bring the fill to grade. To construct the Primary Cap, an additional 213,000 tons of imported material and 31,000 cy of former buttress material were placed. The Primary Cap was completed in August 2005, prior to the POT's planned terminal expansion at Slip 1.

Completion of dredging activities was verified with confirmation sampling. Confirmation sediment sampling was also used to verify whether or not additional dredging or in-situ capping was required.

Figure 2.3 presents the post-dredging survey for the Mouth of the Hylebos Cleanup Action.

Section 3.0 Physical Characteristics

This section of the SCR provides a description of the physical characteristics of the Site and surrounding areas. This information provides the basis for the evaluation of potential contaminant transport pathways and receptor populations. In addition, the Site physical characteristics are important in the development and screening of remedial alternatives.

3.1 Climate

The Site lies within the Puget Sound Lowland at the northern end of the Puyallup River Valley. Figure 3.1 shows the Site location within the Puget Sound Lowlands. The Puget Sound Lowland climate is a mid-latitude humid, Pacific Coast marine climate, which is characterized by moderated summer and winter temperatures and a distinct winter precipitation season and summer dry season. Mean annual precipitation throughout the entire Puget Sound Lowland is 74 inches per year, and approximately 80% of the precipitation falls during October through March (Vaccaro et al., 1998). In general, precipitation is greater than the mean at high altitude regions within the Puget Sound Lowland, and lower than the mean at low altitude regions within the Puget Sound Lowland. The Site is located within the POT, and the mean annual precipitation (1971-2000) for the Tacoma area is estimated to be approximately 38.9 inches per year (National Oceanic and Atmosphere Administration, 2007). This is lower than the mean annual precipitation of 74 inches over the entire Puget Sound Lowland.

3.2 Regional and Site Physiography

3.2.1 Regional Physiography

The Puget Sound Lowland is bordered to the north by the Fraser River in British Columbia, Canada, the Cascade Range to the east, and the Olympic Mountains to the west. Towards the south, the boundary of the Puget Sound Lowland is approximately defined by the southern extent of Pleistocene glaciation. Figure 3.1 presents the location and features of the Puget Sound Lowland.

The Puget Sound Lowland includes alluvial river valleys with glacial outwash and till plains, referred to as "drift plains," which are separated from bordering mountains by uplands with hills and terraces. The transition from lowland valleys to upland drift plains is abrupt in some areas, and typified by steep bluffs. Altitudes of lowland valleys range from sea level to approximately 500 ft above sea level. Upland altitudes range from about 500 ft to 1,500 ft above sea level.

3.2.2 Site Physiography

The Site is located within the POT at the mouth of the Puyallup River Valley. Figure 3.2 presents the topography of the POT and immediately surrounding area, and shows Puget Sound Bluffs (Bluffs) that surround the POT and the mouth of the Puyallup River Valley. The Site is located at the eastern edge of the POT on the peninsula between the Hylebos and Blair Waterways. The Bluffs are present just east of the Site, and rise approximately 350 ft above the ground surface at the Site peninsula.

The POT consists of five man-made peninsulas that were developed in the early 1900s by dredging to create navigable waterways. The dredged materials were used to create the peninsulas. The waterways were dredged through the natural tidal mud flats that existed at the mouth of the Puyallup River Valley. Figures 3.3 and 3.4 show the Site location relative to POT pre-development and post-development conditions, respectively.

The Site peninsula is relatively flat with an elevation of approximately 11.7 ft National Geodetic Vertical Datum (NGVD) (18 ft MLLW[6]). The embankment around the Site peninsula drops off steeply from the upland areas to the bottom of the Hylebos and Blear Waterways with horizontal to vertical slopes that typically range from 2:1 to 1:1.

The bottom of the Waterway is relatively flat at an elevation of approximately -35 ft MLLW (-41 ft NGVD), and consists primarily of silty sediments. Portions of the Waterway, however, have been dredged during the Hylebos Waterway Cleanup and the Area 5106 Removal Action to elevations as deep as approximately -41 ft MLLW (-47 ft NGVD). Along the east side of the Waterway, the bottom slopes up more gradually, becoming a tidal mud flat within the Puyallup Tribe of Indian's property. Bathymetric plots of the Waterway are presented on the USB drive attached as Appendix D.

Figure 3.5 shows the bathymetry of Commencement Bay beyond of the Site peninsula and POT. Figure 3.5 shows that Commencement Bay extends to depths of over 500 ft.

The ground surface on the Site peninsula is generally covered with structures, concrete pads, and asphalt paving. Small areas of gravel and vegetation also are present. Figure 3.6 shows the Site peninsula surface characteristics. The structures within the Former OCC Facility (605) and Mariana Properties (709) have been demolished and removed from the Site, leaving the

---

[6] The conversion between ft MLLW and ft NGVD is: ft NGVD = ft MLLW – 6.32 ft.

roadways, concrete foundation and floor slabs. Only the buildings and structures related to the existing groundwater treatment system remain.

Utilities present on the Site include storm sewers, sanitary sewers, municipal water, power, and communication. Most are located underground, although some, particularly power and communication, are above ground. Components of the extraction and injection systems associated with the existing groundwater remediation system including concrete access vaults, underground piping and underground electrical conduits, are located across the northern portion of the Site.

There are three active docks (Pier 25, Dock 1, and Dock 2) located along the embankment. These docks extend from the top of the embankment, approximately 75 ft to the property line. In addition, there are two inactive docks located at the south end of the embankment. The surface cover of the embankment, from the top of bank to approximately -5 ft MLLW (-11 ft NGVD), consists of primarily of concrete rubble and crushed rock riprap. Debris consisting of brick, slag, and carbon graphite anodes is also present on portions of the embankment. The subtidal portion of the embankment, from -5 ft MLLW (-11 ft NGVD) to the bottom of the slope, consists of silty sediments along with some debris that has fallen from the upper portions of the embankment slope.

3.3 Regional and Site Hydrology

3.3.1 Regional Hydrology

The Site lies within the Puyallup-White Water Resource Inventory Area (WRIA), which is comprised of the Puyallup River, Carbon River, and White River Watersheds. The extent of WRIA 10 is presented on Figure 3.7. The Site is located at the endpoint of the Puyallup River Watershed. The Puyallup River Watershed originates at Mount Rainier (approximately 14,410 ft above sea level) and the Puyallup River flows towards Commencement Bay (at sea level).

The Puyallup River begins in two forks: the North Puyallup River and the South Puyallup River; both forks originating at glaciers on Mount Rainier (Puyallup Glacier and Tahoma Glacier, respectively). These two headwater streams join to form the Puyallup River proper. The main Puyallup River flows north and northwest from Mount Rainier. Along its course, the Puyallup River receives inflow from two main rivers:

- The Carbon River, which also flows from glaciers on Mount Rainier, joins the Puyallup downstream of the City of Orting
- The White River, another glacier-fed river, joins the Puyallup at the City of Sumner

At the White River confluence, the Puyallup River turns northwest, flowing through the cities of Puyallup and Fife, before emptying into Commencement Bay at the POT.

The Puyallup River Watershed is divided into two main portions: the Upper Puyallup River Watershed, which extends from Mount Rainier to approximately Puyallup; and the Lower Puyallup River Watershed, which extends from Puyallup to Commencement Bay.

The uplands opposite the Site that form the eastern bank of the Waterway lie within the Hylebos Creek and Puget Sound Drainages (see Figure 3.7). Hylebos Creek originating in the City of Federal Way, is comprised of three main tributaries, and ultimately flows into the head of the Waterway. The Puyallup River and Hylebos Creek represent regional groundwater discharge features. However, the interaction of the two regional features with groundwater originating from the Site is limited.

3.3.2 Site Hydrology

The Waterway, Blair Waterway, and Commencement Bay surround the Site peninsula and are the primary Site hydrologic features. Surface water drainage from the Site and adjacent properties is primarily by catch basins and storm sewers, with some limited overland flow to the waterways or Commencement Bay. Precipitation that falls on the treatment plant is collected and treated by the treatment system. Precipitation that falls on the remainder of the Site is collected through a series of catch basins and storm sewers ultimately discharging to the Waterway under a Stormwater Discharge Permit.

Tidal fluctuations in the Waterway, Blair Waterway, and Commencement Bay have a significant influence on the Site groundwater flow system. The tidal fluctuations create transient groundwater flow conditions. Depending on the tidal stage, groundwater flow may be directed from the surface water bodies towards the groundwater system (i.e., high tide), or groundwater flow may be directed towards the surface water bodies (i.e., low tide). The tides of Puget Sound are characterized as a mixed semidiurnal tide cycle, in which two high and two low tides of different size occur during each tidal day of 24 hours and 50 minutes (Lincoln, 2000). The maximum amplitude of the tidal fluctuations at the Site varies through approximately 10 to 14 ft, and the maximum amplitude occurs in the transition from lowest to highest tide.

Commencement Bay and the Hylebos and Blair Waterways that surround the Site peninsula contain salt water with an average specific gravity of approximately 1.022 (or density of 63.77 pounds per cubic foot [lbs/ft^3]). Conductivity profiling in the Hylebos and Blair Waterways conducted by USEPA (1990) shows that salt water is present over the full length of both the Hylebos and Blair Waterways. The specific gravity of sea water in the oceans throughout the world is approximately 1.025. Due to the influence of fresh surface water runoff and shallow fresh groundwater discharge, the salt water in Commencement Bay and the Hylebos and Blair Waterways is somewhat less dense than typical sea water. Fresh groundwater has a specific gravity of 1.0 (or density of 62.4 lbs/ft^3). The density difference between salt water and fresh groundwater results in the development of fresh groundwater and salt water distributions within the Site groundwater flow system. The concept of fresh groundwater and salt water distributions is described further in Section 3.4.2 in conjunction with the regional hydrogeology.

3.4 Regional Geology and Hydrogeology

3.4.1 Regional Geology

The geologic framework and stratigraphy for the Puget Sound Lowland have been described within several regional-scale reports, as referenced herein. Most of the available information is derived from the interpretation of data from boreholes and exposed stratigraphic sections located on-shore, with limited regional information available within Puget Sound.

The major geologic features in the Puget Sound Lowland and nearby highlands were formed by regional geologic processes including the tectonic convergence of the continental North American Plate with the oceanic Pacific and Juan de Fuca Plates. The tectonic plate convergence and subsequent subduction of the oceanic plates in the Cascadia subduction zone has resulted in the formation of the Olympic Mountains, Puget Sound Lowland, and the Cascade Range. Also associated with the plate convergence are folding and faulting of strata, and volcanism (Jones, 1999).

Within the Puget Sound Lowland, downwarping and faulting of the crust allowed the accumulation of nearly 2,000 ft of unconsolidated sedimentary deposits in the Tacoma area. During the Tertiary Period (approximately 65 to 1.8 million years ago), thick layers of marine and volcanic deposits accumulated in the Puget Sound Lowland. These deposits are found beneath the younger Quaternary Period (approximately 1.8 million years ago to present) glacial and interglacial units and the post-glacial units which form the geologic units of interest at the Site.

The Puget Sound Lowland was subjected to a series of glacial advances and retreats. At least four major glacial advances and several partial advances have occurred (Jones, 1999). These major and partial glacial advances grew from the Cordilleran ice sheet in southwestern British Columbia and from alpine glaciers within the Cascade Range of Washington State that moved into the Puget Sound Lowland. Glacial deposits typically contain (in order of deposition): advance outwash sand and gravels; glacial till (hard and poorly sorted mixture of clay, silt, sand, and gravel) and ice-contact deposits; and recessional outwash sand and gravels at the top of the sequence. The four glacial advances and retreats deposited a series of geologic units, which are partially preserved and exposed in the areas above sea level. The most recent glacial advance, the Vashon Stade of the Fraser Glaciation, scoured a channel into the pre-Vashon sediments along the Puyallup River Valley. The channel scoured into the pre-Vashon sediments is in-filled by post-Vashon sediments, referred to here as deltaic deposits. The deposition of the deltaic deposits occurred at varying rates and under varying stream flow and sea level conditions, resulting in a series of sand units with interbedded and interfingered silt and clay units with occasional gravelly sand units. These units are often gradational from one to the other laterally and/or vertically. Figure 3.8 shows a conceptual model of the regional geology in the Site vicinity.

Morgan and Jones (1996) developed a generalized regional geologic framework for the Puget Sound Lowlands that is reproduced on Figure 3.9. This framework is directly applicable to the Puyallup River Valley and Bluffs in the Site vicinity, and is consistent with the conceptual model of regional geology shown on Figure 3.8. A major stream valley is depicted on the west side of the section consisting of alluvial deposits (Qal), similar to the Puyallup River Valley. The Bluffs rise steeply to the east of the stream valley and consist of a sequence of older glacial deposits. The older glacial deposits were scoured away within the Puyallup River Valley during the last glacial advance.

Three regional studies of geologic conditions within the Puyallup River Valley and Bluffs key to the Site are:

- *Geology of the Port of Tacoma* (Hart Crowser & Associates, Inc. [Hart Crowser], 1975)
- *Hydrogeologic Analysis of the Federal Way Area* (Robinson & Noble, Inc. [Robinson & Noble], 1992)
- *Hydrogeologic Framework, Groundwater Movement, and Water Budget in the Chambers-Clover Creek Watershed and Vicinity, Pierce County, Washington* (Savoca et al., 2010)

Cross-Sections I-I', II-II', and A-A' developed by Hart Crowser (1975) pass through the Site peninsula, and are reproduced on Figures 3.10, 3.11, and 3.12, respectively. The key aspects shown on these cross-sections are:

- Deltaic deposits consisting of variable layers of sand and silt exist within the Puyallup River Valley extending into Commencement Bay

- Glacial deposits form the east and west walls of the Puyallup River Valley on Figure 3.10, and appear on the west side of the Puyallup River Valley on Figure 3.11
- Fill was placed on the tidal mud flats to develop the waterways and form the POT peninsulas
- Commencement Bay on the west side of Cross-Section I-I (Figure 3.10) is approximately 200 ft deep, and Commencement Bay extends to depths of over 500 ft to the north of the POT, as shown on Figure 3.5

The Hart Crowser (1975) cross-sections (Figures 3.10, 3.11, and 3.12) are consistent with the conceptual model of regional geology shown on Figure 3.8, and the generalized regional geologic framework of Morgan and Jones (1996) shown on Figure 3.9.

Robinson & Noble (1992) conducted a hydrogeologic study of the Bluffs in the Federal Way area east of the Site. Robinson & Noble (1992) developed cross-sections through the Bluffs east of the Site, as presented on Figure 3.13. Cross-Section B-B' approaches the Site, and is reproduced on Figure 3.14. The Bluffs are shown to be heterogeneous, consisting of a sequence of glacial and interglacial sedimentary units with widespread presence of glacial till, outwash sands, and gravels. Consistent with Morgan and Jones (1996) and Hart Crowser (1975), Cross-Section B-B' shows a buried valley wall extending downward from the Bluffs where the pre-Vashon sediments within the Puyallup River Valley were scoured.

Savoca et al. (2010) developed hydrogeologic cross-sections through the Chambers-Clover Creek Watershed and vicinity in Pierce County, approximately 8 to 10 miles south of the Site. The northern portion of the Savoca et al. (2010) study area includes the Puyallup River Valley and much of the POT area. The locations of cross-section in the general vicinity of the Site are presented on Figure 3.15. The eastern limit of Cross-Sections E-E' and F-F' extend into the Puyallup River Valley south of the Site, and are reproduced on Figure 3.16. Cross-Section E-E' ends just west of the Site and Cross-Section F-F' ends approximately 4 miles south of the Site.

On Cross-Section F-F', Savoca et al. (2010) interpret a sequence of aquifers and aquitards under the Bluffs (i.e., Aquifer Unit C/Confining Unit D/Aquifer Unit E) consistent with Robinson & Noble (1992). However, Savoca et al. (2010) continue these units beneath the Puyallup River Valley, which is not consistent with the glacially scoured channel of Morgan and Jones (1996) and Hart Crowser (1975). The characteristics of the deltaic deposits observed in the Site borings suggest that the sequence of aquifers and aquitards within the pre-Vashon sediments under Bluffs may not extend into the Puyallup River Valley, as annotated on Figure 3.16.

The regional cross-sections suggest the continuous presence of low permeability glacial material throughout the POT area. In the Site vicinity, as shown on Figure 3.16, the

Savoca et al. (2010) Cross-Section E-E' positions the top surface of a confining unit (i.e., Unit D) consisting lower permeability glacial material at approximately -200 to -300 ft NGVD in the Puyallup River Valley. To investigate this further, a review was conducted of stratigraphic logs for regional boreholes available within the POT area for evidence of the presence/absence of lower permeability glacial material. Stratigraphic logs for deep regional borings were available from the following sources:

- Logs contained in the Washington State Department of Ecology Water Well Log Database (http://apps.ecy.wa.gov/welllog/)
- Logs provided in Walters and Kimmel (1968)
- Logs made available by the POT

The regional stratigraphic logs are included in Appendix E.

The review of the regional stratigraphic logs for the presence/absence of low permeability glacial material was separated into boreholes extending from -150 to -300 ft NGVD, presented in Table 3.1, and boreholes extending below -300 ft NGVD, presented in Table 3.2. The regional stratigraphic logs are for boreholes completed as water wells. It is noted that the level of detailed geologic observations in the stratigraphic logs for these water wells is limited, which is common for stratigraphic logs completed by water-well drillers. However, the geologic conditions that are noted in stratigraphic logs for these regional boreholes are useful for identifying the regional presence/absence of low permeability glacial material in the POT area.

The review of regional stratigraphic logs extending from -150 to -300 ft NGVD is summarized on Figure 3.17 where locations are identified as having low permeability glacial material present, not present, or possibly present. Figure 3.17 demonstrates that low permeability glacial material is commonly observed in the southwestern portion of the POT, but not in the northeastern portion of the POT or in the Site vicinity. Thus, in the -150 to -300 ft NGVD elevation interval, regional evidence of a continuous low permeability glacial material beneath the POT area is not conclusive.

The review of regional stratigraphic logs extending below -300 ft NGVD is summarized on Figure 3.18 where locations are identified as having low permeability material present that is either glacial or non-glacial in origin. Similar to the -150 to -300 ft NGVD elevation interval, Figure 3.18 demonstrates that low permeability glacial material is commonly observed in the southwestern portion of the POT, but not in the northeastern portion of the POT, or in the Site vicinity. However, low permeability material of non-glacial origin is frequently observed in the southern portion of the Hylebos/Blair peninsula but mostly below -400 ft NGVD. The regional geologic data suggest that glacial deposits exist at depth beneath the Puyallup River Valley, but that it is likely a heterogeneous mixture of both lower and higher permeability material.

3.4.2 Regional Hydrogeology

The regional hydrogeologic conditions in the Site vicinity have been the subject of numerous studies for over 40 years. The various studies that are directly applicable to the Site, either through investigations including at or near the Site, or through generalized conceptual models that are directly applicable to Site and vicinity conditions include:

- *Ground-Water Occurrence and Stratigraphy of Unconsolidated Deposits, Central Pierce County, Washington (Walters and Kimmel, 1968)*
- *Reconnaissance of Sea-Water Intrusion Along Coastal Washington, 1966-68, State of Washington (Walters, 1971)*
- *Hydrogeologic Analysis of the Federal Way Area, Washington (Robinson & Noble, 1992)*
- *Numerical Model Analysis of the Effects of Ground-Water Withdrawals on Discharge to Streams and Springs in Small Basins Typical of the Puget Sound Lowland, Washington (Morgan and Jones, 1996)*
- *Hydrogeologic Framework of the Puget Sound Aquifer System (Vaccaro, et al., 1998)*
- *Geologic Framework for the Puget Sound Aquifer System, Washington and British Columbia (Jones, et al., 1999)*
- *Hydrogeologic Framework, Groundwater Movement, and Water Budget in the Chambers-Clover Creek Watershed and Vicinity, Pierce County, Washington (Savoca, et al., 2010)*

These reports pertain to areas of the Puget Sound Lowlands in the Site vicinity, and are referred to below relative to regional hydrogeologic conditions within the Puget Sound Lowland, Puget Sound Bluffs, and Puyallup River Valley.

Puget Sound Lowland

The Site is located within the Puget Sound Lowland aquifer system. This aquifer system is described in numerous reports, including Vaccaro et al. (1998) and Morgan and Jones (1996). The lateral extents of the Puget Sound Lowland aquifer system are presented on Figure 3.19. Vaccaro et al. (1998) present a detailed description of the hydrogeologic setting and a conceptual hydrogeologic model that is generally applicable to any area within the Puget Sound Lowland aquifer system (including in the vicinity of the Site). The key aspects of the Puget Sound Lowland aquifer system include:

- Classification of the aquifer system into four main types of units: glacial and interglacial aquifers, semi-confining units, confining units, and alluvial valley aquifers.
- The bedrock forms both the lateral and basal boundaries of the aquifer system.
- The primary source of groundwater is through recharge from infiltrating precipitation on the drift plains and alluvial valleys, and from glacial and snowpack melt-water occurring on the mountain ranges surrounding the Puget Sound Lowland.
- Groundwater flow is generally horizontal within coarse-grained aquifer units, and primarily vertical within semi-confining and confining layers.
- Groundwater flow does not occur on a regional scale within the Puget Sound Lowland; rather, groundwater flow occurs on a more localized basis within smaller basins in the Puget Sound Lowland associated with flow towards and discharge to major alluvial valleys.
- Groundwater flow is generally downwards on the drift plains, and generally upwards in the alluvial valleys, with groundwater discharge to upland fresh water rivers.
- Approaching the salt water bodies, such as the Hylebos and Blair Waterway, Commencement Bay, Puget Sound, etc., fresh groundwater from upland areas flows upwards to discharge at shallow depths to the salt water bodies. The shallow fresh groundwater discharge to the salt water bodies tends to occur above salt water zones extending inland from the salt water bodies.

Vaccaro et al. (1998) suggest that within the Puget Sound Lowland, groundwater flow must be considered on the basis of smaller, localized flow regimes due to the heterogeneous and discontinuous nature of the unconsolidated deposits. This is consistent with the approach employed by Walters and Kimmel (1968) in a study of the groundwater occurrence and stratigraphy of unconsolidated deposits in Central Pierce County, described further relative to the Puyallup River Valley.

Puget Sound Bluffs

Like the Puget Sound Lowland, the Bluffs have a heterogeneous geologic composition and stratigraphy. Much of Bluffs in general, including east of the Site, consist of a sequence of glacial and interglacial sedimentary units. The Bluffs also have a widespread presence of glacial till, and outwash sands and gravels that were deposited by streams that drained the advancing and retreating ice sheets (Johannessen and MacLennan, 2007).

Robinson & Noble (1992) identified a series of aquifers within their Layer 4 (see Figure 3.14) immediately east of the Site consisting of highly permeable soils, which they referred to as the North Shore Aquifers. Figure 3.20 shows the location of the North Shore Aquifers in plan view. As shown on Figure 3.20, the North Shore Aquifers are interpreted to extend to the upper portion of the Puyallup River Valley in their Layer 4. Robinson & Noble (1992) indicated that the North Shore Aquifers may consist of upper and lower zones.

As described further in Section 3.6, Site borings advanced along the eastern shoreline of the Waterway extended into the buried valley wall extending down from the Bluffs. These borings encountered permeable sands and gravels, similar to glacial outwash deposits, at upper and lower depths separated by lower permeability silts and clays. These observations are consistent with the presence of the North Shore Aquifers interpreted by Robinson & Noble (1992).

Puyallup River Valley

In their study of the groundwater occurrence and stratigraphy of unconsolidated deposits in Central Pierce County, Walters and Kimmel (1968) delineated several groundwater regions, as shown on Figure 3.21. The Site lies within the Lower Puyallup River Valley Region, as delineated by Walters and Kimmel (1968), which approximately coincides with the lower Puyallup River Valley.

Walters and Kimmel (1968) reported that the alluvial deposits in the Puyallup River Valley are underlain by a thick sequence of alternating fine- and coarse-grained sediments. Walters and Kimmel (1968) reported further that wells tapping the deeper sequence of sediments yielded flows rates commonly approaching 1,000 gallons per minute (gpm), with some yielding flows as high as 2,400 gpm, and some wells exhibiting artesian conditions.

Artesian conditions throughout the State of Washington were historically documented by Molenaar (1961). The greatest number of artesian flowing wells is located within Pierce and King Counties, and many of them occur in Site vicinity. Wells located near the base of upland slopes and beach bluffs or along valleys tend to exhibit artesian conditions. Such hydrogeologic conditions have provided large flows (300 to 1,500 gpm) from wells drilled to depths of 600 ft to 1,200 ft along the bluffs in Pierce County, which includes the Site (Molenaar, 1961). Molenaar (1961) developed a generalized concept of artesian conditions within the Straits-Puget basin that is presented on Figure 3.22. Artesian conditions occur in areas where low permeability geologic units exist to confine and pressurize underlying high permeability water-bearing aquifers, as illustrated on Figure 3.22. The confined aquifers build in pressure due to confined inflow from upland areas, and artesian flow results when they are penetrated by wells.

Molenaar (1961) presents a map of historical flowing artesian wells throughout Washington State, which is reproduced as Figure 3.23. A review of this map indicates that the Lower Puyallup River Valley has one of the highest densities of flowing artesian wells in all of

Washington State. Figure 3.24 presents an enlargement of Figure 3.23 showing the Site and surrounding areas. Figure 3.24 shows a high concentration of flowing artesian wells in the vicinity of the Site. Figure 3.25 provides a more detailed representation of historical artesian wells that surround the Site, as described by Griffin et al. (1962).

Regional groundwater flow in the alluvial aquifer along the Puyallup River Valley has been characterized by Savoca et al. (2010) and is presented on Figure 3.26. The alluvial aquifer is depicted on the Savoca et al. (2010) Cross-Sections E-E' and F-F' presented on Figure 3.16. Based on the groundwater elevations and flow directions presented on Figure 3.26, groundwater flow in the alluvial aquifer is generally toward Commencement Bay, coincident with the direction of surface water flow in the Puyallup River, and horizontal hydraulic gradients decrease toward Commencement Bay. The generalized groundwater flow patterns in glacial and interglacial aquifers are complicated by the presence of low permeability confining units that separate discontinuous aquifers and act as local barriers to groundwater flow. A large proportion of groundwater that makes its way down the Puyallup River watershed discharges to the Puyallup River, local streams, springs, and waterways, or is withdrawn from wells before reaching the proximity of the Site.

The density difference between salt water in Commencement Bay and the POT waterways and fresh groundwater results in the development of fresh groundwater and salt water distributions within the groundwater flow systems adjacent to these surface water bodies. Commencement Bay and the Hylebos and Blair Waterways that surround the Site peninsula contain salt water with an average specific gravity of approximately 1.022 (or density of 63.77 lbs/ft^3). Conductivity profiling in the Hylebos and Blair Waterways conducted by USEPA (1990) shows that salt water is present over the full length of both the Hylebos and Blair Waterways. Fresh groundwater, with a specific gravity of 1.0 (or density of 62.4 lbs/ft^3), discharges into these surface water bodies, as shown schematically on Figure 3.27, after Barlow (2003). Part A of Figure 3.27 shows fresh groundwater discharge to a salt water body for a relatively homogeneous aquifer, and Part B of Figure 3.27 shows fresh groundwater discharge to a salt water body influenced by aquifer heterogeneities. The locations where fresh groundwater discharges along the salt water margins are controlled by the hydraulic pressure and fresh groundwater flow rate in the aquifer, the thickness and hydraulic properties of the aquifer and adjacent confining units, and the relative densities of salt water and fresh groundwater, among other variables. Fresh groundwater tends to remain above the salt water zones because of its lower density, although in heterogeneous or multilayered aquifer systems, fresh groundwater can discharge upward through lower permeability units into overlying salt water, as shown on Part B of Figure 3.27.

The fresh groundwater and salt water zones are separated by a transition zone within which there is mixing between fresh groundwater and salt water, as shown on Figure 3.27. The width of these transition zones varies, but may be on the order of hundreds to over a thousand feet in coastal aquifers (Barlow, 2003). The transition zone width depends on the amount of mixing between the fresh groundwater and salt water that occurs within the aquifer. This mixing is caused by geologic heterogeneities and by dynamic forces that operate over a range of time scales, including daily fluctuations in tide stages, seasonal and annual variations in groundwater recharge rates, and long-term changes in aquifer groundwater elevations and sea level positions. These dynamic forces cause the fresh groundwater and salt water zones to move seaward at times and landward at times (Barlow, 2003).

The inland presence of salt water is limited where the fresh groundwater hydraulic heads are sufficiently high, such as along the Bluffs, to balance the inland-directed salt water pressures within a short distance inland from the shoreline. In the Puyallup River Valley, where lower fresh groundwater hydraulic heads exist, salt water can be present to a considerable distance inland. The influence of the fresh groundwater and salt water distributions on the Site groundwater flow system is described further in Section 3.6.

The extent of inland salt water within the Puyallup River Valley historically was studied by Walters (1971). Chloride content in groundwater was used as a principal indicator for the presence of salt water. The study identified that in most areas the native fresh groundwater had a chloride concentration of less than 10 milligrams per liter (mg/L). Chloride concentrations (in mg/L) indicative of salt water approach values in the several thousands. Walters (1971) reported that salt water extended 1.5 miles (2.4 km) inland from Commencement Bay in the alluvium and marine deposits beneath the Puyallup River Valley. The interaction between salt water and fresh groundwater near the salt water bodies in the Site vicinity is described further in Section 3.6.

In summary, the key features of the regional hydrogeologic conditions within the Puyallup River Valley and Bluffs in the Site vicinity include:

- Regional surface water and groundwater flow through the Puyallup River Valley discharges to Commencement Bay
- Shallow groundwater discharges to rivers, creeks, and waterways as they extend through the Valley
- Groundwater within the Puyallup River Valley is replenished by regional upland groundwater inflow into the Valley and by precipitation infiltration
- Regional groundwater flow within the Bluffs above ground level at the Site peninsula discharges through seepage faces along the Bluffs

- Regional groundwater flow within the Bluffs below ground level at the Site peninsula discharges to the Puyallup River Valley groundwater flow system immediately adjacent to the Bluffs, and ultimately to the POT waterways/Commencement Bay
- Fresh groundwater and salt water distributions exist adjacent to the salt water bodies that are influenced by aquifer heterogeneities, hydraulic pressure and fresh groundwater flow rate in the aquifer, thickness and hydraulic properties of the aquifer and adjacent confining units, and relative densities of salt water and fresh groundwater, among other variables
- The fresh groundwater and salt water zones are separated by a transition zone within which there is mixing between fresh groundwater and salt water

3.5 Site Geology

3.5.1 Overview of Site Geology

Soil and sediment samples were collected during the installation of monitoring wells and advancement of boreholes while performing various subsurface investigations at the Site. Monitoring wells and boreholes have been advanced on the Site peninsula, beneath the Waterway, and along the eastern shoreline of the Waterway opposite the Site peninsula. Figures 3.28a/b present all the locations throughout the Site where geologic conditions have been observed and stratigraphic logs have been prepared.

Historically, monitoring well installation occurred to regular depths, generally grouped into seven aquifer depth zones representing nominal depths of 15, 25, 50, 75, 100, 130, and 160 ft BGS, forming individual zone grouping planes for each depth. The zone grouping planes are primarily used to describe Site hydrogeologic conditions in Section 3.6, and include:

- 15 ft BGS (0 ft NGVD), referred to as the 15-ft zone
- 25 ft BGS (-10 ft NGVD), referred to as the 25-ft zone
- 50 ft BGS (-35 ft NGVD), referred to as the 50-ft zone
- 75 ft BGS (-60 ft NGVD), referred to as the 75-ft zone
- 100 ft BGS (-85 ft NGVD), referred to as the 100-ft zone
- 130 ft BGS (-115 ft NGVD), referred to as the 130-ft zone
- 160 ft BGS (-155 ft NGVD), referred to as the 160-ft zone

The boreholes for more recent monitoring well installations at the Site extend below the 160-ft zone to a maximum depth of approximately 290 ft BGS. Boreholes extending below the 160-ft zone are highlighted on Figures 3.28a/b.

While advancing each borehole, the soil types encountered have been described and logged in accordance with the Unified Soil Classification System (USCS). Stratigraphic logs have been prepared for each location where soil samples were collected for geologic logging. The stratigraphic logs are included in Appendix F and in the e:Dat™ database in Appendix G. Site stratigraphic models have been developed in 3-D based on the stratigraphic logs, as described in Section 3.5.2.

Within the Puyallup River Valley, the primary geologic units identified in the Site borings consist of (from ground surface):

- Fill - variable mixture of sand, silt, and gravel material placed through dredging of the Hylebos and Blair Waterways to develop the Site peninsula
- Deltaic deposits - heterogeneous mixture of interbedded sands, silts, and clays deposited by deltaic processes within the channel scoured along the Puyallup River Valley during the last glacial advance
- Glacial deposits - heterogeneous mixture of interbedded gravel, sands, silts, and clays belonging to the pre-Vashon glacial stages that were scoured/overrode by the last ice advance

These geologic units are described further in Sections 3.5.3 to 3.5.4.

The results from the laboratory analysis of Site soil and sediment samples for soil physical properties were used to aid in characterizing the geologic units at the Site. Figure 3.29 shows the locations of the soil samples analyzed for soil physical properties. The soil and sediment samples were analyzed for one or more of the following soil physical properties:

- Grain size distribution, often including hydrometer analysis
- Density/specific gravity and bulk unit weight
- Moisture content
- Porosity
- Organic carbon content
- Vertical hydraulic conductivity
- Atterberg limits

Table 3.3 summarizes the soil physical properties results. The grain size distribution curves are included in the e:Dat™ database in Appendix G, and were used to confirm detailed stratigraphic picks from the Site stratigraphic logs used in the 3-D stratigraphic models developed for Site. In particular, the results for grain size distribution, dry bulk density, moisture content, porosity, fraction of organic carbon, and vertical hydraulic conductivity were used to aid in differentiating the glacial deposits from the overlying deltaic deposits. Atterberg liquid and plastic limits were used to better understand the nature of the lower permeability soil types. In general, higher plasticity fines would have lower hydraulic conductivity than non-plastic to low plasticity fines, due to the saturated swelling characteristics of the fines.

3.5.2 3-D Stratigraphic Models

The deltaic and glacial deposits are both highly heterogeneous, which precludes defining laterally continuous stratigraphic units within each deposit beneath the Site. However, 3-D stratigraphic models of the soil types observed in both the deltaic and glacial deposits were developed using the indicator kriging approach implemented in the Mining Visualization System/Environmental Visualization System (MVS/EVS) software package, developed by C Tech Development Corporation (CTech) (CTech, 2007). The 3-D stratigraphic models encompass the area over which boreholes have been advanced within the Site peninsula, Waterway, and along the eastern shoreline of the Waterway opposite the Site peninsula (see Figure 3.28a). The 3-D stratigraphic models extend to an elevation of -225 ft NGVD. Two 3-D stratigraphic models were developed: a detailed model based on the specific soil types observed within the deltaic and glacial deposits; and a simplified model based on lumping the soil types of both the deltaic and glacial deposits into four groups having similar hydraulic properties. The two stratigraphic models are described below.

Detailed 3-D Stratigraphic Model

The detailed 3-D stratigraphic model was developed using nine stratigraphic codes based on the various soil types observed in the deltaic and glacial deposits. The nine soil codes are based on soil texture (i.e., relative hydraulic conductivity) and depositional environment. Five stratigraphic codes (0 through 4, inclusive) pertain to the deltaic deposits, and four stratigraphic codes (5 through 8, inclusive) pertain to the glacial deposits. The nine stratigraphic codes and soil types within each code are summarized below.

Stratigraphic Code	***Soil Type Description***	***Estimated Hydraulic Conductivity (cm/sec)***
0	Clayey Silt (CL-ML)	3.0×10^{-5}
1	Sandy Silt (ML)	2.0×10^{-4}
2	Silty Sand (SM)	1.1×10^{-3}
3	Sand (SP or SW)	5.3×10^{-3}
4	Gravel (G or GW)	5.0×10^{-2}

Stratigraphic Code	***Soil Type Description***	***Estimated Hydraulic Conductivity (cm/sec)***
5	Low Permeability Glacial Material, referred to as "Low K Glacial" (Silty Gravel [GM])	5.0×10^{-5}
6	Medium Permeability Glacial Material, referred to as "Medium K Glacial" (SP/SM or GP/GW described as high density, some silt, and/or low moisture content, and corresponding to an elevation horizon where glacial-derived material was observed in adjacent boreholes)	5.0×10^{-4}
7	High Permeability Glacial Material, referred to as "High K Glacial" (SP/GP described as loose, absent silt, and/or high moisture content, and corresponding to an elevation horizon where glacial-derived material was observed in adjacent boreholes)	5.0×10^{-3}
8	ML corresponding to an elevation horizon where glacial material was observed in adjacent boreholes, referred to as "ML in Glacial"	2.0×10^{-4}

A 3-D visualization of the detailed stratigraphic model in the 4DIM viewer format is presented in Appendix H. Figures 3.30 to 3.35 show horizontal slices through the detailed stratigraphic model at the 25-ft, 50-ft, 75-ft, 100-ft, 130-ft, and 160-ft zone grouping planes, respectively. Figures 3.36 to 3.40 show vertical slices through the detailed stratigraphic model along Cross-Sections A-A', B-B', C-C', X-X', and Y-Y', respectively. Figure 3.28a shows the locations of Cross-Sections A-A', B-B', C-C', X-X', and Y-Y'. The horizontal and vertical slices through the detailed stratigraphic model are referenced in the description of the Site geologic units in Sections 3.5.3 to 3.5.5.

Simplified 3-D Stratigraphic Model

The simplified 3-D stratigraphic model was developed using four stratigraphic codes based on similarity in hydraulic properties and regardless of depositional environment. The simplified hydrostratigraphic model approach is documented in a memorandum provided in Appendix I. The simplified stratigraphic model was developed to form a basis for the hydraulic conductivity distribution assigned in the numerical groundwater flow model being developed for the Site.

The four stratigraphic codes and soil types within each code applied for the simplified stratigraphic model are summarized below.

Stratigraphic Code	***Soil Type Description***	***Estimated Hydraulic Conductivity (cm/sec)***
0	Clayey Silt, Silty Clay, Clay, Sandy Clay, and similar clayey materials (corresponds to stratigraphic codes 0 and 5 of the detailed stratigraphic model). Silt and Sandy Silt corresponding to a horizon where glacial-derived material was observed in adjacent boreholes (corresponds to stratigraphic code 8 of the detailed stratigraphic model)	3.0×10^{-5} to 2.0×10^{-4}
1	Sandy Silt, Silt, and very silty similar materials (corresponds to stratigraphic code 1 of the detailed stratigraphic model)	2.0×10^{-4}
2	Silty Sand, Silty Gravels (trace to no clay), and similar materials (corresponds to stratigraphic codes 2 and 6 of the detailed stratigraphic model)	5.0×10^{-4} to 1.1×10^{-3}
3	Sand, Sand and Gravel, Gravel, and similar materials (corresponds to stratigraphic soil codes 3, 4, and 7 of the detailed stratigraphic model)	5.0×10^{-3} to 5.0×10^{-2}

A 3-D visualization of the simplified stratigraphic model in the 4DIM viewer format is presented in Appendix H. Figures 3.41 to 3.46 show horizontal slices through the simplified stratigraphic model at the 25-ft, 50-ft, 75-ft, 100-ft, 130-ft, and 160-ft zone grouping planes, respectively. Figures 3.47 to 3.51 show vertical slices through the simplified stratigraphic model along Cross-Sections A-A', B-B', C-C', X-X', and Y-Y', respectively. The horizontal and vertical slices through the simplified stratigraphic model are referenced in the description of the Site geologic units in Sections 3.5.3 to 3.5.5.

3.5.3 Fill

Fill exists beneath the Site peninsula from ground surface to depths of approximately 10 to 16 ft BGS. The fill consists of a variable mixture of sand, silt, and gravel material placed through dredging of the Hylebos and Blair Waterways to develop the Site peninsula. Since the fill is comprised of material dredged from the deltaic deposits beneath the waterways, the fill and deltaic deposits have similar soil types and are not differentiated on the slices through the 3-D stratigraphic models.

As described in Section 3.2.2, the POT consists of five man-made peninsulas that were developed in the early 1900s by dredging to create navigable waterways. Prior to development, the POT was either a tidal marsh with a network of tidal estuaries, or tidal mud flats. As shown on Figure 3.4, the mud flats extended from approximately East Eleventh Street to the end of the POT at Commencement Bay. Under pre-development conditions, the mud flats would be exposed under the lowest tides. The material dredged from the waterways was placed on top of the mud flats as fill to create the peninsulas.

The mud flats consist of silts and clayey silts deposited during the last phase of delta formation at the mouth of the Puyallup River Valley. The mud flats are illustrated on the regional geologic cross-sections developed by Hart Crowser (1975) and presented on Figures 3.11 and 3.12. The mud flats have not been identified consistently in all borings advanced on the Site peninsula. This may be due to a lack of precision in the stratigraphic logs, or may be due to stream channels that could have incised the fine-grained sediments of the mud flats. As described further in Section 3.6, the mud flats are observed to create a hydraulic separation between the fill and the underlying deltaic deposits in the southern portion of the Site where detailed investigation of groundwater levels within the fill has been completed. Here, groundwater elevations in the fill are approximately 2 ft higher than groundwater elevations in the deltaic deposits immediately beneath the mud flats.

3.5.4 Deltaic Deposits

The horizontal and vertical slices through the detailed stratigraphic model illustrate the highly heterogeneous composition of both the deltaic deposits. The deltaic deposits are found immediately below the fill across the Site. They consist of a heterogeneous mixture of interbedded sands, silts, and clays. The thickness of the deltaic deposits across the Site ranges from approximately 30 to 200 ft in the eastern and northeastern portion of the Site to greater than approximately 300 ft in the southwestern portion of the Site.

As described in Section 3.4.1, the last glacial advance scoured a channel along the Puyallup River Valley. The deltaic deposits have in-filled this channel at varying rates and under varying stream flow and sea level conditions, resulting in a series of sand units with interbedded and interfingered silt and clay units with occasional gravelly sand units. These units exhibit a high degree of heterogeneity and are often gradational laterally and/or vertically, but can also change abruptly over short distances.

In the lower portion of the deltaic deposits, a reduced frequency of higher permeability soil types (i.e., sand) and a corresponding increased frequency of lower permeability soil types (i.e., silty sand, sandy silt, and clayey silt) is noted. This is best shown in the horizontal and vertical slices through the detailed stratigraphic model where the occurrence of the sand soil type (the orange shading on Figures 3.30 to 3.40) diminishes with depth as approaching the glacial deposits. A reduction in higher permeability soil types with depth is also apparent in the horizontal and vertical slices through the simplified stratigraphic model where the occurrence of sand and gravel (the brown shading on Figures 3.41 to 3.51) is reduced in the lower deltaic deposits. Note that deepest zones of sand and gravel apparent on the vertical slices through the simplified stratigraphic model (Figures 3.47 to 3.51) correspond to the glacial deposits.

3.5.5 Glacial Deposits

Glacial deposits underlie the deltaic deposits and consist of a heterogeneous mixture of interbedded gravel, sands, silts, and clays. The horizontal and vertical slices through the detailed stratigraphic model illustrate the highly heterogeneous composition of the glacial deposits. The thickness of the glacial deposits beneath the Site has not been determined, but based on regional information, is more than 1,000 ft. As described below, the top surface of the glacial deposits slopes downward to the north, west, and south from a mound observed under the central portion of the Site peninsula. The glacial deposits were not encountered at borings in the west, southwest, and south portion of the Site peninsula. The glacial deposits are inferred to dip downward in this area below the depth of the Site borings. The glacial deposits likely continue to dip downward towards the middle of the Puyallup River Valley consistent with the channel scoured along the Puyallup River Valley during the most recent glacial advance (i.e., the Vashon Stage of the Fraser Glaciation). The glacial deposits belong to pre-Vashon glacial stages that were scoured/overrode by the last ice advance.

The top surface of the glacial deposits (irrespective of glacial material type) was determined using the top of glacial material picks from historic and 2012 and 2013 CSI borings. A total of 116 boreholes were used to determine the top surface of the glacial deposits, including 80 historic boreholes, 28 2012 CSI boreholes, and 8 2013 CSI boreholes. The borehole logs were reviewed for evidence of glacially-derived materials, which include: presence of gravel, color change to grays and greens from typical brownish colors, change in mineralogy including the loss of the commonly found red and white sand grains (from locally derived sediments), the absence of marine shell fragments, and the absence of wood fragments.

A total of 22 CSI borehole logs intersected glacially-derived materials, at elevations ranging from -128.3 ft NGVD (41C) to -193.6 ft NGVD (MW-G-Deep). In addition, a total of 10 CSI borings in the south and southwest portion of the Site peninsula did not encounter glacially-derived materials. The location and elevation for the top of glacial deposits observations are presented on Figure 3.52. Contours for the estimated top surface of the glacial deposits are presented on Figure 3.52. The contours were developed using all borings with identified presence of glacially-derived materials, as wells as using the bottom elevation of all borings where glacially-derived materials were not encountered.

The glacial deposits are shallowest along the eastern portion of the Waterway where they extend downward from the bluffs. A high exists in the glacial deposits in the eastern-central portion the Site peninsula. From this high, the glacial deposits slope downward to the north, west, and south. A trough in the top surface of the glacial deposits is apparent in the northeastern portion of the Site peninsula that slopes to the northwest.

In the southern portion of the Site peninsula, three deep boreholes (46C, 93C, and 95C) did not encounter glacial deposits at elevations ranging from <-215.1 ft NGVD (95C) to <-276.6 ft NGVD (93C). In the southwestern portion of the Site peninsula, glacial deposits were not encountered at the two deep boreholes 85C and 92C (<-228.0 and <-279.3 ft NGVD, respectively). The top surface of the glacial deposits is inferred to dip downwards to the west and southwest of the Site peninsula towards the center of the glacially-scoured channel that extends along the Puyallup River Valley, consistent with the regional geologic conditions.

Similar to the top surface of the glacial deposits presented on Figure 3.52, the horizontal slices through the detailed stratigraphic model show the top of the glacial deposits progressively sloping downwards to the west from the Bluffs to under of the Waterway in the 25-ft to 100-ft zones (Figures 3.30 to 3.33), and extending beneath Site peninsula in the 130-ft and 160-ft zones (Figures 3.34 and 3.35). The top of the glacial deposits continues to dip downwards to the west and southwest to below the 160-ft zone. A similar trend in the top of the glacial deposits is evident along Cross-Sections A-A' to C-C' (Figures 3.36 and 3.38). The trough in the top surface of the glacial deposits in the northeast portion of the Site peninsula shown on Figure 3.52 is evident in this area on Cross-Sections A-A' and B-B' (Figures 3.36 and 3.37).

3.5.6 Conceptual Site Geologic Model

Figure 3.53 shows the conceptual geologic conditions for the Puyallup River Valley and Bluffs in the Site vicinity based on the Site geologic conditions described above and the regional geologic conditions described in Section 3.4.1. Within the Puyallup River Valley, the generalized geologic conditions consist of fill, deltaic deposits, and glacial deposits. The fill is comprised of the material dredged to create the Hylebos and Blair Waterways and placed on top of the tidal mud flats to create the Site peninsula. The mud flats are colored dark brown on Figure 3.53 where the hydraulic separation between the fill and deltaic deposits is observed in the southern portion of the Site, and a lighter brown where this hydraulic separation is not confirmed.

Within the Bluffs, Figure 3.53 shows an alternating sequence of sand/gravel and silt/clay layers based on the regional geologic conditions described in Section 3.4.1. A buried valley wall is shown to extend downward from the Bluffs to beneath the eastern portion of the Waterway, consistent with the generalized regional geologic framework developed by Morgan and Jones (1996) and shown on Figure 3.9. On Figure 3.53, the buried valley wall is truncated at the top of the glacial deposits. The glacial deposits are shown to extend beneath the Bluffs consistent with the interpretation by Savoca et al. (2010) that deeper geologic units beneath the Bluffs continue beneath the Puyallup River Valley, as shown on Figure 3.16. It is possible that the Bluffs geologic units interpreted by Savoca et al. (2010) were scoured away during the last glacial period, and the glacial deposits under the Site are more recent than what exists beneath the Bluffs. In this case, the buried valley would continue to a greater depth than is shown on Figure 3.53, consistent with Morgan and Jones (1996), and the glacial deposits under the Site would truncate at the buried valley wall. However, knowing the actual vertical extent of the buried valley wall is not critical to understanding the influence of the geologic conditions on groundwater flow conditions beneath the Site.

The top surface of the glacial deposits slopes downward to the north, west, and south from a mound observed under the central portion of the Site, as shown on Figure 3.53. The glacial deposits are not encountered at borings in the west, southwest, and south portion of the Site peninsula. Here, the glacial deposits are inferred to exist below the depth of the Site borings and dip downward towards the middle of the glacially scoured channel along the Puyallup River Valley.

The Site stratigraphic data indicate that there is an increased frequency of lower permeability lenses in the lower deltaic deposits that are comprised mainly of silt and clay. This is shown schematically on Figure 3.53. As described further in Section 3.6, the groundwater quality, density, and hydraulic evidence supports the concept that the increased frequency of lower permeability lenses limits vertical flow creating a zone of apparent confining effect in the lower deltaic deposits.

3.6 Site Hydrogeology

3.6.1 Overview of Site Hydrogeology

The hydrogeologic units at the Site correspond to the primary geologic units described in Section 3.5, as follows:

- Fill
- Deltaic deposits
- Glacial deposits

Groundwater flow within these units is complicated by several factors, including:

- Heterogeneous stratigraphy
- Tidal fluctuations
- Fresh groundwater and salt water distributions
- Anthropogenic density plume (ADP) caused by releases of lime sludge and solvent residue (dense non-aqueous phase liquid [DNAPL]) to the settling ponds and settling barge, sodium hydroxide (caustic soda) through caustic production/storage/handling, and brine (sodium chloride) from operating the Salt Pad

- Density-dependent groundwater flow
- Regional fresh groundwater inflow from beneath the Bluffs east of the Site and from the south along the Puyallup River Valley
- Historical mud flats beneath the Site peninsula
- A zone of apparent confining effect in the lower portion of the deltaic deposits that overlies the glacial deposits

Each of these complexities is described further in Section 3.6.2, and Section 3.6.3 presents the Conceptual Site Model (CSM) of the Site hydrogeologic conditions that accounts for these complexities. A summary of the hydraulic monitoring, hydraulic testing, and investigations of groundwater/surface water interaction conducted at the Site that support the CSM is presented in Section 3.6.4.

The CSM forms the basis for developing the 3-D groundwater flow model for the Site that will be used to aid in the evaluation of remedial alternatives for the Site. The development of the groundwater flow model will be presented in the Model Calibration Report to be prepared subsequent to this SCR.

3.6.2 Groundwater Flow Complexities

3.6.2.1 Heterogeneous Stratigraphy

As described in Section 3.5, both the deltaic and glacial deposits are highly heterogeneous. As a result, laterally continuous stratigraphic units cannot be defined. The high degree of heterogeneity is illustrated on the horizontal and vertical slices through the detailed stratigraphic model developed for the Site presented in Section 3.5.2 (see Figures 3.30 to 3.40). Connection of the more permeable soil units does occur, and these provide preferential pathways for groundwater flow (and contaminant migration. The less permeable soil types form barriers to groundwater flow (and contaminant migration). The high degree of heterogeneity creates tortuous groundwater flow pathways that complicate the interpretation of groundwater flow directions and hydraulic gradients at the Site.

3.6.2.2 Tidal Fluctuations

As described in Section 3.3.2, tidal fluctuations occur in the Waterway, Blair Waterway, and Commencement Bay. The tide cycle is mixed semidiurnal where two high and two low tides of different size occur during each tidal day. The maximum amplitude of the tidal fluctuation varies through approximately 10 to 14 ft, and the maximum amplitude occurs in the transition from lowest to highest tide. Figure 3.54 shows an example of the typical tidal fluctuations in the Waterway adjacent to the Site.

The tidal fluctuations propagate inland and cause groundwater elevation fluctuations throughout the Site. Figure 3.54 shows an example of the typical groundwater elevation fluctuations observed at a Site monitoring well. The fluctuations in groundwater elevations create transient groundwater flow conditions. Depending on the tidal stage, groundwater flow may be directed from the surface water bodies inland (i.e., high tide), or groundwater flow may be directed towards the surface water bodies (i.e., low tide).

Due to the tidal fluctuations, it is not possible to collect manual groundwater elevation measurements across the Site monitoring well network that represent either an instantaneous condition across the Site, or more importantly, an average groundwater flow condition.

The tidally influenced groundwater level fluctuations are short-term transient conditions that are of little value in assessing bulk contaminant transport and overall Site remediation in the long-term. The rate and direction of groundwater flow at the Site, and thus bulk contaminant transport, must be resolved using average groundwater and surface water levels. Average groundwater levels are determined from groundwater levels measured across the Site monitoring well network using electronic pressure transducers and data recorders collecting data at five-minute intervals. Average groundwater and surface water levels are determined using the Serfes (1991) averaging method and approximately 3 days of recorded water level data. It is the average data that are used to assess groundwater flow rate and direction. Several hydraulic monitoring events have been conducted at the Site and the monitoring results are summarized in Section 3.6.4.

3.6.2.3 Fresh Groundwater and Salt Water Distributions

Section 3.4.2 describes the concept of fresh groundwater and salt water distributions in conjunction with the Puyallup River Valley regional hydrogeology. As described in Section 3.4.2, Commencement Bay and the Hylebos and Blair Waterways that surround the Site peninsula contain salt water with an average specific gravity of approximately 1.022 (or density of 63.77 lbs/ft^3). Conductivity profiling in the Hylebos and Blair Waterways conducted by USEPA (1990) shows that salt water is present over the full length of both the Hylebos and Blair Waterways. Fresh groundwater, with a specific gravity of 1.0 (or density of 62.4 lbs/ft^3), discharges into these surface water bodies, as shown schematically on Figure 3.27 (after Barlow, 2003).

The locations where fresh groundwater discharges along the salt water margins are controlled by the hydraulic pressure and fresh groundwater flow rate in the aquifer, the thickness and hydraulic properties of the aquifer and adjacent confining units, and the relative densities of salt water and fresh groundwater, among other variables. Fresh groundwater tends to remain above the salt water zones because of its lower density. The fresh groundwater and salt water zones are separated by a transition zone within which there is mixing between fresh groundwater and salt water, as shown on Figure 3.27. The inland presence of salt water is limited to where the fresh groundwater hydraulic heads are sufficiently high to balance the inland-directed salt water pressures. For example, along the Bluffs east of the Site, fresh groundwater hydraulic heads limit salt water to within a short distance inland from the shoreline. The heterogeneous stratigraphy and variable groundwater flow conditions create complex fresh groundwater and salt water distributions beneath the Site. The fresh groundwater and salt water distributions are further complicated by elevated groundwater densities associated with the ADP, as described in Section 3.6.2.4.

The presence of both salt water and fresh groundwater beneath the Site, as well as elevated groundwater densities associated with the ADP, creates density-dependent groundwater flow conditions that need to be accounted for when interpreting groundwater flow directions and hydraulic gradients. At sites where groundwater and surface water are all fresh, density-dependent groundwater flow is not a concern. Hydraulic gradients and groundwater flow directions are resolved based on groundwater level measurements. In environments with water of varying density, like this Site, the assessment of hydraulic gradients and groundwater flow direction needs to account for variations in groundwater density, as described in Section 3.6.2.5.

An evaluation was conducted of naturally occurring fresh groundwater and salt water distributions beneath the Site. The details of the evaluation are presented in Appendix J, and the evaluation results are summarized below.

The distribution of naturally occurring salt water beneath the Site was estimated based on calculating the percent salt water composition in Site groundwater samples using the concentrations of geochemical parameters detected in each sample. The geochemical parameters considered are those typically associated with ocean salt water, including: boron, bromide, calcium, chloride, iodide, magnesium, potassium, sodium, strontium, and sulfate. Of these parameters, only bromide could be reasonably assumed to not be influenced by anthropogenic releases from the Site or geochemical conditions resulting from anthropogenic releases. Thus, a salt water percentage in Site groundwater samples was calculated using mixing calculations based on bromide only, and these results were used to estimate fresh groundwater and salt water distributions in groundwater beneath the Site.

A 3-D model of the fresh groundwater and salt water distributions was developed using 3-D kriging implemented in the MVS/EVS software package. The natural salt water distribution data were kriged with control points placed along the bottom of the Waterway, Blair Waterway, and Commencement Bay. These control points were placed at -10 ft NGVD and -40 ft NGVD, and were assigned salt water percentages of 100% to eliminate the extrapolation of kriged salt water percentages of less than 100% into the known salt water bodies surrounding the Site. A 3-D visualization of the fresh groundwater and salt water distributions in the 4DIM viewer format is included in Appendix J. Figures 3.55 to 3.60 show horizontal slices through the 3-D model of the natural salt water distribution at the 25-ft, 50-ft, 75-ft, 100-ft, 130-ft, and 160-ft zone grouping planes, respectively. The horizontal slices indicate:

- In the 25-ft and 50-ft zones (Figures 3.55 and 3.56), fresh groundwater (<20% salt water) occurs in the middle of the Site peninsula. The fresh groundwater transitions to salt water percentages of >90% toward Commencement Bay and the Hylebos and Blair Waterways where the 25-ft and 50-ft zones intersect these salt water bodies.
- In the 75-ft zone (Figure 3.57), fresh groundwater occurs primarily under the southeastern portion of the Site peninsula. Beyond the southeastern portion of the Site peninsula, the fresh groundwater transitions to salt water percentages of >90% toward the Hylebos and Blair Waterways where the 75-ft zone passes just under these salt water bodies, and toward Commencement Bay where the 75-ft zone intersects this salt water body.
- In the 100-ft zone (Figure 3.58), three areas of fresh groundwater occur at 17C-100/PZ-SHI-3-75, 90C-100/91C-100, and WW-A1D-47. The fresh groundwater areas at 17C-100/PZ-SHI-3-75 and 90C-100/91C-100 appear to extend downward from the 75-ft zone. The fresh groundwater area at WW-A1D-47 lies below the top surface of the glacial deposits described in Section 3.5.4 and shown on Figure 3.52. As described further in Section 3.6.2.8, a zone of apparent confining effect is identified near the base of the deltaic deposits that hydraulically separates the upper deltaic deposits from the glacial deposits. In the glacial deposits beneath the Site peninsula, hydraulic pressures are typically greater than in the deltaic deposits, and groundwater is predominantly fresh. The zone of apparent confining effect, in combination with increased hydraulic pressures, prevents salt water from entering the glacial deposits. The >60 to >80% salt water on the east side of the Waterway (south of WW-A1D-47) is attributed to the lack of observed salt water percentage data points in this area. There is a transition to salt water percentages of >60 to >80% at the south end of the Site and toward the Blair Waterway on the west side of the Site peninsula.
- In the 130-ft zone (Figure 3.59), fresh groundwater occurs under the eastern portion of the Site peninsula and at WW-A1D-77. As for the 100-ft zone, the fresh groundwater area at WW-A1D-77 lies below the top surface of the glacial deposits and the zone of apparent confining effect. The fresh groundwater area surrounding 17C-130, 65-130, and 75-130 also lies below the top surface of the glacial deposits and the zone of apparent confining effect. This area corresponds to a mound in the top surface of the glacial deposits shown on Figure 3.52. The >40 to >50% salt water on the east side of the Waterway (south of WW-A1D-77) is attributed to the lack of observed salt water percentage data points in this

area. There is a transition to salt water percentages of >70 to >90% at the south end of the Site and toward the Blair Waterway on the west side of the Site peninsula.

- In the 160-ft zone (Figure 3.60), fresh groundwater occurs under the eastern and northeastern portions of the Site peninsula and. The fresh groundwater areas lie below the top surface of the glacial deposits and zone of apparent confining effect. The >90% salt water at WW-A1D-110 lies below the top surface of the glacial deposits and appears inconsistent with the fresh groundwater occurring at this location in the overlying 100-ft and 130-ft zones. However, the >90% salt water at WW-A1D-110 may be due to heterogeneous stratigraphy in this area providing a pathway for salt water migration to this depth beneath the overlying fresh groundwater. The area of >50 to >70% salt water on the east side of the Waterway (south of WW-A1D-110) is attributed to the lack of observed salt water percentage data points in this area, and the salt water distribution in this area is also influenced by the salt water percentage result at WW-A1D-110. There is a transition to salt water percentages of >70 to >90% at the south end of the Site and toward the Blair Waterway on the west side of the Site peninsula.

3.6.2.4 Anthropogenic Density Plume (ADP)

Historical Site operations resulted in releases of high density fluids to groundwater. The high density fluids consist of lime sludge and solvent residue (DNAPL) released to the settling ponds and settling barge, sodium hydroxide (caustic soda) released through caustic production/storage/handling, and brine (sodium chloride) released from operating the Salt Pad. The high density fluids and potential source areas for their release are described further in Section 5.2.

The high density fluids have resulted in a comingled plume of high density, referred to as the ADP, that under current conditions consists of specific gravity values ranging from >1.02 (density of >63.7 lbs/ft^3) to approximately 1.2 (density of 74.9 lbs/ft^3). The ADP has sank due to its higher density water relative to the density of fresh groundwater and salt water beneath the Site, and over time, has migrated away from its release areas via density-dependent flow (i.e., gravity-driven flow). While migrating downwards, the higher density plume displaced the fresh groundwater and salt water initially present beneath the release locations. The fresh groundwater and salt water displacement caused by the downward density plume migration created lateral groundwater flow that has contributed to the lateral spreading of the ADP, as well as the spreading of the impacted groundwater surrounding or comingled with the ADP.

The ADP, along with salt water, creates density-dependent groundwater flow conditions beneath the Site that further complicates interpreting groundwater flow directions and hydraulic gradients beneath the Site. Limited mixing occurs between the ADP, salt water, and fresh groundwater due to the density differences. The ADP is denser than salt water and has penetrated/displaced the salt water in some locations beneath the Site. Interpreting groundwater flow directions and hydraulic gradients must account for the density differences, as described further in Section 3.6.2.5.

The distribution of the ADP in groundwater beneath the Site was interpolated based on temperature corrected laboratory specific gravity measurements taken from groundwater samples collected at the Site during the CSI in 2012 and Subtidal/Hydraulic Investigation in 2005-2006. The specific gravity measurements were converted to density. The combined groundwater density data set used to interpolate the ADP is presented in Appendix K. The specific gravity temperature correction and conversion to density is described in conjunction with the evaluation of hydraulic monitoring data collected at the Site presented in Appendix L.

A 3-D model of the ADP, based on groundwater density, was developed using 3-D kriging implemented in the MVS/EVS software package. A 3-D visualization of the ADP in the 4DIM viewer format is included in Appendix K. Figures 3.61 to 3.66 show horizontal slices through the 3-D model of the ADP at the 25-ft, 50-ft, 75-ft, 100-ft, 130-ft, and 160-ft zone grouping planes, respectively. The primary potential source areas related to the high density fluid releases that comprise the ADP described in Section 5.2 are also shown on Figures 3.61 to 3.66. These primary potential source areas consist of the settling ponds and settling barge (WMUs C, F, G, and H) where lime sludge and solvent residue were placed, the caustic area where caustic production/storage/handling occurred, and the Salt Pad. The horizontal slices through the ADP indicate:

- In the 25-ft and 50-ft zones (Figures 3.61 and 3.62), the ADP is located under the Salt Pad and caustic potential source area, with an area of maximum density of 65-66 lbs/ft^3. A fresh groundwater density (<63 lbs/ft^3) is present in the middle of the Site peninsula in the 25-ft and 50-ft zones consistent with the fresh groundwater and salt water distributions for these zones shown on Figures 3.55 and 3.56. Precipitation infiltration over the Site peninsula provides fresh groundwater recharge to the shallow zones. A fresh groundwater density also occurs east of the Waterway due to fresh groundwater inflow from beneath the Bluffs into Puyallup River Valley.
- In the 75-ft zone (Figure 3.63), the ADP is located under the Salt Pad and caustic potential source area, with an area of maximum density of 67-68 lbs/ft^3. This area approximately corresponds to where there is an absence of salt water in the 75-ft zone along the eastern portion of the Site peninsula adjacent to the Waterway shown on Figure 3.57. Here, salt water may have existed prior to the release of the ADP, and the salt water might have been displaced by the ADP. Much of the remaining area under the Site peninsula has a density in the range of salt water (63-64 lbs/ft^3), which corresponds to the salt water distribution in

the 75-ft zone. A fresh groundwater density (<63 lbs/ft^3) is observed east of the Waterway due to fresh groundwater inflow from beneath the Bluffs into the Puyallup River Valley.

- In the 100-ft zone (Figure 3.64), the ADP is located under the Salt Pad and WMUs C, F, and H, with an area of maximum density of >69 lbs/ft^3. Much of the remaining area under the Site peninsula has a density in the range of salt water (63-64 lbs/ft^3), which corresponds to the salt water distribution in the 100-ft zone shown on Figure 3.57. The fresh groundwater area under the salt pad in the 100-ft zone shown on Figure 3.57 corresponds to the location of the ADP. Here, salt water may have existed prior to the release of the ADP, and the salt water might have been displaced by the ADP. A fresh groundwater density (<63 lbs/ft^3) is observed east of the Waterway due to fresh groundwater inflow from beneath the Bluffs into the Puyallup River Valley. In this area, the fresh groundwater density further supports that the >60 to >80% salt water on the east side of the Waterway (south of WW-A1D-47) shown on Figure 3.58 results from a lack of observed salt water percentage data points in this area. A density in the range of salt water (63-64 lbs/ft^3) occurs in the south and southwestern portion of the Site peninsula, which corresponds to the salt water distribution in this area for the 100-ft zone shown on Figure 3.58. This area is above the zone of apparent confining effect in the lower deltaic deposits described in Section 3.6.2.8. The zone of apparent confining effect slopes downward to the south and southwest following the top surface of the glacial deposits shown on Figure 3.52.
- In the 130-ft zone (Figure 3.65), the ADP is located north of the Salt Pad and WMUs C, F, and H, and has an area of maximum density of >69 lbs/ft^3 that is larger than in the 100-ft zone. The ADP also extends towards the northwest consistent with the trough in the top surface of the glacial deposits that slopes to the northwest, as described in Section 3.5.4 and shown on Figure 3.52. The fresh groundwater area north of the Salt Pad in the 130-ft zone shown on Figure 3.59 corresponds to the location of the ADP. Here, salt water may have existed prior to the release of the ADP, and the salt water might have been displaced by the ADP. A fresh groundwater density (<63 lbs/ft^3) is present in the eastern-central portion of the Site peninsula. This area is within the glacial deposits and the zone of apparent confining effect in the lower deltaic deposits. A fresh groundwater density in the eastern-central portion of the Site peninsula is consistent with the absence of salt water in this area shown on Figure 3.59. A density in the range of salt water (63-64 lbs/ft^3) occurs in the south and southwestern portion of the Site peninsula, which corresponds to the salt water distribution in this area for the 130-ft zone shown on Figure 3.59. This area is within the deltaic deposits above the zone of apparent confining effect that slopes downward to the south and southwest following the top surface of the glacial deposits. The fresh groundwater density east of the Waterway is due to fresh groundwater inflow from beneath the Bluffs into the Puyallup River Valley. Here, the fresh groundwater density further supports that the >40 to >50% salt water on the east side of the Waterway (south of

WW-A1D-77) shown on Figure 3.59 results from a lack of observed salt water percentage data points in this area.

- In the 160-ft zone (Figure 3.66), the downward leading edge of the ADP with an area of maximum density of 65-66 lbs/ft^3 exists in the northern portion of the peninsula. The ADP is located within the trough in the top surface glacial deposits. A fresh groundwater density (<63 lbs/ft3) surrounds the ADP, and extends into the eastern-central portion of the Site peninsula. The fresh groundwater area in the eastern-central portion of the Site peninsula lies within the glacial deposits underneath the zone of apparent confining effect in the lower deltaic deposits, and corresponds to the natural salt water distribution here in the 160-ft zone shown on Figure 3.60. A density in the range of salt water (63-64 lbs/ft^3) occurs in the south and southwestern portion of the Site peninsula, which corresponds to the natural salt water distribution in this area for the 160-ft zone. This area is within the deltaic deposits above the zone of apparent confining effect that slopes downward to the south and southwest following the top surface of the glacial deposits. The fresh groundwater density east of the Waterway is due to fresh groundwater inflow from beneath the Bluffs into the Puyallup River Valley. Here, the fresh groundwater density further supports that the >50 to >70% salt water on the east side of the Waterway (south of WW-A1D-110) shown on Figure 3.60 results from a lack of observed salt water percentage data points in this area. A salt water density (63-64 lbs/ft^3) occurs at WW-A1D-110 consistent with the >90% salt water occurring at this location on Figure 3.60.

3.6.2.5 Density-Dependent Groundwater Flow

At sites where groundwater and surface water are all fresh, density-dependent groundwater flow is not a concern. Hydraulic gradients and groundwater flow directions are resolved based on groundwater level measurements. In environments with water of varying density, like this Site, the assessment of hydraulic gradients and groundwater flow direction is more complex. Density variations at the Site are caused by the fresh groundwater and salt water distributions and the ADP.

Due to the density variations, water level measurements are converted to "freshwater equivalent heads" (FEHs) to interpret horizontal groundwater flow directions (i.e., along horizontal planes), and "environmental heads" (ENVs) to interpret vertical groundwater flow directions (i.e., at a monitoring well nest). Maps of FEHs within a common hydrogeologic unit can be used to interpret horizontal groundwater flow directions in horizontal planes. ENVs, calculated from FEHs and the average water density between screens in a monitoring well nest, are used to interpret vertical groundwater flow directions at a well nest location. The discussions of hydraulic gradients and groundwater flow directions at the Site are based on FEHs and ENVs rather than "groundwater levels."

The theory underlying the calculation of FEH and ENV is developed by Lusczynski (1961). Calculating FEH and ENV is necessary because:

- *"fresh-water heads define hydraulic gradients along a horizontal in groundwater of variable density," and "they are comparable along a horizontal"* (Lusczynski, 1961)
- *"environmental-water heads define hydraulic gradients along a vertical," and "they are comparable along a vertical" in groundwater of variable density* (Lusczynski, 1961)

Calculating FEH and ENV allows both horizontal and vertical hydraulic gradients to be determined in a system of variable density groundwater, which then facilitates the characterization of groundwater flow directions and the development of the conceptual hydrogeologic model for the Site. Lusczynski (1961) defines FEH and ENV as follows:

- FEH – "Fresh-water head at any point i in groundwater of variable density is defined as the water level in a well filled with fresh water from point i to a level high enough to balance the existing pressure at point i"
- ENV – "Environmental-water head at a given point in groundwater of variable density is defined as a fresh-water head reduced by an amount corresponding to the difference of salt mass in fresh water and that in the environmental water between that point and top of the zone of saturation"

Rather than "*fresh-water head,*" as used in Lusczynski (1961), the term 'fresh water equivalent head' is used for the Site, and the acronym "FEH" is used to denote fresh water equivalent head. Similarly, the acronym "ENV" is used to denote "*environmental-water head,*" as used in Lusczynski (1961).

Lusczynski (1961) indicates that the FEHs must be compared along a uniform horizontal plane in order to compute horizontal hydraulic gradients. Therefore, the calculated FEHs were adjusted to common horizontal reference planes, or reference elevations, to correspond to seven aquifer depth zones at the Site, or zone grouping planes, as described in Section 3.5.1. The FEHs are adjusted to the zone grouping planes to account for the fact that the monitoring well screen midpoint elevations for each aquifer depth zone vary by a small amount throughout the Site. Several hydraulic monitoring events have been conducted at the Site. The reduction of the hydraulic data and calculation of FEHs and ENVs is presented in Appendix L. The hydraulic monitoring results are presented in Section 3.6.4.

3.6.2.6 Regional Fresh Groundwater Inflow

Regional Fresh Groundwater Inflow from Bluffs

As described in Section 3.4, Robinson & Noble (1992) conducted a hydrogeologic study of the Bluffs in the Federal Way area east of the Site and developed hydrogeologic model for that area. They identified a series of aquifers within Layer 4 (see Figure 3.14) of their model within the Bluffs immediately east of the Site consisting of highly permeable soils, which they referred to as the North Shore Aquifers. Figure 3.20 shows the location of the North Shore Aquifers in plan view. As shown on Figure 3.20, the North Shore Aquifers are interpreted to extend to the upper portion of the Puyallup River Valley in their Layer 4 along the eastern shoreline of the Waterway opposite the Site. Robinson & Noble (1992) indicated that the North Shore Aquifers may consist of upper and lower zones.

Stratigraphic data from boreholes advanced along the eastern shoreline of the Waterway opposite the Site show an alternating sequence of higher and lower permeability layers extending from beneath the bluffs. Figure 3.67 presents a north-south cross-section through the 3-D stratigraphic model developed for the Site near the eastern shoreline of the Waterway. Soil types interpolated in the 3-D stratigraphic model along this cross-section are colored blue for relatively permeable sands and gravels and brown for low permeability sandy silt, clay silt, and silty gravel. A shallow layer of permeable soils is apparent in the upper portion of the cross-section from ground surface to approximately -15 ft NGVD, referred to as the Bluffs upper aquifer on Figure 3.67. Predominantly low permeability soils exist beneath the Bluffs upper aquifer to an elevation of approximately -60 ft NGVD, referred to as the Bluffs aquitard on Figure 3.67. An intermediate layer of predominantly permeable soils largely exists from approximately -60 to -120 ft NGVD, referred to as the Bluffs middle aquifer on Figure 3.67. Mainly low permeability soils are present beneath the Bluffs middle aquifer that are interpreted as an aquitard on Figure 3.67. Some lenses of permeable soils occur within this aquitard, as shown on Figure 3.67, but these are based on a fewer number of observations at depth and thus are uncertain in terms of continuity and extent.

The observed stratigraphy on Figure 3.67 is consistent with the North Shore Aquifers interpretation of Robinson & Noble (1992) within Layer 4 of their model. Layer 4 intersects the eastern shoreline of the Waterway from just below sea level to an elevation of approximately -125 ft NGVD, as shown on Figure 3.14. The Bluffs upper and middle aquifers illustrated on Figure 3.66 correspond to the suggestion by Robinson & Noble (1992) that the North Shore Aquifers may consist of upper and lower zones.

The aquifer/aquitard/aquifer/aquitard sequence along the eastern shoreline of the Waterway shown on Figure 3.67 is also consistent with the aquifer/aquitard sequence interpreted for the Bluffs east of the Site by Savoca et al. (2010). As shown on Figure 3.16, the eastern limit of

Cross-Section F-F' shows a sequence of C Aquifer/D Confining Unit/E Aquifer/F Confining Unit extending under the Bluffs. This sequence is labeled on Figure 3.67.

The hydraulic monitoring conducted at the Site is summarized in Section 3.6.4 and shows east to west groundwater flow directions from beneath the Bluffs towards the Site peninsula. As shown on Figures 3.61 to 3.66, a fresh groundwater density extends east of the Waterway, which demonstrates that inflow from beneath the Bluffs into the Puyallup River Valley consists of fresh groundwater. The fresh groundwater inflow is introduced to the deltaic deposits at shallow depths and likely to the glacial deposits at greater depths. The fresh groundwater inflow interacts with the salt water zones beneath the Waterway at shallow depths. Elevated hydraulic pressures occur within the Bluffs that limit the inland extent of the salt water zones along the east side of the Waterway. At greater depths, the fresh groundwater inflow interacts with the portion of the ADP that is positioned beneath the Waterway. The fresh groundwater inflow from the Bluffs further reinforces the need to consider variable-density effects when characterizing groundwater flow conditions at the Site.

Regional Fresh Groundwater Inflow from South

As described in Section 3.4, regional groundwater flow in the alluvial aquifer along the Puyallup River Valley has been characterized by Savoca et al. (2010) and is presented on Figure 3.26. Based on the groundwater elevations and flow directions presented on Figure 3.26, groundwater flow in the alluvial aquifer is generally toward Commencement Bay, coincident with the direction of surface water flow in the Puyallup River, and horizontal hydraulic gradients decrease toward Commencement Bay. The regional groundwater flow is derived from upland sources and is fresh. The regional groundwater flow introduced fresh groundwater inflow to both the deltaic and glacial deposits from south of the Site. This fresh groundwater inflow interacts at shallow depths with the salt water zones extending inland from Commencement Bay and the Blair Waterway, and interacts at greater depths with the ADP. The fresh groundwater inflow from the south further reinforces the need to consider variable-density effects when characterizing groundwater flow conditions at the Site.

3.6.2.7 Mud Flats

As described in Section 3.2.2, the POT consists of five man-made peninsulas that were developed in the early 1900s by dredging to create navigable waterways. The waterways were dredged through the natural tidal mud flats that existed at the mouth of the Puyallup River Valley under pre-development conditions. The mud flats consist of silts and clayey silts deposited during the last phase of delta formation at the mouth of the Puyallup River Valley. The materials from dredging the waterways were used to create the peninsulas throughout the POT. Thus, the Site peninsula was developed by placing fill material on top of the pre-existing tidal mud flats.

The mud flats are illustrated throughout the POT peninsulas on the regional geologic cross-sections developed by Hart Crowser (1975) and presented on Figures 3.11 and 3.12. The mud flats have not been identified consistently in all borings advanced on the Site peninsula. This may be due to a lack of precision in the stratigraphic logs, or may be due to stream channels that could have incised the fine-grained sediments of the mud flats. Hydraulic monitoring was conducted in the 15-ft and 25-ft zones at the southern end of the 605 Alexander Avenue property and the 709 and 721 Alexander Avenue properties to investigate whether the former mud flats influenced shallow groundwater flow conditions in this area. Figure 3.68 shows the shallow groundwater zone monitoring locations, and the details of the shallow groundwater zone hydraulic monitoring results are presented in Appendix L. The results that pertain to the former mud flats are summarized below.

Monthly hydrographs, presented in Appendix L, were compiled of the shallow groundwater zone hydraulic monitoring results for September to December 2012 for 16 nested 15-ft/25-ft zone monitoring wells shown on Figure 3.68. The hydrographs show FEH, Serfes (1991) mean FEH, tide elevation, Serfes (1991) mean tide elevation, and precipitation from September to December 2012. The hydrographs show the following:

- FEHs for the 15-ft zone do not respond to the tide
- FEHs for the 15-ft zone increase in response to increased precipitation
- FEH fluctuations in the 25-ft zone correspond directly with tidal fluctuations
- FEHs for the 15-ft zone are approximately 2 ft higher on average than for the 25-ft zone

The absence of tidal fluctuations in the 15-ft zone combined with greater FEHs in the 15-ft zone than in the 25-ft zone demonstrates that the mud flats form a continuous layer of lower permeability soils in this area and separates the two zones.

As presented on Figure 3.12, the fill on the Site peninsula was placed on top of the former tidal mud flats present at an elevation of approximately 0 ft MLLW, which corresponds to an elevation of -6.32 ft NGVD. Figure 3.69 shows the shallow stratigraphic Cross-Section Z-Z' developed along the southern end of the 605 Alexander Avenue property based on the simplified 3-D stratigraphic model for the Site. The location of Cross-Section Z-Z' is shown on Figure 3.68. Several discontinuous layers of silty clay and silt are apparent along Cross-Section Z-Z' at approximately -6 ft NGVD, which corresponds to the location of the former tidal mud flats reported by Hart Crowser (1975). Although the silty clay and silt layers appear as discontinuous on Cross-Section Z-Z', the approximate 2 ft separation between the 15-ft and 25-ft zone FEHs demonstrates that these lower permeability layers are continuous. The appearance of discontinuities in the former tidal mud flats on Cross-Section Z-Z' result because some shallow boreholes do not extend to the depth of the mud flats, or because some of the older boreholes were not logged in enough detail to identify the mud flats. The resulting 3-D interpolation of the stratigraphic observations creates the apparent discontinuities in mud flats presence. Table 3.4 lists the soil descriptions indicated on the stratigraphic logs at the approximate elevation of the former tidal mud flats for the boreholes along Cross-Section Z-Z'. These soil descriptions indicate that mud flats predominantly consist of lower permeability silts and silty clays.

Figure 3.69 presents an average FEHs over the month of October 2012 for the 15-ft and 25-ft zone monitoring wells located along Cross-Section Z-Z'. The average 15-ft zone FEHs are approximately 2 ft above the average FEHs for the 25-ft zone illustrating the hydraulic separation between the two zones. In addition, the average FEHs for the 25-ft zone lie above the former mud flats. This indicates that the 25-ft zone is confined by the former mud flats, there is continuous saturation between the 15-ft and 25-ft zones, and that the 15-ft is not a perched groundwater flow system separated from the 25-ft zone by unsaturated soils.

3.6.2.8 Zone of Apparent Confining Effect in Lower Deltaic Deposits

As described in Section 3.5.2, the 3-D stratigraphic models developed for the Site show a reduced frequency of higher permeability soil types (i.e., sand) and a corresponding increased frequency of lower permeability soil types (i.e., silty sand, sandy silt, and clayey silt) in the lower portion of the deltaic deposits. A discrete continuous layer of low permeability material is not observed in Site borings in the lower deltaic deposits. However, groundwater quality, density, and hydraulic data for the Site support the concept that the increased frequency of lower permeability lenses limits vertical flow creating a zone of apparent confining effect in the lower deltaic deposits. The presence of the zone of apparent confining effect is inferred from:

- Upward vertical hydraulic gradients observed from the upper glacial deposits to the lower deltaic deposits in the east, northeast, and north portion of the Site peninsula where the glacial deposits are encountered[7].
- Fresh to relatively fresh groundwater observed within the glacial deposits.
- The majority of the Site-related contamination exists within the deltaic deposits. Downward migration of the primary COCs appears to be limited within the lower deltaic deposits. Groundwater quality data indicates that the vertical limit of contamination

---

[7] In the west, southwest, and south portion of the Site peninsula, the glacial deposits are not encountered, as described in Section 3.5.4. Here, the deltaic deposits extend to the depth investigated, and observed vertical hydraulic gradients in the deltaic deposits are downward in this area, as described in Section 3.6.4.1. The Site-related contamination does not extend into the southwest portion of the Site peninsula.

appears to coincide with the increased frequency of lower permeability lenses in the lower deltaic deposits.

A review of the specific lines of evidence observed at deep Site monitoring wells/borings was conducted to estimate, or infer, the top surface of the zone of apparent confining effect. The estimated top surface of the zone of apparent confining effect will be applied in the groundwater flow model being developed for the Site. The lines of evidence used to estimate the top surface of the zone of confining effect include:

- Stratigraphy - the observed stratigraphy presented in the Site boring logs identifies the presence of low permeability lenses above the glacial deposits within the lower portion of the deltaic deposits. The zone of apparent confining effect is a not a continuous low permeability aquitard within the lower deltaic deposits. Instead, it is a zone of numerous inter-fingered lower permeability silt and clay layers that vary in frequency and intensity from one location to the next. The net result of these numerous silt and clay layers is a zone of lowered effective vertical hydraulic conductivity within the lower deltaic deposits. An increased occurrence of silt and clay layers in the lower deltaic deposits at a monitoring well nest was considered when selecting the top surface of the zone of confining effect.
- Density - abrupt changes in groundwater density (e.g., elevated density of the ADP changing to a fresh groundwater density) at a monitoring well nest was considered to identify the top surface of the zone of confining effect. Locations of higher density lying above lower density were interpreted to indicate the presence of a lower permeability zone that has prevented downward migration of the ADP.
- TDS, total CVOCs, and pH - abrupt changes in these parameters were evaluated in much the same way as density described above (e.g., an abrupt change from elevated to lower levels of TDS, total CVOCs, and pH). However, an abrupt change in groundwater density was given slightly more weight in estimating the top surface of the zone of confining effect at a monitoring well nest.
- Event 3A FEHs - Event 3A FEHs (presented in Section 3.6.4.1) in each zone grouping plane were compared to a theoretical salt water FEH assuming an inland salt water distribution was present to the depth of each zone grouping plane calculated from:

$$FEH_{Salt\ ZGP} = (Elev_{SW} - Elev_{ZGP}) \times SG_s \ + \ Elev_{ZGP}$$

Where:

$FEH_{Salt\ ZGP}$	theoretical salt water FEH at the zone grouping plane
SG_S	specific gravity of salt water (applied 1.023 based on the average temperature corrected specific gravity measured in Commencement Bay and the Hylebos and Blair Waterways)

$Elev_{ZGP}$ elevation of the zone grouping plane (ft NGVD)

$Elev_{SW}$ average surface water elevation (applied 0.8 ft NGVD for Commencement Bay and the Hylebos and Blair Waterways)

Using the above equation, the theoretical salt water FEH at each zone grouping plane is estimated to be 1.05, 1.62, 2.20, 2.77, 3.46, and 4.38 ft NGVD for the 25-ft, 50-ft, 75-ft, 100-ft, 130-ft, and 160-ft zones, respectively.

The theoretical salt water FEH was used as a guide to evaluate well locations for each zone grouping plane that may be within the salt water distribution extending inland from the surrounding salt water bodies. For example, the theoretical salt water FEH is 3.33 ft NGVD for the 130-ft zone and 130-ft zone well locations within a range of FEHs above and below the salt water FEH were considered to be within the salt water distribution. Monitoring well FEHs that were significantly greater than the calculated salt water FEH, consist of a fresh water density, and overlain by higher density groundwater were considered to be within or below the zone of apparent confining effect.

- Event 3A ENVs - Event 3A ENVs (presented in Section 3.6.4.1) were considered to identify the presence of an upward hydraulic gradient providing evidence of a confining effect. Locations with an upward hydraulic gradient, in addition to having lower density groundwater overlain by higher density groundwater, were considered to be within or below the zone of confining effect, where this occurs above the top surface of the glacial deposits.

Table 3.5 summarizes the lines of evidence used to select the top surface elevations for the zone of apparent confining effect. The selected top surface elevations are considered to be approximate. The actual top surface elevation of the zone of apparent confining effect could be within 10 to 20 ft of the selected top surface elevations shown in Table 3.5.

Figure 3.70 presents the conceptualized contours for the top of the zone of apparent confining effect, the well locations applied in developing the contours, and the well locations that did not encounter the surface. In general, the top surface of the zone of apparent confining effect appears to mimic the top surface of the glacial deposits shown on Figure 3.52. There seems to be a trough present in the northeastern portion of the Site peninsula, with a mound under the central-eastern portion of the Site peninsula. The top surface of the zone of apparent confining effect slopes downward to the south and southwest.

3.6.3 Conceptual Site Model (CSM) of Hydrogeologic Conditions

Figure 3.71 shows the CSM of hydrogeologic conditions for the Puyallup River Valley and Bluffs in the Site vicinity. The hydrogeologic units at the Site correspond to the primary geologic units illustrated on Figure 3.53 for the conceptual Site geologic model and consist of (from ground surface):

- Fill - variable mixture of sand, silt, and gravel material placed through dredging of the Hylebos and Blair Waterways to develop the Site peninsula. The thickness of the fill across the Site ranges from approximately 10 to 16 ft. The fill was placed on top of the former native tidal mud flats that existed at the mouth of the Puyallup River Valley under pre-development conditions (see Figures 3.3 and 3.4). The mud flats consist of silts and clayey silts deposited during the last phase of delta formation at the mouth of the Puyallup River Valley.
- Deltaic deposits - heterogeneous mixture of interbedded sands, silts, and clays. The thickness of the deltaic deposits across the Site ranges from approximately 30 ft to 200 ft in the eastern and northeastern portion of the Site to greater than approximately 300 ft in the southwestern portion of the Site.
- Glacial deposits - heterogeneous mixture of interbedded gravel, sands, silts, and clays. The thickness of the glacial deposits beneath the Site has not been determined, but based on regional information, is more than 1,000 ft. The top surface of the glacially-derived deposits slopes downward to the north, west, and south from a mound observed under the central portion of the Site, as shown on Figure 3.52. The glacial deposits are not encountered at borings in the west, southwest, and south portion of the Site peninsula and is inferred to dip downward in this area below the depth of the Site borings.

The Site stratigraphic data indicate that there is an increased frequency of lower permeability lenses, comprised mainly of silt and clay, in the lower deltaic deposits. This is shown schematically on Figure 3.71. Within the Bluffs, Figure 3.71 shows an alternating sequence of sand/gravel aquifer and silt/clay aquitard layers based on the regional geologic conditions described in Sections 3.4.1 and 3.6.2.6.

Groundwater beneath the Site discharges to the surrounding surface water bodies. Fresh groundwater inflow toward the Site peninsula occurs from the south due to upland regional groundwater flow along the Puyallup River Valley, and from the east due to regional groundwater flow in the Bluffs aquifers discharging to the Valley. Infiltration of precipitation over the Site peninsula contributes a further source of fresh groundwater, and establishes a shallow radial groundwater flow pattern towards the surface water bodies.

The groundwater table at the Site peninsula is located in the fill that was placed on top of the native mud flats. As shown on Figures 3.3 and 3.4, the mud flats historically existed throughout the POT and extended as far south as East Eleventh Street. The mud flats have not been identified consistently in all Site borings. This may be due to a lack of precision in the stratigraphic logs, or may be due to stream channels that could have incised the fine-grained sediments of the mud flats. For the CSM, a mud flats stratigraphic unit is conceptualized as depicted on Figure 3.71. It is understood that this conceptualization is a simplification of the actual complex physical setting.

In general, the mud flats are assumed to have hydraulic conductivity similar to silts and clays identified within the deltaic deposits. While lower permeability sediments within the mud flats may not be entirely continuous, they clearly create a hydraulic separation between the fill and the underlying deltaic deposits in the southern portion of the Site where detailed investigation of groundwater levels within the fill has been completed. Here, groundwater elevations in the fill are approximately 2 ft higher than groundwater elevations in the deltaic deposits immediately beneath the mud flats. The mud flats are colored dark brown on Figure 3.71 where the hydraulic separation between the fill and deltaic deposits is observed in the southern portion of the Site, and a lighter brown where this hydraulic separation is not confirmed.

The majority of the Site-related contamination exists within the deltaic deposits. Groundwater quality data indicates that the vertical limit of contamination appears to coincide with the increased frequency of lower permeability lenses in the lower deltaic deposits or the top of the glacial deposits. A discrete continuous layer of low permeability material is not observed in Site borings in the lower deltaic deposits. However, the groundwater quality, density, and hydraulic evidence supports the concept that the increased frequency of lower permeability lenses limits vertical flow creating a zone of apparent confining effect in the lower deltaic deposits. The presence of this zone of apparent confining effect is inferred from:

- Upward vertical hydraulic gradients observed from the upper glacial deposits to the lower deltaic deposits in the east, northeast, and north portion of the Site peninsula where the glacial deposits are encountered[8]
- Fresh to relatively fresh groundwater observed within the glacial deposits, while fresh groundwater and salt water distributions are observed above the glacial deposits
- Downward migration of the COCs appears to be limited to within the lower deltaic deposits or top of the underlying glacial deposits

A zone of apparent confining effect in the lower deltaic deposits is consistent with some features of the fresh groundwater and salt water distributions observed at the Site. Relatively fresh groundwater is observed in deeper parts of the deltaic deposits and in the glacial deposits. The glacial deposits appear to be an aquifer system composed of several

---

[8] Just west, southwest and south of the Site, the glacial deposits are not encountered. Here, the deltaic deposits extend to the depth investigated, and observed vertical hydraulic gradients in the deltaic deposits are downward in this area.

glacially-derived aquifers and aquitards that are separated from the deltaic deposits by the zone of apparent confining effect. The fresh groundwater in the glacial deposits is derived from upgradient regional inflow. The regional inflow, combined with the zone of apparent confining effect, likely causes higher hydraulic pressures within the glacial deposits that result in the upward vertical hydraulic gradients from the upper glacial deposits to the lower deltaic deposits.

The observed salt water and fresh groundwater distributions are translated to the CSM of hydrogeologic conditions in the Site vicinity on Figure 3.71. The fresh groundwater and salt water distributions, as well as groundwater flow conditions, illustrated on Figure 3.71 are generalized representations of pre-contamination conditions. The groundwater flow conditions illustrated on Figure 3.71 are summarized as follows:

- Recharge from precipitation infiltration contributes shallow fresh groundwater in the fill. This recharge migrates downward into the underlying deltaic deposits and laterally to the waterways
- Fresh groundwater is also introduced to both the deltaic and glacial deposits from the uplands along the Puyallup River Valley and from the east from beneath the Bluffs aquifers that lie below sea level
- Elevated FEHs in the Bluffs limit the inland extent of the salt water along the east side of the Waterway, as shown on Figure 3.71
- Available salinity data from borings completed beneath the waterway show a zone of fresher groundwater from the eastern bluffs extending adjacent to and beneath the Waterway
- Available bromide data used as a tracer for identifying naturally-occurring saltwater suggest a relatively complex pattern of saltwater at intermediate depths underlain by fresher groundwater at depth at some locations

The presence of both salt water and fresh groundwater beneath the Site, as well as elevated groundwater densities associated with the ADP, creates density-dependent groundwater flow conditions that need to be accounted for when interpreting groundwater flow directions and hydraulic gradients. Density-dependent groundwater flow conditions are accounted for using FEHs to interpret horizontal groundwater flow directions, and using ENVs to interpret vertical groundwater flow directions. Maps of FEHs within a common hydrogeologic unit can be used to interpret horizontal groundwater flow directions in horizontal planes. ENVs, calculated from FEHs and the average groundwater density between screens in a monitoring well nest, are used to interpret vertical groundwater flow directions at a well nest location. The discussions of hydraulic gradients and groundwater flow directions at the Site are based on FEHs and ENVs rather than "groundwater levels".

The results of the hydraulic monitoring events conducted at the Site presented in Section 3.6.4 below corroborate the generalized groundwater flow directions presented on Figure 3.71. FEHs determined from the monitoring show a shallow radial groundwater flow pattern sustained by precipitation recharge over the Site peninsula with groundwater flowing toward the Hylebos and Blair Waterways and Commencement Bay. Also evident in the FEHs are regional groundwater inflow from the south along the Puyallup River Valley, and regional groundwater inflow from the east from beneath the Bluffs. The influence of pumping from the Site groundwater extraction system is evident in the FEHs in close proximity to extraction well branches. ENVs demonstrate mainly downward vertical hydraulic gradients within the deltaic deposits, particularly within the ADP. ENVs further demonstrate upward vertical hydraulic gradients from the upper glacial deposits to the lower deltaic deposits.

The ADP, comprised of high density liquid releases from historical Site operations/processes (lime sludge/solvent residue, caustic soda, and salt brine) has a significant influence on groundwater flow and contaminant transport. The ADP has created laterally outward groundwater flow directions as it has migrated downward from its surficial release point due to gravity-driven downward groundwater flow of the high density liquids. The influence of the ADP on COC migration at the Site is described in Section 5.0.

3.6.4 Hydraulic Monitoring and Testing

The hydraulic monitoring and testing completed at the Site have included Site-wide hydraulic monitoring (Section 3.6.4.1), hydraulic monitoring focused on the 709/721 Alexander Avenue properties (Section 3.6.4.2), horizontal and vertical hydraulic conductivity testing (Section 3.6.4.3), and investigations of groundwater/surface water interaction using a geophysical survey and seepage meters (Section 3.6.4.4). The results of the hydraulic monitoring and testing are presented in the following sub-sections.

3.6.4.1 Site-Wide Hydraulic Monitoring

Four Site-wide hydraulic monitoring (groundwater elevation measurement) events have been conducted at the Site, referred to as Events 1, 2, 3A, and 3B. Figure 3.72 shows the locations of all Site monitoring wells, and the monitoring well completion details are presented in Table 3.6. Groundwater pressure data were collected during the hydraulic monitoring events using pressure transducers installed at selected monitoring wells for each event. The pressure transducers were connected to data loggers to record pressure measurements from the transducers at five-minute intervals. The hydraulic monitoring for Events 1 and 2 was continuous from May to June 2006. The hydraulic monitoring for Events 3A and 3B, conducted as part of the CSI, was continuous from September to December 2012. Each of Events 1, 2, 3A, and 3B consist of a 72-hour hydraulic monitoring data period extracted from the continuous monitoring record, which allowed for the gauging of groundwater pressures over a full tidal cycle.

Event 1 consisted of a 72-hour monitoring period while the groundwater extraction/injection system was in operation. Following Event 1, the extraction/injection system was temporarily shut down, in order to allow Event 2 to be conducted under non-pumping conditions after groundwater levels had recovered, or stabilized, in response to the cessation of pumping. The groundwater injection system was not re-started following Event 2. Similar to Events 1 and 2, Event 3A was conducted while the groundwater extraction system was in operation, and Event 3B was conducted after the groundwater extraction system was temporarily shut down and groundwater levels had recovered. Events 1 and 3A represent pumping conditions, while Events 2 and 3B represent non-pumping conditions.

For each monitoring event, the recorded pressure transducer data were reviewed for data quality, which consisted of comparing the transducer data to periodic manually measured groundwater levels. The pressure transducer data were then used to evaluate groundwater levels in terms of FEHs in the horizontal direction along the seven zone grouping planes and ENVs in the vertical direction at monitoring well nests. The seven zone grouping planes consist of the 15-ft, 25-ft, 50-ft, 75-ft, 100-ft, 130-ft, and 160-ft zones described in Section 3.5.1. The methods of pressure transducer data reduction and data quality validation, along with calculation of FEH and ENV are presented in Appendix L. The tidally influenced groundwater elevation data were reduced to mean elevations (Serfes [1991] mean) over each 72-hour monitoring event following procedures described in Appendix L.

The results of Events 1 and 2 are summarized in Section 3.6.4.1.1, and the results of Events 3A and 3B are summarized in Section 3.6.4.1.2.

3.6.4.1.1 Events 1 and 2 Hydraulic Monitoring Results

Event 1 was initiated on May 27, 2006 at 09:00 Pacific Daylight Time (PDT) and was completed on May 30, 2006 at 09:00 PDT. The extraction/injection system was temporarily shut down on May 31, 2006 at 13:55 PDT. Event 2 was initiated on June 12, 2006 at 09:00 PDT and was completed on June 15, 2006 at 09:00 PDT. Figure 3.73 presents the Events 1 and 2 hydraulic monitoring well networks in plan view, and Figure 3.74 provides a graphical illustration of the monitoring well screen intervals by aquifer depth zone, or zone grouping plane. The Events 1 and 2 monitoring well locations are listed in Table 3.7.

The Events 1 and 2 monitoring network consisted of monitoring wells and subtidal piezometers. Events 1 and 2 did not include wells screened in the 15-ft zone (15-ft zone wells were included in the Events 3A and 3B monitoring well network). The wells/subtidal piezometers comprising the hydraulic monitoring network are categorized into 3 general types of transducer installation configurations:

- Type 1: An upland monitoring well instrumented with a vented diaphragm pressure transducer suspended in the water column above the well screen
- Type 2: An upland monitoring well instrumented with a vented diaphragm or non-vented vibrating wire pressure transducer installed within the well screen
- Type 3: A subtidal piezometer within the Waterway instrumented with a down-hole non-vented vibrating wire pressure transducer grouted into position within a screened casing

Figure 3.75 presents a schematic of the three types of transducer installation configurations. The transducer configuration applied at each well/subtidal piezometer included in the Events 1 and 2 hydraulic monitoring networks is indicated on Figure 3.73.

Two (2) models of pressure transducers were installed at the Site for the hydraulic monitoring: Telog-brand vented diaphragm pressure transducers; and Geokon-brand vibrating wire pressure transducers. Generally, the Telog® transducers were installed in upland monitoring wells, and the Geokon transducers were installed in the subtidal piezometers. However, prior to initiating Event 1, the Telog transducers malfunctioned at six upland monitoring wells (1-100R, 14-25R, PZ-SHI-3-42, PZ-SHI-3-75, PZ-SHI-3-100, and 15-120). The Telog transducers at these upland wells were replaced with Geokon transducers installed within the screened interval at each well (i.e., a Type 2 transducer configuration).

Figure 3.76 presents an example of the measured pressure versus time at well 2-100 for Events 1 and 2. The pressure data measured by the transducers during each of Events 1 and 2 were reduced to an average pressure response within the aquifer, and then converted to an average FEH, as described in Appendix L. The average FEHs were then applied to interpret aquifer hydraulic responses, or groundwater flow conditions, under average tide conditions observed during both Events 1 and 2. Although the tide fluctuations in the Hylebos and Blair Waterways and Commencement Bay result in transient groundwater elevations at the Site that vary in response to the tide, average conditions are considered to provide a reasonable representation of the groundwater flow system.

As described in Appendix L, variations in pumping from the Site groundwater extraction system occurred due to performing treatment system maintenance just prior to Event 1. As a result, the groundwater pressures measured during Event 1 do not reflect constant pumping conditions. However, the influence of pumping by the Site groundwater extraction system is apparent in the Event 1 FEH data, as described below.

The Events 1 and 2 calculated FEHs are presented in Appendix L. The calculated FEHs for Events 1 and 2 along each of the 25-ft to 100-ft zones were interpolated throughout each grouping plane using linear kriging with linear drift as implemented in Surfer (Golden Software, Inc., 2002). The kriging approach implemented in Surfer provided a mathematically based, non-biased first trial to developing FEH contours. The Surfer generated FEH contours were then hand-modified to account for knowledge of the CSM of hydrogeologic conditions for the Site (i.e., stratigraphy, groundwater/surface water interaction, regional influences, operation of the Site groundwater extraction system, etc.).

FEH contours were not developed for the 130-ft and 160-ft zones for Events 1 and 2 because these zone grouping planes intersect the zone of apparent confining effect in the lower deltaic deposits, and the bulk of the wells for these two zones are screened within the underlying glacial deposits. The hydrogeologic conditions within the glacial deposits are highly variable, heterogeneous, and complicated, which renders the interpretation of horizontal groundwater flow conditions between adjacent monitoring wells impractical. As a result, only FEH values at each monitoring well are presented.

Figures 3.77 through 3.82 present the Event 1 FEHs for the 25-ft, 50-ft, 75-ft, 100-ft, 130-ft, and 160-ft zones, respectively. Figures 3.83 through 3.88 present the Event 2 FEHs for the 25-ft, 50-ft, 75-ft, 100-ft, 130-ft, and 160-ft zones, respectively. The Events 1 and 2 FEHs demonstrate the following general trends:

- Shallow groundwater mounding over the Site peninsula due to precipitation infiltration
- Shallow groundwater discharge to Commencement Bay and the Hylebos and Blair Waterways
- Regional groundwater inflow from south along the Puyallup River Valley
- Regional groundwater inflow from beneath the Bluffs east of the Site
- Operation of the existing Site groundwater extraction system (for Event 1)

The groundwater flow directions demonstrated by the Events 1 and 2 FEHs are consistent with the CSM of hydrogeologic conditions for the Site described in Section 3.6.3.

3.6.4.1.2 Events 3A and 3B Hydraulic Monitoring Results

The CSI hydraulic monitoring consisted of a Site-wide hydraulic monitoring program conducted from September to December 2012. The Event 3 CSI hydraulic monitoring formally began on September 9, 2012 and ended on December 15, 2012. However, hydraulic monitoring at several shallow monitoring wells began in December 2011. The 72-hour time periods selected for Events 3A and 3B correspond to:

- Event 3A – from October 5, 2012 at 12:00 PDT to October 8, 2012 at 12:00 PDT and representative of pumping conditions immediately before the extraction system shutdown on October 8, 2012 at 14:00 PDT
- Event 3B – from October 11, 2012 at 12:00 PDT to October 14, 2012 at 12:00 PDT and representative of non-pumping conditions after groundwater elevations had recovered following the extraction system shutdown

The hydraulic monitoring program consisted of using pressure transducers to record pressure measurements within a network of existing monitoring wells, and new wells installed as part of the CSI. Figure 3.89 presents the CSI hydraulic monitoring network in plan view. Figure 3.90 provides a graphical illustration of the screen intervals for the CSI monitoring well locations relative to their assigned zone grouping plane. A list of the CSI hydraulic monitoring locations is presented in Table 3.8. The locations that make up the hydraulic monitoring network were selected consistent with the CSI Work Plan to provide reasonable coverage of the Site in both the horizontal and vertical directions. The CSI hydraulic monitoring was performed at wells screened within the 7 aquifer depth zones corresponding to the 15-ft, 25-ft, 50-ft, 75-ft, 100-ft, 130-ft, and 160-ft zones.

Three types of pressure transducers were used for the CSI hydraulic monitoring, as follows:

- Solinst Levelogger Edge series of pressure transducer/dataloggers – these instruments are sealed and non-vented with internal power supply and datalogging capabilities that measure total pressure (i.e., water pressure plus atmospheric pressure) and temperature. These pressure transducers were installed in standard monitoring wells suspended in the well screens using stainless steel cables at elevations corresponding to the 15-ft, 25-ft, 50-ft, 75-ft, 100-ft, 130-ft, and 160-ft zone grouping planes. The raw transducer readings consist of date, time, total pressure, and temperature. A Solinst Barologger Edge pressure transducer/datalogger was used to record barometric pressure at the Site and synchronized to taking readings at the same time as the pressure transducers. The barometric pressure was then subtracted from the Levelogger total pressure readings to give water column pressure for each monitoring well location. A Levelogger pressure transducer was also installed in the Waterway suspended in a screened casing strapped to the side of Dock 1.

- Geokon Model 4500 Vibrating Wire Piezometers – these instruments are sealed and non-vented pressure transducers that use vibrating wire technology to produce a signal that is proportional to the pressure exerted on the transducer. The electronic components (batteries, datalogger) are contained within a weather-resistant datalogger box at ground surface, such that the down-hole equipment consisted solely of the communication cable and pressure sensor. The Geokon transducers were installed at CMT monitoring well locations with the transducers fastened to the outside of the CMT well casing at elevations corresponding to the 25-ft, 50-ft, 75-ft, 100-ft, 130-ft, and 160-ft zone grouping planes. Sand packs were placed around the transducers on the outside of the CMT well casing. At selected CMT well locations, Geokon transducers were installed in boreholes extended below the bottom of the CMT wells where the transducer was suspended by the logger communication cable at the selected elevation, set into a short sand pack and then sealed into place. Geokon transducers were also used at the three previously installed Waterway subtidal piezometer locations WW-A1, WW-B1, and WW-C1 that were found to be functional.
- Micron narrow-diameter pressure transducers – these instruments were installed within the CMT well channels (i.e., groundwater sampling channels and ports) at twelve locations to replace the initially installed Geokon transducers that malfunctioned. The Micron pressure transducer contains a pressure sensor coupled to direct-read vented cable. The power source and datalogger are contained within weather-resistant boxes at ground surface. The Micron dataloggers were installed at similar elevations as the initially installed Geokon transducers they replaced.

The pressure transducers were used to record hydraulic pressures over the duration of the CSI hydraulic monitoring. The pressure data recorded by the transducers were reduced to provide a hydraulic pressure exerted by the formation at the screen intervals of the monitoring locations for each zone grouping plane, as presented in Appendix L. The formation pressures were then converted to FEH and ENV that account for variable density effects on groundwater flow and were used to interpret the groundwater flow conditions under pumping and non-pumping conditions, as presented in Appendix L. The FEHs and ENVs observed throughout the hydraulic monitoring network were applied to interpret horizontal and vertical groundwater flow directions, respectively.

The CSI hydraulic monitoring results were reviewed in terms of:

- Shallow groundwater flow characteristics in the 15-ft and 25-ft zones from December 2011 to December 2012 based on continuous hydraulic monitoring conducted during this time

- Full-depth groundwater flow conditions during pumping and non-pumping conditions based on the Events 3A and 3B 72-hour monitoring events
- Vertical groundwater flow characteristics in the 130-ft zone, 160-ft zone, and below the 160-ft zone based on the Events 3A and 3B 72-hour monitoring events

Shallow Zone Continuous Hydraulic Monitoring - December 2011 to December 2012

Monthly hydrographs of the December 2011 to December 2012 continuous hydraulic monitoring results for the five 15-ft zone and three 25-ft zone monitoring wells are presented in Appendix L. The well locations for the continuous hydraulic monitoring are shown on Figure 3.68. The hydrographs present FEH, Serfes (1991) mean FEH, tide elevation measured at the Site off of Dock 1, running Serfes (1991) mean tide elevation, and precipitation[9] from December 2011 to December 2012.

The FEHs for wells 49-15 and 709-MW5-15 located immediately adjacent to the Waterway respond to tidal fluctuations only under peak high tide. The FEHs for the three remaining 15-ft zone wells (i.e., 50-15, 52-15, and 709-MW6-15) do not respond to tidal fluctuations. The FEHs for the 15-ft zone monitoring wells demonstrate that the 15-ft zone has limited hydraulic connection to the Waterway. In contrast, the FEHs for the 25-ft zone well hydrographs respond to tidal fluctuations on a continuous basis. This indicates that the 25-ft zone has a strong hydraulic connection to the Waterway. The tidal fluctuations in the 25-ft zone are greatest at well 709-MW20-25 located immediately adjacent to the Waterway and the tidal fluctuations are damped at wells 18-25 and 9-25 located at increasing distances inland from the Waterway.

The FEHs for 15-ft zone monitoring wells all show a direct response to increased precipitation. The response is most prominent in the hydrographs during times of increased precipitation. The increased precipitation infiltrates into the unsaturated zone and reaches the groundwater table located within the 15-ft zone causing increased 15-ft zone groundwater elevations, or FEHs.

The 15-ft zone FEHs also show a response to reduced or zero precipitation during dry periods. Limited precipitation occurred during June and July 2012, and essentially no precipitation occurred from August to early October 2012. From June to early October 2012, the 15-ft zone FEHs decrease steadily. The decreasing 15-ft zone FEHs during dry periods are due to a combination of lateral drainage to the Waterway and downward vertical leakage to the 25-ft zone.

---

[9] Precipitation data was obtained from NOAA National Weather Service office at Tacoma Narrows Airport, Tacoma, WA (accessed from http://www.wunderground.com/history/airport/KTIW/2011/12/1/CustomHistory.html?dayend=6&monthend=1&yearend=2012&req_city=NA&req_state=NA&req_statename=NA).

A summary of the minimum (month of occurrence), maximum (month of occurrence), and average 15-ft zone Serfes (1991) mean FEHs over the duration of the continuous hydraulic monitoring is provided below.

15-ft Zone Well	***Approx. Distance From Waterway (ft)***	***Min. Serfes (1991) Mean FEH (ft NGVD)***	***Max. Serfes (1991) Mean FEH (ft NGVD)***	***Avg. Serfes (1991) Mean FEH (ft NGVD)***
52-15	680	3.98 (Oct-2012)	6.96 (Apr-2012)	5.46
50-15	220	3.60 (Oct-2012)	6.39 (Dec-2012)	5.01
709-MW6-15	180	3.49 (Oct-2012)	6.19 (Dec-2012)	4.86
49-15	60	3.63 (Oct-2012)	6.37 (Dec-2012)	4.95
709-MW5-15	40	3.08 (Oct-2012)	5.34 (Dec-2012)	4.14

The 15-ft zone wells in the table inset above are ordered from greatest to least distance from the Waterway. The minimum, maximum, and average FEHs show a relatively consistent groundwater flow direction toward the Waterway in the 15-ft zone. The minimum FEH occurs for the above 15-ft zone wells in mid-October 2012 following the dry period extending from June to mid-October 2012. Except for 52-15, the maximum FEH for the above 15-ft zone wells occurs in December 2012 after the significant rainfall events that took place in November and early December 2012. For 52-15, the maximum FEH occurs in early April 2012 after heavy rainfall events in mid- and late March 2012.

Unlike the 15-ft zone wells, the 25-ft zone hydrographs show that the Serfes (1991) mean FEHs for the 25-ft zone wells do not respond directly to precipitation infiltration. The 25-ft zone Serfes (1991) mean FEHs remain relatively consistent during the continuous hydraulic monitoring. Fluctuations in the 25-ft zone Serfes (1991) mean FEHs correspond directly with fluctuations in the Serfes (1991) mean tide. The only time increases in the 25-ft zone Serfes (1991) mean FEHs appear to coincide with increased rainfall occurs following November 19, 2012, which is when the largest daily rainfall event occurred during the continuous hydraulic monitoring. However, the increased 25-ft zone Serfes (1991) mean FEHs also correspond to an increase in the Serfes (1991) mean tide. The increased Serfes (1991) mean tide occurs when the overall tide cycle was declining and should have resulted in a decreasing Serfes (1991) mean tide. Instead, an increase in the Serfes (1991) mean tide occurs, which is caused by increased watershed run-off discharging to the surrounding surface water bodies following the November 19, 2012 rainfall event. Thus, the increases in the 25-ft zone Serfes (1991) mean FEHs following November 19, 2012 are created by increases in the Serfes (1991) mean tide that are in turn caused by increased watershed run-off.

Shallow Zone CSI Hydraulic Monitoring - September to December 2012

Monthly hydrographs of the September to December 2012 CSI hydraulic monitoring results for the sixteen nested 15-ft/25-ft zone monitoring wells on 709 and 721 Alexander Avenue are presented in Appendix L. The hydrographs present FEH, Serfes (1991) mean FEH, tide elevation measured at the Site off of Dock 1, Serfes (1991) mean tide elevation, and precipitation from September to December 2012.

The Appendix L hydrographs show 15-ft and 25-ft zone hydraulic responses similar to what was observed during the continuous hydraulic monitoring. The Serfes (1991) mean FEH for the 15-ft zone monitoring wells increase in response to increased precipitation, and fluctuations in the 25-ft zone Serfes (1991) mean FEHs correspond directly with fluctuations in the Serfes (1991) mean tide.

Increases in the Serfes (1991) mean FEHs at the 15-ft zone monitoring wells in response to increased precipitation are variable between the southern end of the 605/709 Alexander Avenue and 721 Alexander Avenue properties. The variation in this response is due to the presence of permeable and less permeable ground cover on these properties, as shown on Figure 3.68. The ground cover in the southern end of 605/709 Alexander Avenue consists largely of bare soil with some smaller areas of concrete and asphalt and limited vegetation. The ground cover on 721 Alexander Avenue consists entirely of asphalt. Similarly, the ground cover on the property immediately south of 721 Alexander Avenue consists of asphalt or buildings.

The Appendix L hydrographs for the nested 15-ft/25-ft zone monitoring wells all show that Serfes (1991) mean FEHs for the 15-ft zone are approximately 2 ft higher on average than for the 25-ft zone. This demonstrates that there is a layer of lower permeability soils separating the two zones, which corresponds to the former tidal mud flats underlying the fill present throughout the Site peninsula, as described in Section 3.6.2.7.

Events 3A and 3B

The Events 3A and 3B calculated FEHs are presented in Appendix L. The calculated FEHs for Events 3A and 3B along each of the 25-ft to 100-ft zones were interpolated throughout each grouping plane using linear kriging with linear drift as implemented in Surfer (Golden Software, Inc., 2002). The kriging approach implemented in Surfer provided a mathematically based, non-biased first trial to developing FEH contours. The Surfer generated FEH contours were then hand-modified to account for knowledge of the CSM of hydrogeologic conditions for the Site (i.e., stratigraphy, groundwater/surface water interaction, regional influences, operation of the Site groundwater extraction system, etc.).

As for Events 1 and 2, FEH contours were not developed for the 160-ft zone for Events 3A and 3B because this zone grouping plane intersects the zone of apparent confining effect in the lower deltaic deposits, and the bulk of the wells for these two zones are screened within the underlying glacial deposits. The hydrogeologic conditions within the glacial deposits are highly variable, heterogeneous, and complicated, which renders the interpretation of horizontal groundwater flow conditions between adjacent monitoring wells impractical. As a result, only FEH values at each monitoring well are presented for the 160-ft zone. FEH contours were developed for the 130-ft zone for Events 3A and 3B, but only for the Site area that lies above the zone of apparent confining effect.

Figures 3.91 through 3.97 present the Event 3A FEHs for the 15-ft, 25-ft, 50-ft, 75-ft, 100-ft, 130-ft, and 160-ft zones, respectively. Figures 3.98 through 3.104 present the Event 3B FEHs for the 15-ft, 25-ft, 50-ft, 75-ft, 100-ft, 130-ft, and 160-ft zones, respectively. As for Events 1 and 2, the Events 3A and 3B FEHs demonstrate the following general trends:

- Shallow groundwater mounding over the Site peninsula due to precipitation infiltration
- Shallow groundwater discharge to Commencement Bay and the Hylebos and Blair Waterways
- Regional groundwater inflow from south along the Puyallup River Valley
- Regional groundwater inflow from beneath the Bluffs east of the Site
- Operation of the existing Site groundwater extraction system (for Event 3A)
- For the 130-ft zone, a northwesterly groundwater flow direction is apparent in the northeastern portion of the Site peninsula that appears aligned with the northwesterly dipping trough in the top surface of the glacial deposits

The groundwater flow directions demonstrated by the Events 3A and 3B FEHs are consistent with the CSM of hydrogeologic conditions for the Site described in Section 3.6.3. For Event 3B, residual drawdown is apparent in the FEH contours for the 25-ft to 100-ft zones. The residual drawdown indicates that full groundwater level recovery following shutdown of the Site groundwater extraction system had not been achieved at the time of Event 3B.

130-ft/160-ft Zones Vertical Groundwater Flow Characteristics

Vertical groundwater flow between the 130-ft and 160-ft zones, and between the 160-ft and underlying zones, was evaluated by comparing the Events 3A and 3B ENVs at well nests that intersect these zones and resolving the ENVs into vertical hydraulic gradients. Vertical hydraulic gradients between the 130-ft zone and 160-ft zone wells are presented on Figure 3.105, and vertical hydraulic gradients between the 160-ft zone and underlying zone wells are presented on Figure 3.106.

As presented on Figure 3.105, vertical hydraulic gradients from the 130-ft zone to the 160-ft zone are predominantly downward within, and in close proximity to, the ADP due to the higher density groundwater within the ADP (the position of the ADP in the 130-ft zone is indicated on Figure 3.105). Predominantly upward vertical hydraulic gradients occur from the 160-ft zone to the 130-ft zone elsewhere within the Site peninsula. The intersection of the 130-ft zone grouping plane elevation with the top surface of the zone of apparent confining effect is indicated on Figure 3.105. Wells in the 130-ft zone east of the intersection line lie below the top surface of the zone of apparent confining effect, while wells to the west lie above. Beyond the ADP, vertical hydraulic gradients are mainly upward from the 160-ft zone to the 130-ft zone both above and below the top surface of the zone of apparent confining effect, which is attributable to higher hydraulic pressures at depth consistent with the CSM.

An evaluation of vertical hydraulic gradients between the 160-ft zone and underlying zone is available at only four monitoring well nests where transducers were installed below the 160-ft zone. The locations of these four deep well pairs (46C, 89C, 93C, and 95C) are presented on Figure 3.106. The intersection of the 160-ft zone grouping plane elevation with the top surface of the zone of apparent confining effect is indicated on Figure 3.106, as is the position of the ADP in the 160-ft zone. All four locations are beyond the ADP in the 160-ft zone. For the 46C and 89C locations, both the 160-ft zone and deeper transducers are located below the top surface of the zone of apparent confining effect. For the 93C and 95C locations, the 160-ft zone transducers are located above the top surface of the zone of apparent confining effect, while the deeper transducers are below it. Three of the four locations (46C, 93C, and 95C) show downward vertical hydraulic gradients from the 160-ft zone to deeper zones, which is contrary to the upward vertical hydraulic gradients from the 160-ft zone to the 130-ft zone observed at these locations (see Figure 3.105). The hydraulic pressures for the deeper locations come from Geokon transducers that were buried in place and the pressures could not be verified with manual water level measurements. At the location of 89C, an upward vertical hydraulic gradient between the 160-ft zone grouping plane and the deeper transducer was observed, which is consistent with the upward vertical hydraulic gradient from the 160-ft zone to the 130-ft zone at this location. However, the measured ENV in the deeper transducer at 89C is on the order of 14 ft NGVD, which is well above the ENV measured in the other three deeper transducers. The transducer at 89C-185 is installed within a thick clay soil with moderate to high plasticity that could isolate the 89C-185 transducer from the aquifer. Thus, the hydraulic pressure measured at 89C-185 may not be representative of the active groundwater flow throughout the bulk of the deep groundwater flow zone.

3.6.4.2 709/721 Alexander Avenue Hydraulic Monitoring

The 709/721 Alexander Avenue Investigation was conducted to collect data necessary to evaluate groundwater flow and contaminant migration conditions at these two properties in the 15-ft, 25-ft, and 50-ft zones. A 72-hour hydraulic monitoring event was conducted from June 23, 2004 at 00:00 PDT to June 26, 2004 at 00:00 PDT. During the event, hydraulic monitoring was conducted via pressure transducers connected to data loggers that were programmed to record pressures at 5-minute intervals.

The hydraulic data reduction methodology used for the 709/721 Alexander Avenue Investigation is similar to the methodology used for Events 1 and 2. A full description of the hydraulic investigation including evaluation of the hydraulic data is presented in Appendix M. In general, the hydraulic investigation results show groundwater flow is directed towards the Waterway in the 15-ft, 25-ft, and 50-ft zones on the 709/721 Alexander Avenue properties. These observations are consistent with the findings of the Events 3A and 3B hydraulic monitoring conducted as part of the CSI.

3.6.4.3 Hydraulic Conductivity Testing

Hydraulic conductivity is a measure of the soil (or sediment's) ability to transmit groundwater. Horizontal hydraulic conductivity testing was conducted in the field using single-well response tests, and vertical hydraulic conductivity testing was conducted through a combination of laboratory and field tests. The horizontal and vertical hydraulic conductivity testing and results are summarized below.

Horizontal Hydraulic Conductivity Testing

Scope of Testing

Single-well response (slug) testing was performed on the monitoring wells and subtidal piezometers included in either the groundwater sampling events, the Site-wide hydraulic monitoring events or after installation of new monitoring wells, to determine horizontal hydraulic conductivity. Existing monitoring wells used for the CSI groundwater sampling event were redeveloped if greater than one-half of the screened interval was blocked by sediment or excessive drawdown occurred during purging prior to low-flow sampling. The redeveloped wells were slug tested to determine their new baseline hydraulic conductivity. The new wells that were installed as part of the CSI field program were also slug tested. All CSI slug testing was performed after completing the CSI groundwater sampling program and Event 3 hydraulic monitoring program. A technical memorandum describing the slug testing and providing the results for the slug testing at individual wells is presented in Appendix N. Figure 3.107 presents the locations where the slug testing was performed.

Results

Table 3.9 presents the horizontal hydraulic conductivity values for the monitoring wells and subtidal piezometers at the time of installation and most recent testing. The horizontal hydraulic conductivity values at the Site range as follows:

Soil Classification (Code for Simplified Stratigraphic Model)	***Number of Locations Tested***	***Horizontal Hydraulic Conductivity, K_H***	
		Range (cm/sec)	***Geometric Mean (cm/sec)***
ML-CL (0)	1	1.6×10^{-4}	
ML (1)	16	6.7×10^{-7} to 3.5×10^{-3}	7.1×10^{-5}
SM (2)	123	5.5×10^{-8} to 4.4×10^{-2}	1.1×10^{-3}
SP or SW (3)	143	3.5×10^{-5} to 1.1×10^{-1}	4.8×10^{-3}
GP or GW (3)	0(1)	-	-

Note:
(1) Based on the four integer code for simplified stratigraphic model, there are no tested locations completed in gravel.

The range in horizontal hydraulic conductivity values for the three primary geologic units observed beneath the Site are as follows:

- Fill - approximately 1.0 × 10-4 to 1.0 × 10-2 centimeters per second (cm/sec) (0.3 to 30 feet per day [ft/d])
- Deltaic deposits - approximately 1.0 × 10-5 to 1.0 × 10-2 cm/s (0.03 to 30 ft/d)
- Glacial deposits - approximately 5.0 × 10-5 to 5.0 × 10-3 cm/s (0.15 to 15 ft/d)

Vertical Hydraulic Conductivity Testing

Scope of Testing

Vertical hydraulic conductivity values were estimated through field and laboratory testing. The vertical hydraulic conductivity values from the laboratory testing are considered to be more representative of the actual vertical hydraulic conductivity at the Site since the tests are performed in a more controlled setting than the field testing for vertical hydraulic conductivity. The laboratory hydraulic conductivity values are for small diameter and short length soil samples. The field testing for vertical hydraulic conductivity was conducted down-hole where it could not be certain that the flow induced to conduct the tests actually flowed downward vertically and did not short-circuit in a horizontal direction. The field testing for vertical hydraulic conductivity was further complicated by the presence of heaving sands at many locations. Figure 3.108 presents the locations of vertical hydraulic conductivity testing.

During the installation of the borings, undisturbed sediment/soil samples were collected from selected depth intervals using retrievable cylinder sampling tubes to collect undisturbed samples. The samples were submitted to a soils testing laboratory for determination of vertical hydraulic conductivity, grain size distribution, and moisture content. When undisturbed samples could not be obtained, the samples were not tested for vertical hydraulic conductivity in the laboratory.

Field testing for vertical hydraulic conductivity was also conducted where field conditions allowed. Vertical hydraulic conductivity testing was performed immediately underlying the intervals sampled for laboratory testing. Field vertical conductivity testing was accomplished by inserting an open-ended non-screened pipe into the soil to be tested. Slug testing was performed in the open-ended pipe. The resultant recovery data was used to calculate the vertical hydraulic conductivity at that particular location and elevation. Heaving sands flowed into the open-ended pipes at numerous locations, however, causing the field test to be aborted, thereby preventing the calculation of vertical hydraulic conductivity at these locations.

During the CSI, soil samples were collected from an additional eight glacially-derived material locations, including three in low permeability, three in medium permeability, and two in high permeability glacially-derived materials. Additional soil samples were collected from 28 deltaic sediment locations, including 10 in low permeability clayey silt to silty clay materials. All sediments classified as clayey silt to silty clay exhibit some degree of fines plasticity (where Atterberg limits were analyzed); while the fines in some of the coarser grained material are non-plastic. This indicates that the vertical hydraulic conductivity of the materials with high fines content will be low, in the range of 1.0×10^{-8} cm/sec, based on comparisons with physical properties sample results where both Atterberg limits and vertical hydraulic conductivity testing was performed.

Results

Table 3.10 presents the vertical hydraulic conductivity values determined from the laboratory and field testing. Vertical hydraulic conductivity values at the Site range as follows:

Soil Classification (Code for Simplified Stratigraphic Model)	***Laboratory Vertical Hydraulic Conductivity, K_V***		***Field Vertical Hydraulic Conductivity, K_V***	
	Range (cm/sec)	***Geometric Mean (cm/sec)***	***Range (cm/sec)***	***Geometric Mean (cm/sec)***
CL or CL-ML, GM (0)	2.7×10^{-8} to 2.0×10^{-7}	6.7×10^{-8}	$4.2 \times 10^{-4(1)}$	-
ML (1)	9.0×10^{-8} to 3.0×10^{-4}	8.7×10^{-6}	3.2×10^{-4} to 5.0×10^{-3}	1.3×10^{-3}
SM (2)	4.0×10^{-7} to 1.0×10^{-2}	3.5×10^{-5}	1.1×10^{-4} to 1.1×10^{-1}	2.59×10^{-3}
SP or SW (3)	1.7×10^{-6} to 2.0×10^{-3}	1.8×10^{-4}	3.3×10^{-4} to 7.3×10^{-1}	6.5×10^{-3}

Note:
(1) There is only one field hydraulic conductivity value for the silty gravel (GM) soil type.

3.6.4.4 Groundwater/Surface Water Interaction

Investigations of groundwater/surface water interaction included a Waterway geophysical survey conducted to identify groundwater discharge zones to the Waterway and the Seepage Meter Monitoring Program (SMMP) to evaluate the magnitude of groundwater discharge to the Waterway. The geophysical survey and SMMP are summarized below.

Geophysical Survey

Geophysical Survey Scope

In 2006, a comprehensive geophysical survey of the Waterway was conducted adjacent to the Site. The geophysical survey was performed by Global Remote Sensing (GRS) in conjunction with Northwest Geophysical Associations, Inc. (NGA). The scope of work and objectives for the geophysical survey were developed by USEPA and Ecology and provided to OCC on March 27, 2006. Following minor revisions, the scope of work was finalized and approved by USEPA and Ecology on April 11, 2006. Field activities associated with the geophysical survey were conducted between April 10 and May 5, 2006.

The objectives of the geophysical survey were presented in the April 2006 scope of work and included the following:

1. Identify geophysical conditions which suggest areas of high groundwater discharge into the Waterway.
2. Identify smaller, more localized, high discharge areas (hydraulic piping, fumaroles, etc.) where high pH groundwater might preferentially flow into the Waterway.
3. Track the course of high electrical conductivity brines from the salt pad downward and outward to the Waterway as a tracer of groundwater flow paths from the Site to the Waterway. Similarly, to attempt the same with the chloride signature resulting from the reductive dechlorination of chlorinated ethenes.
4. Delineate lateral and stratigraphic changes in sediment conductivity.

The scope of the geophysical survey included four tasks:

- Task 1 - Sidescan Sonar and Bathymetric Surveys
- Task 2 - High-Resolution Conductivity Survey
- Task 3 - Subbottom Profile Survey

- Task 4 - Marine Electrical Resistivity Imaging Survey

Geophysical Survey Results

The geophysical survey did not identify any locations within the survey area that were obvious points of high groundwater discharge to the Waterway.

Detailed descriptions of each task, along with the data and results of the geophysical survey, are presented in the "Geophysical Survey Report – Hylebos Waterway, Tacoma, Washington" (GRS, 2006).

Seepage Meter Monitoring Program (SMMP)

SMMP Scope

In 2006, as part of the Subtidal/Hydraulic Investigations (2005-2006), the SMMP was conducted in the subtidal portion of the Waterway. The SMMP was performed by Coastal Monitoring Associates (CMA). The primary objective of the SMMP was to determine the nature and extent of groundwater discharge into the Waterway during various phases of the tidal cycle.

The SMMP included the placement of seepage meters at selected subtidal locations to measure groundwater discharge and contaminant flux to the Waterway. Seepage meters were deployed at 26 subtidal locations selected by USEPA and Ecology, and used to monitor specific discharge rates over a 24-hour period. Discharge water samples were collected from the seepage meters at 19 of these locations for chemical analysis. The results of the chemical analysis are discussed in Section 4.9. The locations of the seepage meters installed during the investigation are shown on Figure 3.109. The SMMP was conducted in two phases corresponding to periods of seasonally low tides. The first phase was conducted from June 8 to June 16, 2006 and the second phase from June 21 to June 29, 2006.

SMMP Results

Complete descriptions and results for the SMMP are presented in the "Seepage Meter Monitoring Report" (CMA, 2006).

Table 3.11 presents a statistical summary of the specific discharge measured by each seepage meter during its 24-hour deployment. The statistical summary includes the arithmetic means, minimum, maximum, and standard deviation of the measured specific discharge. The actual specific discharges measured periodically during each deployment period are presented in the tables and graphs included in CMA's report.

Figure 3.109 presents the mean specific discharge observed at each seepage meter location. The range in the observed specific discharge at each location is also presented on Figure 3.109.

The following summarizes the hydraulic data obtained from the SMMP:

- Mean specific discharge rates within the Waterway ranged from a minimum of -1.8 centimeters per day (cm/day) (SM-10) to a maximum of 17.9 cm/day (SM-26)
- The average of the mean specific discharge was 2.3 ±4.1 cm/day (± one standard deviation) over the study area
- The highest discharge rates were observed along the eastern embankment of the Waterway within the Puyallup Tribe marinas extending to approximately the shipping channel
- Higher discharge rates were also observed along the western embankment of the Waterway extending to the shipping channel in limited areas of Dock 1 and Dock 2
- Mean specific discharge rates within the shipping channel were generally less than 1 cm/day, with several areas exhibiting mean recharge as high as -1.8 cm/day

Some general trends become apparent from comparing the seepage meter discharge to the Waterway tide, although the trends are not consistent over all of the seepage meter locations. However, the observations provide further insight into groundwater/surface water interaction at the Site, as follows:

- Under the highest tide conditions, the seepage meters measured surface water recharge or a decreased groundwater discharge
- Under the lowest tide conditions, the seepage meters measured increased groundwater discharge
- The measured discharge rates were greater for seepage meters deployed near the sides of the Waterway, or in the mudflats behind the finger pier on the east side of the Waterway

The general trend of recharge under high tide conditions and discharge under low tide conditions is consistent with there being a higher Waterway pressure under high tide pushing surface water into the formation, and there being a lower Waterway pressure under low tide allowing groundwater discharge to occur. The general trend of greater discharge near the sides of the Waterway is consistent with groundwater from the shallower zones (that are intercepted, or cut away, by the Waterway) discharging to the Waterway.

3.7 Summary of Site Geology/Hydrogeology

Site Geologic Conditions

Figure 3.53 shows the CSM of geologic conditions for the Puyallup River Valley and Bluffs in the Site vicinity. Within the Puyallup River Valley, the generalized geologic conditions are based on Site borings and described as follows (from ground surface):

- Fill - variable mixture of sand, silt, and gravel material placed through dredging of the Hylebos and Blair Waterways to develop the Site peninsula. The fill was placed on top of the former native tidal mud flats that existed at the mouth of the Puyallup River Valley under pre-development conditions (see Figures 3.3 and 3.4). The mud flats consist of silts and clayey silts deposited during the last phase of delta formation at the mouth of the Puyallup River Valley.
- Deltaic deposits - heterogeneous mixture of interbedded sands, silts, and clays.
- Glacial deposits - heterogeneous mixture of interbedded gravel, sands, silts, and clays. The top surface of the glacially-derived deposits slopes downward to the north, west, and south from a mound observed under the central portion of the Site, as shown on Figure 3.52.

The Site stratigraphic data indicate that there is an increased frequency of lower permeability lenses, comprised mainly of silt and clay, in the lower deltaic deposits. This is shown schematically on Figure 3.53. Within the Bluffs, Figure 3.53 shows an alternating sequence of sand/gravel and silt/clay layers based on the regional geologic conditions under the Bluffs described in Sections 3.4.1 and 3.6.2.6.

Site Hydrogeologic Conditions

Figure 3.71 shows the conceptual model of hydrogeologic conditions for the Puyallup River Valley and Bluffs in the Site vicinity. Groundwater beneath the Site discharges to the surrounding surface water bodies. Fresh groundwater inflow toward the Site peninsula occurs from the south due to upland regional groundwater flow along the Puyallup River Valley, and from the east due to regional groundwater flow in the Bluffs aquifers discharging to the Valley. Infiltration of precipitation over the Site peninsula contributes a further source of fresh groundwater, and establishes a shallow radial groundwater flow pattern towards the surface water bodies.

The groundwater table at the Site peninsula is located in the fill that was placed on top of the former native tidal mud flats. The mud flats are assumed to have hydraulic conductivity similar to silts and clays identified within the deltaic deposits, but have been shown to create a hydraulic separation between the fill and the underlying deltaic deposits in the southern portion of the Site. The mud flats are colored dark brown on Figure 3.71 where the hydraulic separation between the fill and deltaic deposits is observed in the southern portion of the Site, and a lighter brown where this hydraulic separation is not confirmed.

The groundwater quality, density, and hydraulic evidence supports the concept that the increased frequency of lower permeability lenses in the lower deltaic deposits limits vertical flow creating a zone of apparent confining effect in the lower deltaic deposits. The presence of this zone of apparent confining effect is inferred from upward vertical hydraulic gradients from the upper glacial deposits to the lower deltaic deposits, fresh to relatively fresh groundwater within the glacial deposits, and downward COC migration that appears to be limited within the lower deltaic deposits or top of the glacial deposits. The glacial deposits appear to be an aquifer system composed of several glacially-derived aquifers and aquitards that are separated from the deltaic deposits by the zone of apparent confining effect. The fresh groundwater in the glacial deposits is derived from upgradient regional inflow. The regional inflow, combined with the zone of apparent confining effect, likely causes higher hydraulic pressures within the glacial deposits that result in the upward vertical hydraulic gradients from the upper glacial deposits to the lower deltaic deposits.

Salt water occurs in the Hylebos and Blair Waterways and Commencement Bay surrounding the Site peninsula. The density difference between salt water and fresh groundwater results in the development of fresh groundwater and salt water distributions within the Site groundwater flow system. The observed fresh groundwater and salt water distributions are translated to the CSM of hydrogeologic conditions in the Site vicinity on Figure 3.71. The fresh groundwater and salt water distributions, as well as groundwater flow conditions, illustrated on Figure 3.71 are generalized representations of pre-contamination conditions. The groundwater flow conditions illustrated on Figure 3.71 are summarized as follows:

- Recharge from precipitation infiltration contributes shallow fresh groundwater in the fill. This recharge migrates downward into the underlying deltaic deposits and laterally to the waterways
- Fresh groundwater is also introduced to both the deltaic and glacial deposits from the uplands along the Puyallup River Valley to the south and from the east from beneath the Bluffs aquifers that lie below sea level
- Elevated hydraulic pressures in the Bluffs limit the inland extent of the salt water along the east side of the Waterway, as shown on Figure 3.71
- Available salinity data from borings completed beneath the Waterway show a zone of fresher groundwater from the eastern bluffs extending adjacent to and beneath the Waterway

- Available bromide data used as a tracer for identifying naturally occurring salt water suggest a relatively complex pattern of salt water at intermediate depths underlain by fresher groundwater at depth at some locations, with predominantly fresh groundwater occurring in the upper glacial deposits

The presence of both salt water and fresh groundwater beneath the Site, as well as elevated groundwater densities associated with the ADP, creates density-dependent groundwater flow conditions that need to be accounted for when interpreting groundwater flow directions and hydraulic gradients. Density-dependent groundwater flow conditions are accounted for using FEHs to interpret horizontal groundwater flow directions, and using ENVs to interpret vertical groundwater flow directions. Maps of FEHs within a common hydrogeologic unit can be used to interpret horizontal groundwater flow directions in horizontal planes. ENVs, calculated from FEHs and the average groundwater density between screens in a monitoring well nest, are used to interpret vertical groundwater flow directions at a well nest location. The discussions of hydraulic gradients and groundwater flow directions at the Site are based on FEHs and ENVs rather than "groundwater levels".

The results of the hydraulic monitoring events conducted at the Site corroborate the generalized groundwater flow directions presented on Figure 3.71. FEHs determined from the monitoring show a shallow radial groundwater flow pattern sustained by precipitation recharge over the Site peninsula with groundwater flowing toward the Hylebos and Blair Waterways and Commencement Bay. Also evident in the FEHs are regional groundwater inflow from the south along the Puyallup River Valley, and regional groundwater inflow from the east from beneath the Bluffs. The influence of pumping from the Site groundwater extraction system is evident in the FEHs in close proximity to extraction well branches. ENVs demonstrate mainly downward vertical hydraulic gradients within the deltaic deposits, particularly within the ADP. ENVs further demonstrate upward vertical hydraulic gradients from the upper glacial deposits to the lower deltaic deposits.

The ADP, comprised of high density liquid releases from historical Site operations/processes (lime sludge/solvent residue, caustic soda, and salt brine) has a significant influence on groundwater flow and contaminant transport. The ADP has created laterally outward groundwater flow directions as it has migrated downward from its surficial release point due to gravity-driven downward groundwater flow of the high density liquids. The influence of the ADP on COC migration at the Site is described in Section 5.0.

Section 4.0 Nature and Extent of Contamination

4.1 Introduction

The chemical characterization of groundwater, soil, and sediment at the Site is based upon the analytical data obtained during the various investigations presented in Section 2.0. To fully characterize the contamination within each matrix, the analytical data for each COC have been considered separately and as classes of parameters (e.g., VOCs, SVOCs, PCBs, etc.).

The complete analytical database for the Site is in e:Dat™ format on a USB drive included in Appendix G. Instructions regarding the use of the e:Dat™ software are also included in Appendix G.

The MVS/EVS software package was utilized to develop 3-D visualizations of the chemical concentrations present in groundwater, soil, and sediment at the Site for the following parameters and classes of parameters:

Parameter/Parameter Class	***Groundwater***	***Soil***
PCE	X	X
TCE	X	X
cis-1,2-DCE	X	X
VC	X	X
Total chlorinated VOCs	X	X
Total VOCs	X	X
Total BTEX	X	X
Total PAH	X	X
Total TPH	X	X
Total PCBs	X	X
Total TEQ	X	X
Arsenic	X	X
Copper	X	X
Lead	X	X
Zinc	X	X
pH	X	
Density	X	
Temperature	X	
DNAPL Distribution	X	X

In general, 3-D visualizations were developed for those parameters that exhibited a significant number of exceedances of their respective groundwater cleanup level, sediment cleanup level or soil screening criterion. 3-D visualizations were not prepared for parameters with few or no exceedances of their respective cleanup levels or screening criteria.

For VOCs (PCE, TCE, cis-1,2-DCE, VC, total VOC, and total CVOC), pH, temperature, and density in groundwater and soil, the analytical data were sufficiently distributed throughout the Site to develop meaningful 3-D interpretive models, or 3-D interpolations, for each parameter or parameter class. These 3-D visualization interpretive models consist of:

- A model showing the locations where samples were analyzed for the parameter, color coded to represent the concentration of the parameter at each sample location relative to other measured concentrations
- Interpretive model of the parameter plume, color coded to represent ranges of concentrations based upon the parameter's groundwater screening criteria
- Plan views cut horizontally through the interpretive model at 25 ft, 50 ft, 75 ft, 100 ft, 130 ft, and 160 ft below upland ground surface (i.e., the 25-ft, 50-ft, 75-ft, 100-ft, 130-ft, and 160-ft zones) with concentration contours and colors to represent ranges of concentrations
- East-west sections cut vertically through the interpretive model at 100-ft intervals (Waterway stations 20+00 through 49+00) with concentration contours and colors to represent ranges of concentrations
- North-south sections cut vertically through the interpretive model at 100-ft intervals (from 1,900-ft west to 700-ft east of the Waterway centerline) with concentration contours and colors to represent ranges of concentrations

At the Agencies' request, 3-D visualization interpretive models were also developed for DNAPL, total BTEX, PAHs, PCBs, dioxin/furans (total TEQ), TPH, and metals (arsenic, copper, lead, and zinc) in groundwater and soil. Sampling for these parameters was targeted to likely potential source areas rather than globally across the Site. As a result, the utility of these models is limited to areas of concentrated investigation.

The MVS/EVS 3-D interpretive and cross-section models are included on the USB drive attached as Appendix O. Appendix O includes a description of the MVS/EVS software package, the parameter values utilized in model development, software to view the visualizations, and instructions regarding the use of the visualization viewing software.

4.1.1 Objectives

The objectives of the Site Characterization activities were to:

i) Determine the three-dimensional extent of VOC and pH contamination in groundwater onshore and beneath the Waterway.

ii) Determine the depth of hydraulic capture required to prevent contaminated groundwater from discharging into the Waterway.

iii) Determine the three-dimensional extent of source material onshore and beneath the Waterway.

iv) Quantify the hydrogeological parameters that will allow the flux of potential contaminants into the Waterway to be determined, and provide data needed to refine the conceptual hydrogeological model for the Site.

These objectives have been achieved through the investigations conducted at the Site as presented in Section 2.1.

4.1.2 Data Used for Delineation

A significant volume of data has been generated over the course of the investigations conducted at the Site. In order to complete a representative analysis of conditions at the Site, the following available analytical data were utilized:

Soil

Soil data generated from the 709 and 721 Alexander Avenue properties will be discussed in relation to the former OCC facility Site COCs (e.g., chlorinated solvents). Data associated with petroleum-related compounds (e.g., benzene, toluene, ethylbenzene, and xylenes (BTEX); polyaromatic hydrocarbons (PAHs), and total petroleum hydrocarbons (TPH)) will be discussed in a separate report in accordance with Agreed Order No. DE 9835 between Ecology, Mariana, and the POT, effective October 3, 2013.

Subtidal soil data from samples that were subsequently excavated as part of the Waterway dredging activities have been excluded from the report. All other upland and subtidal soil data have been utilized in the Site characterization.

Groundwater

Groundwater data generated between January 2004 and October 2013 were used to provide a comprehensive understanding of COC distribution across the Site. For sampling locations with multiple data sets, the most current result was used in the characterization and 3-D modeling.

Groundwater data generated from the 709 and 721 Alexander Avenue properties will be discussed in relation to the former OCC facility Site COCs (e.g., chlorinated solvents). Data associated with petroleum-related compounds (e.g., BTEX, PAHs, and TPH) will be discussed in a separate report in accordance with Agreed Order No. DE 9835 between Ecology, Mariana, and the POT, effective October 3, 2013.

Sediment

Sediment data from samples that were subsequently excavated as part of the Waterway dredging activities have been excluded from the report. All other sediment data have been utilized in the Site characterization.

Porewater/Seeps

All porewater and seep data have been utilized in the Site characterization.

Soil Vapor/Indoor Air

All soil vapor, indoor air, and ambient (outside) air data have been utilized in the Site characterization.

4.1.3 Site Constituents of Concern

COCs have been established for the Site based upon historical site processes, investigations, and characterizations. Tables 4.1 through 4.4 present the COCs for each of the major site media/areas including:

i) Upland Groundwater (Table 4.1)
ii) Embankment Area/Subtidal Groundwater (Table 4.2)
iii) Surface Water (Table 4.3)
iv) Sediment/Porewater (Table 4.4)

4.2 Data Quality Assessment and Validation

Validation of the analytical data generated through 2007 was performed in accordance with the analytical methods and the following documents: "USEPA Contract Laboratory Program

National Functional Guidelines for Organic Data Review," USEPA 540/R-99-008, October 1999; and "USEPA Contract Laboratory Program National Functional Guidelines for Inorganic Data Review," USEPA 540/R-94-013, February 1994.

Validation of the analytical data generated in 2012 and 2013 was performed in accordance with the analytical methods and guidance from the following documents: "USEPA Contract Laboratory Program National Functional Guidelines for Superfund Organic Methods Data Review," EPA 540-R-08-01, June 2008 and "USEPA Contract Laboratory Program National Functional Guidelines for Inorganic Superfund Data Review," EPA 540-R-10-011, January 2010.

Data generated through 2007 were presented by the laboratory in a Contract Laboratory Program (CLP)-like data package. Each data package included calibration summaries, method blank summaries, tuning summaries (where applicable), and QC summaries such as surrogates, internal standards, blank spikes, and matrix spikes. The data packages also included all raw data associated with each sample.

Data generated in 2012 and 2013 were presented by the laboratory in a standard Level II data package. Each data package included method blank summaries, and QC summaries such as surrogates, internal standards, blank spikes, and matrix spikes.

Data were qualified based on method outliers or deviations. Qualifications include estimating the data or rejecting the data. The assessment of analytical data also included checks on data consistency by looking for comparability of duplicate analyses, comparability to previous data from the same sampling location (if available), adherence to accuracy and precision control criteria and anomalously high or low parameter values. The results of the data validations were summarized and reported to the Project Manager. These validation reports included discussions of the following information and their effects on the quality of the data reported:

1. Sample holding times
2. Laboratory/reagent blank data
3. Surrogate spike, matrix spike and matrix spike duplicate (MS/MSD) data
4. Field QA/QC data
5. Pertinent instrument performance per method protocols

In addition, the validation reports summarized all QA problems, and gave a general assessment of QA results versus control criteria for such parameters as accuracy, precision, etc.

A list of CRA validation reports associated with the data presented since 1996 is presented in Appendix P. Copies of these data validation reports have been previously submitted to USEPA and/or Ecology. Validation reports for data collected by entities other than CRA (Hart Crowser, Ecology, HCC, etc.) are not included in the list in Appendix P.

4.3 Site Cleanup/Screening Levels

Performance standards, defined as the cleanup standards, standards of control, and other substantive requirements, criteria, or limitations, were defined in the SOW. These standards are consistent with the remedial objectives for the Site as stated in the SOW. Through the course of the Site characterization activities, screening criteria for additional contaminants and/or media have been defined as required for compounds/media that were not defined in the 2005 SOW. The following sections present the performance standards for the various media. (See endnote

4.3.1 Groundwater Cleanup Standards

Groundwater cleanup standards for the Site, consisting of groundwater cleanup levels and the location (point of compliance) where the cleanup levels must be met, have been established following the procedures described in the MTCA regulations.

Groundwater Cleanup Levels

The use of Site groundwater is restricted to "non-potable" uses through restrictive covenants currently in effect for the Site. Since groundwater at the Site is considered as non-potable (while the covenants are in place) and discharges to the Hylebos or Blair Waterways, the groundwater cleanup standards for the Site are based on the surface water cleanup standards for the Site, described below in Section 4.3.3. The Site-specific groundwater cleanup levels as defined in the SOW are presented in Table 4.5. Note that for arsenic, the groundwater cleanup level of 5 micrograms per liter (µg/L) is based on the presumed natural background level for this constituent in groundwater for the State of Washington in accordance with the MTCA regulations in WAC 173-340-730, the numerical value of which is shown in Table 720-1 of these regulations.

~~*Groundwater Point of Compliance*~~

~~Based upon Site conditions, the nature and extent of the impacted groundwater and current technological limitations, it is anticipated that it will not be practicable to meet the groundwater cleanup levels throughout the Site in a reasonable timeframe. As such, a conditional point of compliance for groundwater cleanup levels will be established based on a demonstration (based on the results of the alternatives analyses (i.e., the feasibility study)~~

~~performed under the SOW) that the selected methods of groundwater remediation will be implemented to the maximum extent practicable. As required under MTCA, the conditional groundwater point of compliance, to be approved by Ecology and USEPA, will be located as close to the potential source or sources of groundwater contamination as possible.~~

4.3.2 Sediment Cleanup Standards

Sediment cleanup standards for the Site, consisting of sediment cleanup levels and the location (point of compliance) where the cleanup levels must be met, have been established by the CB/NT ROD ~~following procedures consistent with the MTCA regulations~~. (See endnote iv. The SMS in its updated form, February 2013, is applicable as an ARAR, subject to USEPA evaluation.)

Sediment Cleanup Levels

MTCA addresses sediment cleanup levels by reference to the Washington State Sediment Management Standards (SMS) (WAC 173-204). Under the SMS, the primary endpoint for sediment quality evaluations is protection of the environment, specifically the benthic community, from adverse effects associated with the Site COCs. SQOs for the Site were developed by USEPA for the entire CB/NT Site and incorporated into the ROD. In the event that sediments are found with high levels of constituents that were not considered when the ROD was developed in 1989, Ecology and USEPA will determine Site-specific concentration limits for these constituents consistent with the methodologies provided by the NCP and WAC 173-204.

Ecology has previously concluded that the implementation of bioassays and interpretive endpoints used in the USEPA risk assessment to develop SQOs was based on a framework similar to that developed in the SMS. Accordingly, Ecology previously concluded that the SQOs provide protective levels for acute and chronic toxicity of biota in sediments at the Site using a risk-based approach similar to the risk-based approach provided by SMS.[iv]

Consequently, Site-specific sediment cleanup levels are based on SQOs, where SQOs exist. If an SQO does not exist for a particular COC, the sediment cleanup level is based on the Sediment Quality Standard (SQS) promulgated under SMS for that constituent, if one exists. Site-specific sediment cleanup levels as defined in the SOW are presented in Table 4.5. (See endnote iv. Revisions or updates may be necessary and will be evaluated during development of the Cleanup Action Plan.)

Sediment Point of Compliance

The point of compliance for achieving the sediment cleanup levels will generally be 0 to 10 cm below the sediment surface. Ecology and USEPA have generally applied the 0 to 10 cm biologically active zone interval within the Waterway based on available information on the distribution of abundance and biomass of biota in Commencement Bay sediments. Radioisotope dating evaluations performed by USEPA and Ecology, as part of the remedial investigation feasibility study for the overall CB/NT Site, revealed that the biologically active zone within the Waterway does not generally extend deeper than 10 cm below the sediment surface. Where habitat is favorable to burrowing organisms, such as burrowing shrimp, the point of compliance should be modified to ensure protectiveness of cleanup remedies with respect to these organisms.

4.3.3 Surface Water Cleanup Standards

Surface water cleanup standards for the Site, consisting of surface water cleanup levels and the location (point of compliance) where these cleanup levels must be met, have been established based on the surface water cleanup standards in the MTCA regulations, WAC 173-340-730, and with the state water quality standards in WAC 173-201A.

Surface Water Cleanup Levels[v]

Surface water cleanup levels for the Site have been developed based on water quality criteria protective of aquatic organisms or risk to human health. Site-specific surface water cleanup levels as defined in the SOW are presented in Table 4.5. Note that for arsenic, the cleanup level has been established based on the National Toxic Rule human health criterion in surface water, as adjusted to the current practical quantitation limit of 1 µg/L for chemical analysis for this constituent. Depending on the selected remedy, this value will be further adjusted upward to 5 µg/L if compliance monitoring is located in discharging groundwater rather than in surface water.

Point of Compliance

As discussed in Section 4.3.2, the biologically active zone in sediment is considered to extend from the sediment surface to a depth of 10 cm, or possibly deeper if the habitat is favorable for burrowing benthic organisms. The point of compliance for achieving surface water cleanup levels is the point of release of porewater into the Waterway, generally defined as the base of the biologically active zone. Therefore, surface water cleanup levels are applicable to a depth of 10 cm below the sediment surface, unless the biologically active zone is deeper.

4.3.4 Soil Screening Criteria

The MTCA regulations require that soil concentrations be protective of groundwater. Accordingly, soil screening criteria were established for unsaturated and saturated soil using the Variable Parameter Three-Phase Partitioning Model presented in WAC 173-340-747.

Table 4.6 presents the soil screening criteria for the Site as defined in the SOW including unsaturated soil (C_u) and saturated soil (C_s). The values used to calculate the criteria are also presented in the table.

4.3.5 Porewater Screening Criteria

The chemical concentrations of groundwater/porewater at the sediment point of compliance cannot exceed concentrations that may re-contaminate the sediments following remediation. Therefore, porewater screening criteria were established for the Site.

Table 4.7 presents the porewater screening criteria established for the Site as defined in the SOW. The values used to calculate the porewater screening criteria are presented in the table.

4.3.6 CSI Soil and Groundwater Screening Criteria

As part of the CSI, OCC and the Agencies collaborated to establish a comprehensive list of groundwater and soil screening criteria based on the existing cleanup standards and screening criteria as defined in the SOW and described in the preceding sections. For parameters not identified as part of the SOW, screening criteria were developed in accordance with MTCA and Ecology's web application tool "CLARC – Cleanup Level and Risk Calculations."

Table 4.8 presents the CSI screening criteria for groundwater and soil. The CSI screening levels have been used for comparison of all groundwater and soil samples throughout this SCR. For parameters that were not analyzed as part of the CSI (e.g., pesticides), the screening levels established in the SOW are used for comparison.

4.3.7 Soil Vapor Screening Criteria

The analytical results for all indoor air (IA) samples submitted to the laboratory for analysis were compared to current MTCA Method B screening levels originally presented in Ecology's Draft VI Guidance (Ecology, 2009; Table B-1), the IA short-term screening level for TCE (8.4 micrograms per cubic meter [$\mu g/m^3$]), and USEPA's November 2012 Regional Screening Levels (RSLs). The analytical results for all sub-slab soil vapor (SS) samples were compared to the same values noted above multiplied by a factor of 10, which is consistent with USEPA and Ecology recommended attenuation factors. The list of target analytes and applicable screening levels along with method reporting limits is presented in Table 4.9.

Outdoor air (OA) samples were collected to establish ambient background and are not compared to screening levels.

4.4 Soil

Soil samples collected from the vadose (unsaturated) zone are compared to the list of unsaturated soil screening criteria (C_u) established in the SOW and expanded for the CSI and are discussed in Section 4.4.1. Soil samples collected from the capillary and saturated zones are compared to the list of saturated soil screening criteria (C_s) established in the SOW and expanded for the CSI and are discussed in Section 4.4.2.

4.4.1 Unsaturated Soil

Through the course of the following site investigations, 173 unsaturated soil samples were collected from the locations listed below (sample locations are shown on Figure 2.1). Multiple samples could be collected from one location at varying depths, resulting in a greater number of samples than locations. Furthermore, different parameter lists often applied to specific investigations, resulting in variability in the sample counts between parameters.

- 4 locations (BH-#-96) as part of the Embankment Investigation (1996) and analyzed for PCE, TCE, Ethylbenzene, Site SVOCs, pesticides, PCBs, and metals
- 5 locations (CH-#) as part of the Additional Supplemental Investigations (2005) and analyzed for the VOCs and metals
- 3 locations (EA-#) as part of the Subtidal/Hydraulic Investigation (2005-2006) and analyzed for the Embankment Area/Subtidal Groundwater COCs
- 12 locations (NL-##) as part of the Supplemental Investigations (2004) and Additional Supplemental Investigations (2005-2006) and analyzed for the Embankment Area/Subtidal Groundwater COCs
- 1 location (Pier 25-32) as part of the Borings Adjacent to Pier 25 (2006) and analyzed for the Embankment Area/Subtidal Groundwater COCs
- 8 locations (SP-#) from the Salt Pad as part of the Additional Supplemental Investigations (2005-2006) and analyzed for the Embankment Area/Subtidal Groundwater COCs
- 28 locations (WMUA-##) from Waste Management Unit A as part of the Supplemental Investigations (2004) and Additional Supplemental Investigations (2005-2006) and analyzed for the Upland Groundwater COCs
- 2 locations (WMUH-#) from Waste Management Unit H as part of the Supplemental Investigations (2004) and analyzed for the Embankment Area/Subtidal Groundwater COCs
- 9 locations as part of the Focused Investigation of Dioxins/Furans and PCB Congeners (2006-2007) and analyzed for PCDD/F and PCB congeners
- 69 locations (709-, 721-) on the 709 and 721 Alexander Avenue properties as part of the PRI Preliminary Site Investigation (1994), PRI Soil and Groundwater Investigation (1995), PRI

Source Area Investigation (1995), 709/721 Alexander Avenue Investigation (2004), and Comprehensive Supplemental Investigation (2012) and analyzed for varying combinations of Site VOCs, BTEX, Site SVOCs, PAHs, PCBs, total petroleum hydrocarbons (TPH), and metals. As discussed in Section 4.1.2, only OCC Site-related COCs are discussed in this report

- 5 locations as part of the 2013 CSI mobilization and analyzed for VOCs

The analytical results are presented in Table 4.10 and are compared to the CSI Screening Criteria listed in Table 4.8. Table 4.11 presents a summary of the nature and extent of contamination in unsaturated soil at the Site by parameter. 3-D visualization models presenting the concentrations of COCs in unsaturated soil are presented on the USB drive attached as Appendix O. Detections of SVOCs (HCB and HCBD) and pesticides were observed in discrete areas. Due to the limited number of samples/observations, 3-D visualization models were not prepared for these compounds/classes.

The nature and extent of contamination in unsaturated soil are discussed in the following sections.

4.4.1.1 Volatile Organic Compounds

Concentrations of VOCs in unsaturated soil exceeded the CSI soil screening criteria at 27 of the 127 locations where unsaturated soil samples were collected for VOC analysis. Site VOC parameters that exceeded the CSI soil screening criteria include:

- PCE – 32 exceedances ranging from 110 µg/kg to 290,000 µg/kg [exceedance factor (EF) range from 1.17 to 3,088]
- TCE – six exceedances ranging from 540 µg/kg to 21,000 µg/kg (EF range from 1.01 to 39)
- VC – one exceedance of 2,630 µg/kg (EF of 176)
- Carbon Tetrachloride – three exceedances ranging from 79 µg/kg to 990 µg/kg (EF of 1.95 to 24)
- Chloroform - one exceedance of 11,000 µg/kg (EF of 4.4)

The greatest exceedance occurred at SB-A at a depth of 9 ft BGS, where PCE exceeded the CSI soil screening criteria by an EF of 3,088.

PCE has the greatest impact to unsaturated soil of the Site VOCs, although TCE and VC also exceed their respective soil screening criteria in a few locations. In general, the exceedances are located in the vicinity of WMU A, WMU G, WMU H, and the N Landfill.

4.4.1.2 Semi-Volatile Organic Compounds

Concentrations of SVOCs in unsaturated soil exceeded the CSI soil screening criteria at 30 of the 74 locations where unsaturated soil samples were collected for SVOC analysis. Site SVOC parameters that exceeded the CSI soil screening criteria include:

- HCB – 19 exceedances ranging from 1.63 µg/kg to 1,300 µg/kg (EF range from 1.3 to 1,048)
- HCBD – 32 exceedances ranging from 21 µg /kg to 28,000 µg/kg (EF range from 1.5 to 1,997)
- Pentachlorophenol (PCPH)– four exceedances ranging from 140 µg/kg to 2,500 µg/kg (EF range from 1.1 to 20)

The greatest exceedance occurred at WMUA-6 at a depth of 6 ft BGS, where HCBD exceeded the CSI soil screening criteria by an EF of 1,997.

Figure 4.1 presents the areal distribution of SVOC concentrations in unsaturated soil at the Site. The extent of these constituents may not be completely defined; however, they are expected to be within the defined CVOC plumes based on lower mobility and similar source areas.

HCB and HCBD have the greatest impact to unsaturated soil of the Site SVOCs, although PCPH also exceeds its respective soil screening criteria. HCB and HCBD exceed the soil screening criteria in the vicinity of WMU A, WMU G, the N Landfill, and several embankment locations. Pentachlorophenol exceeded its soil screening criteria in the vicinity of WMU A and the N Landfill.

4.4.1.3 Pesticides

Concentrations of pesticides in unsaturated soil exceeded the soil screening criteria at 2 of 4 locations where unsaturated soil samples were collected for pesticide analysis. Pesticide parameters that exceeded the soil screening criteria include:

- 4,4'-DDE - two exceedances of 3.0 µg/kg and 7.3 µg/kg (EF of 2.6 and 6.3)

Figure 4.2 presents the areal distribution of pesticide concentrations in unsaturated soil at the Site. The extent of these constituents may not be completely defined; however, they are expected to be within the defined CVOC plumes based on lower mobility and similar source areas.

Analysis of unsaturated soil samples was limited to four locations along the embankment. Only 4,4'-DDE exceeded its soil screening criteria at two locations north of Dock 1.

4.4.1.4 Polychlorinated Biphenyls

In accordance with MTCA, the PCB mixtures have been considered as a single hazardous substance. For the most part, the total PCB concentrations obtained from the site investigations were calculated by the laboratory based upon analysis of PCB aroclors. Several samples, however, were analyzed for select PCB congeners. In these cases, total PCB concentrations for the samples have been calculated from the laboratory measured concentrations of PCB congeners using the methodology outlined by Frame et al., (1998); Spongberg, (2004); and Woolcott, (2001). The calculation methodology is presented in Appendix Q, Table Q.3.

Concentrations of PCBs in unsaturated soil exceeded the CSI soil screening criteria at 10 of the 57 locations where unsaturated soil samples were collected for PCB analysis, with exceedances ranging from 140 µg/kg to 4,000 µg/kg (EF range from 1.5 to 43). The greatest exceedance occurred at location EA-3 at a depth of 11 ft BGS. The greatest area of impact to unsaturated soil is along the embankment near the former Navy-Todd Dump.

Table 4.12 presents a summary of total PCB concentrations for each unsaturated soil sample analyzed for either PCB aroclors or PCB congeners.

4.4.1.5 Dioxins/Furans

In accordance with MTCA, the mixtures of dioxins/furans have been considered a single hazardous substance. As such, the laboratory measured concentrations of dioxin and furan congeners have been multiplied by their respective toxicity equivalency factors (TEFs) to obtain a toxicity equivalency concentration (TEQ) of 2,3,7,8-TCDD for each sample. Table 4.13 presents a summary of the dioxin/furan TEQs calculated for each unsaturated soil sample analyzed for dioxins and furans. The TEQ calculations are presented in Appendix Q, Table Q.5.

4.4.1.6 Metals

Concentrations of metals in unsaturated soil exceeded the CSI soil screening criteria at 74 of 83 locations where unsaturated soil samples were collected for metals analysis. Metals parameters that exceeded the CSI soil screening criteria include:

- Arsenic– 33 exceedances ranging from 3,000 µg/kg to 228,000 µg/kg (EF range from 1.03 to 78)
- Chromium – 32 exceedances ranging from 14,700 µg/kg to 196,000 µg/kg (EF range from 1.04 to 14)

- Copper - exceedances at all locations where copper was analyzed ranging from 7,100 µg/kg to 7,070,000 µg/kg (EF range from 6.7 to 6632)
- Lead - seven exceedances ranging from 5,000,000 µg/kg to 33,200,000 µg/kg (EF range from 3.1 to 20)
- Mercury - 15 exceedances ranging from 47 µg/kg to 1,200 µg/kg (EF range from 1.8 to 46)
- Nickel - 38 exceedances ranging from 10,700 µg/kg to 870,000 µg/kg (EF range from 1.00 to 81)
- Zinc - 16 exceedances ranging from 102,000 µg/kg to 10,200,000 µg/kg (EF range from 1.01 to 101)

Copper is ubiquitous at the Site at concentrations exceeding the CSI soil screening criteria and although presenting the highest EFs, may be indicative of background conditions for the Site and surrounding properties. Excluding copper, the greatest exceedance occurred in a sample collected from the N Landfill at a depth of 5 ft BGS, where zinc exceeded the CSI soil screening criteria by an EF of 101.

Arsenic, zinc, and nickel have the greatest impact to unsaturated soil of the Site metals. Total chromium, lead, and mercury also exceed their CSI soil screening criteria for unsaturated soil, but to a lesser degree. In general, the exceedances are located across the western portion of the facility, including the top of the embankment, the former Salt Pad, the former Caustic House, and the N Landfill.

4.4.1.7 pH

Field pH measurements were collected from soils from the 10 soil borings (PH-##) installed as part of the CSI within and around the suspected pH potential source area. The pH borehole locations are shown on Figure 2.1. The measurements were obtained using litmus paper.

Unsaturated soils were encountered at three locations. The pH measurements ranged from 7 at boring PH-08 to 12 at boring PH-05, as presented in Table 4.14. Fill and debris were present at the other locations; consequently, the first soil samples were obtained within the saturated zone.

4.4.2 Saturated Soil

Through the course of the following site investigations, 2,287 saturated soil samples were collected from the locations listed below. Multiple samples could be collected from one location at varying depths, resulting in a greater number of samples than locations.

Furthermore, different parameter lists often applied to specific investigations, resulting in variability in the sample counts between parameters.

- 3 unknown locations from WMU-C were composited into 1 sample (OXY-1) in 1994 and analyzed for PCE, TCE, Site SVOCs, pesticides, PCBs, and metals
- 8 monitoring well locations (709-MW#-15) and 4 test pit locations (TP-#-93) as part of the PRI Preliminary Site Investigation (1994) and analyzed for VOCs, SVOCs, PCBs, and metals
- 1 monitoring well location (47-15) as part of the PRI Source Identification Investigation (1994) and analyzed for VOCs
- 11 monitoring well locations (709-MW#-15) as part of the PRI Soil and Groundwater Investigation (1995) and analyzed for VOCs. Additionally, 2 test pits (TP-#-95) were also sampled for lead
- 11 borehole locations (BH-#-96) as part of the Embankment Investigation (1996) and analyzed for PCE, TCE, Site SVOCs, pesticides, PCBs, and metals
- 20 subtidal borehole locations (PT-##) as part of the Area 5106 Post-Treatment Characterization (2003) and analyzed for PCE, TCE, HCB, and HCBD
- 5 monitoring well locations (721-MW#-##) and 1 Geoprobe® boring location (721-GP5) as part of the 709/721 Alexander Avenue Investigation (2004) and analyzed for VOCs and SVOCs
- 20 borehole locations at the N Landfill (NL-#), WMU A (WMUA-#), WMU C (WMUC-#), and WMU H (WMUH-#) as part of the Supplemental Investigations (2004) and analyzed for VOCs, SVOCs, PCBs, and/or mercury
- 60 borehole locations at the N Landfill (NL-##), WMU A (WMUA-#), Caustic House (CH-#), and Salt Pad (SP-#) as part of the Additional Supplemental Investigations (2005-2006) and analyzed for VOCs, SVOCs, pesticides, PCBs, and/or metals
- 61 upland, intertidal, and subtidal borehole locations were installed adjacent to Dock 1 (EA-#), around Area 5106 (5106-##), adjacent to Pier 25 (Pier 25-##), and in the subtidal zone of the Waterway (HYD-#, WW-B4) as part of the Subtidal/Hydraulic Investigation (2005-2006), and analyzed for the Embankment Area/Subtidal Groundwater COCs
- 23 locations as part of the Focused Investigation of Dioxins/Furans and PCB Congeners (2006-2007) and analyzed for PCDD/F and PCB congeners
- 6 locations (SB-##, 79-50, 80-25, and 81-50) as part of the pH Pilot Study (2009) and analyzed for metals
- 4 soil boring locations (HC-N6-#) and 7 test pit locations (HC-N##-TP-#-#) installed by the Port of Tacoma on POT property north and west of the Site and analyzed for VOCs, HCBD, and/or lead

- 79 soil boring and monitoring well locations from suspected Site potential source areas (WMUA-##, WMUG-##, WMUL-##, WMUM-##, WMUR-##, PH-02, and 11-75, 17C, 89C), 709 and 721 Alexander Avenue, and subtidal (WW-A1R) as part of the Comprehensive Supplemental Investigation (2012) and analyzed for VOCs, SVOCs, PCBs, dioxins/furans, and/or metals
- 15 locations as part of the 2013 CSI mobilization and analyzed for VOCs and SVOCs

Sample locations are shown on Figure 2.1.

The analytical results are presented in Table 4.15 and are compared to the CSI soil screening criteria listed in Table 4.8. Table 4.16 presents a summary of the nature and extent of contamination in saturated soil at the Site by parameter. 3-D visualization models presenting the concentrations of COCs in saturated soil are presented on the USB drive attached as Appendix O. Detections of SVOCs (HCB and HCBD) and pesticides were observed in discrete areas. Due to the limited number of samples/observations, 3-D visualization models were not prepared for these compounds/classes.

The nature and extent of contamination in saturated soil are discussed in the following sections.

4.4.2.1 Volatile Organic Compounds

Concentrations of VOCs in saturated soil exceeded the CSI soil screening criteria at 230 of the 303 locations where saturated soil samples were collected for VOC analysis. Site VOC parameters that exceeded the CSI soil screening criteria include:

- PCE –896 exceedances at 183 locations at concentrations ranging from 4.9 µg/kg to 120,000,000 µg/kg (EF range from 1.004 to 24,590,164)
- TCE –740 exceedances at 135 locations at concentrations ranging from 31 µg/kg to 58,000,000 µg/kg (EF range from 1.01 to 1,883,117)
- VC – 799 exceedances at 137 locations at concentrations ranging from 0.76J µg/kg to 56,500 µg/kg (EF range from 1.04 to 77,397)
- 1,1-Dichloroethene – 520 exceedances at 114 locations at concentrations ranging from 1.2J µg/kg to 690,000 µg/kg (EF range from 1.06 to 610,620)
- Methylene chloride – 127 exceedances at 46 locations at concentrations ranging from 480 µg/kg to 61,000 µg/kg (EF range from 1.01 to 128)
- Chloroform – 141 exceedances at 51 locations at concentrations ranging from 170J µg/kg to 1,100,000 µg/kg (EF range from 1.06 to 6,875)

- 1,1,2,2-Tetrachloroethane – 54 exceedances at 30 locations at concentrations ranging from 4.6J µg/kg to 670,000 µg/kg (EF range from 1.1 to 166,667)
- 1,1,2-Trichloroethane – 52 exceedances at 25 locations at concentrations ranging from 15.7 µg/kg to 67,000 µg/kg (EF range from 1.03 to 4,408)
- Carbon Tetrachloride – 28 exceedances at 14 locations at concentrations ranging from 3.4J µg/kg to 510,000 µg/kg (EF range from 1.76 to 264,249)
- Trans-1,2-Dichloroethene -13 exceedances at 9 locations at concentrations ranging from 3,300 µg/kg to 250,000 µg/kg (EF range from 1.01 to 77)

The greatest exceedance occurred at WMUR-06/94C at a depth of 137.5 ft BGS, where PCE exceeded the CSI soil screening criteria by an EF of 24,590,164. This location is within an area of confirmed DNAPL.

4.4.2.2 Semi-Volatile Organic Compounds

Concentrations of SVOCs in saturated soil exceeded the soil screening criteria at 89 of the 156 locations where saturated soil samples were collected for SVOC analysis. Site SVOC parameters that exceeded the CSI soil screening criteria include:

- HCB – 140 exceedances at 52 locations at concentrations ranging from 0.0975 µg/kg to 210,000 µg/kg (EF range from 1.6 to 3,387,097)
- PCPH – 19 exceedances at 12 locations at concentrations ranging from 21.6 µg/kg to 1,100 µg/kg (EF range from 3.1 to 159)
- HCBD – 183 exceedances at 81 locations at concentrations ranging from 0.72J µg/kg to 160,000 µg/kg (EF range from 1.03 to 227,920)

The greatest exceedance occurred at PT-15 at a depth of 14.5 ft below mudline (BML), where HCB exceeded the soil screening criteria by an EF of 3,387,097.

Figure 4.3 presents the areal distribution of SVOC concentrations in saturated soil at the Site. For reference, the horizontal extent of contamination in groundwater attributed to the parameter is also shown on the figure. The extent of these constituents may not be completely defined; however, they are expected to be within the defined CVOC plumes based on lower mobility and similar source areas.

HCB has the greatest impact to saturated soil of the Site SVOCs, although HCBD, and to a lesser degree, pentachlorophenol, also exceed their respective soil screening criteria. HCB exceedances occur below the Waterway and in the vicinity of WMU A, WMU G, the N Landfill, and several embankment locations. Pentachlorophenol exceedances are observed in the vicinity of WMU A and the N Landfill. HCBD exceedances occur primarily below the Waterway and in the vicinity of WMU A, the N Landfill, and several embankment locations.

4.4.2.3 Pesticides

Concentrations of pesticides in saturated soil exceeded the soil screening criteria at 8 of the 22 locations where saturated soil samples were collected for pesticide analysis. Pesticide parameters that exceeded the soil screening criteria include:

- 4,4'-DDD – 6 exceedances at 6 locations at concentrations ranging from 1.2 µg/kg to 210 µg/kg (EF range from 28 to 4,884)
- 4,4'-DDE – 13 exceedances at 6 locations at concentrations ranging from 4.56 µg/kg to 75.3 µg/kg (EF range from 79 to 1,298)
- 4,4'-DDT - one exceedance at a concentration of 11 µg/kg (EF of 24)

The greatest exceedance occurred at BH-11-96 at a depth of 6 ft BGS, where 4,4'-DDD exceeded the soil screening criteria by an EF of 4,884.

Figure 4.4 presents the areal distribution of pesticide concentrations in saturated soil at the Site. For reference, the horizontal extent of contamination in groundwater attributed to the parameter is also shown on the figure. The extent of these constituents may not be completely defined; however, they are expected to be within the defined CVOC plumes based on lower mobility and similar source areas.

4,4'-DDD and 4,4'-DDE have the greatest impact to saturated soil. Pesticides exceed the soil screening criteria along the embankment and in the N Landfill.

4.4.2.4 Polychlorinated Biphenyls

In accordance with MTCA, the PCB mixtures have been considered as a single hazardous substance. For the most part, the total PCB concentrations obtained from the Site investigations were calculated by the laboratory based upon analysis of PCB aroclors. Several samples, however, were analyzed for select PCB congeners. In these cases, total PCB concentrations for the samples have been calculated from the laboratory measured concentrations of PCB congeners using the methodology outlined by Frame et al, (1998); Spongberg, (2004); and Woolcott, (2001). The calculation methodology is presented in Appendix Q, Table Q.3.

Concentrations of PCBs in saturated soil exceeded the CSI soil screening criteria at 48 of 118 locations where saturated soil samples were collected for PCB analysis, with exceedances ranging from 0.155 µg/kg to 166,545 µg/kg (EF range from 2.9 to 3,142,358). The greatest exceedance occurred at location PT-15A, located below Dock 1 and adjacent to the Navy-Todd Dump at a depth of 56.5 ft BML. The greatest area of impact to saturated soil is along the embankment near the former Navy-Todd Dump.

Table 4.12 presents a summary of total PCB concentrations for each saturated soil sample analyzed for either PCB aroclors or PCB congeners.

4.4.2.5 Dioxins/Furans

In accordance with MTCA, the mixtures of dioxins/furans have been considered a single hazardous substance. As such, the laboratory measured concentrations of dioxin and furan congeners have been multiplied by their respective TEFs to obtain a TEQ of 2,3,7,8-TCDD for each sample. Table 4.13 presents a summary of the dioxin/furan TEQs calculated for each unsaturated soil sample analyzed for dioxins and furans. The TEQ calculations are presented in Appendix Q, Table Q.5.

4.4.2.6 Metals

Concentrations of metals in saturated soil exceeded the CSI soil screening criteria at 122 of 139 locations where saturated soil samples were collected for metals analysis. Metals parameters that exceeded the soil screening criteria include:

- Arsenic– 372 exceedances at 107 locations at concentrations ranging from 150 µg/kg to 268,000 µg/kg (EF range from 1.03 to 1,836)
- Chromium – 395 exceedances at 113 locations at concentrations ranging from 1,100 µg/kg to 1,200,000 µg/kg (EF range from 1.5 to 1,681)
- Copper – 395 exceedances at 113 locations at concentrations ranging from 2,980 µg/kg to 2,160,000 µg/kg (EF range from 55.8 to 40,374)
- Lead – 68 exceedances at 35 locations at concentrations ranging from 84,100 µg/kg to 37,500,000 µg/kg (EF range from 1.04 to 463)
- Mercury – 181 exceedances at 72 locations at concentrations ranging from 2 µg/kg to 116,000 µg/kg (EF range from 1.5 to 88,550)
- Nickel – 395 exceedances at 113 locations at concentrations ranging from 857 µg/kg to 962,000 µg/kg (EF range from 1.6 to 1,798)
- Thallium – 129 exceedances at 56 locations at concentrations ranging from 34.7 µg/kg to 226J µg/kg (EF range from 1.02 to 6.6)

- Zinc – 384 exceedances at 111 locations at concentrations ranging from 7,070 µg/kg to 3,400,000 µg/kg (EF range from 1.4 to 674)

The greatest exceedance occurred in the vicinity of the N Landfill, where mercury exceeded the soil screening criteria by an EF of 88,550. Other metals, primarily copper, total chromium, and nickel, as well as arsenic and zinc, are present at concentrations exceeding the soil screening criteria in almost all samples analyzed for metals. The highest concentrations occur along the embankment and in the vicinity of the N Landfill. Although presenting some of the highest EFs, these compounds may be indicative of background conditions for the Site and surrounding properties.

4.4.2.7 pH

Field pH measurements were collected from soils from the 10 soil borings (PH-##) installed as part of the CSI within and around the suspected pH potential source area. The pH borehole locations are shown on Figure 2.1. The measurements were obtained using litmus paper.

Borings were completed to a depth of 50 ft BGS and elevated pH measurements are observed throughout the boreholes. A total of 271 pH measurements were obtained with readings ranging from 7 at boring PH-08 to 13 at borings PH-03, PH-06, and PH-07, as presented in Table 4.14. The frequency of observed measurements is shown in the following table. Over 70% of the samples were observed to be in the 11 – 12 pH range.

pH Measurement	***# of Samples***	***Percentage of Samples***
7	2	0.7
7.5	0	0.0
8	9	3.3
8.5	4	1.5
9	8	3.0
9.5	1	0.4
10	28	10.3
10.5	13	4.8
11	75	27.7
11.5	67	24.7
12	50	18.5
12.5	2	0.7
13	12	4.4

4.5 Groundwater

Groundwater samples were generated as either one-time grab samples collected from soil borings, or from sampling of monitoring wells. All groundwater grab samples are reported. Only the most recent groundwater result for each monitoring well location sampled between January 1, 2004 and October 31, 2013 is reported. Groundwater sample locations are shown on Figure 2.1. Multiple samples could be collected from one location at varying depths, resulting in a greater number of samples than locations. Furthermore, different parameter lists often applied to specific investigations, resulting in variability in the sample counts between parameters.

The analytical results are presented in Tables 4.17 through 4.23 and are compared to the groundwater screening criteria established in the SOW and expanded for the CSI listed in Table 4.8. Table 4.24 presents a summary of the nature and extent of contamination in unsaturated soil at the Site by parameter. 3-D visualization models presenting the concentrations of COCs in groundwater are presented on the USB drive attached as Appendix O. Detections of SVOCs (HCB and HCBD) and pesticides were observed in discrete areas. Due to the limited number of samples/observations, 3-D visualization models were not prepared for these compounds/classes.

The nature and extent of contamination in groundwater are discussed in the following sections.

4.5.1 Volatile Organic Compounds

Concentrations of VOCs in groundwater exceeded the groundwater screening criteria at 329 of the 652 locations where groundwater samples were collected for VOC analysis as shown in Table 4.17. Site VOC parameters that exceeded the criteria include:

- VC – 770 exceedances at 278 locations at concentrations ranging from 2.41 µg/L to 870,000 µg/L (EF range from 1.02 to 362,500)
- Cis-1,2-DCE – 633 exceedances at 213 locations at concentrations ranging from 16.7 µg/L to 630,000 µg/L (EF range from 1.04 to 39,375)
- TCE –297 exceedances at 123 locations at concentrations ranging from 82.7 µg/L to 2,500,000 µg/L (EF range from 1.02 to 30,864)
- PCE –342 exceedances at 143 locations at concentrations ranging from 9.3 µg/L to 170,000 µg/L (EF range from 1.05 to 19,209)
- 1,1-Dichloroethene – 315 exceedances at 102 locations at concentrations ranging from 3.3 µg/L to 10,000 µg/L (EF range from 1.03 to 3,125)

- 1,1,2,2-Tetrachloroethane – 13 exceedances at 9 locations at concentrations ranging from 14 µg/L to 8,300 µg/L (EF range from 1.3 to 2,075)
- Carbon Tetrachloride – 6 exceedances at 4 locations at concentrations ranging from 7.3 µg/L to 920 µg/L (EF range from 1.7 to 209)
- Chloroform – 51 exceedances at 31 locations at concentrations ranging from 538 µg/L to 79,800 µg/L (EF range from 1.1 to 170)
- 1,1,2-Trichloroethane – 32 exceedances at 22 locations at concentrations ranging from 47 µg/L to 880 µg/L (EF range from 1.1 to 21)
- Methylene chloride – 19 exceedances at 15 locations at concentrations ranging from 1,700 µg/L to 19,000 µg/L (EF range from 1.06 to 12)

The greatest exceedance occurred at subtidal borehole 5106-002 at a depth of 25.5 ft BML, where VC exceeded the groundwater screening criteria by an EF of 362,500.

Table 4.24 presents a summary of the areal and vertical extents of the groundwater contamination at the Site by parameter.

VOCs associated with the production of chlorinated solvents at the Site are the primary chemical contaminants in groundwater. In particular, PCE, TCE, and VC are considered to be representative indicator parameters of VOC contamination at the Site. 3-D visualization models for PCE, TCE, and VC along with total CVOCs showing the 6 aquifer depth zones at the Site are provided in Appendix O. Conceptual presentations of the plumes for these compounds are also presented in Section 5.0 Figures 5.8, 5.15, 5.16, and 5.17.

The distribution of the VOC contamination in groundwater at the Site can be described in terms of the indicator parameters (PCE, TCE, and VC) and total CVOCs. The areal extent of CVOC impacts to groundwater at the Site are estimated from the 3-D visualization models as follows:

Parameter	***Impact Concentration (µg/L)***	***Aerial Extent by Zone (in Acres)***					
		25'	***50'***	***75'***	***100'***	***130'***	***160'***
PCE	>8.85	13.6	11.9	14.7	19.7	22.4	16.4
TCE	>81	9.7	8.7	9.2	14.7	20.3	15.1
VC	>2.4	30.3	40.3	44.3.8	43.4	47.0	40.2
Total CVOCs	>2.4	51.9	57.4	58.0	58.5	54.2	50.6

For the following discussion, Figures 4.5 through 4.10 present the distribution of total CVOCs at the various depth zones. These figures provide an overview of the total CVOCs impacts in the groundwater at the Site.

25-ft Zone

The 3-D models presented in Appendix O show that the highest concentrations of PCE and TCE (>100,000 µg/L) are located in the vicinity of WMU A and WMU G, with concentrations decreasing radially from these centers. The PCE and TCE plumes extend from the embankment to just west of Alexander Avenue, and from just south of the Salt Pad onto POT property to the north. The VC plume extends beyond the limits of the PCE and TCE plume, particularly to the north direction, toward the A-Branch of the groundwater extraction system. Low level exceedances of PCE and VC are observed near the south end of the former chemical manufacturing facility (Facility) and on the 709 and 721 Alexander Avenue properties, as well as along the Embankment near Dock 2 and the N Landfill. Figure 4.5 presents the distribution of total CVOCs in the 25-ft zone.

50-ft Zone

The highest concentrations of PCE and TCE (>10,000 µg/L) are located within WMU A (PCE and TCE), and below WMU G and along the embankment within the vicinity of Area 5106 (TCE). The extent of both the PCE and TCE plumes is similar to that within the 25-ft zone.

The extent of the VC plume increases significantly in the 50-ft zone, again beyond the limits of the PCE and TCE plume to the north and the south. A separate plume of VC appears on POT property near Commencement Bay. The VC plume is present within the marina on the east side of the Waterway. The highest concentrations of VC (>10,000 µg/L) are located within the marina and in the vicinity of WMU G. Figure 4.6 presents the distribution of total CVOCs in the 50-ft zone.

75-ft Zone

The highest concentrations of PCE and TCE (>10,000 µg/L) are located in the vicinity of WMU G. The shape of both the PCE and TCE plumes are similar, extending from the center of the shipping channel west to the C-Branch of the extraction system. The subtidal portions of both the PCE and TCE plumes are located within the approximate limits of Area 5106.

The extent of the VC plume is significantly greater than the PCE and TCE plumes at the 75-ft zone. The VC plume extends from the marina west to beyond the A-Branch extraction wells, and from the center of the Facility north toward Commencement Bay. The highest VC concentrations (>10,000 µg/L) are located along the north Facility property line and beneath the Waterway and the marina, east of the PCE and TCE plume. Figure 4.7 presents the distribution of total CVOCs in the 75-ft zone.

100-ft Zone

The highest concentrations of PCE (>10,000 µg/L) are located in the vicinity of WMU G. The highest concentrations of TCE (>10,000 µg/L) are located on POT property in the vicinity of extraction well D-5 and extending toward Area 5106. The leading edges of both the PCE and TCE plumes have migrated further north toward Commencement Bay. The TCE plume extends to the middle of the Waterway.

The east to west extent of the VC plume is similar to its extent at the 75-ft zone. The center portion of the VC plume has migrated northward. Figure 4.8 presents the distribution of total CVOCs in the 100-ft zone.

130-ft Zone

The extent of PCE is somewhat reduced at the 130-ft zone, with the highest concentrations of PCE (>10,000 µg/L) located near Pier 25 and below the Waterway in the vicinity of Area 5106. The extent of TCE appears the same but the highest concentrations of TCE (>100,000 µg/L) have increased. Both plumes have migrated north and slightly east.

The extent and concentrations of VC (>10,000 µg/L) are reduced at the 130-ft zone. The VC plume has migrated north toward Commencement Bay. Figure 4.9 presents the distribution of total CVOCs in the 130-ft zone.

160-ft Zone

The concentrations of the PCE and VC plumes are somewhat reduced at the 160-ft zone, while the highest concentrations of TCE are consistent with the 130-ft zone. The highest concentrations of PCE (>1,000 µg/L), TCE (>100,000 µg/L), and VC (>1,000 µg/L) have migrated north toward Commencement Bay, although the overall extent is much the same as at the 130-ft zone. Figure 4.10 presents the distribution of total CVOCs in the 160-ft zone.

4.5.2 Semi-Volatile Organic Compounds

Concentrations of SVOCs in groundwater exceeded the groundwater screening criteria at 47 of the 158 locations where groundwater samples were collected for SVOC analysis as shown in Table 4.18. Site SVOC parameters that exceeded the soil screening criteria include:

- HCBD – 63 exceedances at 17 locations at concentrations ranging from 0.02 µg/L to 610 µg/L (EF range from 1.5 to 46,923)
- HCB – 60 exceedances at 35 locations at concentrations ranging from 0.00089 µg/L to 6.9 µg/L (EF range from 1.2 to 8,961)

- PCPH – 10 exceedances at 7 locations at concentrations ranging from 10 µg/L to 670 µg/L (EF range from 1.3 to 85)

The greatest exceedance occurred at PT-13 at 20.25 ft BML, where HCBD exceeded the groundwater screening criteria by an EF of 46,923.

Figure 4.11 presents the areal distribution of SVOC concentrations in groundwater at the Site. The extent of these constituents may not be completely defined; however, they are expected to be within the defined CVOC plumes based on lower mobility and similar source areas.

HCBD and HCB have the greatest impact to groundwater (EF_{max} = 46,923 and 8,961, respectively) of the Site SVOCs. HCBD and HCB are present in groundwater at concentrations exceeding their groundwater cleanup level below the Waterway and along the embankment, and in the vicinity of the N Landfill and WMU G. Depth of impacts range from 2 ft to 164 ft BML within the Waterway and 10 ft to 111 ft BGS at upland locations.

The impacts of PCPH to groundwater are minor and limited to the vicinity of Area 5106 and WMU G.

4.5.3 Pesticides

Concentrations of pesticides in groundwater exceeded the groundwater screening criteria at only 1 of the 13 locations where groundwater samples were collected for pesticide analysis as shown in Table 4.19. 4,4'-DDT exceeded the groundwater screening criteria at NL-14 at a concentration of 0.247 µg/L (EF of 1123).

Figure 4.12 presents the areal distribution of pesticide concentrations in groundwater at the Site. The extent of these constituents may not be completely defined; however, they are expected to be within the defined CVOC plumes based on lower mobility and similar source areas.

The impact of Site pesticides to groundwater is limited to this one exceedance of 4,4'-DDT in the vicinity of the N Landfill at 17.5 ft BML.

4.5.4 Polychlorinated Biphenyls

In accordance with MTCA, the PCB mixtures have been considered as a single hazardous substance. The majority of the total PCB concentrations obtained from the site investigations were calculated by the laboratory based upon analysis of PCB aroclors. Several samples, however, were analyzed for select PCB congeners. In these samples, total PCB concentrations for the samples have been calculated from the laboratory-measured concentrations of PCB congeners using the methodology developed by Frame et al, (1998); Spongberg, (2004); and Woolcott, (2001). The calculations are presented in Appendix Q, Table Q.3.

Concentrations of PCBs in groundwater exceeded the groundwater screening criteria at 26 of 196 locations where groundwater samples were collected for PCB analysis, with exceedances ranging from 0.000589 µg/kg to 22.21 µg/kg (EF range from 3.5 to 130,647). The greatest exceedance occurred at location PT-15B at a depth of 39 ft BML, located near Dock 1 and adjacent to the Navy-Todd Dump. The greatest area of impact to groundwater is beneath the Waterway near the former Navy-Todd Dump.

Table 4.20 presents a summary of total PCB concentrations for each groundwater sample analyzed for either PCB aroclors or PCB congeners.

4.5.5 Dioxins/Furans

In accordance with MTCA, the mixtures of dioxins/furans have been considered a single hazardous substance. As such, the laboratory-measured concentrations of dioxin and furan congeners have been multiplied by their respective TEFs to obtain a TEQ of 2,3,7,8-TCDD for each sample. Table 4.21 presents a summary of the dioxin/furan TEQs calculated for each groundwater sample analyzed for dioxins and furans. The TEQ calculations are presented in Appendix Q, Table Q.4.

4.5.6 Metals

Concentrations of metals in groundwater exceeded the groundwater screening criteria at 468 of 486 locations where groundwater samples were collected for metals analysis as shown in Table 4.22. Metals parameters that exceeded the groundwater screening criteria include:

- Arsenic– 1,067 exceedances at 439 locations at concentrations ranging from 0.2 µg/L to 4,400 µg/L (EF range from 1.4 to 31,429)
- Chromium – 316 exceedances at 109 locations at concentrations ranging from 50.6 µg/L to 6,350 µg/L (EF range from 1.01 to 127)
- Copper – 1,055 exceedances at 277 locations at concentrations ranging from 2.41 µg/L to 7,230 µg/L (EF range from 1.00 to 3,013)
- Lead – 61 exceedances at 44 locations at concentrations ranging from 8.2 µg/L to 1,5300 µg/L (EF range from 1.01 to 189)
- Mercury – 187 exceedances at 125 locations at concentrations ranging from 0.03 µg/L to 85.2 µg/L (EF range from 1.2 to 3,408)

- Nickel – 920 exceedances at 213 locations at concentrations ranging from 8.26 µg/L to 2,790 µg/L (EF range from 1.01 to 340)
- Thallium – 119 exceedances at 51 locations at concentrations ranging from 0.474 µg/L to 4,680 µg/L (EF range from 1.01 to 9,957)
- Zinc – 143 exceedances at 71 locations at concentrations ranging from 81.67 µg/L to 49,400 µg/L (EF range from 1.01 to 610)

The greatest exceedance occurred in a sample collected beneath the Waterway near Pier 25 at a depth of 21.5 ft BML, where arsenic exceeded the groundwater screening criteria by an EF of 31,429. The next greatest exceedances occurred for thallium at 5106-12 at a depth of 3.5 ft BML beneath the Waterway, mercury at a depth of 100 ft BGS in the vicinity of the former Caustic House, and copper at WW-A1D at a depth of 22 ft BML beneath the Waterway.

The geochemical conditions in the groundwater (i.e., high pH and ionic strength) result in the mobilization of metals. Exceedances of metals parameters occur across the Site, off-Site on the peninsula, and beneath the Waterway and at all depth ranges. The primary potential sources of metals impact at the Site are the Navy-Todd Dump, N Landfill, and embankment soil.

4.5.7 pH

pH measurements are presented in Table 4.23. A 3-D visualization model of the distribution of pH in groundwater at the Site is presented on the USB drive attached as Appendix O. 3-D visualization models showing the six aquifer depth zones at the Site were developed and are provided in Appendix O.

The areal extent of pH impacts to groundwater to the Site are estimated from the 3-D visualization model as follows:

Parameter	***Impact Concentration (su)***	***Aerial Extent by Zone (in Acres)***					
		25'	***50'***	***75'***	***100'***	***130'***	***160'***
pH	>8.5	45.4	62.9	50.4	43.1	30.4	39.3

25-ft Zone

Within the 25-ft zone, the impacts (pH >8.5 su) extend over much of the Facility from the Waterway to west of Alexander Avenue. The highest pH groundwater (>11 su) is located along the eastern portion of the Site beneath the former caustic production and storage areas.

50-ft Zone

Within the 50-ft zone, the pH impacts generally extend over much of the Facility from the Waterway to west of Alexander Avenue. The extent of the highest pH values (>12 su) increases slightly in size relative to the 25-ft zone, and is located more to the north, immediately plant-south of the Salt Pad.

75-ft Zone

The pH plume within the 75-ft zone is reduced, extending from the middle of the Waterway to east of Alexander Avenue. The pH plume has migrated east with the highest groundwater pH (>12 su) located in the vicinity of the former caustic tanks and the south end of Dock 1.

100-ft Zone

The pH plume has migrated north and east and extends from the Waterway to east of Alexander Avenue. In general, the pH plume extent is still limited to beneath the Facility and the Waterway. The highest pH groundwater (>13 su) is located in the vicinity of the north end of Dock 1, extending from the Waterway to the Salt Pad.

130-ft Zone

The pH plume has migrated northeast and is located beneath the northeastern portion of the Facility, the POT property to the north, and the Waterway. The highest pH groundwater (>13 su) is located beneath the Waterway, east of Pier 25.

160-ft Zone

The pH impacts to groundwater at the 160-ft zone are diminished with the highest pH falling in the 10-11 su range and appearing in a narrow band beneath the POT property to the north.

4.5.8 Temperature

The temperature of groundwater was measured during the collection of groundwater samples at the Site. These temperatures varied across the Site due to many factors including seasonal variations, distance from the Waterway, depth of sample, time of day, the ambient air temperature, and sampling techniques.

To eliminate surface-related factors that could affect the temperature readings during sampling, the temperature readings measured during hydraulic monitoring Event 3 from the down-hole and in-place transducers were used to create a 3-dimensional (3-D) model of the temperature data. The temperatures measured by the transducers are believed to more accurately represent in situ conditions. The 3-D model is included in Appendix O. The 3-D model was used to prepare figures of horizontal sections through the temperature model along the six depth zone grouping planes. These plan view sections are shown on Figures 4.13 to 4.18.

Examination of these figures shows that in the 25-ft zone, temperatures are only slightly elevated beneath the facility relative to temperatures measured elsewhere[10]. The increase in temperature beneath the former production areas and WMUs at the Site is more pronounced in the 50-ft zone, where the highest value (18.4°C (65°F) at 15-50R) is 5 to 6°C (9 to 11°F) higher than the temperatures measured off Site. Temperatures in the former solvent manufacturing area, and specifically near the salt pad, are significantly higher than the off-Site water in the 75-ft, 100-ft, and 130-ft depth zones. The highest groundwater temperatures were measured in the 100-ft (23.1°C (73.6°F) at 82-100) and 130-ft (24.3°C (75.7°F) at T5-120) depth zones. In the 160-ft zone, the temperature difference between the area beneath the salt pad and the surrounding water is negligible.

The distribution of elevated temperature measurements is similar to the distribution of the pH plume. The pattern of groundwater temperature is consistent with a surface release of caustic and subsequent interaction with the porous media. The dissolution of sodium hydroxide released to the subsurface would be exothermic, which would cause an increase in the temperature of the surrounding groundwater. The interaction of sodium hydroxide and other caustics with the porous media would cause chemical reactions that temporarily sequester alkalinity in the soil, which is subsequently released. The reactions of the re-released caustic with the aquifer material would also be exothermic, which would maintain the elevated temperature in the high-pH zones.

The highly-elevated temperature groundwater (i.e., >20°C or 68°F) in the 100-ft and 130-ft depth zones has migrated to areas of lower pH either by migration with ADP and/or groundwater flow. This has resulted in higher groundwater temperatures to the north and east in these zones. Vertical migration of the elevated-temperature groundwater has resulted in the slightly elevated temperature in the 160-ft depth zone (16°C or 60.8°F) north of the Salt Pad.

---

[10] Natural groundwater at the Site has a temperature ranging from 11°C to 13°C (52°F to 55°F).

4.6 Sediment

For characterization purposes, geologic samples collected within 3 ft of the Waterway mudline are considered to be sediment samples. Through the course of the following site investigations, 89 discrete sediment samples and 15 composite sediment samples were collected from the locations shown on Figure 4.19.

- 9 locations (PT-#) as part of the Area 5106 Post-Treatment Characterization (2003) and analyzed for PCE, TCE, HCB, and HCBD
- 18 locations (5106-###) as part of the Area 5106 Borings and analyzed for the Embankment Area/Subtidal Groundwater COCs
- 13 locations (Pier 25-#) as part of the Borings Adjacent to Pier 25 (2006) and analyzed for the Embankment Area/Subtidal Groundwater COCs
- 6 composite locations (52##) as part of the Hylebos Pre-Remedial Design Program (1994) and analyzed for VOCs, SVOCs, pesticides, and metals
- 9 composite locations (A-#/##) as part of the Embankment Investigation (1996) and analyzed for VOCs, SVOCs, PCBs, pesticides, gasoline range organics (GRO), diesel range organics (DRO), total petroleum hydrocarbons (TPH), metals, and general chemistry
- 9 locations (NL-##) from the N Landfill as part of the Supplemental Investigations (2004) and Additional Supplemental Investigations (2005-2006) and analyzed for the Embankment Area/Subtidal Groundwater COCs or Sediment/Porewater COCs
- 14 locations as part of the Focused Investigation of Dioxins/Furans and PCB Congeners (2006-2007) and analyzed for PCDD/F and PCB congeners
- 1 location (WW-A1R) as part of the Comprehensive Supplemental Investigation (2012) and analyzed for PCBs and dioxins/furans

The analytical results are presented in Tables 4.25 through 4.27 and are compared to the sediment cleanup levels listed in Table 4.5. Table 4.28 presents a summary of the nature and extent of contamination in sediment at the Site by parameter. 3-D visualization models presenting the concentrations of COCs in sediment are included in Appendix O. Detections of SVOCs (HCB and HCBD) and pesticides were observed in discrete areas. Due to the limited number of samples/observations, 3-D visualization models were not prepared for these compounds/classes.

The nature and extent of contamination in sediment are discussed in the following sections.

4.6.1 Volatile Organic Compounds

Concentrations of VOCs in sediment exceeded the sediment cleanup levels at 14 of the 65 locations where sediment samples were collected for VOC analysis. Of the Site VOCs, only ethylbenzene and PCE have established sediment cleanup levels. Only PCE exceeded the sediment cleanup level at concentrations ranging from 84 µg/kg to 195,000 µg/kg. The highest detection of PCE occurred at boring PT-7 where PCE exceeded the sediment cleanup level by an EF of 3,421.

Exceedances of sediment cleanup levels are limited to PCE within Area 5106 and along the embankment in the vicinity of the N Landfill.

4.6.2 Semi-Volatile Organic Compounds

Concentrations of SVOCs in sediment exceeded the sediment cleanup levels at 33 of 35 locations where sediment samples were collected for SVOC analysis. Site SVOC parameters that exceeded the sediment cleanup levels include:

- 1,2,4-trichlorobenzene – 3 exceedances ranging from 60 µg/kg to 86 µg/kg (EF range from 1.2 to 1.7)
- bis(2-ethylhexyl)phthalate - one exceedance of 1800 µg/kg (EF of 1.4)
- HCB – 36 exceedances ranging from 24 µg/kg to 2,630 µg/kg (EF range from 1.1 to 120)
- HCBD – 45 exceedances ranging from 18 µg/kg to 24,300 µg/kg (EF range from 1.6 to 2209)
- Pentachlorophenol - one exceedance of 700 µg/kg (EF of 1.9)

The greatest exceedance occurred at PT-7, where HCBD exceeded the sediment cleanup level by an EF of 2209.

Figure 4.20 presents the areal distribution of SVOC concentrations in sediment at the Site. The extent of these constituents may not be completely defined; however, they are expected to be within the defined CVOC plumes based on lower mobility and similar source areas. Furthermore, future planned sampling in the Hylebos Waterway will determine the nature and extent of potential residual-chemical concentrations in the sediment.

HCBD and HCB have the greatest impact to sediment of the Site SVOCs. HCBD and HCB exceed their sediment cleanup levels along the entire embankment and within Area 5106. The remaining 3 Site SVOCs have limited or no impact to sediment along the embankment.

4.6.3 Pesticides

Concentrations of pesticides in sediment exceeded the sediment cleanup levels at 6 of 23 locations where sediment samples were collected for pesticide analysis. Pesticide parameters that exceeded the sediment cleanup levels include:

- 4,4'-DDD - six exceedances ranging from 140 µg/kg to 2,200 µg/kg (EF range from 8.8 to 138)
- 4,4'-DDE - one exceedance of 740 µg/kg (EF of 82)

The greatest exceedance occurred in a composite sample from Embankment Area 4, samples 13 through 16, where 4,4'-DDD exceeded the sediment cleanup level by an EF of 138.

Figure 4.21 presents the areal distribution of pesticide concentrations in sediment at the Site. The extent of these constituents may not be completely defined; however, they are expected to be within the defined CVOC plumes based on lower mobility and similar source areas. Furthermore, future planned sampling in the Hylebos Waterway will determine the nature and extent of potential residual-chemical concentrations in the sediment.

4,4'-DDD has the greatest impact to sediment of the Site pesticides. 4,4'-DDD is present in sediment at concentrations exceeding its sediment cleanup level along the embankment in the vicinity and south of Dock 2.

4.6.4 Polychlorinated Biphenyls

In accordance with MTCA, the PCB mixtures have been considered as a single hazardous substance. For the most part, the total PCB concentrations obtained from the site investigations were calculated by the laboratory based upon analysis of PCB aroclors. Several samples, however, were analyzed for select PCB congeners. In these cases, total PCB concentrations for the samples have been calculated from the laboratory measured concentrations of PCB congeners using the methodology outlined by Frame et al. (1998); Spongberg (2004); and Woolcott (2001). The calculations are presented in Appendix Q, Table Q.3.

Concentrations of PCBs in sediment exceeded the sediment cleanup level at 14 of 36 locations where sediment samples were collected for PCB analysis, with exceedances ranging from 335 µg/kg to 34,033 µg/kg (EF range from 1.1 to 113). The greatest exceedance occurred at location PT-17A.

Table 4.26 presents a summary of total PCB concentrations for each sediment sample analyzed for either PCB aroclors or PCB congeners.

4.6.5 Dioxins/Furans

In accordance with MTCA, the mixtures of dioxins/furans have been considered a single hazardous substance. As such, the laboratory measured concentrations of dioxin and furan congeners have been multiplied by their respective TEFs to obtain total TEQ of 2,3,7,8-TCDD for each sample. Table 4.27 presents a summary of the dioxin/furan TEQs calculated for each sediment sample analyzed for dioxins and furans. The TEQ calculations are presented in Appendix Q, Table Q.5.

4.6.6 Metals

Concentrations of metals in sediment exceeded the sediment cleanup levels at 19 of 25 locations where sediment samples were collected for metals analysis. Metals parameters that exceeded the sediment cleanup levels include:

- Arsenic - five exceedances ranging from 60,000 µg/kg to 140,000 µg/kg (EF range from 1.0 to 2.5)
- Copper - three exceedances ranging from 980,000 µg/kg to 2,500,000 µg/kg (EF range from 3.8 to 6.4)
- Lead - sixteen exceedances ranging from 519,000 µg/kg to 150,000,000 µg/kg (EF range from 1.2 to 333)
- Mercury - three exceedances ranging from 990 µg/kg to 2,100 µg/kg (EF range from 1.7 to 3.6)
- Nickel - four exceedances ranging from 150,000 µg/kg to 450,000 µg/kg (EF range from 1.1 to 3.2)
- Zinc - four exceedances ranging from 470,000 µg/kg to 1,500,000 µg/kg (EF range from 1.1 to 3.7)

The greatest exceedance occurred in a composite sample from Embankment Area 4, samples 13 through 16, where lead exceeded the sediment cleanup level by an EF of 333.

Exceedances of metals in sediment were observed in the intertidal zone along the embankment and in the vicinity of the N Landfill. Lead has the greatest impact to sediment of the Site metals. Arsenic, copper, mercury, nickel, and zinc also exceed their sediment cleanup levels along the embankment, but to a lesser degree (less than an order of magnitude above the respective sediment cleanup levels), and in fewer samples.

4.7 Soil Vapor/Indoor Air

The soil vapor/indoor air investigations were performed as described in the May 2014 Revised Draft Vapor Investigation Report (CRA, 2014b) (VI Report) attached as Appendix R. Figure 4.22 identifies the buildings investigated, including the Army Reserve Facility (ARF), Buildings 326, 407, 532, 592, 595, and 596, and the Guard Shack located on properties owned and/or controlled by the POT, and the OCC Office Building.

The SS samples at each building were collected concurrent with associated IA and OA sampling activities. The following sections summarize the analytical results and conclusions of the vapor investigation conducted through March 2014 at the nine buildings located at or in the vicinity of the OCC Site. The Vapor Investigation is ongoing.

4.7.1 Army Reserve Building

Analytical results for samples collected at the Army Reserve Building are presented in Table 4.29 and detected parameters summarized on Figure 4.23.

IA screening level exceedances for benzene (BZ) and carbon tetrachloride (CT) are likely attributable to an outdoor source and possibly an indoor source for BZ (round two). IA screening level exceedances for chloroform (round one) and naphthalene are likely attributable to an indoor source. Potential indoor sources of naphthalene include the operation of vehicles in the maintenance area. IA detections of TCE are attributed to a potential indoor air source and potentially an isolated source beneath the maintenance area unrelated to the OCC plume.

This building is proposed for no further action by Glenn Springs Holdings (GSH) due to the apparent outdoor source, indoor source, and potentially subsurface source unrelated to the OCC Site

4.7.2 Building 326

Analytical results for samples collected at Building 326 are presented in Table 4.30 and detected parameters summarized on Figure 4.24.

IA screening level exceedances for 1,2,4-trimethylbenzene (1,2,4-TMB), 1,4-dichlorobenzene (1,4-DCB), and chloroform (round one) are likely attributable to an indoor source. No specific obvious indoor sources were noted in the building; however, painting, carpeting, and new ceramic tile floors were installed in the last 2 years. IA screening level exceedances for BZ and CT (round one) are likely attributable to an outdoor source. Round two sampling further identified an IA exceedance for ethylbenzene (EB); however, data suggest this exceedance is likely attributable to an outdoor source with a potential contribution from indoor sources. Both round one and two sampling events identified IA screening level exceedance for TCE (3.9 and 3.1 $\mu g/m^3$, respectively) is likely attributable to a sub-slab source and the concentrations were below the short-term criterion of 8.4 $\mu g/m^3$.

This building is proposed for mitigation by GSH in response to concentrations of TCE in both SS and IA.

4.7.3 Building 407

Analytical results for samples collected at Building 407 are presented in Table 4.31 and detected parameters summarized on Figure 4.25.

IA screening level exceedances for 1,2,4-TMB, chloroform (round one), EB (round two), naphthalene, o-xylene (round two), and styrene (round two) are likely attributable to indoor sources (Citadel Marine paint bay operations, miscellaneous power and hand tools, parts washing tubs, chemical storage tanks, three flammable material storage lockers, paint cans, cleaning products, and miscellaneous building materials). IA screening level exceedances for BZ and CT are likely attributable to an outdoor source and an indoor source for BZ. SS concentrations of HCBD in round one were being adequately attenuated evidenced by HCBD not being detected in IA. Additionally, HCBD was not detected in any SS or IA samples in round three.

This building is proposed for no further action by GSH due to the identified indoor source and apparent outdoor sources unrelated to the OCC Site.

4.7.4 Building 532

Analytical results for samples collected at Building 532 are presented in Table 4.32 and detected parameters summarized on Figure 4.26.

IA screening level exceedances for 1,4-DCB and EB are likely attributable to an indoor source (aerosol cans containing chemical cleaners, lubricants, paints, and diesel fuel were observed). IA screening level exceedances for BZ and CT are likely attributable to an outdoor source. The IA screening level exceedance for TCE (0.86 $\mu g/m^3$) is likely attributable to a sub-slab source and the concentration was below the short-term criterion of 8.4 $\mu g/m^3$. Round two sampling did not confirm the presence of TCE exceeding IA screening criteria in any of the collected IA samples. However, SS sampling did identify TCE again exceeding soil gas screening levels.

This building is proposed for mitigation by GSH in response to concentrations of TCE in both SS and IA.

4.7.5 Building 592

Analytical results for samples collected at Building 592 are presented in Table 4.33 and detected parameters summarized on Figure 4.27.

IA screening level exceedances for BZ, chloroform (round three), EB (rounds two and three), naphthalene (rounds one and three), and 1,2,4-TMB (round two) are likely attributable to an indoor source and possibly outdoor source for BZ and chloroform. IA screening level exceedances for CT (rounds one and three) are likely attributable to an outdoor source. IA screening level exceedances for TCE are likely attributable to an indoor source. The building survey identified TCE in degreasers used in maintenance areas in Building 592. The TCE concentration at IA-2 (13 $\mu g/m^3$) in round one exceeded the short-term criterion of 8.4 $\mu g/m^3$. The rounds two and three maximum concentrations were 1.9 $\mu g/m^3$ and 8.3 $\mu g/m^3$, respectively, below the criterion. IA screening level exceedances for PCE in round three appear to be attributable to an indoor source. The data indicates that a potential isolated source exists beneath the shop area. The potential contribution to IA concentrations from location SS-32 is unclear. There were no exceedances for PCE in IA and SS samples in rounds one and two.

This building is proposed for additional monitoring by GSH in the shop area in this building to confirm SS vapor concentrations and further assess this portion of the building.

4.7.6 Building 595

Analytical results for the samples collected at Building 595 are presented in Table 4.34 and detected parameters summarized on Figure 4.28.

IA screening level exceedances for BZ CT (rounds one and three), and chloroform (round three) are likely attributable to an outdoor source (no specific obvious indoor sources were noted in the building). IA screening level exceedance for naphthalene (round three) may be attributable to indoor and/or outdoor sources. SS concentrations of BZ, chloroform, PCE, and TCE in exceedance of the SS screening levels are being adequately attenuated.

This building is proposed for no further action by GSH at this time due to confirmation that BZ, chloroform, PCE, and TCE in soil vapor are adequately attenuated under the current use of the building.

4.7.7 Building 596

Analytical results for the samples collected at Building 596 are presented in Table 4.35 and detected parameters summarized on Figure 4.29.

IA screening level exceedances for 1,2,4-TMB (round two), 1,4-DCB, chloroform (round one), EB (round two), naphthalene (rounds one and three), PCE, and TCE are likely attributable to an indoor source (numerous flammable storage lockers and stored chemicals including cleaners, and cutting oils were observed). IA screening level exceedances for BZ and EB (round three) are likely attributable to an indoor and possibly outdoor source. IA screening level exceedances for CT (rounds one and three) and chloroform (round three) sampling are likely attributable to an outdoor source. The TCE concentrations for both rounds one and two at IA-21 (19 and 15 $\mu g/m^3$, respectively) exceeded the short-term criterion of 8.4 $\mu g/m^3$ and the concentrations at IA-3 (6.6 and 2.9 $\mu g/m^3$) did not. The TCE concentrations for round three at IA-21 (7.1 $\mu g/m^3$), IA-3 (2.8 $\mu g/m^3$), and IA-35 (1.5 $\mu g/m^3$) are below the short-term criterion of 8.4 $\mu g/m^3$.

This building is proposed for no further action by GSH due to the identified indoor sources and apparent outdoor source unrelated to the OCC Site.

4.7.8 Guard Shack

Analytical results for the samples collected at the Guard Shack are presented in Table 4.36 and detected parameters summarized on Figure 4.30.

IA MTCA screening level exceedances for BZ and CT are likely attributable to an outdoor source.

This building is proposed for no further action by GSH as the observed exceedances of screening levels for IA appear to be due to outdoor source unrelated to the OCC Site, the location of the Guard Shack relative to the main plume, and the nature of the day-to-day operations at this location.

4.7.9 OCC Office Building

Analytical results for samples collected at the OCC Office Building are presented in Table 4.37 and detected parameters summarized on Figure 4.31.

An IA screening level exceedance for 1,4-DCB is likely attributable to an indoor or sub-slab source. No specific obvious indoor sources were noted in the building. IA screening level exceedances for BZ are likely attributable to an indoor, outdoor, or sub-slab source. IA screening level exceedances for CT are likely attributable to an outdoor source. IA screening level exceedances for chloroform and TCE are likely attributable to a sub-slab source. IA TCE concentrations (up to 5.3 $\mu g/m^3$) were below the short-term criterion of 8.4 $\mu g/m^3$. SS concentrations of 1,1,2,2-tetrachloroethane (1,1,2,2-PCA), 1,1,2-trichloroethane (1,1,2-TCA), HCBD, and PCE in exceedance of the SS screening levels are being adequately attenuated.

This building is proposed for mitigation by GSH in response to concentrations of chloroform and TCE; however, given the low usage of the building, the need for mitigation is not urgent.

4.8 VOC Source Zones

One of the data gaps identified in the revised Data Gap Evaluation Report (CRA, 2012) was the extent of PCE/TCE contamination in saturated soil north of the WMU G and northwest/west of WMU-A. In order to fill this data gap, a VOC source zone investigation was conducted as described in Section 2.1.23 of this SCR. The VOC source zone investigation consisted of the advancement of boreholes, screening of soil cores, and the collection of soil and groundwater samples for chemical analysis. This investigation was designed to specifically identify the presence of DNAPL in the area. This section presents the assessment methods, areal extent of the VOC source zones, DNAPL composition, and the estimated mass of DNAPL.

4.8.1 Assessment Methods

The assessment of the presence of DNAPL was conducted by both OCC/CRA and the Agencies/Weston Solutions using different methods. Both assessments were based on a common data set. The assessment methods used are presented below.

Kueper-Davies Method

The delineation of VOC source zones by OCC/CRA was based on the methods described in Kueper and Davies (2009). This method uses field screening and laboratory data to determine the likelihood of DNAPL presence at a location. Consistent with the procedures described in Kueper and Davies (2009), multiple lines of evidence were used to delineate areas of confirmed and potential DNAPL.

Indicators of confirmed DNAPL included:

- Visible NAPL in a sample
- A positive dye test result
- Soil chemical concentrations above the DNAPL saturation threshold (set at 5%) for that compound (Kueper and Davies Calculation #1)

Indicators of potential DNAPL included:

- High PID readings and chemical odor in a sample
- Staining and chemical odor in a sample
- Concentrations in a soil sample above the partitioning threshold (Kueper and Davies Calculation #4) based on six chlorinated ethenes: PCE, TCE, 1,1-DCE, cis-1,2-DCE, trans-1,2-DCE, and VC
- Concentrations in a groundwater sample above 1% of the effective solubility (Kueper and Davies Calculation #6) based on six chlorinated ethenes: PCE, TCE, 1,1-DCE, cis-1,2-DCE, trans-1,2-DCE, and VC

The DNAPL indicators were plotted in plan view by depth zone and the areas of confirmed and potential DNAPL were delineated based on the DNAPL indicators, knowledge of potential source locations defined in Section 5.2, and professional judgment.

NAPL Calculator Method

The Agencies/Weston solutions used the available soil data from the Site to calculate DNAPL saturation (NSAT) at each sample location where the result of the Kueper and Davies Calculation #4 was equal to or greater than 0.1. The calculations were completed using an analytical model called NAPL Calculator (NAPLCALC) developed by the Savannah River National Laboratory. NAPLCALC is a self-executing Microsoft Excel based, analytical model. The model solves standard portioning equations (the same as those used in Kueper and Davies [2009]) and provides DNAPL saturation at each soil sample location. NSAT values were determined using the concentrations of five chlorinated ethenes (PCE, TCE, cis-1,2-DCE, trans-1,2-DCE, and VC) and soil physical properties (volumetric water content, porosity, fraction of organic carbon).

To determine the extent of the DNAPL source zones, the NSAT values were interpolated using the 3-D geospatial model EarthVision 8.2 by Dynamic Graphics. The source zone model was then processed to develop estimates of NAPL mass and volume. The NSAT plume was portioned into isoshells using NSAT values of 0.1, 0.2, 0.5, 2, 5, 10, and 20%.

The complete details of the assessment method and results are presented in Appendix S.

4.8.2 VOC Source Zone Extent

Kueper-Davies Method

The DNAPL indicators and the data used in the evaluation and calculations completed are provided in Appendix S. The DNAPL indicators were separated by the seven depth zones (15-ft, 25-ft, 50-ft, 75-ft, 100-ft, 130-ft, and 160-ft zones) and plotted on maps of the Site (one for each depth zone). Where multiple samples were taken for a single location in a depth zone, the indicators for confirmed DNAPL were given precedence over the indicators for potential DNAPL or absence of DNAPL. This is a conservative approach, as DNAPL is difficult to detect. Consistent with the procedures outlined in Kueper and Davies, the areas of DNAPL for each depth zone were delineated using professional judgment, based not only on the field and laboratory indicators, but also on the locations of the known potential source areas.

The results of the delineation are presented on Figures 4.32 through 4.38. Examination of these figures shows that confirmed DNAPL is found mainly in the 15-ft, 25-ft, and 130-ft zones. Note that there was no confirmed DNAPL detected in the 50-ft and 75-ft zones. The confirmed DNAPL source zones in the 15-ft zone are located in the former solvent production area, primarily in the area of WMU-G and WMU-A. These source zones appear to have migrated plant north. Vertical migration from the 15-ft zone to the 25--ft zone occurred as evidenced by the confirmed DNAPL source zones below WMU-G and the former solvent production plant. Another area where DNAPL entered the subsurface is along the Waterway. Here the principal potential sources were the effluent settling barge (WMU-F), former discharge line, and WMU-D. These potential sources may have resulted in the deeper confirmed DNAPL source zones located in the 130- and 160-ft depth zones.

NAPL Calculator Method

In addition to the evaluation of DNAPL saturation, Weston Solutions also developed figures and cross-sections illustrating VOC source zones. These figures are provided in Appendix T. Weston Solutions provided three estimates of the probable DNAPL source zone extent (best estimate extent, maximum extent, and minimum extent) based on sensitivity analysis. These are shown on Figures 3.4 to 3.6 of Appendix S. These figures represent the zone of residual NAPL (similar to confirmed DNAPL in the Kueper-Davies method). Examination of these figures shows that the predicted DNAPL source zones using this method are thin and lenticular in shape with no vertical connection. The absence of a vertical connection is most likely due to the high anisotropy (factor of 250) applied in the kriging process to allow horizontal connection. The lateral spreading of the DNAPL source zones shown on Figures 3.4 to 3.6 in Appendix S is consistent with the conceptual model of DNAPL spreading laterally on lower hydraulic conductivity units. However, the absence of any vertical connection among DNAPL source zones is inconsistent with the known potential sources at the Site. DNAPL migrated vertically downward from the VOC potential source areas associated with the former WMUs illustrated on Figures 1.2 and 5.1. This vertical migration would result in a residual "trail" between the depth zones.

A close review of Figures 3.4 to 3.6 in Appendix S shows one of the short-comings of the NAPLCALC method. There are boreholes where positive dye tests were noted in the soil core; but the associated soil sample had and NSAT value of 0.1% or less (e.g., WMUR-9, WMUR-10, and SB-B). Kueper and Davies (2009) use positive dye tests as a line of evidence to confirm the presence of DNAPL at the sample depth. However, the confirmed presence of DNAPL without an NSAT value above the threshold was not considered in the delineation of DNAPL source zones. If the positive dye tests were considered, the DNAPL source zones would be more vertically extensive than currently depicted by this method.

The NSAT method does show that the DNAPL source zones have the greatest extent in the 100- and 130-ft zone, similar to the results of the Kueper and Davies method.

Given the above, it is likely that the distribution of DNAPL source zones determined by the NAPLCALC method underestimates the actual extent of confirmed DNAPL source zones. This is principally due to the use a single line of evidence (i.e., NSAT values) in delineating the DNAPL source zones.

4.8.3 DNAPL Composition

As discussed in Section 1.5, TCE was produced at the Hooker Chemical/OCC facility from 1947 to 1973. PCE was produced from 1960 to 1973. Plant records indicate a fairly consistent production rate of 1,100,000 and 660,000 pounds per month of TCE and PCE, respectively. TCE and PCE were stored and handled at the Site. Both TCE and PCE are denser than water and are the principal components of the VOC source zones defined on Figures 4.32 through 4.38. An evaluation of the variability of DNAPL composition was undertaken and is presented below.

During Site investigations, free-phase DNAPL was not encountered. As a result, no DNAPL analysis is available. Soil analyses for soil samples that exceeded the partitioning threshold were used as a surrogate to evaluate the variability in DNAPL composition. A total of 132 soil samples had partitioning threshold values greater than 1 and were used in the evaluation as summarized below:

Depth Zone	***Number of Samples***	***Percentage of Samples***	***PCE/TCE Ratio***			***Samples PCE/TCE<1***
			Average	***Minimum***	***Maximum***	
15	29	22	27.4	0.3	228.0	5
25	25	19	10.3	0.2	142.0	7
50	22	17	7.5	0.1	28.5	1
75	5	4	7.0	0.8	28.5	1
100	15	11	3.4	0.1	22.6	6
130	28	21	0.9	0.0	2.4	20
160	8	6	1.3	0.5	6.0	6

Examination of the summary above shows that the greatest number of samples exceeding the partitioning threshold occurred in the shallow depth zones. In total, 76 of the 132 samples (58%) occurred in the 15-, 25-, and 50-ft zones. In these shallow depths, PCE was generally found at higher concentrations than TCE, although both compounds were detected in all of these soil samples. Only 13 of the 76 soil samples which exceeded the partitioning threshold had TCE concentrations greater than PCE. The DNAPL in the shallow depth zones likely originated during the period when both TCE and PCE were produced at the Site (i.e., 1960 to 1973). Even though TCE was produced in greater quantities over this period, the DNAPL, for the most part, is PCE dominant. This is most likely due to the higher effective solubility of TCE in a mixed component DNAPL resulting in differential weathering and higher residual PCE content.

In the 75- and 100-ft zones, the composition of the DNAPL is more equally distributed between PCE and TCE, with slightly greater PCE content. The DNAPL in these zones may have resulted from migration through the shallower zones from the former production plant, settling barge, and WMUs D, G, and H.

In the 130- and 160-ft zones, the DNAPL has a higher TCE content. This may be due to the fact the DNAPL source zones in these intervals are located farthest from the VOC potential source areas and likely represents DNAPL released earlier in the solvent production period when only TCE was produced. TCE was produced for 13 years (1947-1960) before PCE production began.

Based on the soil samples examined, DNAPL at the Site consists primarily of PCE and TCE. The composition varies with depth, with PCE being dominant in the shallower depth zones (15-, 25-, and 50-ft zones). TCE is the major component in the 130- and 160-ft zones. In the 75- and 100-ft zones the composition is generally equal content of PCE and TCE.

4.8.4 Estimated DNAPL Mass

Kueper-Davies Method

The DNAPL source zone areas and volumes, and DNAPL mass were calculated for both confirmed DNAPL and potential DNAPL in each depth zone based on the source zone extents shown on Figures 4.32 through 4.38. The volumes of the DNAPL source zones were calculated by multiplying the areas presented by the thickness of the zone grouping plane where the DNAPL was detected. The assumption was that the DNAPL presence was uniform over the entire thickness of each depth zone. While this assumption may result in a greater source zone volume, it is consistent with the fact that DNAPL will migrate vertically downward from the surface potential source areas (i.e., former production plant, settling barge, and WMUs D, G, and H).

The DNAPL source zone volume (in ft^3) was converted to liters, and the DNAPL mass present in the zone was calculated assuming 100% PCE composition at a DNAPL saturation of 1% (0.01). The volume of PCE was multiplied by the density of PCE (1.623 kg/L) to estimate the total DNAPL mass in kg. The DNAPL composition is known to be principally PCE and TCE (see Section 4.8.3). PCE is present in the DNAPL in all depth zones and is the dominant component in all depth zones except the 130-ft zone. Therefore, the simplifying assumption of single-component DNAPL does not markedly affect the estimated mass. The application of a DNAPL saturation of 1% (0.01) throughout the DNAPL source zone was selected to reflect the expected variability in DNAPL saturation and is considered reasonably conservative.

A summary of the area and mass estimates for the confirmed and potential DNAPL zones are presented in Tables 4.38 and 4.39, respectively. The tables show that the estimated total confirmed DNAPL mass is approximately 6.4 million pounds (2.9 million kg). The greatest percentage of this total mass (58%) occurs within the 130-ft zone. Approximately 26% of the total mass occurs in the 15- and 25-ft zones.

NAPL Calculator Method

The DNAPL saturation values generated using NAPLCALC were used as inputs into the EarthVision geospatial model. Ordinary kriging was used to calculate a 3-D grid of NSAT values and to volumes of the DNAPL-impacted soil at various NSAT values (isoshells). The DNAPL volume for each zone grouping plane was calculated using EarthVision by slicing the 3-D model using the upper and lower limits of each horizontal zone grouping plane. The impacted soil volume within the zone grouping plane was split into zones (area between isoshells) based on NSAT values. The volume of each isoshell was multiplied by the median NSAT value for that volume and then multiplied by porosity (0.43) to provide the volume of DNAPL within that soil volume. The DNAPL mass was calculated by multiplying the DNAPL volume by a density of 1.58 kg/L.

The DNAPL mass and volume estimates are presented in Table 3.4 in Appendix S. The best-case total estimated DNAPL mass is 606,270 pounds (275,000 kg) and the total volume is 46,000 gallons. Much like for the Kueper-Davies model, the greatest proportion (67%) of the DNAPL mass occurred in the 130-ft zone, and more than 90% was calculated to be in and below the 100-ft depth zone. However, the percentage of mass in the shallower zones (25-ft and 50-ft zones) predicted using NSAT values is much less that that obtained in the Kueper-Davies method.

By way of comparison, the groundwater treatment and containment system has removed approximately 150,000 pounds of VOCs in the period from January 2000 to June 2014. The groundwater extraction wells were installed to prevent plume migration and were placed on the edges of the areas of highest concentration (see Figure 2.2). The mass removed by the groundwater treatment and containment system is approximately 25% of the best-case DNAPL mass determined by the NAPLCALC method. Given the location of the extraction wells (i.e., around the area of highest CVOC concentration) and that the influent concentrations are relatively stable, this percentage of DNAPL mass removal is high. This may indicate that the DNAPL mass estimated by the NAPLCALC method is too low.

The total mass of DNAPL estimated using the NAPLCALC method is approximately a factor of ten less that the mass estimated using the Kueper-Davies method. The much lower mass predicted by the NAPLCALC method is due to the much smaller DNAPL source zones defined. As stated previously, the DNAPL source zones developed using NSAT values only do not reflect vertical migration for the known surface potential sources and did not considered zones where positive dye test were noted. Thus, the mass estimated by the NAPLCALC method likely underestimates the residual DNAPL mass at the Site.

Summary and Discussion

The following table summarizes the mass of confirmed and potential DNAPL using the Kueper-Davies method and the confirmed DNAPL mass determined using the NAPLCALC method.

	Kueper-Davies Method		***NAPLCALC Method***	
	(lbs)	***(kg)***	***(lbs)***	***(kg)***
Confirmed Mass	6,451,059	2,926,151	606,270	275,000
Potential Mass	48,501,066	22,045,939	Not considered	Not considered
TOTAL DNAPL MASS	54,952,125	24,972,090	606,270	275,000

As stated in Section 1.5, the total solvent production at the Hooker/OCC facility was on the order of 457 million pounds. The above estimates of in situ DNAPL mass are small compared to the production volumes.

The results shown above for the mass of confirmed DNAPL differ by an order-of-magnitude. The reason for the differences in mass estimates is due to the assumptions in the two methods. The table below provides a comparison of the two methods used to estimate the total confirmed DNAPL mass in the subsurface:

Kueper-Davies Method	***NAPLCALC Method***
• Qualitative method • Six chlorinated ethenes used in calculations • Assumed DNAPL density equivalent to PCE (1.623 kg/L) • Area of DNAPL drawn by hand • Assumed DNAPL source zone extended through entire depth zone • Assumed uniform DNAPL saturation (1%) for total volume to calculate mass	• Quantitative method • Five chlorinated ethenes used in calculations • Assumed DNAPL density of 1.58 kg/L • Positive dye test results not considered • Volume of residual DNAPL calculated by kriging with high anisotropy, using medial residual saturation for each calculated isoshell • Does not consider potential DNAPL zones

Based on the above, it appears that the DNAPL source zones depicted by the NAPLCALC method may underestimate the extent of DNAPL. The depicted zones do not show any vertical connection, which is inconsistent with known potential sources. Also, the NAPLCALC method used only NSAT values and did not consider other lines of evidence such as positive dye tests. Also, the estimated DNAPL mass determined by the NAPLCALC method seems too low when compared to the mass recovered to date by the groundwater treatment and containment system.

The Kueper-Davies method is more qualitative; but the delineation of DNAPL source zones is based on numerous lines of evidence. The assumption that the source zone extends through the entire depth zone may overestimate the source zone volume; but is consistent with vertical migration from known potential sources. The potential overestimate in source zone volume was offset by assuming a uniform residual saturation of only 1%.

4.9 Groundwater/Surface Water Interface (Seeps)

A Seepage Meter Monitoring Program (SMMP) was conducted by CMA in the subtidal portion of the Waterway to determine the nature and extent of groundwater discharge into the Waterway during various phases of the tidal cycle.

Table 4.40 presents the analytical results from the groundwater discharge samples collected during the SMMP for the Site COCs. The analytical results have been corrected using the discharge factors calculated and presented by CMA in their Seepage Meter Monitoring Report. CMA's calculated discharge factors account for the dilution that occurs within the seepage meter funnels. The corrected concentrations were calculated as follows:

$$C_{corrected} = \frac{C_{lab}}{DF} \qquad \text{Equation 4.1}$$

Where:

$C_{corrected}$ is the corrected concentration for sample *i*
C_{lab} is the concentration measured by analytical laboratory for sample *i*
DF is the discharge fraction calculated by CMA for sample *i*

The corrected analytical results are compared to the groundwater screening criteria listed in Table 4.8. Corrected concentrations that exceed their respective groundwater screening criteria are highlighted with a box.

Figure 4.39 presents the maximum corrected concentrations of PCE, TCE, and VC in the groundwater discharge samples collected from the seepage meters.

The following summarizes the groundwater discharge analytical results from the SMMP:

i) Concentrations of VOCs exceeded the groundwater screening criteria at 5 of the 19 seepage meter locations where discharge samples were collected. VOC parameters that exceeded the groundwater screening criteria include PCE, TCE, and VC. The maximum exceedance occurred at seepage meter location SM-5, where VC exceeded the groundwater screening criteria by an EF of 8.

ii) Concentrations of SVOCs did not exceed the groundwater screening criteria at any of the 6 seepage meter locations where discharge samples were collected for SVOC analysis.

iii) Concentrations of metals exceeded the groundwater screening criteria at all 12 of the seepage meter locations where discharge samples were collected for metals analysis. Metals parameters that exceeded the groundwater screening criteria include arsenic, total chromium, copper, lead, mercury, nickel, and zinc. The greatest exceedance occurred at seepage meter location SM-2 where arsenic exceeded the groundwater screening criteria by an EF of 6585.

iv) pH measurements did not exceed the Site criteria of 8.5 su at any of the 19 seepage meter locations where discharge samples were collected.

In addition to the SMMP data, the investigations to characterize the nature and extent of groundwater discharge to the Waterway have included:

i) Subtidal groundwater samples collected within 3 ft of the Waterway mudline (i.e., within the sediment) and presented in Tables 4.17 through 4.23.

ii) Seep samples collected from the intertidal zone of the embankment and presented in Table 4.41.

iii) SPLP analytical data obtained from sediment samples collected within the intertidal zone of the embankment and presented in Table 4.42.

For the purposes of characterization, samples collected within 3 ft of the Waterway mudline have been conservatively considered to represent the nature of groundwater discharge. The point of compliance, however, is defined as the base of the biologically active zone. The biologically active zone within the Waterway does not generally extend deeper than 10 cm below the sediment surface. Therefore, cleanup levels will generally be applicable to a depth of 10 cm rather that the 3 ft conservatively considered for the characterization presented below.

4.9.1 Subtidal Groundwater Discharge

Figure 4.40 presents the areal distribution of chemical concentrations for Site VOCs and SVOCs in groundwater discharge. The sample locations are color coded on the figure to represent the maximum EF at that location.

As shown, the exceedances of groundwater screening criteria for Site VOCs and SVOCs are limited to PCE, TCE, and VC. PCE exceeds its groundwater screening criterion on the embankment near the south end of Dock 2 and adjacent to the N Landfill. TCE exceeds its groundwater screening criterion in the center of Area 5106. The exceedances of VC generally extend from Area 5106 east to the other side of the shipping channel.

It should be noted that of the 18 locations where groundwater screening criteria are exceeded, only two of the samples (SM1 and SM5) were collected within the generally defined 10 cm biologically active zone.

Figure 4.41 presents the areal distribution of chemical concentrations for PCBs in groundwater discharge. The sample locations are color coded on the figure to represent the maximum EF at that location. As shown, PCBs exceed the groundwater screening criteria on the embankment near Dock 1 and adjacent to the N Landfill, and in Area 5106.

Figure 4.42 presents the areal distribution of chemical concentrations for metals COCs in groundwater discharge. The sample locations are color coded on the figure to represent the maximum EF at that location.

4.9.2 Embankment Seeps

During the Embankment Area Investigation (1998), the Supplemental Embankment Area Investigation (1998), the Rapid pH Assessment (2002/2004), and the 709/721 Alexander Investigation (2004), seep samples were collected along the embankment within the intertidal zone. Seep sample locations are shown on Figure 4.43.

Chemistry

The concentrations in seeps exceed the groundwater screening criteria for 15 of the Site COCs. Table 4.43 summarizes the nature and extent of the contaminants present in the seeps. Figures 4.44 through 4.48 present the areal distribution of the seep concentrations of the Site VOCs, SVOCs, pesticides, PCBs, and metals, respectively. The sample locations are color coded on the figures to represent the maximum EF at that location.

Seep concentrations exceed the groundwater screening criteria for Site COCs throughout the embankment. The exceedances appear to be more concentrated near Dock 2, the N Landfill, and the Navy dock. The majority of the exceedances of groundwater screening criteria are for metal COCs.

pH

Table 4.43 also summarizes the extent of the pH present in the seeps. Figure 4.49 presents the areal distribution of pH measurements in seeps at the Site. The sample locations are color coded on the figure to represent the pH measured at each seep location.

The pH data demonstrate that there are two main areas of the embankment where seeps exceeding the groundwater screening criterion for pH are discharging to the Waterway. These areas are located in the vicinity of Dock 2 and the Navy dock.

Geochemistry

The geochemical data for the embankment seeps and the Waterway collected during the Rapid pH Assessment (2002/2004) have been plotted on Piper diagrams and presented on Figures 4.50 through 4.55. Review of the Piper diagrams shows that the composition of the seeps and the Waterway are essentially the same, predominantly sodium, potassium, and chloride.

The geochemical data for the groundwater samples collected during the Rapid pH Assessment (2002/2004) have also been plotted on Piper diagrams and presented on Figures 4.56 through 4.58. Comparison of the Piper diagrams for seeps and groundwater in each segment reveals the following:

i) **Segment 1:** the composition of both seep water and groundwater in Segment 1 is predominantly sodium, potassium, and chloride. However, the concentrations of these elements are higher in the groundwater than in the seeps. There is little variation in geochemical composition of groundwater at varying depths.

ii) **Segment 2:** the composition of groundwater in the northern portion of Segment 2 (sample ESI-2-17) is somewhat different than in the southern portion (samples ESI-2-14, 3-25, and 3-50) and there is some variability by depth. Groundwater in the northern portion exhibits higher concentrations of sodium and potassium than in the south. In addition, carbonate and bicarbonate concentrations are higher at 15 ft BGS than deeper and chloride is significantly lower. With the exception of the 25-ft depth in the area of monitoring well nest 3, groundwater in the southern portion of Segment 2 closely resembles the groundwater in Segment 1 as well as the embankment seeps in Segment 2. The sample collected from monitoring well 3-25 exhibited low pH (5.9) as well as high calcium and lower chloride compared to the other samples. The low pH measured in the sample collected from well 3-25 is consistent with historic data from this location.

iii) **Segments 3 and 4:** the composition of groundwater in Segments 3 and 4 is similar to that in the other segments with the exception of the 25-ft depth level in Segment 4. In this sample, ESI-4-7(25), carbonates and bicarbonates are higher than elsewhere and this is accompanied by lower chloride concentration. More variability between the composition of groundwater and seeps is observed in Segments 3 and 4 than in the other segments. This may be influenced by the distance of the groundwater sample locations from the Waterway which was not a factor in Segments 1 or 2 where all groundwater samples were collected within approximately 70 ft of the top of the bank.

The evaluation of the embankment seep and groundwater data suggests that the embankment seeps consist primarily of groundwater discharging from the bank diluted by tidal effects. The variability in the geochemical composition of the groundwater in the different segments suggests different sources of impact on groundwater. The lower concentrations present in the seeps indicate that attenuation of the compounds present in groundwater is occurring before the groundwater discharges to the Waterway as seeps.

4.9.3 Milky Seeps

During the Embankment Area Investigation (1998) and the Rapid pH Assessment (2002/2004) samples were collected from so-called "milky seeps" in the sub-tidal zone of the embankment. Twelve (12) milky seeps, shown on Figure 4.43 as Milky Seep-1, Milky Seep-2, and MS-1 through MS-10, were sampled during these investigations. As shown, the milky seeps were all located in Segment 2 in the vicinity of Dock 2.

Milky seeps are visually characterized by one or more of the following appearances:

i) The appearance of the overlying water, suspended white solids in the water column giving it the "milky" appearance
ii) The presence of encrusted white solids overlying the seep discharge point
iii) The strong upward discharge flow which is apparent by the column of milky water which extends vertically up into the Waterway over the seep discharge point

The elevations of the milky seep discharge points are at or below the lowest lower tide elevations. Therefore, the milky seeps are rarely exposed and direct sampling of discharging water is not possible. During the Rapid pH Assessment (2002/2004), to obtain representative samples of the discharging water, sediment core samples were collected and porewater was extracted at a soils laboratory. Samples of the porewaters extracted were then analyzed to characterize the quality of the milky seep discharge.

Chemistry

The concentrations of milky seeps exceed the groundwater screening criteria for 3 of the Site COCs. Figures 4.44 through 4.48 present the areal distribution of the milky seep concentrations (with the embankment seep concentrations) of the Site VOCs, SVOCs, pesticides, PCBs, and metals, respectively.

pH

Figure 4.49 presents the areal distribution of the milky seep concentrations (with the embankment seep concentrations) for pH. The sample locations are color coded on the figures to represent the pH measured at each seep location.

The milky seeps are included in Table 4.43, which summarizes the extent of the pH present in the embankment seeps.

Geochemistry

The geochemical data from the analyses of milky seep porewater samples collected during the Rapid pH Assessment (2002/2004) (MS-1 through MS-10) have been plotted on a Piper diagram and presented on Figure 4.59. Comparison of the milky seep Piper diagrams to the embankment seep Piper diagrams shows that the milky seep porewaters exhibit greater variability in their characteristics than the embankment seeps. This comparison also shows that the milky seep porewaters are generally more similar to Segment 2 groundwater prior to dilution from surface water than to either Waterway water or embankment seeps. As discussed in Section 4.9.2, the embankment seeps appear to represent bank storage where significant dilution from tidal exchange with surface water has occurred.

The milky seeps are the result of the high pH seep water, which is high in silicates, mixing with Waterway water, which is high in dissolved solids, specifically magnesium and calcium containing solids. The water that is emitted from seeps MS-1, and MS-3 to MS-10 has a pH higher than 9.5, soluble magnesium and calcium concentrations in the range of 1.4 to 203 mg/L, and dissolved silica concentrations one or more magnitudes higher than embankment seeps in the same area. Waterway water has a pH of 7.7, soluble calcium and magnesium concentrations of 435 and 1200 mg/L, respectively, and dissolved silica concentrations similar to those of the embankment seeps. When the elevated pH seep water mixes with the Waterway water as the seep discharges, the high pH of the seep water causes the soluble minerals in the Waterway water to precipitate, either as hydroxide or carbonate. In addition, as the pH of the milky seep discharge is lowered, silicates come out of solution and mix with the Waterway precipitates. The precipitates formed from the mixed waters are white and cause the milky appearance observed in the water column overlying the seep discharge point. The precipitates settle near the seep discharge point forming mounds of white solid materials. Hydroxides present in the solids are slowly converted to carbonates by excess carbon dioxide dissolved in the Waterway water. The magnesium and calcium carbonates and water form a solid crystalline mass that sets to form a hard solid material (encrustation) composed of calcium and magnesium from the Waterway water reacted with hydroxide, carbonate and silica from the seep.

As part of the pH Treatability Study performed for the Rapid pH Assessment (2002/2004), tests were performed to determine the effects that high pH groundwater has upon contact with the Waterway water. Titration of high pH groundwater into Waterway water at the CRA laboratory produced a milky precipitate similar to that observed in the Waterway. The precipitate was separated by filtration and analyzed to determine its composition. Analyses included metals and silica. This data was reported in the Treatability Study Report.

The quality of the porewater obtained from location MS-2 is not consistent with the other milky seep porewater samples. The sample from MS-2 exhibited a positive redox potential and significantly higher dissolved magnesium and calcium content than the other milky seep samples. This more closely resembles Waterway water than groundwater in Segment 2. No flow was apparent at MS-2 at the time of sampling. Samples were collected because sediments in the area exhibited an appearance suggesting that precipitates were present. Based on the analytical data from MS-2, this was not a milky seep at the time of sampling. The presence of apparent precipitate in the area of MS-2 is likely a result of historic or intermittent discharge in this area.

4.9.4 Leachate Discharge

The SPLP procedure involves pulverizing and mixing of a solid sample which creates a leachate which is "worst case." The embankment materials have been in place and undisturbed for many years. The actual leachability of the constituents contained in the embankment materials is expected to be lower than predicted by the SPLP leachate data.

The concentrations of SPLP leachate exceed the groundwater screening criteria for 14 of the Site COCs. Table 4.44 summarizes the nature and extent of the contaminants present in the SPLP leachate. Figures 4.60 through 4.64 present the areal distribution of the SPLP leachate concentrations of the Site VOCs, SVOCs, pesticides, PCBs, and metals, respectively.

SPLP leachate concentrations exceed the groundwater screening criteria for Site COCs throughout the embankment. The relative magnitudes and distribution of the exceedances, however, show that there are no identifiable areas which are distinct from the rest of the embankment.

4.10 Summary of Chemical Characterization

The characterization of the nature and extent of the subsurface presence of Site COCs and the environmental media impacted is summarized in the following subsections.

4.10.1 Unsaturated Soil

The nature and extent of contamination in unsaturated soil is summarized as follows:

i) CVOCs, primarily as PCE, are present in unsaturated soils at concentrations exceeding the unsaturated soil screening criteria. This presence is limited primarily to the vicinity of WMU A, WMU G, WMU H, and the N Landfill.

ii) Site SVOCs, primarily HCB and HCBD, are present in unsaturated soils at concentrations exceeding the soil screening criteria within the same general areas as CVOCs, as well as at several embankment locations.

iii) PCBs are present in unsaturated soil at concentrations exceeding the soil screening criteria primarily near the former Navy-Todd Dump and the N Landfill.

iv) Metals, primarily copper, but to a lesser degree arsenic, zinc, and nickel, are present at concentrations exceeding the soil screening criteria in the vicinity of WMU G, the former Caustic House, and the N Landfill.

4.10.2 Saturated Soil

The nature and extent of contamination in saturated soil is summarized as follows:

i) CVOCs, primarily as PCE, TCE, and associated degradation products, are present in saturated soils at concentrations exceeding the saturated soil screening criteria. This presence is greatest below the Facility near WMU A, WMU G, and WMU R, as well as below the Waterway. CVOCs are present to a lesser degree along the embankment and in the vicinity of the N Landfill.

ii) Site SVOCs, primarily as HCB, are present in saturated soils at concentrations exceeding the soil screening criteria within the same general areas as CVOCs.

iii) Pesticides and PCBs are present in saturated soil at concentrations exceeding the soil screening criteria along the embankment primarily near the former Navy-Todd Dump and the N Landfill.

iv) The greatest exceedance for metals was for mercury in the vicinity of the N Landfill. Other metals, primarily copper, total chromium, nickel, arsenic, and zinc, are present at concentrations exceeding the soil screening criteria in almost all samples analyzed for metals. The highest concentrations occur along the embankment and in the vicinity of the N Landfill.

4.10.3 Groundwater

The nature and extent of contamination in groundwater is summarized as follows:

i) The presence of DNAPL has been confirmed in the vicinity of WMU-G and WMU-R within the 15-ft, 25-ft, and 130-ft zones:

ii) CVOCs are present in groundwater at concentrations above the groundwater screening criteria:
  - 25-ft zone – The areas of highest concentrations are located near WMU A and WMU G
  - 50-ft zone – The extent of PCE and TCE is similar to the 25-ft zone, but the extent of VC increases significantly within the 50-ft zone area beyond the limits of PCE and TCE toward the eastern side of the Waterway
  - 75-ft zone – The highest CVOC concentrations extend eastward under the Waterway, with lower concentrations extending further north
  - 100-ft zone – The area of highest concentration is somewhat reduced, but has migrated further north
  - 130-ft zone – The area of highest concentration are somewhat reduced, but have migrated north and east when compared to the 100-ft zone
  - 160-ft zone – CVOC concentrations in the 160-ft zone are reduced compared to the 130-ft zone, but the plume continues to migrate northward

iii) Site SVOCs, primarily HCB and HCBD, are present along the embankment and beneath the Waterway at depths up to 111 ft BGS upland and 164 ft BML below the Waterway.

iv) PCBs are present in groundwater primarily along the embankment in the vicinity of the Navy-Todd Dump and N Landfill and below the Waterway.

v) Metals, primarily arsenic, copper, and nickel, are present at concentrations exceeding the groundwater screening criteria. The highest concentrations occur in the vicinity of the Salt Pad, along the embankment, and beneath the Waterway.

vi) Elevated pH groundwater is present above the groundwater screening criteria:
  - 25-ft zone – elevated pH was measured across the Site, with the highest values (>13 su) detected along the eastern portion of the Site beneath the former plant production areas
  - 50-ft zone – the extent of the highest pH values increases in size relative to the 25-ft zone and is located more to the north toward the Salt Pad

- 75-ft zone – the extent of the pH plume within the 75-ft zone is reduced relative to the 50-ft zone, but has migrated east with the highest groundwater pH (>12 su) located in the vicinity of the former caustic tanks and the south end of Dock 1
- 100-ft zone – the pH plume has migrated north and east, with the highest pH near the north end of Dock 1, but is limited to beneath the Facility and Waterway
- 130-ft zone – the pH plume continues to migrate northeast
- 160-ft zone – the area of high pH values is much smaller in the 160-ft zone, with the highest readings diminishing

vii) The seep study performed in the Waterway confirmed that seepage of impacted groundwater was occurring to some extent into the Waterway.

4.10.4 Sediment

The nature and extent of contamination in sediment is summarized as follows:

i) PCE is present in sediment at concentrations exceeding the sediment cleanup level. This presence is limited primarily to Area 5106 and adjacent to the N Landfill

ii) Site SVOCs, primarily as HCB and HCBD, are present in sediment at concentrations exceeding the sediment cleanup levels within the same general areas as PCE, as well as along the embankment near Dock 1

iii) Pesticides, primarily 4,4'-DDD, are present in sediment along the embankment near Dock 1 and the N Landfill

iv) PCBs are present in sediment along the embankment at concentrations exceeding the sediment cleanup level primarily near Pier 25, the former Navy-Todd Dump, and the N Landfill

v) Metals, primarily lead, are present in sediment at concentrations exceeding the sediment cleanup levels along the embankment

4.10.5 Soil Vapor/Indoor Air

The most frequently attributed sources for IA screening level exceedances were as follows:

i) **Indoor Sources:** 1,2,4-trimethylbenzene, 1,4-dichlorobenzene, benzene, chloroform, ethylbenzene, naphthalene, TCE, PCE, o-xylene, and styrene

ii) **Outdoor Sources:** benzene, carbon tetrachloride, chloroform, and ethylbenzene.

iii) **Sub-slab source:** TCE

Section 5.0 Contaminant Fate and Transport

5.1 Introduction

Site investigations have confirmed that there are four primary groundwater plumes: the ADP, pH plume, CVOCs, and metals. Other COCs at the Site include SVOCs, PCBs, and dioxins/furans. The distributions of these COCs have been defined through the Site monitoring well network as presented in Section 4.0. An understanding of the physical and chemical fate and transport processes is important for describing the behavior of the COCs at the Site. The following section describes the subsurface fate and mobility of the Site-related COCs and is divided into the following sections:

5.2 Potential sources of contamination – which describes the potential sources of COCs at the Site
5.3 Overview of routes of migration – which presents an overview of the COC migration routes
5.4 Contaminant Transport processes – which describes the various physical, chemical, and processes biological that affect the fate and transport of COCs
5.5 Degradation Processes – which describes the various processes that lead to the destruction of COC mass in the groundwater
5.6 Conceptual Site Model (CSM) – which presents a summary of the Site conditions and describes COC transport at the Site

5.2 Potential Sources of Contamination

Manufacturing operations at the Site generated wastes that were managed on Site. Waste management practices included: wastewater treatment (settling) ponds, settling barges, landfills, disposal pits, and waste piles. In total, seventeen (17) WMUs were historically located at the Site, in addition to the Navy Todd Dump. Detailed discussions of the WMUs and the chemicals associated with them are presented in Section 2.2.2. WMUs that are significant potential sources of COCs are identified below.

Environmental investigations at the Site began in the 1980s and have shown that the following parameters are the principal COCs:

- Chlorinated volatile organic compounds (CVOCs)
- Fuel-related volatile organic compounds (fuel-related VOCs)
- Caustic (sodium hydroxide)

- Salt (NaCl)
- Metals (arsenic, chromium, copper, lead, mercury, nickel, thallium, zinc)
- Semi-volatile organic compounds (SVOCs) (HCB and HCBD, which are by-products of solvent production)
- PCBs
- Dioxins/furans

Several of the principal COCs were used, produced, and stored in many locations across the Site. In addition, wastes generated in the production processes were managed on Site. Key potential "source areas" where the vast majority of releases occurred are described below.

The metals listed above as principal COCs were used in former OCC operations at the Site. Geochemical conditions created by the release of caustic and brine (dissolved NaCl), and reducing conditions in groundwater, have resulted in the mobilization of some of these metals in the subsurface. Some of the metals listed above as principal COCs were used in the ship building, maintenance, and dismantling operations at the Site. Other metals were used and produced on Site (e.g., aluminum oxide, sodium aluminate, calcium chloride). However, these metals are not COCs.

The principal COCs listed above do not represent every chemical detected in the subsurface at the Site. However, examination of these principal COCs provides the range of potential source locations, migration pathways, and ultimate distributions necessary to illustrate the CSM for the Site presented in Section 5.4.

5.2.1 VOC Potential Sources

Chlorinated solvents (TCE and PCE) were produced at the Site from 1947 to 1973. The former solvent production plant and associated WMUs are shown on Figure 5.1. A single area around the former solvent production plant and WMUs is shown on Figure 5.1 as the potential "CVOC Source Area". The TCE and PCE impacts in soil and groundwater appear to be primarily associated with the former solvent production plant (S1), former settling ponds (WMU A [S3], WMU G [S4], and WMU H [S5]), former settling barge (WMU F [S2]), and Area 5106. Lime sludge and solvent residue from the chlorinated solvents process were sent to settling ponds and the settling barge over time, and in the first year of operation were discharged to the Waterway through the direct discharge line shown on Figure 1.3.

The chlorinated solvents were present in the solvent residue released to the environment over time, and once released would behave as a dense non-aqueous phase liquid (DNAPL). The DNAPL potential source locations correspond to the WMUs within the potential CVOC Source

Area. Areas of confirmed DNAPL have been identified below the groundwater table through hydrophobic dye testing and evaluation of soil and groundwater concentrations. Suspected DNAPL has been identified in areas surrounding the confirmed DNAPL. The DNAPL zones are on-going sources of CVOCs to groundwater. Considering the wide distribution of the DNAPL areas and the several decades that have passed since releases occurred, the DNAPL likely exists as residual ganglia that are largely stable and no longer mobile.

CVOC and fuel-related VOC groundwater contamination is present on the 709 and 721 Alexander Avenue properties. These properties will be further investigated under MTCA Agreed Order No. DE 9835 effective October 3, 2013, being implemented by Mariana Properties, Inc. and the POT under Ecology oversight. Response actions conducted under the MTCA Agreed Order and the Occidental Site AOC, respectively, will be coordinated.

5.2.2 Caustic Potential Sources

The elevated pH present in groundwater at the Site is primarily due to the release of sodium hydroxide (caustic soda) produced at the Site. Historical locations of the production and handling of caustic soda are shown on Figure 5.2. The principal potential source area appears to be the Caustic House (S8). A single area around the locations of the Caustic House and caustic soda storage/handling is shown on Figure 5.2 as the potential "Caustic Source Area".

The sodium hydroxide released to the subsurface resulted in elevated soil alkalinity. Some of the hydroxide ions subsequently reacted with silicon dioxide (found in sand) to release silicate ions, so that a portion of the alkalinity currently present in the soil and groundwater is attributable to those ions. Soil alkalinity is highest in the potential Caustic Source Area, and the soil acts as a continuing source of ions that elevate the pH of the groundwater. As water with lower pH infiltrates through soil in this area, the hydroxide and silicate ions currently in the soil solution will be flushed out, but others will be released from the soil to replace them. Eventually (albeit only after a long time if no acids are injected into the ground), the vast majority of the hydroxide and silicate ions will be flushed out of the system, although a small fraction of the silicate will be converted back to silicon dioxide solids.

5.2.3 Salt Potential Sources

Salt was used as a feedstock in the production of chlorine, chlorinated solvents, and caustic soda. Salt was delivered to the Site by ship and stored in open piles on the asphalt Salt Pad. Figure 5.3 shows the location of the Salt Pad. Uncovered salt piles were maintained on this pad from the early 1960s until operations ceased. Water was sprayed on the salt piles to make brine. The asphalt pad was diked and sloped to a sump; however, cracks in the asphalt pad or leaks in the sump likely led to the salt impacts beneath the Salt Pad.

The produced brine was collected in the sump and pumped for purification and processing before use in the chemical production processes. Brine sludge, or residue, resulted from impurities in the brine after it was filtered and may have been kept in storage tanks on the southern portion of the Site (the southern portion of S10 and S11 as shown on Figure 5.2) prior to disposal. Brine sludge is not known to have been disposed on Site as it was reportedly taken to an industrial landfill, although some may have been disposed in the N Landfill.

5.2.4 Metals Potential Sources

Figure 5.4 shows the N Landfill and the Navy Todd Dump located adjacent to the embankment of the Waterway. The N Landfill was used between 1929 and 1971 and received the following waste materials: lead, corrosives, chlorinated organics, and non-burnable wastes. N Landfill investigations have shown that the waste material contains metals (primarily copper and lead). The Navy Todd Dump was created in approximately 1945, as a result of World War II ship construction and waste disposal/incineration activities. Navy Today Dump investigations have shown that the waste material contains metals (primarily cadmium, chromium, copper, mercury, nickel, and zinc). The N Landfill and Navy Todd Dump are considered a metals potential source.

Figure 5.4 also shows the approximate boundary of metals contaminated embankment contaminated fill areas. In addition to the N Landfill and Navy Todd Dump, metals contaminated waste material, derived from shipbuilding and dismantling activities during and after World War II and chemical production using electrolysis methods, were disposed along the embankment of the Waterway.

The vast majority of metals in the groundwater are present across the areal extent of the Site as a result of geochemical conditions (high pH and ionic strength) created by the release of other COCs. The geochemical conditions mobilize (dissolve) metals at concentrations above what would naturally be observed in groundwater. This process is described in Section 5.4.5.3.

5.2.5 SVOC Potential Sources

Potential sources of SVOCs are shown on Figure 5.5. The two SVOCs detected most often at concentrations above their respective criteria are HCB and HCBD. These compounds are by-products of the production of chlorinated solvents, and are found (to some degree) in areas where chlorinated solvents were manufactured, or where the waste products of this process were handled and disposed.

About 36,000 cubic yards (cy) of VOC and SVOC contaminated sediment were removed from Area 5106 in 2002-2003 (EPA, 2002). Post-dredging characterization of the Area 5106 footprint identified SVOC (mostly HCB and HCBD) and VOC contamination in subsurface sediment and groundwater. Concentrations of HCB and HCBD above Site screening levels have been found (mixed with VOCs) in upland soil beneath and adjacent to potential source areas.

5.2.6 PCB and Dioxins/Furans Potential Sources

Potential sources of the PCBs in the soils and sediments at the Site would be spills from equipment such as transformers and capacitors filled with PCBs. Another significant potential source of PCBs at the Site would be from the US Navy shipbuilding operations performed at the Site. The World War II shipyard purchased and used many transformers, according to purchase and inventory records obtained from the National Archives. World War II site diagrams from the National Archives depict transformer houses located immediately adjacent to the Waterway bulkhead line and along the outfitting piers at 401 Alexander Avenue in and near the Site.

The Navy used PCB-containing materials such as hydraulic fluids, electrical equipment fluids and paints in their shipbuilding operations. Waste materials, including the PCB–containing materials, from the shipbuilding operations performed at the Site were disposed at the Navy-Todd Dump and were burned in the Navy's on-site incinerator.

Records from the Port of Tacoma confirm the presence of PCBs in transformers at 401 Alexander Avenue, and provide evidence of PCB releases from those transformers. The reports generated during the sampling of the storm water catch basins at 401 Alexander Avenue provide data regarding the contamination resulting from flows discharging to the Site. Contaminants detected included PCBs, lead, arsenic, mercury, copper, and zinc (Letter from Port of Tacoma to Ecology dated November 19, 1993, containing sampling reports and laboratory data from Harding Lawson Associates). According to historical site data, PCBs were detected in the 401 Alexander Avenue storm sewers after the sewer system was cleaned twice. The sampling was performed to assess the cleaning process. While pre-cleaning data (if any) have not been located, the post-cleaning data showed PCB concentrations as high as 2,050 ppb remained in the sewers even after the second cleaning. The upland storm sewer catch basins drained the transformer bank area at 401 Alexander Avenue, and fed the sewer line that empties onto the shoreline sampling area where PCBs were detected by the Hylebos Cleanup Committee at 24,000 ppb (Station 5203I). The data, maps, diagrams, and photographs summarized in Appendix B demonstrate that past operations related to ship construction, maintenance, and demolition, as well as transformer releases, were significant contributors of PCBs to the Site.

Figure 5.6 presents the suspected potential sources of PCBs at the Site.

Dioxins (the common name for polychlorinated dibenzo-para-dioxins) and furans (polychlorinated dibenzofurans) are two closely related groups of chemical byproducts that are found at background levels in most industrial areas.

Both groups consist of chlorinated compounds that have a range of congeners (members of the same structural group with different configurations). The congeners differ in terms of the number, position and combination of chlorine atoms on the molecule. There are 75 possible dioxins (PCDD) and 135 possible furans (PCDF). They differ by the position and number of chlorine atoms attached to the two benzene rings. The different forms are referred to as "congeners." The dioxin and furan congeners thought to be most toxic to humans are the seven dioxins and ten furans with a particular pattern of chlorines known as the 2,3,7,8-substituted dioxins and furans.

Dioxins and furans are not synthesized or formulated for industrial or domestic use. They are formed from the thermal breakdown and molecular rearrangement of chlorinated precursor compounds. Almost any chlorinated compound has the potential to form dioxin if subjected to high temperatures (such as in a fire). Typically, incidental formation of dioxins requires a source of carbon, chlorine, and oxygen, and a temperature of at least 300°C. Some precursor compounds include PCBs, chlorinated phenols, and chlorinated benzenes. Combustion is the primary source of dioxin/furan formation, and Cleverly et al., (1997) reported that combustion sources will typically emit all 2, 3, 7, 8-substituted dioxins/furans, although the relative congener concentrations vary.

A potential source of dioxins/furans was the incinerator installed and used at the Site for waste disposal by the United States Navy and Todd Shipyards during World War II. Site maps/diagrams from the National Archives prepared during World War II depict the location of the incinerator on the "North Ten Acres" of 605 Alexander Avenue in a scrap disposal and salvage yard, which is the Navy-Todd Dump.

A photograph of that location dated August 29, 1945, indicates that some of the waste materials in the Navy-Todd Dump were burned in place. The composition of wastes incinerated at the Site and located in the Navy-Todd Dump are revealed, in part, by two indexes from the National Archives containing specifications for Navy ship components prepared by the U.S. Bureau of Ships for the Navy during World War II. Those indexes identify numerous components containing the hazardous substances that have been detected at the Site, including transformer oil and other PCB-containing materials. The burning of such wastes in the incinerator and along the embankment at the Navy-Todd Dump, including PCB-containing wastes and fluids, would have been a prime potential source for dioxins/furans detected at the

Site. Various other forms of combustion and smelting processes (e.g., welding), occurred at the World War II shipyard, which also may have produced dioxins/furans.

Another potential source of dioxins/furans is spent graphite anodes used at the former chemical production facility, and disposed on site (European Commission, 2001). Other potential sources of dioxins/furans at the Site would have included overheated electrical equipment (such as transformers and capacitors) filled with PCBs. The World War II shipyard purchased and used many transformers located adjacent to the Waterway, according to records obtained from the National Archives. Figure 5.6 presents the suspected potential sources of dioxins/furans at the Site.

5.2.7 Anthropogenic Density Plume Potential Sources

A plume of elevated groundwater density, termed the "Anthropogenic Density Plume" (ADP), exists beneath the Site due to releases of high density materials from historical operations. The potential sources for the ADP consist of:

- Chlorinated solvents/solvent residue, as well as lime sludge, were sent to WMUs A, F, G, H, and C shown on Figure 5.1. Lime sludge (calcium chloride) is miscible in water, and a calcium chloride solution with water can have a specific gravity of approximately 1.3 (at 15 degrees Celsius). The chlorinated solvents/solvent residue consisted mainly of TCE and PCE each having a specific gravity in pure form of 1.46 and 1.62, respectively. Lime sludge and solvent residue were sent to in WMU A, WMU F, WMU G, and WMU H, while lime/calcium chloride was placed in WMU C, and represent potential source locations for the ADP.
- Caustic soda, with a specific gravity of approximately 1.3 to 1.5, is another component of the ADP. The potential Caustic Source Area shown on Figure 5.2 represents a potential source location for the ADP.
- Brine (sodium chloride) was created at the Salt Pad and had a specific gravity of approximately 1.2 and is a further component of the ADP. The Salt Pad, shown on Figure 5.3, represents a potential source location for the ADP.

The effects of the ADP on contaminant transport at the Site are described in Sections 5.4.

5.3 Overview of Routes of Migration

Site investigations have confirmed that there are four primary impacted groundwater plumes: the ADP, pH plume, CVOCs, and metals. These plumes have been defined through the Site monitoring well network. Other COCs have not developed large, distinct groundwater plumes.

This is likely due to a combination of factors, such as low mobility in groundwater, limited contaminant mass, and attenuation processes.

Contaminants may migrate from the potential source areas noted in Section 5.2 via several routes of migration:

- Density-dependent flow
- Migration of dissolved-phase with the ADP
- Displacement migration at the perimeter of the ADP
- Migration of dissolved-phase with fresh groundwater
- Volatilization to indoor and ambient air
- Migration with surface runoff

These potential routes of migration are defined below.

The potential sources of COCs originated at the surface or near surface in various locations around the Site. The organic COCs are from liquids disposed on or released at the surface. The ADP is derived from the dissolution of salt, caustic, and lime sludge, the solubilities of which were enhanced by high-pH source materials.

When a DNAPL is released, it will migrate downward through the unsaturated zone primarily by gravity-driven, density-dependent flow. Depending on the volumes released, the DNAPL can be trapped by capillary forces and result in residual DNAPL. If sufficient volume is released, migration to the water table and beyond can occur. Based on data collected, DNAPL at the Site has penetrated over 100 ft into the subsurface.

The ADP behaves similarly to a DNAPL, in that the liquid has a higher density than natural fresh water and salt water, and therefore will migrate downward by density-dependent flow. Also, like a DNAPL, the density plume will not mix readily with the groundwater due to the density difference between the groundwater and the ADP.

Groundwater flowing past DNAPL can dissolve a quantity of the COCs and transport them away from the release locations. The shallow groundwater has the potential to discharge to the Waterway, and the deeper groundwater may discharge to Commencement Bay. This would result in the discharge of dissolved COCs to the adjacent waterways.

Precipitation, as runoff, could have carried COCs released to the surface into the storm sewers and/or into adjacent water bodies. The waste liquids would have also penetrated into the soil and migrated downward, contacting the groundwater and soil beneath the Site.

Once away from the potential source areas, the VOCs dissolved in the Shallow groundwater may volatilize into the soil gas and potentially into the air near the Site.

The metals in the soil and groundwater at the Site originate not only from Site-related processes, but are also occurring naturally in the soil to some extent. The metals can be mobilized into the groundwater from contact with liquid waste (e.g., high-pH water) and/or infiltrating precipitation. The metals would then migrate downward to the water table and would be transported by the groundwater to potentially discharge to the Waterway adjacent to the Site. The high density flow would also transport the metals deeper beneath the Site potentially discharging to Commencement Bay.

The primary groundwater plumes have migrated from the potential sources noted in Section 5.2 via several transport mechanisms that are summarized below.

5.4 Contaminant Transport Processes

5.4.1 DNAPL Migration

The subsurface migration of DNAPL is a complex process that is strongly influenced by geology, properties of the DNAPL, and release location. DNAPL has a high density and tends to migrate vertically downward, similar to the ADP. The DNAPL density is greater than that of the ADP and can displace the high density water within the ADP. Unlike the ADP which is totally miscible in water, DNAPL is essentially immiscible. During transport, some DNAPL is immobilized in pore spaces in the form of disconnected blobs and ganglia referred to as residual DNAPL. In this way, the volume of DNAPL is gradually distributed along the flow path, and the mass of DNAPL subject to active migration is depleted. The DNAPL will continue to migrate until the DNAPL mass becomes immobile, or stable (i.e., remains as residual bound in pore spaces, or "pools" above a low permeability layer).

The distribution of DNAPL in the subsurface is shown on Figure 5.7. This figure shows the general distribution of the confirmed and suspected DNAPL beneath the Site. DNAPL is observed beneath the former solvent production plant, WMU A, and WMU G. Historical DNAPL release rates and mass would likely have been highly variable, resulting in the separation between confirmed DNAPL at the upper and lower depths within the Shallow Aquifer shown on Figure 5.7. During vertical migration of the DNAPL, significant lateral migration has occurred, likely due to the DNAPL encountering low permeability lenses within the deltaic deposits, and, in some areas, the glacial deposits. DNAPL is also spread to the north at depth, apparently following the northward dipping slope of the top surface of the zone of confining effect in the deeper deltaic deposits. Given the significant timeframe since the initial releases occurred, the tortuous migration of the DNAPL through the heterogeneous deltaic deposits and lower permeability of the zone of confining effect, the current DNAPL distribution is likely stable.

Residual DNAPL will result in a continuing source of CVOCs. Additionally, diffusion into lower permeability (i.e., silt and clay) lenses adjacent to DNAPL will accumulate CVOC mass. The silt and clay then act as secondary sources of aqueous contamination through back-diffusion once groundwater concentrations in higher permeability zones decline. The process of back-diffusion from lower permeability lenses into higher permeability zones, where the bulk of the active groundwater flow occurs, will significantly prolong groundwater remediation timeframes.

5.4.2 Density-Dependent Flow

The ADP has evolved from the release locations at ground surface by migrating vertically downwards through gravity-driven density-dependent flow. Figure 5.8 shows the current distribution of total CVOCs in groundwater at the Site. The CVOC potential sources were in close proximity to ADP potential sources (e.g., settling barge, settling ponds, Salt Pad) and as a result, dissolved CVOCs have comingled and migrated with the ADP.

While migrating downwards, the ADP displaces the fresh or salt water initially present beneath the release locations. As the ADP displaced fresh groundwater or salt water in the subsurface, comingled CVOCs within the ADP were transported by the ADP as it migrated laterally and vertically.

Mixing between the ADP and the groundwater is limited due to the density differences between the groundwater and the ADP. Therefore CVOCs already dissolved in groundwater at the periphery of the ADP would have been forced to migrate laterally and vertically in advance of the ADP migration. The lateral ADP migration is the reason for the presence of CVOCs beneath the Waterway east of the CVOC potential source areas. This eastward migration with the ADP is contrary to the observed general north to northwest groundwater flow direction.

5.4.3 Dissolution

The solubility of a chemical is the maximum amount of the chemical that will dissolve in water at a specific temperature. Highly soluble contaminants are distributed more rapidly in the environment. The pure phase solubility values of the Site organic COCs are presented in Table 5.1. In mixed contaminant plumes, such as the one at the Site, the presence of multiple organic compounds in the groundwater can affect the solubility values of the organic compounds. For most compounds, this results in a lower solubility value than pure-phase solubility. It is also possible that the presence of some compounds can enhance the solubility of other compounds. The probability of this co-solvency effect occurring over much of the Site is low, however, because it requires concentrations of the second solvent to be above 10,000,000 µg/L, which is above the solubility of the Site COCs. In the absence of significant ionizable organics, solute-solute interactions of non-polar organics are negligible (USEPA, 1991). Therefore, co-solvency is not considered an important transport process at the Site.

There is a potential that lower chlorinated dioxins, furans, and PCBs will be more soluble than the higher chlorinated congeners creating a chromatography effect where solvent mobilization would result in lower chlorinated congeners migrating while the higher chlorinated congeners would remain in place. This effect could also contribute to weathering, where the lower chlorinated congeners by virtue of their higher solubility are more likely to be degraded than the higher chlorinated congeners. The chromatographic effect is not expected to be pronounced in samples that are spaced close together.

Solubility values for metals are not presented due to the many variables in the environment that dictate the solubility of a metal. For example, the pH of groundwater has a strong influence on the solubility of most metals.

5.4.4 Advection/Dispersion

Advection refers to the transport of contaminants along with the bulk flow of the groundwater. Advection spreads the contamination out from a source area along the groundwater flow path.

Dispersion refers to the contaminant spreading out due to the tortuous flow of groundwater in porous or fractured media, reducing the concentration (but not the mass) of contaminants in solution. Dispersion results from the micro-scale variations in speed of groundwater flow through a porous or fractured medium depending on the flow path of the groundwater. The variations are due to groundwater moving faster in larger pores relative to smaller ones, groundwater moving faster in the center of pores relative to the sides, and the variability in tortuosity of the groundwater flow as the groundwater moves through different pores. The spreading of the contaminants can be in any direction from the same direction as the bulk groundwater flow (longitudinal dispersion), to perpendicular to groundwater flow (transverse dispersion).

5.4.5 Sorption

Contaminants in the environment are distributed among different matrices (i.e., groundwater, soil) due to various processes that may be generally quantified by partition coefficients. A partition coefficient is the ratio of the equilibrium concentration of a contaminant in one environmental matrix with respect to another matrix, such as the equilibrium partitioning of contaminant concentrations between soil and groundwater.

The simplest and most common method of estimating the adsorption onto soil of a contaminant is based on the distribution coefficient (K_d). K_d relates the equilibrium partitioning of a contaminant between the solid and aqueous phases. This soil-water distribution coefficient is the ratio of a contaminant's sorbed concentration to the dissolved concentration at equilibrium. For organic contaminants, K_d can be estimated by multiplying the K_{oc} by the fraction of organic carbon content (f_{oc}) in soil.

The soil-water organic carbon partition coefficient (K_{oc}) is the ratio of the mass of a contaminant that is adsorbed onto soil per unit mass of organic carbon in soil per the equilibrium chemical concentration. The soil organic carbon partition coefficient describes the degree that a contaminant tends to adsorb to soil or sediment. K_{oc} values reflect the mobility of organic contaminants in groundwater where high K_{oc} values indicate that a contaminant has a greater tendency to adsorb onto soil, and thus, is less mobile. Low K_{oc} values indicate that a contaminant has less of a tendency to adsorb onto soil, and thus, is more mobile.

5.4.5.1 Effect of Site Geochemical Conditions on Sorption of Organics

A literature review was conducted on the effect of Site geochemical conditions, particularly pH and ORP, on the mobility of organic COCs, particularly chlorinated ethenes. Based on the literature review, it was determined that Site conditions of high pH, low ORP, and high ionic strength will not have a direct effect on the mobility of non-polar organic compounds. These compounds do not readily dissolve in water, as they exist as electrically neutral species, and do not have a charge or valence state that will be altered by changes in the pH, ORP, or ionic strength of the solution. Sorption of non-polar molecules such as chlorinated ethenes to organic matter is not affected by changes in Eh or pH.

The only effect that Eh, pH, or ionic strength may have on the sorption/retardation of non-polar organic compounds would be indirect. The effect would be as a result of changes that may occur to the organic matter in the soil and groundwater. Organic matter provides the bulk of these attachment (sorption) sites in the subsurface (Stumm and Morgan, 1996; Fetter, 1999). Partitioning in this way into the organic matter in soil is controlled by the distribution coefficient (K_d), which is related to its octanol-water partitioning coefficient (K_{ow}). The more chlorine atoms a chlorinated ethene has, the more likely it is to sorb to non-polar areas of organic matter (Site, 2001). Sorption of chlorinated ethenes to soil particles is dominated by the type and amount of organic matter (Allen-King et al., 1997). Changes in pH will affect pH-dependent exchange sites and surface complex formation, but will not affect sorption to hydrophobic sites. Under hyperalkaline conditions such as those found at the Site, the high concentration of hydroxide ions increases the number of negatively charged exchange sites available on minerals and organic matter surfaces (Stumm and Morgan, 1996). In column studies using a fine-medium sand with 1.04% organic matter, Sahoo and Smith (1997) found that TCE sorption decreased by 7% at a pH of 10 (K_d = 0.68 ±0.022 L/kg) relative to sorption at a pH of 7. They postulated that this small decrease was likely due to swelling of the organic matter due to like-charge repulsion within the organic matter, which would increase under high pH conditions. This may have increased its polarity and reduced its affinity for TCE. Pavlostathis and Jaglal (1991) found the effect of pH to be negligible when examining the desorption behavior of TCE in a contaminated silty clay (TOC = 0.13%) at pH values of 3, 5, 7, 9, 11, and 13.

Redox potential does not affect the sorption of non-polar organic molecules for the same reasons that pH does not affect their sorption (Site, 2001). Some degradation of organic matter typically occurs under reducing conditions, but it is unlikely that the soil organic matter will be affected such that a significant portion of relevant sorption sites would become unavailable (Appelo and Postma, 2005).

Site data indicate that soil organic matter is not affected significantly by variable geochemical conditions. Measured total organic carbon (TOC) content of aquifer materials on Site was compared to the corresponding pH and Eh values measured in those samples. There is no indication of a correlation between changing redox and pH conditions at the site and concentrations of TOC in soil.

For the organic COCs, Site-specific K_d values for soil values were calculated using the K_{oc} values established for the Site COCs, multiplied by the average fraction of organic carbon content in soil (TOC = 0.057 g/g) measured during the investigations conducted at the Site. K_{oc} values are published by the USEPA and vary depending on the literature source. Typically, K_{oc} values range from 1 to 10^7 L/kg. Table 5.1 presents the K_{oc} values established for the Site COCs from USEPA.

Dioxins, furans, and PCBs are very insoluble in water and therefore will be very strongly bound to the organic carbon in soils and sediments. The presence of high concentrations (1%) of secondary solvents can increase the solubility of dioxins and furans, although the relatively low concentrations of solvents detected in the Site groundwater will not significantly increase dissolution of dioxins or furans from soils or sediments.

5.4.5.2 Effect of Site Geochemical Conditions on Sorption of Metals

For metals partitioning, various competing conditions such as ion exchange, oxidation—reduction (redox) reactions, pH, complexation, and precipitation may complicate metals migration in groundwater. Precipitation of mineral phases can be an important attenuation mechanism for metals in some cases. However it is more likely that sorption reactions, which happen quickly, will be more important than precipitation reactions, which tend to happen more slowly.

Metals, which are generally positively-charged in solution, adsorb to minerals with increasing affinity as pH increases and mineral surface charge becomes more negative. However, at pH values greater than 9, aqueous hydroxo species (i.e., OH^-) can strip cations from the mineral surface causing increased metals concentrations in solution. Similarly, anions will adsorb to mineral surfaces when there is a positive charge on the mineral, and will be increasingly found in solution at high pH values because of the increasingly negative charge on the mineral surface.

Metals may exist in solution as free ions, but more commonly they form various oxides, mobile organic/inorganic ligands, or are associated with mobile organic or mineral colloids. These processes are susceptible to changes in pH and Eh. The formation of precipitates may depend on the presence of other species, such as sulfate.

The metals of concern at the Site include arsenic, chromium, copper, lead, mercury, nickel, thallium, and zinc. The following discusses the solubility of these metals based on published literature within the context of the Site environmental conditions.

Arsenic

In the environment, arsenic can be present in several oxidation states: arsine (-3); arsenic metal (0); and arsenite (+3) and arsenate (+5), which are the trivalent and pentavalent states that form stable compounds. The mobility of arsenic in the environment depends strongly on the pH of groundwater and redox conditions. The alkali metal arsenites and arsenates are very soluble in water over a wide pH range, while the other arsenites and arsenates are soluble only under acidic conditions. Arsenic is capable of dissolution in pH ranges from 2.0 to 11.0, under suitable physical and chemical conditions. Arsenic can also be very sensitive to solubilization at typical groundwater pH values, which range from 6.5 to 8.5. Arsenic is also mobile under both oxidizing and reducing redox conditions. Arsenic is an amphoteric metal and is soluble under the high pH conditions as well as under acidic conditions. It is less soluble at a neutral pH. Arsenic sorbs to the surface of metal oxide (e.g., iron hydroxide) coatings on soil grains and therefore the mobility of arsenic can also be affected by changes in the geochemical conditions that affect the solubility of iron oxides. Under oxidizing conditions, iron oxides will form solids and provide sorption sites for arsenates, but under reducing conditions, the iron oxides will dissolve, reducing the number of available sorption sites for arsenic species, thereby releasing arsenic into solution.

Redox conditions at the Site are generally reducing and therefore iron oxides will tend to dissolve, increasing the amount of arsenic in solution. The pH at the Site ranges from neutral to above 13, which will also result in higher arsenic mobility.

Chromium

Chromium (VI) is the more mobile and the more toxic form of chromium. The chromium (VI) anion is highly soluble and mobile as chromate (CrO42-) or as bichromate (HCrO4). Generally, chromium will become soluble as the pH of a solution decreases, but Evanko and Dzombak (1997) stated that the leachability of chromium may also increases as the soil pH increases. Under reducing redox conditions, chromium (VI) may convert to chromium (III), which is insoluble, will strongly adsorb onto soil particles, and is less toxic (Ellis et al., 2002). Like arsenic, chromium is an amphoteric metal and is soluble under the high pH conditions as well as under acidic conditions. It is less soluble at a neutral pH.

Site conditions are generally reducing, and therefore the chromium will tend to be chromium (III) which is less mobile. However, the high pH values in Site groundwater will enhance the mobility of the chromium in groundwater.

Copper

Copper is not redox-sensitive, and has a high affinity to soluble organic ligands and the formation of these complexes may greatly increase its mobility in groundwater. It is relatively insoluble at the high pH conditions encountered at the Site.

Lead

Due to the amphoteric nature of lead, its compounds may be soluble at low pH and at high pH. In general, lead will become adsorbed to soil with increased cation exchange capacity, organic carbon content, redox potential, and phosphate levels. At the Site, the redox conditions are reducing and the pH values are very high over a large area, enhancing the mobility of lead.

Mercury

The transport and partitioning of mercury in groundwater, surface water, and soil is influenced by the form of mercury. Inorganic forms of mercury include 0, 1 and 2 valences (i.e., metallic, mercurous ion and mercuric ion, respectively). Mercury cells were not used at the Site, however, and so elemental mercury is not present at the Site in significant quantities.

The ionic forms of mercury form compounds with sulfur, sulfate, chloride, hydroxide, oxygen and nitrate, with preference according to typical rules of metallic compound formation (charge density) and the oxidation states and pH of the soil solution or groundwater.

The most soluble form of mercury is mercuric chloride (70,000 mg/L), which can form under oxidizing conditions, which are typical of many shallow groundwater sites. Under reducing conditions, such as those encountered over much of the Site, mercuric sulfide is the most stable form of mercury. Mercuric sulfide has a very low solubility, on the order of 2 μg/L, as a result of the low polarity of metallic sulfide compounds.

The higher pH values encountered at the Site can result in the formation of mercuric hydroxide and mercuric oxides, even at relatively low Eh (to 0 meV). Although not as soluble as mercuric chloride, mercuric oxides are far more soluble than mercuric sulfide.

Organic forms of mercury, including methyl mercury, dimethyl mercury and ethyl mercury (collectively organomercury compounds), can form under reducing conditions. However, Kongchum, et al (2006) determined that methylation is inhibited by high salinity conditions and elevated sulfate concentrations, such as those encountered over much of the Site.

Nickel

For nickel, as the pH decreases, nickel may become more mobile (solubility increases). Most nickel compounds are relatively soluble at pH values less than 6.5. Nickel is not an amphoteric metal, and will therefore relatively insoluble at the high pH conditions encountered at the Site.

Thallium

The chemical behavior of thallium is similar to that of lead; it occurs almost exclusively in natural waters as monovalent thallium (Tl^{+1}). The solubility of thallous (Tl^{+1}) compounds (e.g., thallous hydroxide) is relatively high so that Tl^{+1} is readily transported in the aqueous phase within the environment. At the Site, the redox conditions are reducing and the pH values are very high over a large area, enhancing the mobility of thallium.

Zinc

Zinc may exhibit amphoteric behavior in the environment. Studies show that zinc may precipitate at pH values greater than 8.0. It may also form stable organic complexes, with organics such as humic and fulvic acids. Zinc solubility in groundwater may increase with increases in redox potential (E_h). The solubility may also increase with decreasing pH (Pedroli et al., 1990). Zinc is an amphoteric metal and is soluble under the high pH conditions as well as under acidic conditions. It is less soluble at a pH of around 10. The redox and the high pH conditions at the Site will therefore enhance the mobility of zinc.

The University of Washington, at the direction of Ecology, conducted a study to investigate the effects of pH and ORP on the K_d of various heavy metals within Site soils. The University of Washington report is included as Appendix W. The report makes several conclusions with respect to the relationships and sensitivity of varying pH and ORP on the values of K_d. The K_d values determined through the study are presented in the University of Washington report.

A summary of some of the principal findings of the report are as follows:

i) Heavy metals at the site are likely to be sorbed on the surfaces of, and/or occluded in the bulk of minerals formed by iron oxyhydroxides, or mixed aluminum-iron solid phases.

ii) The site soils can be operationally separated into two major groups. The first group (denoted as Group A) comprises soils for the site areas that do not appear to have been affected by high pH plumes and reducing conditions. The second group (denoted as Group B) comprises soils from the areas deemed affected by high pH and reducing conditions.

iii) The log Kd values determined for Group A soils tend to increase nearly linearly with the pH when it is varied in an 8 to 14 range. This indicates that metal mobility decreases with pH for these soils. In contrast with the results for Group A, the log Kd values for Group B soils tend to exhibit little sensitivity to pH variations.

iv) The data for Group A and Group B soils can be combined to determine pH-specific log Kd constants for the entire set of the examined soils. This approach allows generating reasonably strong linear functions correlating pH and metal-specific log Kd values. Calculations employing these linear correlations can yield log Kd values for any particular pH.

v) Variations of redox potential for Group A soils are accompanied by decreases of the log Kd constants that are nearly linearly correlated with the redox potential. This is indicative of increased metal release from Group A soils when they interact with oxygen-free water.

vi) In contrast with the sensitivity of Group A soils to variations of redox potential, metal release from Group B soils was largely unaffected by the presence of reducing agent.

vii) Redox and pH variations are of relatively little importance for metal release in the most affected areas of the site.

5.4.6 Discharge to Surface Water

Shallow groundwater containing dissolved COCs has the potential to discharge to the waterways adjacent to the Site.

5.4.7 Air-Water Partitioning

Where surface water comes into contact with the atmosphere or shallow groundwater comes into contact with the soil gas at the water table, the COCs dissolved in the groundwater have the potential to volatize into the air. The Henry's Law Constant (H_{cc}) provides a measure of the extent a contaminant will partition between the air and water phases. This parameter determines whether a contaminant will volatilize from groundwater to air. As a general guideline, for contaminants where H_{cc} (unit-less form) ranges from 4.5×10^{-6} to 4.5×10^{-4}, volatilization is low. For Site-related COCs, only organic COCs and mercury are considered to have the potential to partition into the soil gas. Table 5.1 presents the Henry's Law Constants established for the Site COCs. Once partitioned into the soil gas, the COCs have the potential to migrate into the ambient or indoor air, where there is the potential for human exposure.

Although the Henry's law constant predicts a potential for volatility, the dioxins, furans, and PCBs would not be very volatile, but would remain adsorbed to particulates rather than dissolve or be volatilized. This means that dioxins, furans, and PCBs would not be very mobile in the groundwater and would not form large, distinct plumes. The area of impact would be relatively small and close to a source area(s).

5.5 Degradation

5.5.1 Biotic Degradation

Microbial biodegradation involves the utilization of carbon from an organic compound (the primary substrate) for microbial cell growth. As part of the biodegradation process, electrons are transferred from the primary substrate (electron donor) to an available electron acceptor. This transfer of electrons is defined as a redox reaction. Energy derived from this transfer of electrons is utilized by soil microorganisms for cellular respiration.

Microbial biodegradation will only occur if suitable quantities of the primary substrate and electron acceptors are available for the necessary redox reactions. Certain forms of organic matter (e.g., fuel hydrocarbons, landfill leachate, and natural organic matter) are readily utilized as primary growth substrates during microbial biodegradation. The biodegradation of a primary substrate often will result in the cometabolic biodegradation of a secondary substrate, such as VOCs. The secondary substrate is defined as an organic compound that does not undergo direct biodegradation, but is transformed to degradation products as a secondary reaction.

Typical electron acceptors available in groundwater, in the order of those that release the greatest energy to those that release the least energy, are: DO, nitrate, manganese and iron coatings on soil, dissolved sulfate, and carbon dioxide. The sequential use of these electron acceptors occurs as groundwater becomes increasingly reducing during the biodegradation of organic compounds.

The redox conditions at a Site are important to understand as they control the types of degradation reactions possible at a Site and the rates of these reactions. A natural attenuation evaluation for the Site was completed and the results are presented in Appendix U and are summarized in Section 5.5.3. As part of this evaluation, the redox parameter concentrations were evaluated, and it was concluded that conditions at the Site range from mildly aerobic to methanogenic. Conditions at the Site are generally reducing, especially at depth.

5.5.1.1 Biodegradability of Chlorinated Ethenes

PCE, TCE, cis-DCE, and VC are the chlorinated COCs primarily present in groundwater at the Site, both beneath the Waterway area and the upland areas at the Site. A brief discussion of the biodegradation of chlorinated ethenes and ethanes in general is presented below, with emphasis on PCE, TCE, cis-DCE, and VC biodegradation.

As stated above, biodegradation of chlorinated ethenes is mediated through a series of redox reactions, in which electrons are transferred between electron donors and electron acceptors. Biodegradation of chlorinated ethenes and ethanes occurs through any one of the following three mechanisms:

i) The organic compound is used directly by microorganisms as an electron donor (i.e., primary substrate)
ii) The organic compound is used directly by microorganisms as an electron acceptor
iii) The organic compound undergoes biodegradation as a secondary reaction during microbial biodegradation of another organic compound

PCE and TCE Biodegradation

PCE is the most oxidized of the chlorinated ethenes and is not susceptible to oxidation mechanisms (electron donor) for biodegradation (i.e., PCE cannot be used as a primary substrate) unless it is via a cometabolic pathway. However, reductive dechlorination is a fully documented pathway for biodegradation of PCE. Therefore, PCE is biologically recalcitrant under aerobic conditions and typically requires an anaerobic environment in order to undergo biodegradation. The reductive dechlorination pathways for chlorinated ethenes and ethanes are summarized on Figure 5.9.

TCE also is highly oxidized and is typically not susceptible to oxidation reactions. TCE is mainly biodegraded by reductive dechlorination under anaerobic conditions. Although the main biodegradation mechanism for TCE is reductive dechlorination, TCE may, in some cases, undergo aerobic cometabolism resulting in partial dechlorination.

cis-DCE and VC Biodegradation

cis-DCE and VC (the most reduced chlorinated ethenes) are susceptible to both aerobic degradation (through oxidation) and anaerobic degradation (through oxidation or reduction). cis-DCE and VC biodegradation has been documented to occur by each of the three principal biodegradation mechanisms (i.e., anaerobic, aerobic, and cometabolism).

VC is the most susceptible of the chlorinated ethenes to electron donor reactions. cis-DCE is also susceptible. Oxidation (also referred to as mineralization) of cis-DCE and VC is associated with the transformation of cis-DCE and VC to carbon dioxide, water, and chloride. Aerobic oxidation of cis-DCE and VC is characterized by a loss of mass and a decreasing molar ratio of cis-DCE and VC compared to that of other chlorinated ethenes.

cis-DCE and VC are the least susceptible to electron acceptor (i.e., reduction) reactions because they are the most reduced forms of the chlorinated ethenes; therefore, reductive dechlorination of cis-DCE and VC is slow relative to other degradation mechanisms. Reductive dechlorination of cis-DCE and VC has been documented in anaerobic environments, and is characterized by reductions in mass, increased concentrations of chloride ions, and production of daughter products, which are VC for cis-DCE and ethene for VC. The occurrence of reductive dechlorination relies on the presence of a primary substrate (i.e., electron donor).

At the Site, the reducing conditions present are conducive to the reductive dechlorination of chlorinated ethenes. The presence of VC and cis-DCE at the Site is good evidence that the biodegradation of PCE and TCE is occurring. The concentrations of cis-DCE are much higher than the concentrations of trans-DCE and 1,1-DCE in many locations, indicating that the presence of cis-DCE is the result of biodegradation and not the release of DCE. The presence of ethene in the groundwater in the potential source area is also good evidence that VC is being fully degraded to some extent.

5.5.1.2 Biodegradability of Hexachlorobutadiene and Hexachlorobenzene

Tabak et al. (1981) conducted biodegradation of HCBD, at concentrations of 5 to 10 mg/liter, using aerobic microorganisms from an inoculum from settled domestic waste water. Another study found that a bacterium can utilize HCBD as sole carbon and energy sources (Li et al., 2008).

Studies have found that HCB can undergo anaerobic reductive chlorination (Chang et al., 1996) (Adrian and Görisch, 2002). Kengara et al. (2013) were able to enhance HCB biodegradation using two anaerobic - aerobic cycles in model laboratory experiments.

The redox conditions at the Site are generally reducing and range up to methanogenic, indicating that conditions are conducive to the degradation of HCB, but may be less conducive for HCBD.

5.5.1.3 Biodegradability of Dioxins, Furans and PCBs

Bacterial degradation of dioxins/furans and PCBs is possible but studies have shown it to be a very slow process. Biodegradation may be limited by the populations of organisms in the native soil. ATSDR (1998) estimated that the half-life for dioxin/furans in surface soils may range from 1 to 3 years. However, for contaminants a few inches below the surface, the half-life may be 10 to 12 years or more.

Biodegradation of PCBs may occur under aerobic or anaerobic conditions that will, theoretically, yield carbon dioxide and other innocuous compounds such as chlorine and water. Biodegradation of PCBs is dependent upon the position of the chlorine atoms attached to the biphenyl molecule and the degree of chlorination. In general, higher chlorinated PCBs (five or more chlorine atoms) are more persistent and not easily bio-transformed. Specific biodegradation processes that may alter PCBs include aerobic dechlorination, hydrolytic dehalogenation, and anaerobic reductive dechlorination. The heavier PCB congeners (tetra- and penta-) will generally biodegrade anaerobically, while the lighter congeners (mono-, di-, and tri-) will biodegrade aerobically (USEPA, 2003).

The redox conditions at the Site are generally reducing and range up to methanogenic, indicating that conditions are conducive to the degradation of some dioxins, furans, and PCBs, even if these processes can be very slow.

5.5.1.4 Biodegradability of Other Organic COCs

1,1,2,2-TeCA and 1,1,2-TCA

Similar to all highly chlorinated aliphatic compounds, 1,1,2,2-TeCA biodegrades under anaerobic conditions through reductive dechlorination. During reductive dechlorination, chlorine atoms are sequentially removed from the 1,1,2,2-tetrachloroethane molecule to form 1,1,2-TCA, 1,2-dichloroethane (1,2-DCA), chloroethane (CA), and finally ethane. Strong reducing environments are necessary for biodegradation to occur. Reductive dechlorination of 1,1,2,2-TeCA and 1,1,2-TCA is most rapid under methanogenic conditions, but will also occur under sulfate-reducing and iron-reducing conditions at a slower rate (Aronson and Howard, 1997). The reductive dechlorination pathways for chlorinated ethanes are presented on Figure 5.9.

Carbon tetrachloride and trichloromethane

CTeT and TCM are highly oxidized chlorinated compounds and therefore only readily degrade under anaerobic conditions (Aronson and Howard, 1997). During anaerobic (reductive) biodegradation chlorine atoms are sequentially removed from the carbon tetrachloride molecule to form primarily trichloromethane, then dichloromethane, then methyl chloride, and finally methane. Reductive dechlorination quickly occurs under methanogenic conditions and at a slower rate under sulfate-reducing and iron-reducing conditions.

Methylene chloride

DCM is a less highly chlorinated compound and will biodegrade under both aerobic and anaerobic conditions. Numerous studies have shown that DCM is fairly readily biodegraded under most aerobic environmental conditions to form formaldehyde and hydrochloric acid.

During anaerobic (reductive) biodegradation chlorine atoms are sequentially removed from the dichloromethane molecule to form methyl chloride, and finally methane. Other potential biodegradation products of dichloromethane under anaerobic conditions include methanol, acetic acid, and carbon dioxide. Some studies have demonstrated that biodegradation of dichloromethane (DCM) to environmentally acceptable products even when DCM is the only carbon source occurs under methanogenic conditions (Freedman and Gussett, 1991; and Braus-Stromeyer et al., 1993). Another study has demonstrated that biodegradation of DCM in contaminated aquifers may occur under nitrate-reducing conditions via oxidation pathways (Freedman et al., 1997).

The redox conditions at the Site are generally reducing and range up to methanogenic, indicating that conditions are conducive over parts of the Site for the degradation of 1,1,2,2-TeCA, 1,1,2-TCA, CTeT, TCM, and DCM.

5.5.2 Abiotic Degradation

It has been recognized that while biological degradation is the most important degradation mechanism for chlorinated solvents, some of the compounds can degrade abiotically (USEPA, 1998; Lee and Batchelor, 2002). Potential abiotic reactions include hydrolysis (addition of OH-), dehydrohalogenation (removal of a chlorine and hydrogen atom to form a carbon-carbon double bond), hydrogenolysis (replacement of a chlorine atom with hydrogen), and dihaloelimination (removal of two chlorines and the formation of a carbon-carbon double bond). Only hydrogenolysis and dihaloelimination occur under reducing conditions, such as those encountered at the Site. The abiotic degradation of PCE, TCE, and DCE can also produce acetylene under anaerobic conditions such as those found at the Site.

In 2012, select wells were analyzed for the presence of acetylene, and the results (presented in Appendix U) indicate that acetylene is present in the groundwater at the Site, and concentrations are greatest at locations where the concentration of VOCs is also greatest. This is good evidence that the abiotic degradation of chlorinated ethenes is occurring to some extent.

1,1,2,2-tetrachloroethane can degrade abiotically by hydrogenolysis to TCE. Under continued reducing conditions, the TCE produced from the abiotic degradation of 1,1,2,2-tetrachloroethane can be degraded to 1,1-dichloroethene (1,1-DCE), cis- and trans-1,2-dichloroethene, vinyl chloride and ultimately to ethene (Aronson and Howard, 1997).

Information regarding abiotic degradation of dioxins, furans, PCBs, and other Site-related COCs appears to be limited and therefore any degradation of these compounds is expected to be minor.

5.5.3 Natural Attenuation Overview

An evaluation of the natural attenuation at the Site was completed to determine the types and, if possible, the rates of natural attenuation processes at the Site. The complete evaluation is presented in Appendix U.

For all COC groups, physical attenuation mechanisms (dispersion, diffusion, and dilution) occur at every site. This natural attenuation evaluation focused on the biological and chemical attenuation processes that are occurring at the Site.

For chlorinated VOCs, it was determined that reductive dechlorination was occurring at the Site. This evidence was based on the redox conditions, which are conducive to reductive dechlorination, and the presence of degradation products including ethene, which indicates that complete degradation of chlorinated solvents is occurring to some extent at the Site. The presence of acetylene also indicates that the abiotic degradation of PCE and/or TCE is occurring to some extent at the Site.

The natural concentration changes over time could not be evaluated at the Site due to the presence of the groundwater extraction system and the low number of sampling events in the areas outside the influence of the groundwater extraction system. However, approximate biodegradation half-lives for the chlorinated solvents along the northern flow path were estimated using BIOCHLOR, and are as follows:

- PCE 8 years
- TCE 23 years
- cis-DCE 17 years
- VC 9 years

Multiple BIOCHLOR simulations were performed to estimate the biodegradation half-lives presented above. Observed concentrations for each of the above CVOCs at each monitoring well along the northern flowpath were used as a calibration targets, along with the estimated groundwater flow and transport parameters along the northern flowpath. The wells chosen were those that lie along the apparent centerline of the northern flowpath. The half-life for PCE was first altered until the BIOCHLOR results most closely matched the observed PCE concentrations. The process then was repeated in sequence for TCE, cis-DCE, and VC.

At first, it may seem counter-intuitive that the half-life of VC is lower than the half-life for cis-DCE when considering VC is consistently detected in groundwater at the Site. However, because the biodegradation of CVOCs and their daughter products is a first-order process, the amount degraded depends not only on the rate, but also on the amount of CVOCs present. Because cis-DCE biodegrades to VC, the concentration of VC depends not only on the biodegradation rates of both VC and cis-DCE, but also on the amount of cis-DCE present. At the wells used as calibration targets for the BIOCHLOR simulations, the cis-DCE concentrations were much greater than the VC concentrations. The greater cis-DCE concentrations led to the production of greater VC concentrations, and a lower VC half-life was required to reduce these VC concentrations to levels that matched the observed VC concentrations. Thus, the greater cis-DCE concentrations had a high degree of influence on determining the half-life for VC. In fact, because of the greater cis-DCE concentrations, the BIOCHLOR model results were fairly insensitive to changes in the half-life for VC required to match the observed VC concentrations. The half-lives presented above are the best estimates obtained based on matching the observed Site data.

The effect of Site geochemical conditions on the rate of biodegradation was evaluated, but could not be determined due to the complexity of the geochemical interactions at the Site. The degree of biodegradation did not show a strong correlation to pH, ORP, nitrate, iron, alkalinity, or sulfate concentrations.

The other compounds that comprise the ADP do not degrade, but are susceptible to physical attenuation mechanisms. Attenuation rates could not be calculated for chloride or any other inorganic constituents of the ADP, however, because concentrations of these same elements are also elevated in the salt water surrounding the Site.

SVOCs, PCBs, dioxins, and furans can be degraded under the reducing conditions at the Site, but the literature indicates that rates will be slower than under oxidizing conditions. Distinct plumes of these compounds were not delineated outside the potential source area, and therefore degradation rates along the flow path could not be calculated. Degradation products of these compounds have not been analyzed; therefore, the types of degradation that may be occurring are unconfirmed.

The concentration of natural DOC at the Site is generally at or below 10 mg/L, which is enough to support biodegradation, but is less than the optimal level for robust dechlorination of CVOCs to occur. While the concentrations in the groundwater at the Site are generally below 10 mg/L; concentrations of ethene, which is a degradation product of VC, were detected at some locations. The presence of ethene is good evidence that some biodegradation of VC is occurring, even if the concentration of DOC is less than the optimal level for robust dechlorination of CVOCs to occur.

While the biodegradation of CVOCs is occurring at the Site, the CVOCs are migrating off the former OCC property and are discharging to the Waterway. This means that natural attenuation alone is not an appropriate remedy for the Site.

5.6 Contaminant Transport Conceptual Site Model

The CSM describes the key processes that influence groundwater flow directions, and thus contaminant migration, beneath the Site. The CSM is derived by considering separately, and then reconciling, three primary components: the observed geologic conditions, the observed hydraulic data, and the interpreted contaminant migration. Section 3.7 provides a summary of the CSM of geologic and hydrogeologic conditions for the Puyallup River Valley and Bluffs in the Site vicinity. An overview of the CSM is presented in Section 5.6.1. Contaminant transport processes for the key Site COCs based on the CSM are described in Section 5.6.2.

5.6.1 Site Geologic/Hydrogeologic Conditions

Site Geologic Conditions

The Site is part of the Puget Sound Lowlands, which are surrounded by the Puget Sound Bluffs (Bluffs). The Bluffs extend along the sides of the Puyallup River Valley, and correspond to the highland areas at the east and west sides of the POT. Figure 3.53 shows the CSM of geologic conditions for the Puyallup River Valley and Bluffs in the Site vicinity. The CSM of geologic conditions consists of (from ground surface): fill; deltaic deposits; and glacial deposits. The fill was placed on top of the former native tidal mud flats that existed at the mouth of the Puyallup River Valley under pre-development conditions. The Site stratigraphic data indicate that there is an increased frequency of lower permeability lenses, comprised mainly of silt and clay, in the lower deltaic deposits, as depicted schematically on Figure 3.53. Figure 3.53 also shows an alternating sequence of sand/gravel and silt/clay layers within the Bluffs based on the regional geologic conditions.

Site Hydrogeologic Conditions

Figure 3.71 shows the conceptual model of hydrogeologic conditions for the Puyallup River Valley and Bluffs in the Site vicinity. Groundwater beneath the Site discharges to the surrounding surface water bodies. Fresh groundwater inflow toward the Site peninsula occurs from the south due to upland regional groundwater flow along the Puyallup River Valley, and from the east due to regional groundwater flow in the Bluffs aquifers discharging to the Valley. Infiltration of precipitation over the Site peninsula contributes a further source of fresh groundwater, and establishes a shallow radial groundwater flow pattern towards the surface water bodies.

The groundwater table at the Site peninsula is located in the fill that was placed on top of the native mud flats. The mud flats are assumed to have hydraulic conductivity similar to silts and clays identified within the deltaic deposits, but have been shown to create a hydraulic separation between the fill and the underlying deltaic deposits in the southern portion of the Site. The mud flats are colored dark brown on Figure 3.71 where the hydraulic separation between the fill and deltaic deposits is observed in the southern portion of the Site, and a lighter brown where this hydraulic separation is not confirmed.

The majority of the Site-related contamination exists within the deltaic deposits. Groundwater quality data indicates that the vertical limit of contamination appears to coincide with the increased frequency of lower permeability lenses in the lower deltaic deposits. Although a discrete continuous layer of low permeability material is not observed in Site borings in the lower deltaic deposits, the groundwater quality, density, and hydraulic evidence supports the concept that the increased frequency of lower permeability lenses limits vertical flow creating a zone of apparent confining effect in the lower deltaic deposits.

The glacial deposits appear to be an aquifer system composed of several glacially-derived aquifers and aquitards that are separated from the deltaic deposits by the zone of apparent confining effect. The fresh groundwater in the glacial deposits is derived from upgradient regional inflow. The regional inflow, combined with the zone of apparent confining effect, likely causes higher hydraulic pressures within the glacial deposits that result in the upward vertical hydraulic gradients from the upper glacial deposits to the lower deltaic deposits.

Salt water occurs in the Hylebos and Blair Waterways and Commencement Bay surrounding the Site peninsula. The density difference between salt water and fresh groundwater results in the development of fresh groundwater and salt water distributions within the Site groundwater flow system. The observed salt water and fresh groundwater distributions are translated to the CSM of hydrogeologic conditions in the Site vicinity on Figure 3.71. The salt water distributions and groundwater flow conditions illustrated on Figure 3.71 are generalized representations of pre-contamination conditions, as described in Section 3.7.

The presence of both salt water and fresh groundwater beneath the Site, as well as elevated groundwater densities associated with the ADP, creates density-dependent groundwater flow conditions. Releases of high density liquids from historical Site operations/processes (lime sludge/solvent residue, caustic soda, and salt brine) that have created the ADP have a critical influence on groundwater flow and contaminant transport, as described in Section 5.6.2.

5.6.2 Contaminant Transport and Fate

Site investigations have confirmed that there are four primary groundwater plumes: the ADP, pH plume, CVOCs, and metals. These plumes have been defined through the Site monitoring well network as described in Section 3.0. Other COCs have not developed large, distinct groundwater plumes. This is likely due to a combination of factors, such as low mobility in groundwater, limited contaminant mass, and attenuation processes.

The Site monitoring well network consists of wells screened within seven depth zones, or ZGPs, representing nominal depths of 15, 25, 50, 75, 100, 130, and 160 ft BGS. The depth zones are referred to as the 15-ft zone, 25-ft zone, 50-ft zone, 75-ft zone, 100-ft zone, 130-ft zone, and 160-ft zone. These depth zones are indicated on Figure 5.10.

The primary groundwater plumes have migrated from the potential sources noted in Section 5.0 via several transport mechanisms that are summarized below.

COC Type	***Transport Mechanism***
ADP	• Density-dependent flow
	• Migration with groundwater
pH plume	• Density-dependent flow
	• Migration with groundwater
CVOCs	• DNAPL migration
	• Migration with the ADP • Displacement by the ADP
	• Migration with groundwater
	• Volatilization to ambient air and indoor air
Metals	• Migration with the ADP • Migration with groundwater
	• Surface water runoff
SVOCs	• Migration with groundwater • Surface water runoff • Volatilization to ambient air and indoor air
PCBs	• Migration with groundwater • Surface water runoff
Dioxins/Furans	• Migration with groundwater • Surface water runoff

5.6.2.1 COC Migration Rate

Bulk Migration Rate

A conceptual average bulk COC migration rate is estimated for the dissolved groundwater plumes for each main group of COCs. The distance each COC group has traveled from the suspected potential source areas was divided by the time since the potential source is thought to have been in place. Due to the uncertainty in the starting time for the potential sources, a range of values were used for the start times (1940 – 1960).

The table below presents the conceptual migration rates for each of the COC groups.

COC Group	***Assumed Starting Area***	***Estimated Lateral Migration Distance as of 2013 (ft)***	***Range in Estimated Migration Rates (ft/yr)***
CVOCs (vinyl chloride)	WMU H	1,700	23 - 32
Caustic (pH)	Caustic House	1,500	21 - 29
ADP	Salt Pad/WMUs C, F, G, H	1,600	22 - 30
Metals	Navy-Todd Dump	400	6 - 8

Vinyl chloride and zinc were chosen because, of the COCs from their respective groupings, they have traveled farthest from their respective potential source areas. SVOCs, PCBs, and dioxins/furans were not included because these COCs do not form distinct enough groundwater plumes to allow the calculation of migration rates.

It should be noted that the estimated migration rates presented above are conceptual in nature. These historical plume migration rate estimates are not representative of current conditions and are not predictive of future migration rates.

Uncertainty in the estimates is due to the following:

i) Higher density releases, greater than what is currently observed in the ADP, likely occurred at early time and likely caused faster initial (downward) migration rates. As dilution of the ADP has occurred over time, the migration rates due to density effects have likely slowed.

ii) The assumption of a starting point: Input to the subsurface would have started immediately after the initial discharge of solvent waste to the subsurface. However, the time for the initial release of a large enough volume of product to cause DNAPL migration is not available.

iii) The assumption that the flow was uniform over time: The presence of DNAPL at depth beneath the Site is direct evidence that a dense, separate phase migrated downward vertically from discharge point(s) at the surface. Accounts of experimental vertical DNAPL migration from the literature indicate that the DNAPL migration rates would be different from the dissolved groundwater plume migration rates. Currently there is no reliable method to separate DNAPL migration rates from estimates of dissolved groundwater plume migration rates.

iv) The presence of the ADP: The conceptual migration calculation method proposed requires the assumption the groundwater flow field was uniform, which would not have been the case with the density effects associated with the early time high density releases. It is understood that the mixing of the high-density and low density waters is limited. Therefore the migration rate of CVOCs within the ADP will depend, to some extent, on the ADP migration, and will be different from the migration rate within the groundwater outside the ADP. There is no way to account for these differences that occurred historically.

Groundwater Flow-Based Migration Rates

A migration rate for each of the COC groups was calculated based on the estimated groundwater flow rate and the transport properties of the most mobile member of each of the COC group. The distribution coefficient (K_d) was calculated using the organic carbon partitioning coefficient (K_{oc}) to obtain a conservative distribution coefficient to represent each COC group. Vinyl chloride was used for CVOCs, Aroclor 1221 for PCBs, HCBD for SVOCs, and dibenzofuran for dioxins and furans. Maximum and minimum K_d values were calculated using the maximum and minimum organic carbon contents measured on-Site. The coefficient of retardation (R) was calculated for each group assuming linear sorption. Mean Site values for porosity, hydraulic conductivity, and bulk density were used. A Site-specific range of hydraulic gradients were used to calculate groundwater velocity and migration rates. Full details are presented in Appendix U and the results are summarized in the table below.

COC Group	***K_d***		***R***		***Migration Rate (ft/yr)***	
	Min	***Max***	***Min***	***Max***	***Min***	***Max***
CVOCs (vinyl chloride)	0.0035	0.48	1.0	2.8	2.7	67
SVOCs (HCBD)	0.14	19	1.5	71	0.11	45
PCBs (Aroclor 1221)	1.3	180	6.0	690	0.011	11
Dioxins/Furans (dibenzofuran)	1.5	200	6.5	760	0.010	10
ADP (Cl^-)	0	0	1.0	1.0	7.5	67
pH (OH^-)	0	0	1.0	1.0	7.5	67

The previously calculated bulk migration ranges for CVOCs, ADP and pH fall within the broader range of compound-specific migration rates. These values account for adsorption only, and do not consider the contribution of degradation to the organic COC migration rates.

5.6.2.2 Anthropogenic Density Plume

Historical Site operations resulted in surface releases of high density fluids from the potential sources described in Section 5.2 (primarily the settling ponds/barge, Caustic Source Area, and Salt Pad). Mixing of lime sludge/solvent residue, caustic soda (sodium hydroxide), and brine (sodium chloride) in groundwater has resulted in a comingled plume of high density that under current conditions consists of specific gravity values ranging from >1.02 (density of >63.7 lbs/ft^3) to approximately 1.2 (density of 74.9 lbs/ft^3). The ADP tends to sink due to its higher density impacted water (relative to the density of fresh groundwater and salt water). A conceptual figure showing the ADP during the early period of Site operations is shown on Figure 5.11. The early time ADP is envisioned as being within the fill and upper portion of the deltaic deposits below the settling ponds/barge (WMU C, F, G, and H[11]), Salt Pad, and Caustic Source Area. The solvent residue, comprised of PCE and TCE, is the highest density material that was released, and thus the early time ADP is shown to extend somewhat deeper under the settling ponds/barge on Figure 5.11.

Over time, the ADP migrated away from the potential source areas via density-dependent (i.e., gravity-driven) flow. While migrating downwards, the higher density plume displaced the fresh and salt water initially present beneath the release locations. The fresh groundwater and salt water displacement caused by the downward density plume migration caused lateral groundwater flow that has contributed to the lateral spreading of the density plume, as well as the spreading of the impacted groundwater surrounding or comingled with the density plume. This lateral spreading has resulted in a portion of the CVOC plume migrating eastward, beneath the Waterway, opposite the average groundwater flow directions currently observed. The lateral spreading of the CVOC plume caused by the early time ADP is illustrated on Figure 5.12. The primary CVOC found beneath the Waterway currently is vinyl chloride, which is the biodegradation product of the initially released PCE and TCE.

The ADP has spread laterally and migrated vertically until encountering lower permeability soil layers or counterbalancing hydraulic pressures, as follows:

i) Lateral migration will continue until reaching equilibrium, or counterbalancing hydraulic pressures (i.e., opposing horizontal hydraulic gradients counterbalancing the lateral density-driven gradients), or until encountering a vertical low permeability barrier, such as the buried valley wall along the Bluffs east of the Waterway. These factors prevent eastward migration of the ADP into the sediments beneath the Bluffs.

ii) Vertical migration will continue until reaching a combination of the upward vertical hydraulic gradients from the upper glacial deposits to lower deltaic deposits and the increased frequency of lower permeability lenses in the lower deltaic deposits (i.e., the zone of apparent confining effect). Upward vertical hydraulic gradients in the upper glacial deposits counterbalance the tendency of the dense water to sink, and the increased frequency of lower permeability lenses in the lower deltaic deposits limits the vertical rate of migration.

---

[11] Although lime sludge/solvent residue reportedly was sent to WMU A, the ADP under current conditions is not focused beneath this area. As a result, WMU A was not shown on Figure 5.3 as a source location for the ADP.

The distribution of the current ADP is shown on Figure 5.13. The ADP is centered beneath the settling ponds/barge and Salt Pad, with the southern portion of the ADP underlying the potential Caustic Source Area. The ADP has remained relatively consistent since 2006.

The highest densities of the ADP are well below the groundwater table, reflecting the fact that the major density potential sources ceased or were removed prior to Site investigations. The ADP has also spread laterally beneath the Waterway and to the north towards Commencement Bay. The vertical migration of the ADP is limited by the zone of apparent confining effect in the lower deltaic deposits and upward vertical hydraulic gradients within the upper glacial deposits. The ADP has migrated northwards into the salt water transition zone with Commencement Bay due to northward-directed hydraulic gradients. The northward ADP migration also appears to be influenced by a northwestward dipping trough in the glacial deposits observed beneath the northeastern portion of the Site peninsula. The zone of apparent confining effect in the lower deltaic deposits appears to follow the trough, and correspondingly the ADP above this. Once the density-driven gradients of the ADP dissipate, diffusion and groundwater advection will be the predominant mechanism for any further migration of the ADP, and COCs comingled with the ADP.

The distribution of the ADP shown on Figure 5.13 is based on, and is consistent with, the observed density data. The highest density observations occur east of the Salt Pad, corresponding to the locations of the settling ponds/barge, and elevated density observations also occur to the north/northwest of the Salt Pad. The highest density beneath the settling ponds/barge indicates this area is where the releases of highest density material occurred historically, consistent with the release of lime sludge and solvent residue in this area. The elevated density to the north/northwest of the Salt Pad is consistent with the trough in the surface of the glacial deposits that appears to slope downward to the northwest. The current ADP distribution appears centered beneath the settling ponds/barge just east of the Salt Pad, where the release of highest density material occurred, spreads radially outward from this area and then northwestward consistent with the zone of apparent confining effect in the lower deltaic deposits following the trough in the glacial deposits.

Much of the ADP is composed of inorganic compounds (e.g., salt, caustics, and dissolved minerals) which will not degrade. The salt will also not likely form precipitates to reduce the mass in solution. Therefore, the reduction in the ADP concentrations will mainly come from mechanical attenuation: dispersion, diffusion, and dilution.

5.6.2.3 pH Plume

Historical Site operations resulted in surface releases of high density/high pH caustic fluids from the potential Caustic Source Area described in Section 5.2. The caustic fluids co-mingled with the brine released from the Salt Pad to form the ADP. Thus, the pH plume is largely consistent with the ADP plume. The distribution of the current pH plume is shown on Figure 5.14.

Interaction of historical caustic releases with the aquifer materials has resulted in the formation of new mineral phases, primarily within the shallow fill material. These new minerals react with fresh precipitation infiltration to produce high pH groundwater. Thus, shallow soils that were impacted with caustic are a continuing source of elevated pH to groundwater.

Reaction of the pH plume with the aquifer material is an exothermic reaction that results in a localized increase in groundwater temperature. This process is most apparent in the areas of the highest pH groundwater where geochemical reactions are actively occurring. Currently the temperature data indicate this is occurring under the Salt Pad and surrounding area where the reactions would be most vigorous. Groundwater temperatures measured under the Salt Pad and surrounding area are up to 10 degrees Celsius warmer than the groundwater temperatures measured upgradient of the Site.

The position and extents of the pH plume has remained relatively consistent since 2006.

5.6.2.4 CVOCs

The migration of CVOCs occurs by several mechanisms:

- DNAPL migration
- Migration of dissolved-phase with the ADP
- Displacement migration at the perimeter of the ADP
- Migration of dissolved-phase with fresh groundwater
- Migration to indoor and ambient air

These CVOC migration mechanisms are summarized below.

5.6.2.4.1 DNAPL Migration

The subsurface migration of DNAPL is a complex process that is strongly influenced by geology, properties of the DNAPL, and release location. DNAPL has a high density and tends to migrate vertically downward. The DNAPL density is greater than that of the ADP and can displace the high density water within the ADP. Unlike the ADP which is totally miscible in water, DNAPL is essentially immiscible. During transport, some DNAPL is immobilized in pore spaces in the form of disconnected blobs and ganglia referred to as residual DNAPL. In this way, the volume of DNAPL is gradually distributed along the flow path, and the mass of DNAPL subject to active migration is depleted. The DNAPL will continue to migrate until the DNAPL mass becomes immobile, or stable (i.e., remains as residual bound in pore spaces, or "pools" above a low permeability layer).

The distribution of DNAPL in the subsurface is shown on Figure 5.7. This figure shows the general distribution of the confirmed and suspected DNAPL beneath the Site. DNAPL is observed beneath the former solvent production plant, WMU A, and WMU G. Historical DNAPL release rates and mass would likely have been highly variable, resulting in the separation between confirmed DNAPL at the upper and lower depths within the Shallow Aquifer shown on Figure 5.7. During vertical migration of the DNAPL, significant lateral migration has occurred, likely due to the DNAPL encountering low permeability lenses within the deltaic deposits that increase in frequency in the lower portion of the deltaic deposits. DNAPL has also moved northwestward at depth consistent with the zone of apparent confining effect in the lower deltaic deposits following the trough in the glacial deposits. Given the significant timeframe since the initial releases occurred, the tortuous migration of the DNAPL through the heterogeneous deltaic deposits, and increased frequency of lower permeability lenses in the lower deltaic deposits, the current DNAPL distribution is likely stable.

Residual DNAPL will result in a continuing source of CVOCs. Additionally, diffusion into lower permeability (i.e., silt and clay) lenses adjacent to DNAPL will accumulate CVOC mass. The silt and clay then act as secondary sources of aqueous contamination through back-diffusion once groundwater concentrations in higher permeability zones decline. The process of back-diffusion from lower permeability lenses into higher permeability zones, where the bulk of the active groundwater flow occurs, will significantly prolong groundwater remediation timeframes.

5.6.2.4.2 Migration with the ADP

Figure 5.8 shows the current distribution of total CVOCs in groundwater at the Site. The CVOC potential sources were in close proximity to the Salt Pad, and as a result, dissolved CVOCs have comingled and migrated with the ADP. As the ADP displaced fresh groundwater or salt water in the subsurface, comingled CVOCs within the ADP were carried by the ADP as it migrated laterally and downward. In addition, CVOCs already dissolved in groundwater at the periphery of the ADP would have been displaced laterally and vertically in advance of the ADP migration. The lateral ADP migration is a primary reason for the presence of CVOCs beneath the Waterway east of the CVOC potential source areas even though the average groundwater flow direction observed under current conditions is more north to northwest.

5.6.2.4.3 Migration in Fresh Groundwater

Dissolved-phase CVOCs in groundwater beyond the ADP will migrate with fresh groundwater. This will lead to northward migration as the regional groundwater flow direction in the deltaic deposits is generally toward Commencement Bay, with groundwater discharge to the surrounding surface water bodies. This northward flow has resulted in an apparent shallow component of total CVOC plume at the northern end of the Site peninsula illustrated on Figure 5.8. Some eastward flow is also occurring, where shallow groundwater is discharging to the Waterway.

Migration of dissolved-phase CVOCs in groundwater is attenuated by the following processes: adsorption; diffusion into low permeability (i.e., silt and clay) lenses; and degradation.

Adsorption of CVOCs onto soil particles depends on the amount of organic matter naturally present in soil and the relative affinity of individual hydrophobic compounds to adhere to organic matter. Adsorption results in the dissolved-phase CVOC plume migrating more slowly than the average groundwater flow velocity.

Diffusion of dissolved-phase CVOCs into lower permeability (i.e., silt and clay) lenses also slows the rate of CVOC migration relative to the average groundwater flow velocity in higher permeability zones. The silt and clay then act as secondary sources of dissolved-phase contamination through back-diffusion once groundwater concentrations in higher permeability zones decline.

The concentrations of CVOCs at the base of the Waterway are much lower than groundwater concentrations at depth. The shallow concentrations are attenuated because of flushing (dilution) with surface water, which is enhanced via tidal fluctuation. Also, within the salt water zone adjacent to the waterway mudline, the expected net flow condition is for salt water recharge to the aquifer to maintain salt water zone. The lower concentrations could also be due to surface water influence during sampling and dilution from unimpacted groundwater migrating from the bluff. These processes contribute to the presence of low to non-detectable CVOC concentrations near the mudline observed at some Waterway sample locations. In particular, this is expected to occur in areas that are not affected by the ADP where high density groundwater discharge can occur against the salt water equilibrium or in areas that are not affected by high water levels from the eastern bluffs, although, impacted groundwater has been detected near the mudline along the center and eastern shores of the Waterway.

Degradation of the CVOCs is occurring both biologically and abiotically. Figure 5.9 shows generally accepted degradation pathways for PCE and TCE (USEPA, 1998; Weidemeier et al., 1999). Biological degradation of PCE and TCE (parent compounds) has produced cis-1,2-dichloroethene (cis-1,2-DCE) and vinyl chloride (daughter products) at the Site. The distribution of the parent and daughter products in groundwater is shown on Figures 5.15 through 5.17. In general, PCE/TCE occur near the surface potential sources and DNAPL source zones. The daughter products occur in the source zones and beyond the PCE/TCE plume. The presence of cis-1,2-DCE and vinyl chloride, daughter products of the biological degradation of PCE and TCE, confirms that PCE/TCE biodegradation is occurring. The abiotic degradation of PCE and TCE also is occurring as indicated by the presence of dissolved acetylene in groundwater.

It does not appear that the high ionic strength of the sea water, ADP, and pH plume have a direct effect on CVOC migration because CVOCs are non-polar molecules. However, biological activity is normally inhibited under high pH conditions. An evaluation was completed to determine the degree to which the Site pH inhibits the microbial activity. The results, presented as part of the natural attenuation evaluation in Appendix U, indicate that there is no clear relationship between pH and the degree of biodegradation at the Site.

The lack of an obvious relationship does not indicate that microbial activity is unaffected by high pH conditions, but, the lack of a simple relationship between pH and the degree of biodegradation is likely because there are many complex geochemical and microbiological interactions occurring simultaneously at the Site, which cannot be characterized by a simple relationship.

The literature indicates that elevated biological activity is inhibited under high pH values. The USEPA Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Ground Water (USEPA, 1998) indicates that the pH values between 5 and 9 comprise the optimal range for the reductive dechlorination of chlorinated solvents. It will, therefore, be assumed that microbial activity will be inhibited (but not necessarily prevented) above a pH value of 9.0.

Appendix U also presents the results of the evaluation of the effects of DOC on the degree of biodegradation. It is recognized that a sufficient amount of DOC is required for robust microbial activity (e.g., biodegradation); however, the Site data do not show a distinct relationship between the amount of DOC and the degree of biodegradation. The complexity of the geochemical conditions at the Site may prevent the observation of simple relationships expected between parameters and processes.

5.6.2.4.4 Migration to Ambient Air and Indoor Air

CVOCs will volatilize from impacted shallow groundwater or from the impacted vadose zone soils. CVOCs in the vapor phase will then migrate by diffusive and advective mechanisms through the unsaturated soil and be emitted to ambient air and potentially indoor air of enclosed buildings.

5.6.2.5 Metals

The migration of metals occurs by several mechanisms:

- Migration of dissolved metals with the ADP
- Migration of dissolved-phase with fresh groundwater
- Metals transport in surface water runoff

These metals migration mechanisms are shown schematically on Figure 5.18 and are summarized below.

5.6.2.5.1 Migration with the ADP

As the ADP displaced fresh groundwater or salt water in the subsurface, comingled dissolved metals within the ADP were carried by the ADP as it migrated laterally and downward. In addition, metals already dissolved in groundwater at the periphery of the ADP would have been forced to migrate laterally and vertically in advance of the ADP migration.

5.6.2.5.2 Migration in Groundwater

Infiltrating groundwater that comes into contact with soils containing metals will dissolve some of the metals, carrying them to the water table and into groundwater. Once in groundwater, the metals will be transported along with groundwater flow, and will eventually discharge to the Waterway and Commencement Bay, if the metals remain in solution.

The metals concentrations and migration in groundwater are influenced by numerous mechanisms, the most important at the Site are:

- Sorption onto naturally occurring ferric oxide coatings on aquifer soil particles. This sorption slows the transport of metals in groundwater
- Suppression of sorption onto the ferric oxide coatings by the high pH of the water in the pH plume mobilizing metals (that would otherwise be adsorbed) and keeping the metals in solution longer

- Enhancement of the solubility of some metals in soil (both naturally occurring and anthropogenic) by the high pH of the water in the pH plume
- Limitation of the sorption of metals due to ion-ion interactions associated with the high ionic strength of the ADP (i.e., competition for sorption sites) keeping the metals in solution

Remediation of metals in groundwater is highly dependent on addressing the pH plume and the ADP. Metals do not biodegrade; the most active attenuation mechanisms are physical (dispersion, diffusion and dilution) and chemical (sorption, precipitation). Once the groundwater pH decreases and the ADP dissipates, natural sorption processes will result in the sorption and precipitation of metals thereby reducing their concentrations dissolved in groundwater.

5.6.2.5.3 Surface Runoff

Precipitation at the Site comes into contact with impacted surficial soil and carries soil particles with the surface runoff, especially during heavy rainfall events. The surface water at the Site is conveyed by overland flow and the storm sewer system to adjacent surface water bodies.

There has been a storm sewer monitoring program undertaken at the Site designed to determine if storm water discharge is within regulatory limits. The monitoring program has not identified any significant impacts. It is unlikely that future impacts will occur and this migration pathway is not considered significant.

5.6.2.6 SVOCs

The migration of SVOCs could potentially occur via several mechanisms:

- DNAPL migration
- Migration of dissolved phase with the ADP
- Migration of dissolved phase with fresh groundwater
- Migration to indoor and ambient air

5.6.2.6.1 DNAPL Migration

Because the SVOCs were formed as by-products of the solvent manufacturing process, they could be present in the DNAPL released to the subsurface at the Site. The SVOCs would have then migrated downward along with the DNAPL as described in Section 5.6.2.4.1. The presence of HCB and HCBD in deep soil and sediment samples is consistent with this hypothesis.

5.6.2.6.2 Migration in Groundwater

In general, SVOCs tend to sorb strongly to the soil and are conceptualized as having limited mobility in groundwater compared to the CVOCs. Some dissolution will occur, as will the sorption to suspended particles (i.e., colloids) in groundwater. However, the migration of the SVOCs in the groundwater will be minimal. This observation is consistent with the distribution of SVOCs in the groundwater, which indicates detected concentrations tend to be near to the identified potential source areas described in Section 5.2.

HCB and HCBD can degrade under anaerobic conditions, such as those found over much of the Site. The degradation rates are likely to be fairly slow however, and the elevated pH will likely inhibit the microbial activity responsible for the biodegradation. Although the pH value is unclear, it will be assumed that the threshold above which microbial activity is inhibited will be 9 su, as presented in Section 5.6.2.4.3.

5.6.2.6.3 Migration to Ambient Air and Indoor Air

More volatile SVOCs (e.g., HCBD) will volatilize from impacted shallow groundwater or from the impacted vadose zone soils. SVOCs in the vapor phase will then migrate by diffusive and advective mechanisms through the unsaturated soil and be emitted to ambient air and potentially indoor air of enclosed buildings.

5.6.2.7 PCBs and Dioxins/Furans

PCBs and dioxins/furans sorb very strongly to soil particles and are relatively insoluble in water; therefore migration in the groundwater is limited, although some sorption to colloids may occur, which could result in a limited enhancement of PCBs and dioxins/furans migration. Surface runoff could carry suspended soil particles with PCBs or dioxins/furans into surface water bodies, and sediment impacted with PCBs and dioxins/furans could be carried along the waterways adjacent to the Site.

However, the mobility of PCBs and dioxins/furans is considered to be very limited. This observation is consistent with the distribution of PCBs and dioxins/furans in groundwater, which indicates detected concentrations tend to be near to the identified potential source areas described in Section 5.2.

The biodegradation of PCBs has been documented, but the rate of degradation tends to be slow and very dependent on the congener (Pieper and Seeger, 2008). While biodegradation of dioxins and furans is possible, these compounds are regarded as resistant to biodegradation.

Section 6.0 Exposure Pathway Assessment

Formatted: Highlight

Based on the analytical results, an Exposure Pathway Assessment (assessment) was conducted in accordance with Ecology and USEPA guidance. The assessment included both human health exposure pathway assessment (HHEPA) and ecological exposure pathway assessment (EEPA) and evaluated potential impacts on Properties (605 and 709 Alexander Avenue) and off Properties (beyond 605 and 709 Alexander Avenue), and is included as Appendix V. A brief summary of the assessment is provided below.

The purpose of the assessment was to identify media and locations that may need corrective action, risk management measures, or further evaluation during remedy design. For this purpose, risk-based concentrations (RBCs) were developed and used to identify potentially impacted media and locations. The RBCs were developed to be protective of all potential human health and ecological receptors exposed to Constituents of Concern (COCs) in on-Properties and off-Properties media under current and continued future industrial use, assuming no additional remedial actions are taken. The Properties and off-Properties were evaluated separately due to the institutional controls that have been implemented on the Properties through the use of deed restrictions.

While risk assessments often include development of quantitative risk estimates that are used to identify media and locations requiring corrective action, RBCs were used in this assessment for this purpose for the following reasons:

i) Multiple receptors were included in this assessment, and for certain of these receptors (i.e., outdoor industrial/commercial worker and trespasser), identification of exposure areas and determining areal average contaminant levels (i.e., development of 95% upper confidence levels in risk estimates) is appropriate. However, for other receptors such as the indoor worker and construction worker, potential exposures can be much more localized. In these cases, areal averaging of contaminant concentrations is arguably inappropriate. Therefore, for consistency, a screening-level approach was considered appropriate for all receptors.

ii) For certain pathways, MTCA specifies that media concentrations need to be compared to screening criteria. In particular, because groundwater at the Site is non-potable and shallow groundwater could potentially discharge to surface water via seeps and subtidal discharge along the embankment immediately adjacent to the Waterway, MTCA requires that groundwater concentrations should not exceed applicable surface water criteria. Therefore, a screening-level approach for the groundwater-to-surface water pathway is required by MTCA. As noted previously, for consistency a screening-level approach was considered appropriate for all receptors.

iii) In many locations, impacts from multiple chemicals were evident that exceeded RBCs developed for the screening-level evaluation. In these media and locations, development of quantitative risk estimates would not likely add to, or help inform, decision-making related to the need for corrective action or risk management measures.

iv) Vapor intrusion (VI) pathway investigation is in progress and will more directly determine the need for mitigation relative to that exposure pathway.

For the reasons listed above, a screening level exposure pathway assessment was deemed most appropriate to identify media and locations that may need corrective action, risk management measures, or further evaluation during remedy design.

This section is structured as follows:

Section 6.1	Human Health Exposure Pathway Assessment
Section 6.2	Ecological Health Exposure Pathway Assessment

6.1 Human Health Exposure Pathway Assessment

This section is structured as follows:

Section 6.1.1	Identification of Complete Exposure Pathways
Section 6.1.2	Summary of Potential Human Health Exposures

6.1.1 Identification of Complete Exposure Pathways

The Site is located in the industrial tideflats area of Tacoma, Washington. The zoning of the properties which comprise the Site is "S-10" (Port Industrial Shoreline District), "M-3" (Heavy Industrial District), and "PMI" (Port Maritime Industrial). Restrictive covenants restricting land use on the properties to non-residential industrial use are contained and set forth in the Quit Claim Deed (Corrected) recorded on April 28, 1997, in the records of the Pierce County Auditor (Recording No. 9704280734). Pertinent property owned by the POT is the subject of a restrictive covenant recorded on May 5, 2003, in the records of the Pierce County Auditor (Recording No. 200305050452) that prohibits groundwater extraction, supply or use for drinking or other human consumption or domestic use of any kind.

The nearest residential properties are situated approximately 1 mile to the east, on the bluff across the Waterway from the Site, 3/4 of a mile across the Waterway to the northeast, and approximately 3 miles to the south.

Based on the information noted above, the current and foreseeable future land use for on-Properties and adjacent off-Properties is commercial/industrial. Therefore, the identified receptors that may be present include an outdoor industrial/commercial worker, an indoor industrial/commercial worker, a construction/utility worker, and a trespasser. Because shallow groundwater on-Properties and adjacent off-Properties is impacted and potentially discharges to the Waterway via seeps and subtidal discharge along the embankment, a fisher receptor was also included in the HHEPA.

In consideration of the restrictions on the Properties, the following media and potential human exposures were identified for quantitative evaluation for on and off Properties:

Media and Potential Human Exposure	***On-Properties***	***Off-Properties***
Industrial/commercial worker inhalation exposure to chemicals in indoor air due to migration of volatile chemicals in soil and groundwater	√	√
Trespasser and industrial/commercial worker direct contact (incidental ingestion and dermal contact) and ambient air inhalation exposure to chemicals in surface soil	√	√
Trespasser and industrial/commercial worker direct contact (incidental ingestion and dermal contact) exposure to chemicals in sediment	√	√
Trespasser and industrial/commercial worker inhalation exposure to chemicals in ambient air due to migration of volatile chemicals in groundwater	√	√
Construction/utility worker direct contact (incidental ingestion and dermal contact) and ambient air inhalation exposure to chemicals in surface and subsurface soil		√
Construction/utility worker direct contact (incidental ingestion and dermal contact) and ambient air inhalation exposure to chemicals in groundwater		√
Fisher ingestion exposure to chemicals in ingested fish tissue	√	√

Formatted: Highlight
Formatted: Highlight
Formatted: Highlight
Formatted: Highlight
Formatted: Highlight
Formatted: Highlight
Formatted: Highlight
Formatted: Highlight

These potentially complete exposure pathways and receptors are shown schematically on Figure 6.1.

The soil data considered in the HHEPA consisted of all soils less than or equal to 10 ft BGS (based on the maximum expected depth of excavation for utilities).

The sediment data considered in the HHEPA consisted of all sediment data collected within 3 ft of the Waterway mudline, located above the approximate lowest tide elevation of -10.32 ft NGVD (-4 ft MLLW).

The groundwater data considered in the HHEPA consisted of all groundwater data collected during the period of January 2002 through October 2013. For monitoring wells, the most recent groundwater data for each COC collected during this period was considered. A shallow groundwater data set was derived consisting of all groundwater data collected within 25 ft of the upland ground surface, and was used in the HHEPA to evaluate volatilization of COCs from groundwater to indoor air and from groundwater to ambient air. The evaluation was limited to shallow groundwater because only the shallow groundwater will directly impact these media. All deeper volatile impacts would need to pass through the shallow groundwater prior to impacting indoor air or ambient air. This shallow groundwater data set was also used to evaluate the groundwater-to-surface water pathway because hydraulic monitoring shows that there is the potential for shallow groundwater adjacent to the embankment along the Waterway to discharge to surface water within the Waterway by seeps through the embankment and by shallow subtidal groundwater discharge along the embankment (see Section 3.6). In addition, shallow fresh groundwater at the northern end of the peninsula will discharge to Commencement Bay. The hydraulic monitoring showed that deep impacted groundwater may not directly discharge to the Waterway or Commencement Bay, or the discharge may be limited, due to the naturally occurring inland salt water distribution from these two salt water bodies. On the Site, downward vertical hydraulic gradients occur due to density effects caused by the elevated groundwater densities associated with the ADP. The vertical migration of the ADP is limited by the zone of apparent confining effect in the lower deltaic deposits and upward vertical hydraulic gradients within the upper glacial deposits. The ADP has migrated northward due to northward-directed hydraulic gradients. The northward ADP migration also appears to be influenced by a northwestward dipping trough in the glacial deposits observed beneath the northeastern portion of the Site peninsula. The zone of apparent confining effect in the lower deltaic deposits appears to follow the trough, and correspondingly the ADP above this. Once the density-driven gradients of the ADP dissipate, diffusion and groundwater advection will be the predominant mechanism for any further migration of the ADP, and COCs comingled with the ADP. Lateral migration at depth to Commencement Bay may be limited by inland-directed hydraulic gradients associated with the naturally occurring inland salt water distribution from Commencement Bay.

6.1.2 Summary of Potential Human Health Exposures[vi]

Formatted: Highlight

The results of the HHEPA showed that corrective action, risk management measures, or further evaluation during remedy design may be needed to address impacts to soil, sediment, and groundwater on-Properties and off-Properties. Exceedances of RBCs by exposure pathway in each of the environmental media are discussed in the following sections:

Section 6.1.2.1	On-Properties
Section 6.1.2.2	Off-Properties
Section 6.1.2.3	On-/Off-Properties

6.1.2.1 On-Properties

Soil

- The soil-to-indoor air RBCs developed for the industrial/commercial worker were exceeded by 1,1,2,2-tetrachloroethane, benzene, carbon tetrachloride, chloroform, ethylbenzene, methylene chloride, PCE, TCE, vinyl chloride, 1,2,4-trimethylbenzene, HCB, HCBD, and mercury in on-Properties shallow soil. Figure 3.1 in Appendix V shows the location of the exceedances of the RBCs in on-Properties shallow soil. Based on the Vapor Investigation, the OCC Office Building was found to need mitigation measures as discussed previously.
- The soil direct contact RBCs developed for the trespasser were exceeded by chloroform, total PCBs, 2,3,7,8-TCDD (TEQ), arsenic, and lead in on-Properties shallow soil. Figure 3.3 in Appendix V shows the location of the exceedances of the RBCs in on-Properties shallow soil.
- The soil direct contact RBCs developed for the industrial/commercial worker were exceeded by benzene, chloroform, PCE, TCE, HCB, HCBD, total PCBs, 2,3,7,8-TCDD (TEQ), arsenic, and lead in on-Properties shallow soil. Figure 3.5 in Appendix V shows the location of the exceedances of the RBCs in on-Properties shallow soil.

Sediment

- The sediment direct contact RBCs developed for the trespasser were exceeded by total PCBs, arsenic, and lead in on-Properties intertidal sediment. Figure 3.14 in Appendix V shows the location of the exceedances of the RBCs in on-Properties intertidal sediment.
- The sediment direct contact RBCs developed for the industrial/commercial worker were exceeded by total PCBs, arsenic, and lead in on-Properties intertidal sediment. Figure 3.16 in Appendix V shows the location of RBC exceedances in on-Properties intertidal sediment.

Groundwater

- The groundwater-to-indoor air RBCs developed for the industrial/commercial worker were exceeded by 1,1,2,2-tetrachloroethane, 1,1,2-trichloroethane, benzene, carbon tetrachloride, chloroform, PCE, trans-1,2-dichloroethene, TCE, and vinyl chloride in on-Properties shallow groundwater. Figure 3.8 in Appendix V shows the location of exceedances of the RBCs in on-Properties shallow groundwater. Based on the Vapor Investigation, the OCC Office Building was found to need mitigation measures as discussed previously.
- The groundwater-to-ambient air RBCs, developed for the trespasser, were exceeded by vinyl chloride in on-Properties shallow groundwater. Figure 3.10 in Appendix V shows the location of exceedances of the RBCs in on-Properties shallow groundwater.
- The groundwater-to-ambient air RBCs, developed for the industrial/commercial worker, were exceeded by chloroform, TCE, and vinyl chloride in on-Properties shallow groundwater. Figure 3.11 in Appendix V shows the location of exceedances of the RBCs in on-Properties shallow groundwater.

6.1.2.2 Off-Properties

Soil

- The soil-to-indoor air RBCs, developed for the indoor industrial/commercial worker, were exceeded by 1,1,2,2-tetrachloroethane, benzene, ethylbenzene, tetrachloroethene, and mercury in off-Properties shallow soil. Figure 3.2 in Appendix V shows the location of the exceedances of the RBCs in off-Properties shallow soil. Based on the Vapor Investigation, POT Buildings 326 and 532 were found to need mitigation measures as discussed previously.
- The soil direct contact RBCs, developed for the trespasser, were exceeded by benzene in off-Properties shallow soil. Figure 3.4 in Appendix V shows the location of the exceedances of the RBCs in off-Properties shallow soil
- The soil direct contact RBCs, developed for the industrial/commercial worker, were exceeded by 1,1,2,2-tetrachloroethane, benzene, and arsenic in off-Properties shallow soil. Figure 3.6 in Appendix V shows the location of the exceedances of the RBCs in off-Properties shallow soil.
- The soil direct contact RBCs, developed for the construction/utility worker, were exceeded by lead in off-Properties shallow soil. Figure 3.7 in Appendix V shows the location of the exceedances of the RBCs in off-Properties shallow soil.

Sediment

- The sediment direct contact RBCs, developed for the trespasser, were exceeded by total PCBs in off-Properties intertidal sediment. Figure 3.15 in Appendix V shows the location of the exceedances of the RBCs in off-Properties intertidal sediment.
- The sediment direct contact RBCs developed for the industrial/commercial worker were exceeded by total PCBs and 2,3,7,8 TCDD (TEQ) in off-Properties intertidal sediment. Figure 3.17 in Appendix V shows the location of the RBC exceedances in off-Properties intertidal sediment.

Groundwater

- The groundwater-to-indoor air RBCs developed for the industrial/commercial worker were exceeded by benzene, chloroform, PCE, trans-1,2-dichloroethene, TCE, and vinyl chloride in off-Properties shallow groundwater. Figure 3.9 in Appendix V shows the location of exceedances of the RBCs in off-Properties groundwater. . Based on the Vapor Investigation, POT Buildings 326 and 532 were found to need mitigation measures as discussed previously.
- The groundwater-to-ambient air RBCs, developed for the trespasser, were not exceeded for any COCs in off-Properties shallow groundwater.
- The groundwater-to-ambient air RBCs, developed for the industrial/commercial worker, were exceeded by vinyl chloride in off-Properties shallow groundwater. Figure 3.12 in Appendix V shows the location of exceedances of the RBCs in off-Properties shallow groundwater.
- The groundwater direct contact RBCs, developed for the construction/utility worker, were exceeded by benzene, chloroform, cis-1,2-dichloroethene, PCE, trans-1,2-dichloroethene, TCE, and vinyl chloride in off-Properties shallow groundwater. Figure 3.13 in Appendix V shows the location of exceedances of the RBCs in off-Properties shallow groundwater.

6.1.2.3 On-/Off-Properties

The groundwater RBCs for the fisher based on preliminary surface water cleanup levels were exceeded by 1,1,2,2-tetrachloroethane, 1,1,2-trichloroethane, 1,1-dichloroethene, benzene, carbon tetrachloride, chloroform, methylene chloride, PCE, TCE, vinyl chloride, pentachlorophenol, 2,3,7,8-TCDD (TEQ), arsenic, chromium, copper, lead, mercury, nickel, thallium, and zinc conservatively assuming no mixing of shallow Site groundwater with surface waters. Figure 3.18 in Appendix V shows the location of exceedances of the preliminary cleanup levels for groundwater

6.2 Ecological Health Exposure Pathway Assessment

This section is structured as follows:

Section 6.2.1	Identification of Complete Exposure Pathways and Potentially Affected Ecological Receptors
Section 6.2.2	Media Screened in the EEPA
Section 6.2.3	Selection of Ecological Screening Values
Section 6.2.4	Summary of Ecological Screening

6.2.1 Identification of Complete Exposure Pathways and Potentially Affected Ecological Receptors

Potential ecological receptors and complete exposure pathways were identified based on consideration of the available habitat, and the distribution, fate and transport characteristics of the Site COCs. These ecological receptors and exposure pathways are shown schematically on Figure 6.1. Exposure pathways between terrestrial ecological receptors and Site COCs in soil and groundwater were considered incomplete because of the following factors:

1. The upland portion of the Site has no functional terrestrial habitat and is subject to ongoing human activity that discourages habitation by terrestrial wildlife
2. Adjacent properties are similarly devoid of terrestrial habitat and also subject to human disturbance
3. Much of the upland portion of the Site is covered with impermeable covers or buildings that will prevent contact between ecological receptors and Site COCs in soil

Consequently, exposure to Site COCs and attendant risks to terrestrial ecological receptors was assumed to be negligible.

Ecologically significant exposures to biota in nearshore Commencement Bay sediments were also considered to be negligible even though a plume of high CVOC concentrations occurs at the northern end of the peninsula, proximate to Commencement Bay. However, the highest CVOC concentrations occur deep below the mudline and are within the dense salt water zones and the ADP. These CVOCs migrated down into the salt water zones with the ADP. Given the relatively high density of the ADP and its considerable depth below the mudline, the high concentrations of CVOCs within the salt water zones likely will not discharge to nearshore Commencement Bay sediments. A much less concentrated CVOC plume exists at shallower depths within freshwater lens atop the ADP. These CVOCs will discharge to nearshore Commencement Bay sediments; however, the concentrations of CVOCs in shallow groundwater are below problematic levels.

Complete exposure pathways do exist between Site COCs and the biota of the nearby Waterway. The EEPA focused on potential risks to aquatic and semi-aquatic biota of the Waterway. The following exposure pathway-receptors were explicitly considered.

i) The primary exposure pathway is from discharge of shallow contaminated groundwater to the Waterway via seeps and subtidal discharge along the embankment in the immediate vicinity of the Waterway. In turn, the primary ecological risks from shallow groundwater discharge to the Waterway pertain to direct toxicity to the benthic macroinvertebrates and sediment-associated fish (e.g., sole and other flatfish) that reside in or on the sediments.

ii) A secondary exposure pathway exists between aquatic biota and Site COCs in surface sediments located in the embankment area and Area 5106. Although Area 5106 was dredged, residual chemicals persist in some of the surface sediments. The primary Site COCs present in Area 5106 do not readily bioaccumulate, so this exposure pathway pertains primarily to direct toxicity to aquatic benthos. Future planned sampling in the Waterway will determine the nature and extent of potential residual chemical concentrations in the sediments.

iii) There are also small areas in which bioaccumulative compounds (PCBs, dioxin/furans, DDT and its metabolites) have been released to embankment materials and intertidal sediments. The primary receptors considered for these chemical were benthic fish, which were assessed to be both most exposed and most sensitive to these chemicals[12].

---

[12] Because the bioaccumulative substances are taken up by both benthic invertebrates and benthic fish, all of the organisms consuming these organisms also are exposed. However, the exposures to predators further up the food chain are greatly limited by the very small area of contamination compared to home and foraging ranges of upper predators. This limitation is well illustrated by considering risks to birds that forage on benthic invertebrates and fish impacted by the Site's PCBs. The area of sediments with elevated PCB concentrations is less than 4 acres and may be considerably smaller. This very small area is not amenable to foraging by wading birds such as herons because it is either subtidal or sharp-sloped intertidal. Hence, fish eating birds foraging here will be limited to diving predators, such as gulls, eagles, and osprey. These birds have very large home ranges. For example, EPA's 1993 Wildlife Exposure Factors Handbook Volume I states that osprey will travel "10 to 15 km" to forage. Using the lower number and assuming a half-circle of foraging area (as for foraging from a nest on a straight shoreline) suggests a foraging area of about 60 square miles, or about 39,000 acres. Conservatively dividing this area by 10 still suggests a foraging area of about 4,000 acres, which is at least 1,000 times larger than the area with elevated PCBs next to the Site. Exposure to fish eating birds to this small area also is reduced because these fish-eating birds primarily eat fish at the water surface, which are fish species facing comparatively limited exposure to sediment bound contaminants. Lastly, the nearshore where much of the higher PCB contamination occurs is an intertidal area of mostly rocky habitat. Bioaccumulation and food chain exposure to PCBs, which will adhere to silty sediments under and in the interstices of the rocks, will be very limited here because the food chain is largely epilithic (i.e., based on rock surfaces). The epilithic food chain essentially is based on the very negligible water column concentrations. Consequently, foraging birds' exposure is, as assumed above, considerably below that faced by benthic invertebrates and benthic fish, which are both conservatively assumed to always reside in the relatively small area contaminated with PCBs.

Other aquatic and semi-aquatic biota are exposed to Site COCs. However, their exposures to Site COCs are greatly limited by tidal dilution, fate processes, and/or by the small areal extent of contamination compared to the home ranges of biota. Hence, levels of Site COCs protective of benthic invertebrates and benthic fish were assumed to provide ample protection to the other biological communities of the Waterway.

6.2.2 Media Screened in the EEPA

Based on the complete exposure pathways identified above, the most critical exposures of Site COCs are to benthic macroinvertebrates and benthic fish. In turn, the most critical exposure media are the sediments and associated porewater in the surface sediments in which benthic organisms actually live (i.e., top 10 cm). Chemical concentrations have been measured in a variety of media that can potentially be used to estimate, with varying degrees of validity, chemical concentrations in those top layers of sediments. These include groundwater, seeps, surficial sediments, seepage meter samples, and groundwater collected in the top 3 ft of sediments. Conservatively, the last is treated as sediment porewater even though most of these samples were collected from sediment strata 1 ft or more below the biological zone.

6.2.3 Selection of Ecological Screening Values

The Site COCs fall into four general groups: high pH, non-polar organics (VOCs and SVOCs), heavy metals, and bioaccumulating substances (PCBs, dioxin/furans, and DDT and metabolites). Potential toxic effects of these four groups were considered separately as follows. Potential toxicity of high pH was assessed with Washington State's water quality criterion (WQC) for protection of aquatic life. Similarly, potential effects of metals in water were assessed with WQC, while those in bulk sediment were assessed with Commencement Bay SQOs.

Potential risks from non-polar organics were screened based on recent USEPA guidance (USEPA, 2008c). This guidance suggests that most all of the SVOCs and VOCs have the same mode of toxicity (narcosis). The potential narcotic toxicity of all of the SVOCs and VOCs was summed to account for the potential additive toxicity of all of the organics. The method produces targets for each organic in the water column, which are applicable to groundwater, seepage, and sediment porewater concentrations. These water column targets were then extrapolated to bulk sediment concentrations using equilibrium partitioning and Site-specific concentrations of organic carbon in surface sediments. In turn, these sediment targets can be used to screen bulk sediment concentrations for toxicity from the organics. The screening levels for non-polar organics described above differ from those previously used at the Site. In general, the previously-used screening levels for sediments and porewater pertain to human health risks and, thus, are not useful for assessing ecological risk.

Concentrations for bioaccumulative compounds including PCBs, DDT and metabolites, and dioxin/furans, were screened against the preliminary clean-up levels for the Site. In general, these clean-up levels were based on protection of human health rather than criteria protective of ecological receptors. However, these preliminary clean-up levels were found sufficiently protective of ecological receptors and were used for the EEPA.

6.2.4 Summary of Ecological Screening

To make the screening more informative, chemical concentrations in individual samples of relevant media were screened against ecological screening values (ESVs). This method identified the samples, media, areas, and chemicals that are potentially most problematic (i.e., having highest levels of chemicals compared to ESVs). In turn, these would be most warranting of further assessment or risk management or remediation. As noted above, individual samples of the five media were screened for potential risks from elevated pH, non-polar organics, metals, and the bioaccumulating substances.

As explained in more detail in Appendix V, ESVs are, by intent, very conservative and some ESVs, especially those for bulk sediments, lack a rigorous scientific basis. Consequently, minor to moderate exceedances of ESVs are not strong evidence of ecological impacts; rather, these exceedances suggest that more refined analyses should be conducted. Moreover, ecological risks pertain to communities and populations of animals; consequently, impacts on small areas or on small numbers of individuals are considered *de minimis*. These limitations of screening for ecological risk are discussed in more detail in the Exposure Pathway Analysis (Appendix V).

Screening of pH

While pH was above the WQC in some samples, these exceedances tended to occur most often in undiluted groundwater, the least valid surrogate for surficial sediment porewater. In contrast, pH was never above the WQC in the media most relevant to actual exposure (surficial sediments and seepage meter samples), and only infrequently in sediment porewater and seeps. Consequently, elevated pH is not likely to cause ecologically significant impacts because exceedances were limited to very small areas and in media that are less representative of actual exposure. In addition, societally important receptors such as finfish and crabs are not expected to be directly impacted by elevated pH because these more mobile species will just move away from the high pH seeps. However, impacts to sedentary benthos caused by elevated pH in limited areas cannot be dismissed, although these small-scale impacts are not likely to pose population level risks even to most exposed, sedentary benthos. Thus, it is uncertain whether these limited areas should prompt remediation and/or risk management.

Screening of Non-Polar Organics

Chemical concentrations of non-polar organics (SVOCs and VOCs) in groundwater under the Site frequently exceeded ESVs. However, groundwater is the medium least relevant to actual exposure to benthos. Although shallow impacted groundwater beneath the Site can discharge to the Waterway, actual data from the more relevant exposure media (i.e., surface sediments, sediment porewater, seepage meter samples, and seeps) are almost always below ESVs. There are infrequently elevated concentrations in some Area 5106 sediments and embankment intertidal sediments. The areal extents of these exceedances is too small to cause ecologically-significant population level impacts on benthos.

In summary, non-polar organics likely do not currently pose ecologically significant impacts to aquatic life, although potential impacts in small localized areas are possible. As with pH, these potential localized impacts are not likely to cause population-level effects. Therefore, it is uncertain whether these small, localized areas may need remediation, risk management, and/or further refined risk assessment.

Screening of Metals

Based on metals concentrations in bulk sediments, most surface sediments are likely not toxic to benthos. However, a small number of sediment samples collected along the embankment exceeded their respective conservative ESVs.

Concentrations of metals measured in water media (groundwater, sediment porewater, seeps, and seepage meter samples) appear to be biased high due to interferences associated with the Site's groundwater matrix. Therefore for the purposes of the EEPA, empirically derived correction factors were applied to measured concentrations of arsenic, chromium, copper, nickel, and zinc. The corrected water concentrations were then compared to ESVs protective of aquatic life. The low level of potential risk associated with bulk sediment chemistry was generally corroborated by the corrected metals concentrations measured in seepage meter samples, groundwater, and sediment porewater. However, concentrations of metals in several embankment water samples were above the ESVs. In general, however, the exceedances were due to metals, such as lead and mercury, for which correction factors were not applied. Therefore, it is not known whether these exceedances are real or due to uncorrected matrix interference. Moreover, the levels of exceedances were often nominal - less than 5 times the ESV[13], suggesting little potential for toxicity. Nonetheless, risks from metals in the embankment sediments and water media could not be dismissed with available information.

---

[13] ESVs are intentionally conservative and sometimes lack good scientific basis and/or quality control. Given the very conservative nature of ESVs, concentrations of less than 5 times EVSs are typically considered ecologically unimportant.

Therefore, these areas may need remediation, risk management, and/or further refined risk assessment.

Screening of Bioaccumulating Substances

Concentrations of PCBs, DDT and its metabolites, and dioxin-furans exceeded their respective ESVs in a small number of the embankment sediment samples. Again, the areal extent and magnitude of these exceedances are potentially too small to cause population level impacts, but ecological risks from these chemicals cannot be dismissed with the available information. Therefore, these areas may require some remediation, risk management, and/or further refined risk assessment.

6.3 Conclusions

Human health and ecological exposures are discussed in Sections 6.3.1 and 6.3.2, respectively. Primary risk drivers are summarized in Section 6.3.3.

6.3.1 Human Health Exposures

Corrective action, risk management measures, or further evaluation during remedy design may be needed to mitigate potential human exposure to COCs in various media on and off Properties. Figures 6.1 through 6.7 in Appendix V present on- and off-Properties locations where the concentration of one or more COCs exceeded the risk-based standards (RBSs) developed for the various Site media.

- Figures 6.1 and 6.6 in Appendix V present areas that may need further action based on indoor air inhalation exposure due to vapor intrusion of: a) COCs in soils (5 areas); or b) COCs in groundwater (5 areas), respectively. Based on the Vapor Investigation, POT Buildings 326 and 532 and the OCC Office Building were found to need mitigation measures as discussed previously
- Figures 6.2 and 6.3 in Appendix V present areas that may need further action based on direct contact with COCs in: a) soils (5 areas); or b) sediments (2 areas), respectively
- Figures 6.4 and 6.5 in Appendix V present areas that may need further action based on inhalation exposure to COCs volatilizing from: a) soil vapor-to-ambient air (4 areas); or b) groundwater-to-ambient air (3 areas), respectively
- Figure 6.7 in Appendix V presents areas that may need further action based on direct contact with off-Properties shallow groundwater (4 areas)

As noted previously, Figure 3.18 in Appendix V presents locations that may need corrective action, risk management measures, or further evaluation during the remedy design to address the groundwater-to-surface water pathway.

6.3.2 Ecological Exposures

In general, the EEPA did not find evidence of unacceptable ecological risk. Moreover, for the bulk of the Waterway aquatic ecosystem (e.g., the water column everywhere and sediments of the dredged channel bottom and far shore embankment), ecological risks could be dismissed with certainty. However, ecological risks associated with some receptor/COC combinations in the nearshore embankment could not be dismissed with available data or could potentially pose risk under some future scenarios.

For example, pH exceeds ARARs in some seeps and sediment porewater samples of the embankment. These areas are too limited in size compared to the total sediment area and too limited in terms of severity of impact to cause unacceptable ecological risk. Additionally, exceedances of pH did not occur in the media that more reliably indicate actual exposure (e.g., surface sediment samples, seepage meter samples). Similarly, small areas of embankment sediment exceeded ESVs for bioaccumulating organics (e.g., PCBs, DDT and metabolites). Again, however, these areas and levels of exceedance are probably both too limited to cause ecological impacts. In both cases, then, the receptor/COC combinations may need additional information/input to reduce the uncertainty about the ecological risk. For example, the Site-specific bioavailability of these bioaccumulative chemicals is uncertain and critical to refining estimates of risk. Alternately, these receptor/COC combinations may need risk management, especially in those areas where multiple contaminants are elevated.

Concentrations of metals in sediments, porewater, seeps, and groundwater were above screening levels in some areas of the nearshore embankment area. As with pH and bioaccumulating organics, the spatial extent and level of exceedances for heavy metals are both generally limited, again suggesting limited potential for ecologically significant risks. However, the assessment for metals is limited by uncertainty concerning the quantification of metals, which was apparently significantly impacted by matrix interference. Thus, potential risk to aquatic benthos from metals may need additional analyses to better assess actual metals concentrations and refine the risks from heavy metals. Future planned sampling in the Waterway will determine the nature and extent of potential residual metals concentrations in the sediments.

A last issue pertains to VOCs and SVOCs. These COCs pose additive risk to aquatic life. As a result, the potential toxicity and risks of these different classes of compounds were conservatively, and appropriately, considered together in the EEPA. In general, there were very little if any areas where these organics were found to be problematic in more reliable exposure media (e.g., surface sediments, porewater, or seepage meter samples). Thus, current ecological risks from combined toxicity of VOCs and SVOCs likely are not problematic. However, high concentrations of VOCs/SVOCs were found in groundwater under the Site adjacent to the Waterway. This concentrated VOC/SVOC plume could cause ecologically significant effects if it discharged to the Waterway without attenuation in the future.

6.3.3 Primary Risk Drivers

Figure 6.2 presents a schematic CSM of the various exposure pathways for both human and ecological receptors evaluated within the Exposure Pathway Assessment as well as the primary risk drivers in the Site media.

Section 7.0 Summary, Conclusion, and Recommendation

7.1 Summary

OCC has been working with the USEPA and Ecology to address remaining environmental issues at the Alexander Avenue Site located in Tacoma, Washington, under an AOC [USEPA Docket No. 10-07-0011 CERCLA]. The work activities required under the AOC are outlined in the "Statement of Work for the Administrative Order on Consent" (SOW) (CRA, 2005). OCC has completed field investigations ~~required under all Tasks of the SOW~~necessary to complete this RI. Additional work not anticipated in the SOW has also been scheduled and conducted consistent with the AOC.

The purpose of this Site characterization is to evaluate the data collected from all investigations at the Site and to adequately characterize the contamination of soil, sediment, and groundwater underlying the Site; evaluate the environmental risks posed; and allow development and evaluation of remedial design alternatives to address those risks. The Site characterization presented in this SCR is based upon the analytical and hydraulic data collected from various groundwater, soil, and sediment investigations performed at the Site. The presented data includes both "new" data collected during the most recent investigations (May 2005 through October 2013) and relevant "historical" data collected during previous investigations (1993 through 2004).

Site Description

The Site is located on the eastern-most peninsula of the area of ownership and operations of the POT that extends into Commencement Bay at the mouth of the Puyallup River Valley and is defined in the AOC. The properties owned and/or operated on by OCC or its predecessors include: 605 and 709 Alexander Avenue. These properties are bounded on the west, north, and south by former U.S. Navy property (now owned by the POT or U.S. Navy), and on the east by the Waterway.

Prior to 1920, the properties which comprise the Site were undeveloped tidal mudflats. Between 1920 and 1936, the area was filled with approximately 16 ft of dredge material, primarily sand, as part of an upland expansion project.

OCC and its predecessor's chemical manufacturing operations began at the Site in 1929 and continued until 2002. OCC Tacoma, a wholly owned subsidiary of OCC, acquired the property at 709 Alexander Avenue from PRI Northwest, Inc. (PRI) in 1997. Previous owners of the 709 Alexander Avenue property included Fletcher Oil, which acquired it in 1938 from Norton and Mary Clapp. Historic activities conducted on the property at 709 Alexander Avenue, as well as the POT property at 721 Alexander Avenue, have included fuel storage, blending, and distribution activities.

Physical Setting

The geologic deposits beneath the Site consist of the following:

- Fill - variable mixture of sand, silt, and gravel material placed through dredging of the Hylebos and Blair Waterways to develop the Site peninsula. The thickness of the fill across the Site ranges from approximately 10 to 16 ft).
- Deltaic deposits - heterogeneous mixture of interbedded sands, silts, and clays. The thickness of the deltaic deposits across the Site ranges from approximately 30 ft to 200 ft in the eastern and northeastern portion of the Site to greater than approximately 300 ft in the southwestern portion of the Site.
- Glacial deposits - heterogeneous mixture of interbedded gravel, sands, silts, and clays. The thickness of the glacial deposits beneath the Site is more than 1,000 ft. The top surface of the glacially-derived deposits slopes downward to the north, west, and south from a mound observed under the central portion of the Site. The glacial deposits were not encountered at borings in the west, southwest, and south portion of the Site peninsula and is inferred to dip downward in this area below the depth of the Site borings.

The Site stratigraphic data indicate that there is an increased frequency of lower permeability lenses, comprised mainly of silt and clay, in the lower deltaic deposits. A discrete continuous layer of low permeability material is not observed in Site borings in the lower deltaic deposits. However, the groundwater quality, density, and hydraulic evidence supports the concept that the increased frequency of lower permeability lenses limits vertical flow creating a zone of apparent confining effect in the lower deltaic deposits.

Groundwater beneath the Site discharges to the surrounding surface water bodies. Fresh groundwater inflow toward the Site peninsula occurs from the south due to upland regional groundwater flow along the Puyallup River Valley, and from the east due to regional groundwater flow in the Bluffs aquifers discharging to the Valley. Infiltration of precipitation over the Site peninsula contributes a further source of fresh groundwater, and establishes a shallow radial groundwater flow pattern towards the surface water bodies. Naturally occurring influences on groundwater flow at the Site include:

- The presence of discontinuous, low-permeability mud flats that, where present, create a hydraulic separation with the underlying deltaic deposits
- The presence of a zone of apparent confining effect in the lower deltaic deposits that results in upward vertical hydraulic gradients between the upper glacial and lower deltaic deposits
- Fresh groundwater and salt water distributions exist adjacent to the salt water bodies that are influenced by aquifer heterogeneities, hydraulic pressure and fresh groundwater flow rate in the aquifer, thickness and hydraulic properties of the aquifer and adjacent confining units, and relative densities of salt water and fresh groundwater
- The fresh groundwater and salt water zones are separated by a transition zone within which there is mixing between fresh groundwater and salt water

Releases of high density liquids from historical Site operations/processes (lime sludge/solvent residue, caustic soda, and salt brine) have a critical influence on groundwater flow and contaminant transport.

Nature and Extent of Contamination

The SCR describes the nature and extent of contamination in the following media: unsaturated soil, saturated soil, groundwater, sediment, soil vapor, ambient air, and indoor air.

The nature and extent of contamination in unsaturated soil is summarized as follows:

- CVOCs, primarily as PCE, are present in unsaturated soils at concentrations exceeding the CSI soil screening criteria for unsaturated soils. This presence is limited primarily to the vicinity of WMU A, the Salt Pad/WMU G, WMU H, and the N Landfill
- Site SVOCs, primarily as HCB, are present in unsaturated soils at concentrations exceeding the CSI soil screening criteria within the same general areas as CVOCs

- PCBs are present in unsaturated soil at concentrations exceeding the CSI soil screening criteria primarily near the former Navy-Todd Dump and the N Landfill
- Metals, primarily copper, but to a lesser degree arsenic, total chromium, and nickel, are present at concentrations exceeding the CSI soil screening criteria in the vicinity of the Salt Pad/WMU G and along the embankment

The nature and extent of contamination in saturated soil is summarized as follows:

- CVOCs, primarily as PCE, TCE, and associated degradation products, are present in saturated soils at concentrations exceeding the CSI soil screening criteria for saturated soils. This presence is greatest below the Facility near WMU A, the Salt Pad/WMU G, and WMU R, as well as below the Waterway. CVOCs are present to a lesser degree along the embankment and in the vicinity of the N Landfill.
- Site SVOCs, primarily as HCB, are present in saturated soils at concentrations exceeding the CSI soil screening criteria within the same general areas as CVOCs.
- Pesticides and PCBs are present in saturated soil at concentrations exceeding the CSI soil screening criteria along the embankment primarily near the former Navy-Todd Dump and the N Landfill.
- The greatest exceedance for metals occurs in the vicinity of the N Landfill, where mercury exceeds the CSI soil screening criteria by an EF of 88,550. Other metals, primarily copper, total chromium, nickel, and zinc, are present at concentrations exceeding the CSI soil screening criteria in almost all samples analyzed for metals. The highest concentrations occur along the embankment and in the vicinity of the N Landfill.

The nature and extent of contamination in groundwater is summarized as follows:

- The presence of DNAPL has been confirmed in the vicinity of the Salt Pad/WMU-G and WMU-R within the 25-ft and 130-ft zones
- CVOCs are present in groundwater at concentrations above the groundwater screening criteria
  - 25-ft zone – The areas of highest concentrations are located near the Salt Pad and WMU A
  - 50-ft zone – The extent of PCE and TCE is similar to the 25-ft zone, but the extent of VC increases significantly within the 50-ft zone area beyond the limits of PCE and TCE toward the eastern side of the Waterway
  - 75-ft zone – The highest CVOC concentrations extend eastward under the Waterway, with lower concentrations extending further north

  - 100-ft zone – The area of highest concentration is somewhat reduced, but has migrated further north
  - 130-ft zone – The area of highest concentration are somewhat reduced, but have migrated north and east when compared to the 100-ft zone
  - 160-ft zone – CVOC concentrations in the 160-ft zone are reduced compared to the 130-ft zone, but the plume continues to migrate northward
- Site SVOCs, primarily as HCB, are present along the embankment and beneath the Waterway at depths up to 122 ft BGS
- PCBs are present in groundwater primarily along the embankment in the vicinity of the Navy-Todd Dump and N Landfill and below the Waterway
- Metals, primarily copper, nickel, and arsenic are present at concentrations exceeding the groundwater screening criteria. The highest concentrations occur in the vicinity of the Salt Pad, along the embankment, and beneath the Waterway
- Elevated pH groundwater is present above the groundwater screening criteria
  - 25-ft zone – elevated pH was measured across the Site, with the highest values (>13 su) detected along the eastern portion of the Site beneath the former plant production areas
  - 50-ft zone – the extent of the highest pH values increases in size relative to the 25-ft zone and is located more to the north toward the Salt Pad
  - 75-ft zone – the extent of the pH plume within the 75-ft zone is reduced relative to the 50-ft zone, but has migrated east with the highest groundwater pH (>12 su) located in the vicinity of the former caustic tanks and the south end of Dock 1
  - 100-ft zone – the pH plume has migrated north and east, with the highest pH near the north end of Dock 1, but is limited to beneath the Facility and Waterway
  - 130-ft zone – the pH plume continues to migrate northeast
  - 160-ft zone – the area of high pH values is much smaller in the 160-ft zone, with the highest readings diminishing
- The seep study performed in the Waterway confirmed that seepage of impacted groundwater was occurring to some extent into the Waterway

The nature and extent of contamination in sediment is summarized as follows:

- PCE is present in sediment at concentrations exceeding the sediment cleanup level. This presence is limited primarily to Area 5106 and adjacent to the N Landfill

- Site SVOCs, primarily as HCB and HCBD, are present in sediment at concentrations exceeding the sediment cleanup levels within the same general areas as PCE, as well as along the embankment near Dock 1
- Pesticides, primarily 4,4'-DDD, are present in sediment along the embankment near Dock 1 and the N Landfill
- PCBs are present in sediment along the embankment at concentrations exceeding the sediment cleanup level primarily near Pier 25, the former Navy-Todd Dump, and the N Landfill
- Metals, primarily lead, are present in sediment at concentrations exceeding the sediment cleanup levels along the embankment

The nature and extent of contamination in soil vapor and indoor air is summarized as follows:

- Indoor sources: 1,2,4-TMB, 1,4-DCB, BZ, chloroform, EB, naphthalene, TCE, PCE, o-xylene, and styrene
- Outdoor sources: BZ, CT, chloroform, and EB
- Sub-slab source: TCE

The nature and extent of VOC Source Zones is summarized as follows:

- DNAPL is found mainly in the 15-ft, 25-ft and 130-ft zones
- No confirmed DNAPL was detected in the 50 and 75 ft zones
- The confirmed DNAPL source zone in the 15-ft zone is primarily located in the area of WMU-G and appears to have migrated plant north
- The estimated total confirmed DNAPL mass is approximately 6.4 million pounds (2.9 million kg)
- The greatest percentage of confirmed DNAPL mass (58%) occurs within the 130-ft zone
- Approximately 26% of the confirmed DNAPL mass occurs in the 15- and 25-ft zones

Contaminant Fate and Transport Processes

Site investigations have confirmed that there are four primary groundwater plumes: the ADP, pH plume, CVOCs, and metals. Other COCs at the Site include SVOCs, PCBs, and dioxins/furans. Manufacturing operations at the Site generated wastes that were managed on Site. Waste management practices included: wastewater treatment (settling) ponds, settling barges, landfills, disposal pits, and waste piles. In total, seventeen (17) WMUs were historically located at the Site, in addition to the Navy Todd Dump. Key potential "source areas" where the vast majority of releases of the principal COCs occurred have been defined as summarized below:

- VOC potential sources – former solvent production and WMUs
- Caustic potential sources – primarily sodium hydroxide released from the Caustic House and caustic storage/handling areas
- Salt potential sources – primarily piles of salt stored on the Salt Pad and brine sludge kept in storage tanks
- Metals potential sources – primarily Navy Todd Dump, N-Landfill, and metals contaminated embankment fill areas
- SVOC potential sources – HCB and HCBD are by-products of solvent production and are found in the areas of solvent production or waste handing/disposal areas
- PCB potential sources
- Dioxin/Furan potential sources

Contaminants may migrate from the potential source areas noted above via several routes of migration, as listed below:

- DNAPL migration
- Migration of dissolved-phase with the ADP
- Displacement migration at the perimeter of the ADP
- Migration of dissolved-phase with fresh groundwater
- Migration to indoor and ambient air

The potential sources of COCs originated at the surface or near surface in various locations around the Site. The organic COCs are from liquids disposed on or released at the surface. The ADP is derived from the dissolution of salt, caustic, and lime sludge, the solubilities of which were enhanced by high-pH source materials.

When a DNAPL is released, it migrates downward through the unsaturated zone by gravity-driven flow. Depending on the volumes released, the DNAPL can be trapped by capillary forces and result in residual DNAPL. If sufficient volume is released, migration to the water table and beyond can occur. Based on data collected, DNAPL at the Site has penetrated over 130 ft into the subsurface.

The ADP behaves similarly to a DNAPL, in that the liquid has a higher density than natural fresh water and salt water, and therefore will migrate downward by gravity-driven flow. Also, like a

DNAPL, the density plume will not mix readily with the groundwater due to the density difference between the groundwater and the ADP. The ADP has migrated away from the potential source areas via density-dependent flow and has spread laterally.

Groundwater flowing past DNAPL can dissolve a quantity of the COCs and transport them away from the release locations. The shallow groundwater has the potential to discharge to the Waterway, and the deeper groundwater may discharge to Commencement Bay. This would result in the discharge of dissolved COCs to the adjacent waterways.

Precipitation, as runoff, could carry COCs released to the surface into the storm sewers and/or into adjacent water bodies. The waste liquids would have also penetrated into the soil and migrated downward, contacting the groundwater and soil beneath the Site.

Once away from the potential source areas, the VOCs dissolved in the shallow groundwater may volatilize into the soil gas and potentially into the indoor and ambient air at the Site.

The metals in the soil and groundwater at the Site originate not only from Site-related processes, but also occur naturally in the soil. The metals can be mobilized into the groundwater from contact with liquid waste (e.g., high-pH water) and/or infiltrating precipitation. The metals would then and migrate downward to the water table and would be transported by the groundwater to potentially discharge to the Waterway adjacent to the Site. The high density flow would also transport the metals deeper beneath the Site.

Exposure Pathway Assessment[vii]

Formatted: Highlight

Formatted: Highlight

The HHEPA indicated that corrective action, risk management measures, or further evaluation during remedy design may be required to mitigate potential human exposure to COCs in various media on and off Properties. Potential complete exposure pathways include:

- Indoor air inhalation exposure due to vapor intrusion of: a) COCs in soils (5 areas); or b) COCs in groundwater (5 areas), respectively
- Direct contact with COCs in: a) soils (5 areas); or b) sediments (2 areas), respectively
- Ambient air inhalation exposure to COCs volatilizing from: a) soil vapor-to-ambient air (4 areas); or b) groundwater-to-ambient air (3 areas), respectively
- Direct contact with Off-Properties shallow groundwater (4 areas)
- Groundwater-to-surface water pathway

In general, the EEPA did not find evidence of unacceptable ecological exposure. For the bulk of the Waterway aquatic ecosystem (e.g., the water column everywhere and sediments of the dredged channel bottom and far shore embankment), ecological risks could be dismissed with good confidence[14]. However, ecological exposures associated with some receptor/COC combinations in the nearshore embankment could not be dismissed with available data or could potentially result in unacceptable exposure under some future scenarios. It is noted that future planned sampling in the Waterway will determine the nature and extent of potential residual chemical concentrations in the sediments, and the conclusions of the EEPA will be revisited.

7.2 Conclusion and Recommendation

Based on the data collected and presented in this report, it is concluded that Site conditions have been sufficiently characterized, and it is recommended to proceed with development and evaluation of remedial alternatives.

Section 8.0 References

Akagi, T., and H. Haraguchi, 1990. Simultaneous multi-element determination of trace metals using 10 mL of seawater by inductively coupled plasma atomic emission spectrometry with gallium coprecipitation and microsampling technique. Analytical Chemistry. 62:81-85.

Allen-King, R.M., L.D. McKay, and M.R. Trudell, 1997. Organic Carbon Dominated Trichloroethene Sorption in a Clay-Rich Glacial Deposit. Ground Water 35(1):124-130.

Appelo, C.A.J., and D. Postma, 1993. Geochemistry, Groundwater and Pollution, A.A. Balkema, Rotterdam, Netherlands.

Aronson, D., Citra, M., Shuler, K., Printup, H., and Howard, P.H., 1999. Aerobic Biodegradation of Organic Chemicals in Environmental Media: A Summary of Field and Laboratory Studies, Environmental Science Center Syracuse Research Corporation.

Aronson, D., and Howard, P.H., 1997. Anaerobic Biodegradation of Organic Chemicals in Groundwater: A Summary of Field and Laboratory Studies, Environmental Science Center Syracuse Research Corporation.

ATSDR, 1998. Toxicological Profile for CDDs. http://www.atsdr.cdc.gov/toxprofiles/tp104-c5.pdf.

Baird, C., 1999. Environmental Chemistry. 2nd Edition. W.H Freeman and Co., New York.

---

[14] There is some uncertainty regarding this issue since samples of dredged areas and far shore sediments were not analyzed for SVOCs. Thus, it is possible that Site-related SVOCs (e.g., HCB and HCBD) might occur in these areas. This is, however, a small uncertainty given that these compounds do not move readily in either groundwater or surface water. Moreover, this small potential will be addressed by the future planned sampling of the Waterway.

Borden, R.K. and K.G. Troost, 2001. Late Pleistocene Stratigraphy in the South-Central Puget Lowland, Pierce County, Washington, Washington State Department of Natural Resources, Washington Division of Geology and Earth Resources, Report of Investigations 33. Available online at http://www.dnr.wa.gov/geology/pdf/ri33.pdf.

Cleverly, D.J. Schaum, G. Schweer, J. Becker, and D. Winters, 1997. The congener profiles of anthropogenic sources of chlorinated dibenzo-p-dioxins and chlorinated dibenzofurans in the United States. Organohal. Comp. 32: 430–435.

CMA, 2006. Seepage Meter Monitoring Report, Subtidal/Hydraulic Investigation, Groundwater and Sediment Remediation, Occidental Chemical Corporation, Tacoma, Washington, Draft, November.

Cohen, R.M. and J.W. Mercer, 1993. DNAPL Site Evaluation, EPA/600/R-93/022, February 1993.

CRA, 1994. Hylebos Waterway Pre-Remedial Design Report.

CRA, 1996. Work Plan; Characterization of the Embankment Along the Hylebos Waterway at the OxyChem Tacoma Facility, ref. no. 7842 (1).

CRA, 1996. PRI Source Identification Program Report, ref. no. 1002 (143), February.

CRA, 1997. Sample and Analysis Plan – Embankment Area Removal Action, ref. no. 7842 (6), June.

CRA, 1999. Embankment Area Characterization Report, ref. no. 7842 (12), January.

CRA, 1999. Supplement A to the Embankment Area Characterization Report, ref. no. 7842 (13), July.

CRA, 2003. Post-Treatment Work Plan, ref. no. 7421 (36), April.

CRA, 2003. Draft Post-Treatment Characterization Report, ref. no. 7421 (37), September.

CRA, 2004. Draft Work Plan 721 Alexander Avenue, Groundwater Investigation, ref. no. 7843 (58), June.

CRA, 2004. Draft Rapid pH Assessment Report (Revised July 1, 2004), ref. no. 7843 (21), July.

CRA, 2004. Draft Work Plan, Groundwater Remediation, Embankment Area Removal Action and Area 5106 Capping, ref. no. 7843 (58), June.

CRA, 2004. Summary of Previous Investigations, March.

CRA, 2004. Interim Groundwater Analytical Data Report, 709/721 Alexander Avenue, August.

CRA, 2004. Interim Data Report, Supplemental Field Investigations, ref. no. 7843 (67), October.

CRA, 2005. Statement of Work for Administrative Order of Consent, ref. no. 7843 (59), January.

CRA, 2007. Interim Deliverable 4.6: Presentations of Hydraulic Data from 709/721 Alexander Investigation.

CRA, 2012. Comprehensive Supplemental Investigation Work Plan, ref no. 7843 (111), April.

CRA, 2013a. Extraction Well Pilot Test Installation Work Plan, ref no. 7843 (124), June.

CRA, 2014a. Final Conceptual Site Model Report, ref no. 7843 (131), April.

CRA, 2014b. Revised Draft Vapor Investigation Report, ref no. 7843 (129), May.

CTech, 2007. MVS (Mining Visualization System)/EVS (Environmental Visualization System), Version 8.54, Kaneohe, Hawaii.

Ecology, 2009. Guidance for Evaluating Soil Vapor Intrusion in Washington State: Investigation and Remedial Action, Toxics Cleanup Program, Publication No. 09 09 047, Review Draft, October.

Ecology, 2009. Long-Term Marine Water Quality Data, Marine Water Monitoring, State of Washington, April 2, 2009 (http://www.ecy.wa.gov/apps/eap/marinewq/mwdataset.asp?ec=no&scrolly=0&htmlcsvpref=csv&estuarycode=1&theyear=2004&themonth=2&staID=20)

Ellis, A.S., Johnson, T.M., and T.D. Bullen, 2002. Chromium Isotopes and the Fate of Hexavalent Chromium in the Environment. Science v. 295 no. 5562.

European Commission, 2001. Integrated Pollution Prevention and Control (IPPC). Reference Document on Best Available Technicques in the Chlor-Alkali Manufacturing Industry. December. (http://eippcb.jrc.ec.europa.eu/reference/BREF/cak_bref_1201.pdf)

Evanko, C.R., and Dzombak, D.A. (1997) Remediation of Metals-Contaminated Soil and Groundwater. Groud-Water Remediation Technologies Analysis Center.

Fetter, C.W., 1999. Contaminant Hydrogeology. 2nd ed. Waveland Press Inc., Long Grove, IL.

Frame, G.M., Cochran, J.W., and S.S Bowadt, 1998. Complete PCB congener distributions for 17 aroclor mixtures determined by 3 HRGC systems optimized for comprehensive quantitative congener specific analysis. Journal of High Resolution Chromatography. Vol. 19, pp. 657-668.

GRS and NGA, 2006. Final Draft of Geophysical Survey Report, Occidental Chemical Corporation, Tacoma, Washington, August 2006.

Geokon Inc., 2005. Geokon Instruction Manual.

Golden Software, Inc., 2002. Surfer, Version 8.05, Surface Mapping System.

Greengrove, C., 2005. Water Resources and Pollution, Estuarine Field Studies, Course Number TESC 431, Spring 2005, University of Washington, (http://courses.washington.edu/uwtoce05/webg1/index.html)

Hart-Crowser and Associates, Inc., undated. Geology of the Port of Tacoma.

Hart-Crowser and Associates, Inc., 1994. Preliminary Site Investigation Report, June.

Hart-Crowser and Associates, Inc., 1994. Supplemental Monitoring Well Installation and Groundwater Sampling and Analysis Report.

Hart-Crowser and Associates, Inc., 1995. Soil and Groundwater Investigation (March and August 1995).

Hem, J.D., 1985. Study and Interpretation of the Chemical Characteristics of Natural Water, Third Edition, U.S. Geological Survey Water-Supply Paper 2254.

Hermann, R., and Neumann-Mahlkau, P. (1985). The mobility of zinc, cadmium, copper, lead, iron and arsenic in ground water as a function of redox potential and pH. The Science of the Total Environment, 43: 1–12.

Hirata et al., 2003. Determination of trace metals in seawater by on-line column preconcentration inductively coupled plasma mass spectrometry using metal alkoxide glass immobilized 8-quinolinol. Analytica Chimica Acta 499:157-165.

HCC, 1993. Combined Sample and Analysis Place for the Commencement Bay Nearshore/Tideflats Superfund Site – Hylebos Waterway Problem Areas.

HCC, 1999. Hylebos Waterway Pre-Remedial Design Evaluation Report.

Johannessen, J. and A. MacLennan, 2007. Beaches and Bluffs of Puget Sound, Coastal Geologic Services, Inc., Technical Report 2007-004, 27 p.

Jones, et al., 1999. Geologic Framework for the Puget Sound Aquifer System, Washington and British Columbia. USGS Professional Paper 1424-C. Available online at http://pubs.er.usgs.gov/usgspubs/pp/pp1424C.

Jones, et al., 1999. Ground-Water Hydrology of the Tacoma -Puyallup Area, Pierce County, Washington, USGS Water-Resources Investigations Report 99-4013. Selected portions available online at http://wa.water.usgs.gov/pubs/wrir/wrir.99-4013.

Kueper, B.H. and K.L. Davies, 2009. Assessment and Delineation of DNAPL Source Zones at Hazardous Waste Sites, EPA/600/R-09/119.

Kongchum, M., I. Devai, R.D. DeLaune and A. Jugsujinda, 2006. Total mercury and methyl mercury in fresh water and salt water marsh soils of the Mississippi River Delta Plain. Chemosphere (2006) 1300-1303.

Lee, W., and B. Batchelor, 2002. Abiotic reductive dechlorination of chlorinated ethylenes by iron-bearing soil minerals. 1. Pyrite and magnetite. Environ. Sci. Technol. 36:5147-5154.

Lincoln, J.H., 2000. The Puget Sound Model Summary, Online Resource: http://exhibits.pacsci.org/puget_sound/PSSummary.html.

Lusczynksi, N.J., 1961. Head and flow of ground water of variable density, Journal of Geophysical Research, vol. 66, no 2, pp. 4247-4256.

Lyngkilde, J., and T.H. Christensen, 1992a. Redox Zones of a Landfill Leachate Pollution Plume (Vejen, Denmark), Journal of Contaminant Hydrology, Vol. 10, pp. 273-289.

Lyngkilde, J., and T.H. Christensen, 1992b. Fate of Organic Contaminants in the Redox Zones of a Landfill Leachate Pollution Plume (Vejen, Denmark), Journal of Contaminant Hydrology, Vol. 10, pp. 291-307.

McGinnis and Jensen, 2007. Groundwater Metals Analytical methods, Port of Tacoma Pier 25, Commencement Bay Tacoma, WA. Memo of Feb. 7, 2007 from Hart Crowser to Bill Evans, Port of Tacoma.

Molenaar, D., 1961. Water Supply Bulletin Number 16: Flowing Artesian Wells in Washington State, Department of Conservation. Available online at http://www.ecy.wa.gov/programs/eap/wsb/pdfs/WSB_16_Book.pdf and http://www.ecy.wa.gov/programs/eap/wsb/pdfs/WSB_16_Plate.pdf.

Morgan, D.S. and J.L. Jones, 1996. Numerical Model Analysis of the Effects of Ground-Water Withdrawals on Discharge to Streams and Springs in Small Basins Typical of the Puget Sound Lowland, Washington, USGS Open-File Report 95-470. Available online at http://pubs.er.usgs.gov/usgspubs/ofr/ofr95470.

Olmsted, T.L., 1969. Geological Aspects and Engineering Properties of Glacial Till in the Puget Lowland, Washington, Shannon & Wilson, Inc.

Pavlostathis, S.G. and K. Jaglal, 1991. Desorptive Behavior of Trichloroethylene in Contaminated Soil. Environ. Sci. Technol. 25(2):274–279.

Pedroli, G.B.M., Maasdam, W.A.C., and Verstraten, J.M. (1990). Zinc in poor sandy soils and associated groundwater. A case study. The Science of the Total Environment, 91: 59-77.

Plantz et al., 1989. Separation of trace metal complexes for analysis of samples of high salt content by inductively coupled plasma mass spectrometry. Analytical Chemistry 61:149-153.

Robinson & Noble, Inc., 1992. Hydrogeologic Analysis of the Federal Way Area, Washington, December.

Sahoo, D. and J.A. Smith, 1997. Enhanced Trichloroethene Desorption from Long-Term Contaminated Soil Using Triton X-100 and pH Increases. Environ. Sci. Technol. 31(7):1910–1915.

Savoca, M.E., W.B. Welch, K.H. Johnson, R.C. Lane, B.G. Clothier, and E.T. Fasser, 2010. Hydrogeologic Framework, Groundwater Movement, and Water Budget in the Chambers-Clover Creek Watershed and Vicinity, Pierce County, Washington, U.S. Geological Survey Scientific Investigations Report 2010–5055, 46 p.

Serfes, M.E., 1991. Determining the mean hydraulic gradient of ground water affected by tidal fluctuations, Ground Water, vol. 29, no. 4, pp. 549-555.

Site, A.D., 2001. Factors Affecting Sorption of Organic Compounds in Natural Sorbent/Water Systems and Sorption Coefficients for Selected Pollutants: A review. J. Phys. Chem. 30(1): 187-439.

Spongberg, A.L., 2004. PCB contamination in surface sediments in the coastal waters of Costa Rica. Rev. of Biol. Trop. 52 (Suppl. 2): 1-10.

Stumm, W. and J.J. Morgan, 1996. Aquatic Chemistry: Chemical Equilibria and Rates in Natural Waters. 3rd ed. John Wiley & Sons, Inc., New York. 1022 pp.

Suarez, M., and Rifai, H., 1999. Biodegradation Rates for Fuel Hydrocarbons and Chlorinated Solvents in Groundwater, Bioremediation Journal, 3(4): 337-362

UNEP, 1999. Guidelines for the identification of PCBs and materials containing PCBs. http://www.chem.unep.ch/pops/pdf/PCBident/pcbid1.pdf.

U.S. AFCEE, 1999. Technical Protocol for Implementing Intrinsic Remediation with Long-Term Monitoring for Natural Attenuation of Fuel Contamination Dissolved in Groundwater, March.

USEPA, 1990. Commencement Bay / Port of Tacoma, Field Study - June 3, 1980, EPA 910/9-90-028.

USEPA, 1991. Solubility, Sorption and Transport of Hydrophobic Organic Chemicals in Complex Mixtures, Office of Research and Development, Ada, OK, EPA/600/M-91/009, March.

USEPA, 1992. Estimating Potential for Occurrence of DNAPL at Superfund Sites. Publication 9355.4-07FS, January 1992.

USEPA, 1993. Evaluation of the Likelihood of DNAPL Presence at NPL Sites. Publication 9355.4-13, September 1993.

USEPA, 1998. Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Ground Water, Office of research and Development, Washington, DC, EPA/600/R-98/128, September.

USEPA, 1999. PCBs Update: Impacts on Fish Advisories. EPA-823-F-99-019 http://www.epa.gov/waterscience/fish/files/pcbs.pdf.

USEPA, 2001. Characterization and Eh/pH-based leaching tests of mercury-containing mining wastes from the Sulfur Bank Mercury Mine, Lake County, California. EPA/600/R-02/032.

USEPA, 2003. Dioxin-Like PCBs. http://www.epa.gov/greatlakes/bns/dioxin/pres/winters_dec2003.pdf.

USEPA, 2009. Assessment and Delineation of DNAPL Source Zones at Hazardous Waste Sites. EPA/600/R-09/119.

USEPA, 2009. Vapor Intrusion Framework, Interim Final, June 2009.

Vaccaro, et al., 1998. Hydrogeologic Framework of the Puget Sound Aquifer System, Professional Paper 1424-D, USGS. Available online at http://pubs.er.usgs.gov/usgspubs/pp/pp1424D.

Van den Berg, M., Birnbaum L, Bosveld A.T., Brunstrom B, Cook P, Feeley M, Giesy JP, Hanberg A, Hasegawa R, Kennedy SW, Kubiak, T., Larsen, JC., van Leeuwen, FX, Liem, AK, Nolt, C., Peterson, R.E., Poellinger L, Safe S, Schrenk D, Tillitt D, Tysklind M, Younes M, Waern F, Zacharewski T., 1998. Toxic equivalency factors (TEFs) for PCBs, PCDDs, PCDFs for humans and wildlife. Environmental Health Perspectives. Dec; 106(12):775-92.

Van den Berg, M., Birnbaum, L., Denison, M., De Vito, M., Farland, W., Feeley, M., Fiedler, H., Hakansson, H., Hanberg, A., Haws, R., Rose, M., Safe, S., Schrenk, D., Tohyama, C., Tritscher, A,. Tuomisto, J., Tysklind, M., Walker, N., and Peterson, R.E., 2006. The 2005 World Health Organization Reevaluation of Human and Mammalian Toxic Equivalency Factors for Dioxins and Dioxin-Like Compounds. Toxicological Sciences; 93(2):223-241.

Walters, K.E. and G.E. Kimmel, 1968. Water Supply Bulletin Number 22: Ground-Water Occurrence and Stratigraphy of Unconsolidated Deposits, Central Pierce County, Washington, Department of Water Resources. Available online at http://www.ecy.wa.gov/programs/eap/wsb/pdfs/WSB_22_Book.pdf and http://www.ecy.wa.gov/programs/eap/wsb/pdfs/WSB_22_Plates.pdf.

Walters, K.L., 1971. Reconnaissance of Sea-Water Intrusion Along Coastal Washington, 1966-68, State of Washington, Department of Ecology, Water-Supply Bulletin No. 32.

Weidemeier, T.H., Rifai, H.S., Newell, C.J., and J.T. Wilson, 1999. Natural Attenuation of Fuels and Chlorinated Solvent in the Subsurface, John Wiley & Sons, Inc., New York, NY.

Woolcott, C.G., Aronson, K.J., Hanna, W.M., SenGupta, S.K., McCready, D.R., Sterns, E.E., Miller, A.B., 2001. Organochlorines and breast cancer risk by receptor status, tumor size, and grade (Canada). Cancer Causes and Control.

Appendix A

Historical Aerial Photographs

Appendix B

Summary of Information Regarding Occidental Site Chemistry Resulting from Past Shipyard Activities

Appendix C

Sample Collection and Analysis Tables

Appendix D

Bathymetric Plots

Appendix E

Regional Stratigraphic Logs

Appendix F

Site Stratigraphic Logs

Appendix G

Analytical Database e:Dat™

Appendix H

MVS/EVS Detailed and Simplified 3-D Stratigraphic Models

Appendix I

Simplified Stratigraphic Model Approach

Appendix J

Naturally Occurring Fresh Groundwater/Salt Water Distribution Evaluation

Appendix K

Groundwater Density Distribution

Appendix L

Evaluation of Site-Wide Hydraulic Data

Appendix M

Evaluation of 709-721 Alexander Avenue Hydraulic Data

Appendix N

Single-Well Response Tests Technical Memorandum

Appendix O

3-D Chemistry Visualization Models

Appendix P

List of Data Validation Reports

Appendix Q

Dioxin, Furan, and PCB Congener Data

Appendix R

Vapor Investigation Report (May 2014)

Appendix S

DNAPL Assessment

Appendix T

Weston Cross-Sections Drawings

Appendix U

Natural Attenuation Evaluation

Appendix V (See endnote vi.)

Exposure Pathway Assessment Report

Appendix W

University of Washington Report on Site-Specific Partition Coefficients of Heavy Metals

---

[i] Many of the referenced investigations in this summary were reviewed and approved either by the USEPA or the Washington Department of Ecology, or both. Any referenced report in this summary not already approved by the agencies is not considered endorsed by the formal approval of this RI Report.

[ii] The workplans for these pH pilot studies were approved by the agencies under the Scope of Work attached to the Agreement on Consent. The reports provided for this work were not approved or accepted by the agencies. OCC agreed to provide further research on the chemistry and characteristics of the pH plume by contracting with the University of Washington to conduct work under a separate Scope of Work approved by the agencies.

[iii] Extraction well pilot tests were not completed as the paragraph states. The workplans for Extraction Well #7 and for #9 were submitted to the agencies and approved. OCC declined to complete the workplans as written.

[iv] The SMS rules were revised in February, 2013. Until a final cleanup of the OCC site is complete the Department of Ecology is obligated under Chapter 173-340 WAC to revise any decisions based on standards that have changed during the investigation and up until cleanup is achieved. The regulatory process of evaluating the success of cleanup continues with a required 5-year review process. This process obligates Ecology to reevaluate cleanups against any new, updated, standards.

[v] Cleanup levels will be reevaluated and adjusted to the most current standards in the Cleanup Action Plan.

[vi] The entire highlighted section is not approved. The risk assessment work performed by OCC was not approved by the agencies, and is not endorsed by approval of this RI. The information is retained only for background and as reference material. Ecology intends to evaluate the need for further risk assessment work after new data is provided from sampling sediments and porewater from the Hylebos Waterway.

[vii] See endote vi.