The Boeing Company
P.O. Box 3707
Seattle, WA 98127-2207

October 30, 2019
DAT-2019-039

Li Ma and Christa Colouzis
Department of Ecology
NWRO 3190 160th Ave SE
Bellevue, WA 98008-5452

Subject: Submittal of Draft Feasibility Study Report
Boeing Auburn Facility
Agreed Order No. 01HWTRNR-3345

Dear Mr. Ma and Ms. Colouzis:

The Boeing Company (Boeing) is pleased to submit the draft Feasibility Study (FS) report for the Boeing Auburn Fabrication Division Plant (Boeing Auburn Plant) under Agreed Order (No. 01HWTRNR-3345). This report was prepared in response to The Washington State Department of Ecology (Ecology) request for the FS report and approval of the FS work plan letter dated April 25, 2019.

Boeing appreciates the opportunity to present cleanup alternatives for the five areas of concern (AOCs) at the Boeing Auburn Site (Site) that were carried forward for evaluation in the FS. The FS evaluation of remedial alternatives was completed in accordance with the Model Toxics Control Act (MTCA) regulation (Chapter 173-340 of the Washington Administrative Code [WAC]) and Resource Conservation and Recovery Act (RCRA) regulations for Corrective Action (WAC 173-303-64610 through 173-303-64630).

In order to assist with Ecology's review of this document, Boeing has provided a checklist in Attachment 1 to this letter that provides references to the sections of the report where each of the requirements for the FS, as identified by Ecology's FS Checklist,[1] are addressed. Additionally, a summary of the AOCs, remedial alternatives evaluated, selected alternatives, and proposed points of compliance (POCs) are provided in Table 7-1 of the enclosed FS report.

Thank you for the opportunity to provide this FS and the collaboration between Boeing and Ecology leading up to its preparation. We look forward to discussing the FS with you and moving closer to implementation of the selected remedies at the Boeing Auburn Site.

[1] FS Checklist, Ecology Publication No. 16-09-007, May 2016.

Please feel free to contact me if you have any questions.

Sincerely,

Debbie Taege
Project Manager
Boeing EHS Remediation
PO Box 3707, MC 9U4-26
Seattle WA 98124-2207
deborah.a.taege@boeing.com
Office (425) 965-3745

CC:
Katie Moxley, The Boeing Company
Stanley N. Alpert, Senior Environmental Counsel, The Boeing Company
Jim Swortz, The Boeing Company
Jennifer Wynkoop, Landau Associates
Sarah Fees, Landau Associates

Attachment 1
Feasibility Study Checklist
Boeing Auburn Feasibility Study
Auburn, Washington

			Feasibility Study (FS) Checklist Guidance, Ecology Publication No. 16-09-007	Location in Text
FEASIBILITY STUDY REPORT BODY				
I.			**COVER LETTER**	Included
II.			**INTRODUCTION**	
	a.		Site Background, Site Investigations, Interim Actions (if any)	Site Background (Section 1.1, 2.0), Site Investigations (Section 4.0,) and Interim Actions (Section 2.4)
	b.		Results of any additional investigations conducted since completion of the RI	Section 4.0
	c.		Conceptual Site Model (CSM)	Section 2.2 and 2.3
	d.		Preliminary cleanup levels for indicator hazardous substances in each medium	Section 3.2
	e.		Proposed point of compliance for each affected medium, if different from the standard	Section 3.3
	f.		Applicable local, state, and federal laws	Section 3.1
III.			**ALTERNATIVES**	
	a.		Identify remedial action objectives. Describe the cleanup objectives and their compliance with MTCA.	Section 1.2
	b.		Identify a reasonable number and type of alternatives, including a brief description of each alternative.	Section 5.0: 5.2 - 5.5
IV.			**DETAILED EVALUATION AND SELECTION OF ALTERNATIVES**	
	a.		Threshold and Other Requirements	Section 6.0 (Description of Threshold and Other Requirements provided in Section 6.1)
		i.	Protect human health and the environment.	Section 6.2.1, 6.3.1; Table 6-1 and 6-5
		ii.	Comply with cleanup standards.	Section 6.2.1, 6.3.1; Table 6-1 and 6-5
		iii.	Comply with applicable state and federal laws.	Section 6.2.1, 6.3.1; Table 6-1 and 6-5
		iv.	Provide for compliance monitoring.	Section 6.2.1, 6.3.1; Table 6-1 and 6-5
		v.	Reasonable restoration time frame.	Section 6.2.4, 6.3.4; Table 6-1 and 6-5, Appendix D and E
	b.		DCA Ranking Criteria	Section 6.0 (Description of DCA Ranking Criteria provided in Section 6.1.2.1) Conclusion of DCA provided in Section 6.2.3, 6.3.3; Tables 6-2, 6-3, 6-4, 6-6, 6-7, and 6-8
		i.	Protectiveness	Section 6.2.2, 6.3.2; Table 6-2 and 6-6
		ii.	Permanence	Section 6.2.2, 6.3.2; Table 6-2 and 6-6
		iii.	Cost	Section 6.2.2, 6.3.2; Table 6-2, 6-3, 6-4, 6-6, 6-7, and 6-8
		iv.	Effectiveness over the long-term	Section 6.2.2, 6.3.2; Table 6-2 and 6-6
		v.	Management of short-term risks	Section 6.2.2, 6.3.2; Table 6-2 and 6-6
		vi.	Technical and administrative implementability	Section 6.2.2, 6.3.2; Table 6-2 and 6-6
		vii.	Consider public concerns	Section 6.2.2, 6.3.2; Table 6-2 and 6-6
V.			**REMEDY SELECTION**	Section 7.0

Attachment 1
Feasibility Study Checklist
Boeing Auburn Feasibility Study
Auburn, Washington

		Feasibility Study (FS) Checklist Guidance, Ecology Publication No. 16-09-007	Location in Text
FS FIGURES			
I.		**VICINITY MAP(S)**	
	a.	Show property in relation to surrounding region.	Figure 1-1
	b.	Other applicable items: surface topography, natural areas, land use, groundwater supply, and monitoring wells.	Figures 1-1, 2-2, 2-3, 2-4,
II.		**SITE MAP(S)**	
	a.	Overall site layout with existing wells, borings, and sample locations labeled.	Figure 1-3; Figures 2-2, 2-3; Figures 4-1, 4-6, 4-11
	b.	COC locations, concentrations, estimated vertical and horizontal extent of contamination.	Figure 2-1; Figure 4-3, 4-4 (AOC A-01); Figure 4-8, 4-9 (AOC A-09); Figure 4-14, 4-15 (AOC A-13); Figure 4-17, 4-19, 4-20, 4-23, 4-24, 4-25 through 4-33 (AOC A-14); Figure 4-36 (AOC A-15)
	c.	Geologic/hydrogeologic information including soil types, wells, screened intervals, and water levels (cross sections). Show groundwater flow direction and gradient.	Figure 4-2 (AOC A-01); Figure 4-7 (AOC A-09); Figure 4-13 (AOC A-13); Figure 4-22, 4-35a, 4-35b (AOC A-14)
	d.	Other relevant information: site and property boundaries, buildings, facilities, etc.	Figure 1-2; Figures 2-1, 2-5
III.		**CONCEPTUAL SITE MODEL**	Figure 2-4
FS TABLES			
I.		**ARARs**	Table 3-1
II.		**EVALUATION OF REMEDIAL ALTERNATIVES**	Table 5-2, 6-1 through 6-3 (AOC A-09) ; Table 5-3, 6-5 through 6-7 (AOC A-14)
III.		**COST/QUANTITY SUMMARY**	Table 6-4 (AOC A-09); Table 6-8 (AOC A-14)
IV.		**COST DETAIL FOR ALTERNATIVES**	Appendix G
V.		**Additional site investigations conducted after completion of the RI**	Section 4 tables
FS APPENDICES			
VI.		**Contractor bids or other documents showing how quantity and/or cost estimates were made**	Appendix G
VII.		**Documentation related to additional site investigations conducted after completion of the RI**	FS Data Submittals (Data submittals are discussed in Section 4.0 and References are provided in Section 9.0)
VIII.		**Limitations that apply to work**	Section 8.0
IX.		**Additional context or contribution to the understanding of the site or remedial alternatives**	Appendix A, B, C, D, E, F
MISCELLANEOUS ITEMS			
X.		**CERTIFICATION (LICENSED PROFESSIONAL STAMP)**	Will be added to the final version of the report.
XI.		**ENVIRONMENTAL INFORMATION MANAGEMENT (EIM)**	EIM submittals for the Site have been completed and are up to date through June 2019.
XII.		**Additional information requested by Ecology to fully assess remedial alternatives**	Boeing has addressed all Ecology requests for documentation to be included in the FS report as documented in letters from Ecology.
XIII.		**SUBMITTAL REQUIREMENTS**	Boeing will provide required hard copies of the final report as requested by Ecology.

Draft Feasibility Study
Boeing Auburn Facility
Auburn, Washington

October 30, 2019

Prepared for

The Boeing Company

LANDAU ASSOCIATES

2107 South C Street
Tacoma, WA 98402
(253) 926-2493

Draft Feasibility Study
Boeing Auburn Facility
Auburn, Washington

This document was prepared by, or under the direct supervision of, the technical professionals noted below.

Document prepared by: Sarah Fees — Sarah E. Fees, LG
Senior Geologist; Project Manager

Document reviewed by: Piper Roelen — Piper M. Roelen, PE
Principal; Technical Reviewer

Document reviewed by: Jennifer Wynkoop — Jennifer W. Wynkoop
Principal; Quality Reviewer

Date:	October 30, 2019
Project No.:	0025164.170
File path:	Y:\025\164\R\FS\Ecology Review Draft FS Rpt.docx
Project Coordinator:	tam/ljl

LANDAU ASSOCIATES

This page intentionally left blank.

TABLE OF CONTENTS

FIGURES

TABLES

APPENDICES

LIST OF ABBREVIATIONS AND ACRONYMS

µg/L ..... micrograms per liter
µg/m^3 ..... micrograms per cubic meter
1,1-DCE 1,1-dichloroethene
Agreed Order ..... Agreed Order No. 01HWTRNR-3345
AMB ..... AMB Corporation; now Prologis
AOC ..... area of concern
ARAR ..... applicable or relevant and appropriate requirement
bgs ..... below ground surface
Boeing ..... The Boeing Company
Boeing Auburn Plant ..... Auburn Fabrication Division Plant
BTEX ..... benzene, toluene, ethylbenzene, xylenes
cDCE cis-1,2-dichloroethene
CFR ..... Code of Federal Regulations
CLARC ..... Ecology's Cleanup Levels and Risk Calculation
CMT ..... continuous multi-channel tubing
COC ..... constituent of concern
CPOC ..... conditional point of compliance
CSM ..... conceptual site model
CVOC ..... chlorinated volatile organic compound
DCA ..... disproportionate cost analysis
DGR ..... dynamic groundwater recirculation
DNAPL ..... dense non-aqueous phase liquid
DO ..... dissolved oxygen
DOD ..... US Department of Defense
DRO ..... diesel-range organics
Ecology ..... Washington State Department of Ecology
EISB ..... enhanced *in situ* bioremediation
EPA ..... US Environmental Protection Agency
EPH ..... extractable petroleum hydrocarbons
ESTCP ..... Environmental Security Technology Certification Program
FS ..... feasibility study
FSWP ..... feasibility study work plan
ft ..... feet, foot
ft^2/day ..... square feet per day
GAC ..... granular activated carbon
GPM ..... gallons per minute
GRO ..... gasoline-range organics
GSA ..... general services administration

ID ..... identification
IHS ..... indicator hazardous substance
IRA ..... interim remedial action
ISCO ..... *in situ* chemical oxidation
JA ..... Junior Achievement
LAI ..... Landau Associates, Inc.
LNAPL ..... light non-aqueous phase liquid
MCL ..... maximum contaminant level
mg/kg ..... milligrams per kilogram
mg/L ..... milligrams per liter
MNA ..... monitored natural attenuation
MTCA ..... Model Toxics Control Act
NAPL ..... non-aqueous phase liquid
nmol/L ..... nanomole per liter
NTR ..... National Toxics Rule
NWTPH-Dx ..... northwest total petroleum hydrocarbon diesel-range extended
OMB ..... Office of Management and Budget
ORC® ..... Oxygen Release Compound
ORO ..... oil-range organics
ORP ..... oxidation reduction potential
PCE ..... tetrachloroethene
pCUL ..... proposed cleanup level
POC ..... point of compliance
PQL ..... practical quantitation limit
PRB ..... permeable reactive barrier
PSE ..... Puget Sound Energy
RCRA ..... Resource Conservation and Recovery Act
RCW ..... Revised Code of Washington
redox ..... reduction-oxidation
REL ..... remediation level
RI ..... remedial investigation
ROI ..... radius of influence
Safeway ..... Safeway Corporation
SR ..... State Route
SVE ..... soil vapor extraction
SWMU ..... solid waste management unit
SWQS ..... surface water quality standards
TCA ..... trichloroethane
TCE ..... trichloroethene
tDCE trans-1-2-dichloroethene

TEE ..... terrestrial ecological evaluation
TOC ..... total organic carbon
TPH ..... total petroleum hydrocarbon
UST ..... underground storage tank
VC ..... vinyl chloride
VOC ..... volatile organic compound
VPH ..... volatile petroleum hydrocarbons
WAC ..... Washington Administrative Code
WDOH ..... Washington State Department of Health
yd^3 ..... cubic yards
yr ..... year
ZVI ..... zero-valent iron

1.0 INTRODUCTION

This document presents the results of a feasibility study (FS) conducted for cleanup of contaminant releases associated with The Boeing Company's (Boeing) Auburn Fabrication Division Plant (Boeing Auburn Plant). The Boeing Auburn Plant is located at 700 15th Street Southwest, Auburn, Washington (State Dangerous Waste Identification [ID] No. WAD041337130). The location and current extent of property that Boeing owns as part of the Boeing Auburn Plant is shown on the vicinity map (Figure 1-1).

The Boeing Auburn Plant is currently undergoing Resource Conservation and Recovery Act (RCRA) corrective action as required by Agreed Order No. 01HWTRNR-3345, dated May 15, 2002 (Washington State Department of Ecology [Ecology] 2002), the First Amended Agreed Order, dated April 7, 2006 (Ecology 2006), and the currently effective Second Amended Agreed Order, dated November 1, 2018 (Ecology 2018; collectively referenced herein as the Agreed Order). The Agreed Order includes a requirement to conduct a remedial investigation (RI) to investigate the nature and extent of contamination and an FS to select cleanup actions for contamination impacts both within the Boeing Auburn Plant and at affected downgradient properties. Boeing conducted investigations to characterize releases from the Boeing Auburn Plant that have affected soil, groundwater, and downgradient stormwater features as documented in the RI report (Landau Associates, Inc.[LAI] 2017h). The nature and extent of contamination was compared to screening levels developed for the RI. The RI report concluded that evaluation of remedial actions may be warranted for a number of historical releases from the Boeing Auburn Plant.

This FS develops and evaluates remedial action alternatives and identifies preferred remedial action alternatives to address releases from the site. This FS also develops soil, groundwater, and surface water proposed cleanup levels (pCULs) and identifies proposed points of compliance (POCs). This FS was performed in accordance with the Model Toxics Control Act (MTCA) regulation (Chapter 173-340 of the Washington Administrative Code [WAC]) and RCRA regulations for Corrective Action (WAC 173-303-64610 through 173-303-64630).

1.1 Site Description

The Boeing Auburn Plant is located within the City of Auburn and consists of 312 acres of industrial land. Historically, Boeing has owned up to 482 acres of land in this area (385 acres acquired from the general services administration [GSA] in 1966 and an additional 97 acres of land adjacent to the southwest of the original Boeing Auburn Plant). Boeing has used the Boeing Auburn Plant for airplane skin and spar manufacturing, machine fabrication, tooling, emergent manufacturing, welding, sheet metal work, process assembly, and other work related to the manufacturing of airplane tools and parts. Boeing sold approximately 105 acres of its property to the Safeway Corporation (Safeway) in 2003, donated approximately 22.5 acres of its property to The YMCA and Junior Achievement (JA) in 2004, and sold 0.91 acres of its property consisting of an electrical transfer station to Puget Sound Energy (PSE; shown as "Area 5" on Figure 1-2) in 2005. All three of these areas were removed from

the RCRA permit definition of the "Facility" (see further discussion of the definition of the Facility below) prior to property transfer. Boeing also sold "Area 1," the northern 41.3 acres of the Facility, in December 2005 to AMB Corporation (AMB; now Prologis). Area 1 remains a part of the permit definition of the Facility and, thus, the RCRA permit was issued jointly to Boeing and AMB. The locations of the Safeway parcel, the PSE/Area 5 parcel, the YMCA parcel, the JA parcel, and Prologis parcel are shown on Figure 1-2.

MTCA defines a "Facility" or "Site" as:

> "any building, structure, installation, equipment, pipe or pipeline (including any pipe into a sewer or publicly owned treatment works), well, pit, pond, lagoon, impoundment, ditch, landfill, storage container, motor vehicle, rolling stock, vessel, or aircraft; or any site or area where a hazardous substance, other than a consumer product in consumer use, has been deposited, stored, disposed of, or placed, or otherwise come to be located (WAC 173-340-200)."

However, in order to clarify discussion in this FS, the following terms and definitions are used to describe and provide a distinction between the property currently owned by Boeing, property that is currently part of the RCRA facility permit, and property that is part of the "Site" as a result of contaminant migration:

- The **Boeing Auburn Plant** or **Boeing Property** includes property currently owned and operated by Boeing that is used for manufacturing and other auxiliary purposes. Specifically, this does not include properties formerly owned by Boeing including Prologis (formerly AMB), Safeway distribution center, YMCA, JA, and PSE properties.
- The **Boeing Auburn Facility (Facility)** includes properties owned by parties to the Agreed Order. This includes property currently owned by Boeing and property owned by Prologis (Figure 1-2).
- The **Site** includes the Facility and all contiguous property affected by releases of hazardous substances that are confirmed or suspected to have originated at the Facility. The approximate extent of the current Site is shown on Figure 1-3. The Site boundary may change over time as additional data is gathered and/or areas are remediated.

1.2 Objectives

The objective of this FS is to select a cleanup action or actions for the remediation of environmental media with contaminant concentrations above pCULs resulting from releases at the Site.

1.3 Report Organization

This FS contains nine sections as described below:

- Section 1.0 introduces the purpose of this FS, provides definitions for important terminology, briefly describes the Site history, defines the objectives of this FS, and lays out the organization of the report.
- Section 2.0 describes the site background and conceptual models.

- Section 3.0 proposes cleanup standards and pCULs to be implemented during the cleanup action at the Site.
- Section 4.0 describes each area of concern (AOC) and activities completed as part of the FS work plan (FSWP) to define the current conditions at the Site. Data presented in this FS consist of data collected after the cutoff date for the RI report (January 2016) through the cutoff of FS data (December 2018). Additionally, where needed or appropriate, more recent data for sample locations or analyses for constituents of concern (COCs) for each AOC were included for a more comprehensive understanding of current Site conditions.
- Section 5.0 provides descriptions of the cleanup action alternatives developed for AOCs that were carried forward for FS evaluation.
- Section 6.0 describes the regulatory FS criteria used for evaluation of each and compares the cleanup action alternative benefits and costs for each AOC.
- Section 7.0 provides a recommended cleanup action alternative for each AOC.
- Section 8.0 describes the appropriate use of this FS.
- Section 9.0 provides a list of report references.

2.0 BACKGROUND

Boeing completed RI activities to characterize the nature and extent of contamination above Site-specific screening levels; data collection for the RI was completed in 2015 and the Ecology-approved RI report was finalized in 2017 (Ecology 2017a; LAI 2017h). The focus of the RI was to identify and characterize potential releases from solid waste management units (SWMUs) and AOCs and to determine the nature and extent of these impacts. As part of the RI, Boeing investigated two groundwater plumes impacted by chlorinated volatile organic compounds (CVOCs) apparently emanating from the Facility and extending off Boeing property to the north and northwest. In addition to groundwater, the plumes impact several stormwater drainage and collection features northwest of the Facility. The groundwater plumes are identified as the "Area 1 Plume" (originating from the northern portion of the Facility, former Area 1) and the "Western Plume" (originating from the west side of the Facility in or near Building 17-07). The plumes are primarily comprised of trichloroethene (TCE) and its breakdown products cis-1,2-dichloroethene (cDCE) and vinyl chloride (VC). TCE and VC are the indicator hazardous substances (IHS)[1] in Site-wide groundwater because of their prevalence and relative toxicity; while cDCE is also present in Site groundwater, the concentrations do on exceed cDCE screening levels or pCULs. Some localized areas of TCE soil contamination are also present at the identified groundwater contamination release areas at the Facility. The RI also identified localized areas with heavy metals, cyanide, and petroleum hydrocarbons in soil and groundwater within the Boeing property; these impacts do not extend off of the Boeing property.

The RI report documented investigation activities at SWMUs and AOCs at the Facility and in downgradient areas of the Site. Data collected as part of the RI was sufficient to determine the nature and extent of contamination and provide recommendations for SWMUs and AOCs to be carried forward to the FS for evaluation of remedial alternatives. No individual SWMUs were carried forward to the FS;[2] however, five AOCs were carried forward to the FS:

- AOC A-01: Underground Storage Tanks (USTs) TAU-01 and TAU-02 northwest of Building 17-06
- AOC A-09: Building 17-07 Acid Scrubber Drain Line Leak
- AOC A-13: Building 17-06 (east side) Petroleum Hydrocarbon Contamination
- AOC A-14: Site-wide TCE and VC Soil and Groundwater Contamination
- AOC A-15: Site-wide TCE and VC contamination in surface water and stormwater collection, treatment, and conveyance features.

The list of AOCs carried forward to the FS is summarized in Table 2-1. The Facility AOCs (AOC A-01, AOC A-09, and AOC A-13) carried forward to the FS are shown on Figure 2-1. AOC A-14 was designated to address Site-wide CVOC contamination in groundwater, specifically TCE and VC; it also includes TCE

[1] Per WAC 173-340-200, IHS are defined as "the subset of hazardous substances present at a site selected under WAC 173-340-708 for monitoring and analysis during any phase of remedial action for the purpose of characterizing the site or establishing cleanup requirements for that site."

[2] Investigation of SWMU S-15a/16 is carried forward as part of AOC A-13.

soil contamination in the groundwater plume release areas at the Facility (VC is not detected in soil at the Facility). The two plumes originating from the Facility (the Area 1 Plume and the Western Plume) extend approximately 1 mile northwest of the Facility. The approximate extent of the two groundwater plumes along with the wells that are part of the current monitoring well network are shown on Figure 2-2. AOC A-14 comprises the two groundwater plumes and associated release areas (Area 1 plume release areas at former Buildings 17-03 and 17-05 and Western Plume release areas at Building 17-07), and detections of TCE and VC in groundwater upgradient and cross-gradient of the plume release areas. The stormwater and surface water features at the Site are shown on Figure 2-3. AOC A-15 was designated to address the impacts of groundwater contamination discharging to stormwater and/or surface water features. Investigation activities completed for each AOC during the FS are described in Section 4.0.

2.1 Site Geology and Hydrogeology

Site geology and hydrogeology are described in detail in the RI Report (LAI 2017h) and are summarized below.

2.1.1 Geology

The Site lies within the Auburn valley formed during the Vashon glaciation approximately 14,000 years ago. Approximately 5,700 years ago an eruption of Mount Rainier sent a large lahar (the Osceola Mudflow) down the White River and into the Auburn valley. The Osceola Mudflow deposited a low-porosity layer of sands and gravels suspended in a silt and clay matrix. This layer forms the aquitard below the present day upper alluvial aquifer of the Auburn valley.

The upper aquifer is comprised of alluvial deposits from the White and Green Rivers (Qaw and Qag formations). The deposits consist of highly variable, but predominantly coarse, alluvial sands and gravels with occasional interbedded silt layers consistent with a relatively high energy, dynamic, alluvial depositional environment. Finer-grained deposits and peat, indicative of a lower energy depositional environment, are more prevalent in the northwest portion of the Site (toward the valley wall) where smaller water courses and overbank flooding probably contributed more significantly to the deposition. As a result, the northwest portion of the Site generally has higher concentrations of natural organic carbon in the aquifer.

For the purposes of investigation and discussion, groundwater within the upper aquifer is divided into three hydraulically interconnected zones, based on depth below ground surface (bgs; Geomatrix 2003):[3]

- A shallow zone, from the water table[4] to 35 feet (ft) bgs:

[3] The RI work plan (Geomatrix 2003) defined these zones as follows: Shallow zone (10 ft–30 ft), intermediate zone (40 ft –60 ft), and deep zone (80 ft–100 ft). The definitions were subsequently revised to incorporate additional depth intervals (e.g., 30 ft – 40 ft) that were missing from the Geomatrix definition.

[4] The depth to the water table is variable across the Site from less than 5 ft bgs to more than 20 ft bgs.

  - The shallowest wells within this zone are screened at or near the water table; water table data is considered a subset of the shallow zone data.
- An intermediate zone, from 35 to 75 ft bgs
- A deep zone, from 75 ft bgs to the contact with the Osceola Mudflow (typically between 80 and 100 ft bgs):
  - The depth of the Osceola Mudflow varies based on location.

2.1.2 Groundwater Flow and Velocities

Contributions to groundwater in the upper aquifer primarily consist of infiltration from the White River with a smaller contribution from precipitation. Groundwater flow in the Auburn valley is generally northward, parallel to the valley walls (PGG 1999), and recharges the Green River. At the Site, there is a northwesterly component to groundwater flow as a result of features on the west side of the valley that capture shallow groundwater. The features that capture shallow groundwater near the Site include stormwater and surface water features along the western portion of the Auburn valley including wetland features, Mill Creek, and stormwater features like the Chicago Avenue ditch and the Auburn 400 stormwater retention basins. The Chicago Avenue ditch and Auburn 400 stormwater retention basins collect stormwater from local roadways and parking lots but also intercept shallow groundwater.

Groundwater is generally shallow with depth to groundwater near the Facility in the range of 8 to22 ft bgs. In the northwest portion of the Site, groundwater depths are shallower and generally range from 0 to 10 ft bgs. Differences in the depth of the water table across the Site are primarily due to changes in ground surface elevation. Seasonally, groundwater elevations fluctuate on average approximately 5 ft. Somewhat larger fluctuations are generally observed at the Facility, and smaller fluctuations are generally observed in the northwest portion of the Site where groundwater is also shallower.

Groundwater velocities vary across the Site because of the heterogeneity of the alluvial deposits, but are relatively high, in the range of 150 ft/year (yr) to 700 ft/yr. Seepage velocities across the Site are estimated to average approximately 300 ft/yr. These relatively high seepage velocities reflect the relatively high hydraulic conductivity of the alluvium and the high rates of recharge to the aquifer system because of infiltration from the White River and underflow.

The coarse alluvial sands and gravels at the Site and fast-moving groundwater have a significant impact on contaminant fate and transport. The contaminant fate and transport conceptual site model is described in greater detail in Section 2.2. In general, the aquifer dynamics have resulted in CVOC groundwater plumes that are relatively low concentration and the bulk of the contaminant mass has migrated downgradient of the release areas. The highest CVOC concentrations are mid-plume and the remaining dissolved mass in the release areas is the result of back diffusion processes from fine-grained soils interbedded with the coarse sands and gravels.

2.1.3 Stormwater and Surface Water Flow

A surface water divide is present in Algona at approximately 4th Avenue North. Surface water north of 4th Avenue North flows to Mill Creek; surface water south of 4th Avenue North, including Government Canal, flows south to the White River. Water courses that drain to Mill Creek are discussed below.

Stormwater in the Chicago Avenue ditch flows north and enters the City of Auburn's piped stormwater system at Boundary Boulevard. Water from the O Street wetland is also channelized and flows into the City of Auburn's piped stormwater system at Boundary Boulevard. The piped water flows west to the Auburn 400 south stormwater retention basin, which then flows to the Auburn 400 north stormwater retention basin. The Auburn 400 north stormwater retention basin also captures stormwater from 15th Street SW and the southern portion of The Outlet Collection complex. Water from The Outlet Collection stormwater basins flows into a ditch on the northwest side of the stormwater basins. This ditch combines with flow from the Auburn 400 north stormwater retention basin and flows through a culvert under State Route (SR) 167 to a wetland on the west side of the highway. The wetland carries water north where it joins Mill Creek at the east end of Peasley Canyon Road. Mill Creek then flows northward through various wetland complexes before it joins the Green River several miles downstream. Surface water features and flow directions are presented on Figure 2-3.

2.2 Subsurface Contaminant Fate and Transport Conceptual Model

The contaminant fate and transport conceptual model provides a general explanation of the processes that affect CVOC movement and behavior in the subsurface. This conceptual model, along with an understanding of how CVOCs were released into the subsurface, provides a framework for understanding the characteristics of the groundwater CVOC plumes at the Site and relative effectiveness of remedial technologies proposed to clean them up. The conceptual model provides the technical basis for much of the analysis and conclusions presented later in this document. The contaminant fate and transport conceptual model is different than the exposure and risk conceptual site model (CSM), which deals with potential human exposure and is described separately in Section 2.3.

Contaminant fate and transport processes for CVOCs in groundwater include advection, sorption, dispersion, diffusion, and degradation. These processes are largely a function of the hydrogeologic setting. The hydrogeologic setting in the Auburn valley is unique and complex because of the relatively recent geologic history and unique groundwater recharge patterns (See Section 2.1). The valley in the area of the Site was inundated by the Osceola mudflow off the flanks of Mt. Rainer approximately 5,700 years ago. The mudflow engulfed the southern part of the valley with an unsorted mix of boulders, gravel, sand, silt, and organic material which was reworked by the north-flowing braided stream environment of the White River (which now flows to the south). The resulting alluvial valley infill produced a highly heterogeneous layering of cobbles, gravel, and sand and silt as

seen in boring logs and geologic cross sections. There are very coarse gravel areas which have a very high permeability (hence the very high pumping rates associated with dewatering) and numerous discontinuous layers and pockets of finer grained moderate-to-low permeability material. An additional unique factor is the high rates of recharge to the aquifer from the losing reach of the White River as it flows off the uplands into the valley. The water loss from the river results in a higher rate of recharge to the aquifer system than would be caused by precipitation alone. This results in higher groundwater flux rates through the aquifer beneath the Site. The Site hydrogeologic heterogeneity is important in understanding CVOC plume characteristics on a number of levels. For example, this heterogeneity contributes to the relatively low but persistent CVOC concentrations beneath the release areas and in the downgradient plumes. Cross-sections that show the geology and total CVOC concentrations along the centerline of the Western and Area 1 plumes are presented in Section 4 (Figure 4-35a and 4-35b, respectively).

2.2.1 Release Area Characteristics

The CVOC plumes originated from historical releases at the Facility of dense non-aqueous phase liquid (DNAPL) TCE to the subsurface. TCE is denser than water, relatively immiscible, and a non-wetting fluid. These properties result in the tendency of the DNAPL to travel vertically downward beneath the water table. The DNAPL mass would travel relatively freely through coarse-grained soil but would be impeded by fine-grained soil with small pore spaces (low porosity) and high capillary pore-entry pressures. Additionally, based on physical characteristics (e.g., surface area) and chemical and mineralogical characteristics (e.g., organic carbon content and cation exchange capacity), CVOCs tend to have a greater affinity and adsorb more readily to fine-grained soils, such as clays and silts, than to coarse-grained soil. The geologic heterogeneity at the Site results in a complex and relatively widespread mass distribution associated with the original TCE release with persistent mass present in lower permeability lenses of the aquifer.

The DNAPL source immediately starts to attenuate after a release occurs through dissolution and diffusion. Dissolution causes the source material to dissolve into groundwater as a solute and travel downgradient through advection (i.e., travel with flowing groundwater). This process, which reduces source mass in the release areas, occurs preferentially in highly permeable portions of the aquifer that are constantly being flushed from upgradient with uncontaminated water. Advection is the main process that causes formation of the downgradient plume. Diffusion is the net flux of solutes from high concentration areas to low concentration areas. Diffusion is also a mechanism by which contamination makes its way from coarse-grained, highly permeable zones to finer-grained, lower permeability zones. As the more permeable zones of the aquifer cleanup (i.e., deplete the original DNAPL) through dissolution and flushing, the mass that is relatively sequestered in the finer-grained, low-permeability portions of the aquifer, then slowly diffuse (as a result of an eventual concentration gradient reversal) back into the permeable portions creating a low concentration, but long-lived secondary “source” of downgradient contamination (this process is termed back-diffusion).

The processes of source redistribution and attenuation have been characterized into the concept of DNAPL source zone lifecycle (Kueper et al. 2014). The lifecycle consists of five stages: 1) Initial DNAPL Release, 2) DNAPL Redistribution, 3) Continued DNAPL Dissolution and Aging, 4) Complete DNAPL Depletion, and 5) Desorption and Back Diffusion. Completion of the lifecycle from initial release of DNAPL to complete DNAPL depletion can occur over vastly different time periods depending on characteristics of the release, hydrogeologic site conditions, and chemical and biologic aquifer conditions and characteristics. The Site progressed through this lifecycle relatively quickly due to high groundwater flux rates through the very high permeability coarse-grained zones that quickly depleted DNAPL in these zones.

2.2.2 Plume Characteristics

Advection causes dissolved CVOC solutes to travel downgradient with flowing groundwater to form a plume. These solutes are subject to the processes of dispersion (including diffusion) and sorption that affect the nature and extent of the plume. Dispersion causes longitudinal and transverse spreading of the plume relative to the principal direction of groundwater flow. Dispersion is predominantly a mechanical mixing process caused by variations in aquifer pore geometry and fluctuations in local groundwater gradients. The result is a more widespread and dilute plume.

The current horizontal extent of the Area 1 and Western plumes is due to dissolution of TCE at the release areas (as described above) and migration of dissolved TCE downgradient with the bulk motion of flowing groundwater (i.e., advection). The resulting spatial distribution of the plumes is affected by aquifer heterogeneity, contaminant transport process such as sorption, dispersion, and contaminant degradation. Other factors that affect the distribution of the plumes are the source history, differences in public supply well pumping scenarios over time (as presented in the RI report; LAI 2017h), and the presence of complex boundary conditions that capture groundwater that include stormwater control and conveyance structures (e.g., the Chicago Avenue ditch and the Auburn 400 stormwater retention basins) and surface water features (Mill Creek and associated wetlands) that receive groundwater. The combination of these factors along with contribution from CVOC sources outside the Facility[5] has resulted in complex plume geometries in the shallow, intermediate, and deep zones.

Similar to a source zone lifecycle (described above), the formation of a CVOC plume can be characterized as part of a CVOC contaminated site lifecycle (Sale and Newell 2011). Three lifecycle stages are:

- Early stage with initial or ongoing release and concurrent expanding plume;
- Middle stage with redistribution of contaminants through diffusion and sorption and a slowly expanding plume; and

[5] These off-Facility sources are described in the RI Report Section 8.1.4.2 (LAI 2017h).

- Late stage with desorption and back diffusion of contaminants and a stable or shrinking plume.

The principal behind defining plume stage is that concentration gradients that drive diffusion and sorption/desorption change over time. In the early stage, concentrations are greatest in high permeability zones and contaminants migrate into lower permeability zones by diffusion; there is also significant sorption of contaminants to the aquifer matrix. In the middle stage, contaminants are redistributed within the aquifer driven by dissolved CVOC concentration gradients and diffusion. Additionally, the redistribution of contaminants during the middle stage of the plume lifecycle, redistributes contaminant mass from the release areas to downgradient areas. The center of mass in the plume would continue to migrate downgradient until the rate of attenuation is equal to the rate of migration, at which point the center of mass would stabilize. Once the center of mass has stabilized this typically marks the transition to the late stage of the plume lifecycle. In high flux aquifers such as at the Site, the center of mass would stabilize downgradient of the release areas. The resulting CVOC plumes have the highest concentrations and center of mass downgradient of the release areas. Also, in the late stage, contaminant concentrations in the higher permeability zones are less than the lower permeability zones; this shift in concentration gradient causes contaminants to desorb from the aquifer matrix and back diffuse from the low permeability zones back to the high permeability zones. In aquifers with very high permeability zones, such as at the Site, the early stage may be relatively short (lasting only a few years) because of high groundwater velocities, while the late stage can last for decades or beyond because desorption and back diffusion are relatively slow processes. This process of contaminant storage in lower permeability zones during plume generation and expansion and subsequent back diffusion of that mass into the more permeable zones as the plume attenuates has been widely studied and determined to be a principal cause of the longevity of CVOC plumes regardless of the remedial alternative selected (Sale and Newell 2011; Stroo and Ward 2010).

2.2.3 CVOC Degradation

CVOC degradation is also a significant factor in attenuation of the plume. Degradation causes overall reduction in dissolved CVOC mass through chemical and biological processes. The main degradation process occurring at the Site is reductive dechlorination that occurs in anaerobic portions of the aquifer.

TCE and breakdown products cDCE and VC can degrade through either biotic (biological) or abiotic (chemical) mechanisms; aquifer conditions are the primary factor in determining what mechanisms are active. Anaerobic aquifer conditions are required for biotic reductive dechlorination and for abiotic degradation of TCE, while TCE breakdown products cDCE and VC can be degraded under both anaerobic and aerobic conditions. TCE, cDCE, and VC can also be degraded cometabolically under aerobic conditions. Aerobic and anaerobic conditions (called reduction-oxidation [redox] state) are characterized by sequential redox reactions, whereby, aquifer micro-organisms obtain energy. These redox reactions require an electron donor (i.e., a source of organic carbon) and an electron acceptor (e.g., oxygen, nitrate, iron). These redox reactions can be compared to the process whereby humans

obtain energy through consumption of food (electron donor) and oxygen (electron acceptor). When oxygen is depleted in an aquifer, anaerobic bacteria use the less oxidized electron acceptors in sequential order: nitrate, manganese (IV), iron (III), sulfate, and carbon dioxide. Depleted nitrate and sulfate concentrations as well as elevated iron (II) and methane concentrations indicate anaerobic aquifer conditions. Concentrations of these geochemical indicators can be used to assess the aquifer redox state of the aquifer. TCE and its breakdown products are also electron acceptors and are used preferentially at various redox states. Anaerobic aquifer conditions are present at the majority of the Site and reductive dechlorination is a well-documented process at the Site (LAI 2019d).

CVOC degradation is evident along horizontal flow paths extending from the release areas to the distal ends of the Western and Area 1 plumes, as groundwater flows through areas with significant levels of organic carbon and associated anaerobic aquifer conditions. While degradation takes place to varying degrees throughout the heterogeneous aquifer, the most anaerobic aquifer conditions and the highest degradation rates take place in the shallow and intermediate zones. Groundwater moves upward as it nears wetland areas at and near Mill Creek. Increased levels of CVOC degradation are occurring in the biologically active and organic rich zones in the shallow groundwater in these areas. Degradation significantly attenuates CVOC concentrations near wetland areas at and near Mill Creek; therefore, concentrations of CVOCs in groundwater are degraded to non-toxic end products before entering surface water.

2.2.4 Effectiveness of Remedial Technologies

Aquifer heterogeneity, permeability and the late stage characteristics of the release areas and the CVOC plumes have significant implications on the degree to which remedial technologies can be effectively applied to shorten the longevity of the plume. In the release areas, the limited remaining contaminant mass is present mainly in low permeability portions of the aquifer. Additionally, this mass is relatively spread out vertically and horizontally in pockets or zones because of the aquifer heterogeneity.

Because of these conditions, the application of remedial technologies at the Site would tend to lack effectiveness. For example, implementing *in situ* technologies would be difficult because of the technical difficulty of defining the limits of and accessing the sequestered source material widely distributed in lower permeability portions of the aquifer (which are somewhat sporadically distributed across the Site). Also, it is highly likely that back diffusion and desorption within the plumes downgradient of the release areas are adequate to sustain CVOC concentrations above regulatory thresholds for many years after the remaining limited release area mass is completely removed. In addition to difficulties in effectively remediating release areas, there are also difficulties in remediating the low concentration CVOC plumes downgradient of release areas. The large size of the plumes and the high density of buildings, roads, and infrastructure overlying the Site tends to limit the practicality of implementing remedial technologies. The low CVOC concentrations and negligible resulting risk to human health and the environment tend to limit the benefit of these technologies

beyond what is already being achieved by naturally occurring degradation processes. Heterogeneity and the overall high permeability of the aquifer also limit the practicality of technologies like dynamic groundwater recirculation. Pumping rates and treatment volumes would have to be extremely high to influence groundwater gradients and the infrastructure and operation and maintenance necessary to capture, flush, treat, and dispose of contaminated groundwater would be impractical.

2.3 Exposure Scenarios and Site Risks Conceptual Model

As part of the RI Report, Boeing developed, and Ecology approved, a CSM to assist in understanding the potential for exposure to contaminated media at the Site. The CSM takes into account contamination release areas, transport mechanisms, points of exposure, and routes of exposure. The CSM in combination with results and data from the RI and FS investigations indicate that under current Site conditions there is negligible exposure risk to human and ecological receptors.

Identified release areas are located in the central to north portion of the Facility and are related to the release of contaminants to soil and groundwater at or near the ground surface. Transport of contaminants from the release areas occurs through leaching (from soil) and dissolution of contaminants into groundwater and volatilization into soil gas. Downgradient of the release areas, advection and dispersion via groundwater flow are the primary transport mechanisms; volatilization of contaminants from groundwater into soil gas is also a transport mechanism, but Site data show that it is minor and localized based on soil gas measurements and relatively low concentrations of contaminants in groundwater at the water table. Data also indicate that transport of CVOC vapors to indoor air (vapor intrusion) is not a pathway of concern. Soil contamination outside the Facility release areas has not been identified. The Boeing Auburn CSM is presented on Figure 2-4 and summarized below.

Exposure pathways are characterized as complete (exposure is occurring under current conditions), potentially complete (exposure could occur in the future if conditions change), or incomplete (exposure is unlikely to occur in the future). For exposure to occur, a receptor must come in contact with contaminated media and the contaminants must enter the body through absorption (i.e., touching soil), ingestion (i.e., drinking water), or inhalation (i.e., breathing air). No complete exposure pathways have been identified either on or off the Facility. Potentially complete and incomplete exposure pathways differ on and off the Facility.

At the Facility, soil and groundwater are covered by pavement or buildings and potential exposure could only occur during subsurface construction or exploration activities. Groundwater at the Facility is not used for drinking water, and this exposure pathway is considered incomplete because all water is supplied by a municipal drinking water system. Air testing has confirmed that contaminants in soil gas are not migrating into the buildings or ambient air at measureable concentrations. While there may be potential for exposure to occur during future temporary construction, investigation, or remediation work, it would be minimized and mitigated through institutional controls and proper

health and safety measures and planning. There are no complete exposure pathways for receptors at the Facility (i.e., potential receptors are not currently being exposed to contaminants at the Facility).

Outside of the Facility, potential exposure pathways include exposure to contaminated groundwater (incidental ingestion), stormwater (ingestion or absorption), or air (inhalation). Site groundwater outside the Facility is not used for drinking water, and this exposure pathway is considered incomplete because drinking water is not being extracted from the impacted portion of the aquifer (water in the area is supplied by municipal drinking water systems from the lower aquifer). Contact with contaminated groundwater would only occur during subsurface construction or exploration activities. While concentrations of contaminants are present above pCULs in several stormwater features (stormwater ditches and basins) where workers or children may have incidental contact with the water;[6] contaminant concentrations in these stormwater features are below risk-based human health screening levels for worker and child exposure scenarios (LAI 2013; Washington State Department of Health [WDOH] 2013; WDOH 2014). Based on results of air testing in commercial and residential buildings outside the Facility, vapor intrusion of TCE and VC is not occurring. Site-specific evaluation of current conditions has determined that human exposure to contaminants at levels expected to cause adverse health effects is not currently occurring at the Site.

Boeing evaluated the need for a terrestrial ecological evaluation (TEE) in accordance with MTCA. TEEs address potential impacts on terrestrial plant and animal receptors from contaminated soil. The Site qualifies for an exemption from TEE because contaminated soil is located only on the Facility and all areas with contaminated soil are paved or covered by buildings, and the site is fenced. Boeing plans to place institutional controls on its property limiting future land use in compliance with the TEE exemption.

2.4 Previous Interim Actions/Remedial Actions

An interim remedial action (IRA) and a pilot test were previously performed at two separate Site locations using enhanced *in situ* bioremediation (EISB) in groundwater at the Site. The locations of the IRA and the pilot test are shown on Figure 2-5. A full description of the IRA is provided in the IRA reports (LAI 2004a, c, 2005a, b, 2008) and in the RI report (LAI 2017h). A full description of the pilot test is provided in the pilot test reports (LAI 2017e, 2018b). Brief summaries of the IRA and the pilot test are provided below.

2.4.1 Former Building 17-05 Interim Remedial Action

An IRA was completed in former Building 17-05 in 2004 and 2005 for treatment of releases from SWMU S-12b (a former TCE degreaser) and AOC A-08 (a former tank line adjacent to the degreaser). Concentrations of TCE historically detected in groundwater indicated that S-12b and A-08 were TCE

[6] Site-specific risk assessments conducted by WDOH indicate that the populations with the most potential for exposure are workers who clean the ditches and children who may play in the ditches. The general adult population is not expected to have significant exposure to ditch water.

release areas contributing to the Area 1 groundwater plume. The IRA consisted of injecting electron donor amendments (sodium lactate and emulsified vegetable oil) into the subsurface to enhance reductive dechlorination of TCE in groundwater. The Injection was completed at the Area 1 release area near current wells AGW002R and AGW106R. Nested injection wells were used to deliver donor to the shallow groundwater zone and the upper portion of the intermediate groundwater zone. Three donor injections were completed utilizing 32 injection wells and an additional monitoring well in July 2004, January 2005, and October 2005. The donor injections created sulfate-reducing to methanogenic conditions that have persisted more than 10 years post-injection at some locations. The IRA was highly effective in reducing release area concentrations of TCE and breakdown products. The combination of injected electron donor and the highly reduced aquifer conditions facilitated reductive dechlorination of TCE through cDCE, VC, and to the non-toxic end product ethene. Even though the IRA was highly successful in decreasing total CVOCs in the injection area, concentrations of VC in some wells in the injection area remain above the surface water quality standards (SWQS) for groundwater described in Section 3.0. The SWMU S-12b and AOC A-08 release areas have been incorporated into AOC A-14 for evaluation of Site-wide TCE and VC groundwater remediation.

2.4.2 Algona Enhanced Natural Attenuation Pilot Test

The enhanced natural attenuation pilot test was performed upgradient of an area where low concentrations (less than 5 micrograms per liter [µg/L]) of volatile organic compounds (VOCs) in groundwater extend beneath the northeast corner of the Algona residential neighborhood. The purpose of the pilot test was to evaluate the potential to enhance natural attenuation of low concentrations of VOCs through injection of electron donor substrates into groundwater. The pilot test also evaluated substrate injection design. The enhanced natural attenuation pilot test injection was conducted in August and September 2015 (LAI 2017e, 2018b). Approximately 80,000 gallons of electron donor solution was injected into the shallow groundwater zone in five injection/extraction wells. Monitoring of the results following this pilot test injection is still ongoing. The donor injection enhanced the moderate total organic carbon (TOC) and methanogenic redox conditions that were already present in the area. Total CVOC concentrations initially increased following the injection because of enhanced desorption, but then decreased substantially below baseline because of mass destruction. Reduction of total CVOC concentrations related to the pilot test injection occurred up to 385 ft downgradient of injection wells. TCE and cDCE concentrations are mostly below laboratory reporting limits at wells impacted by the Algona pilot test injection. VC concentration trends increased following the injection because of breakdown of parent compounds; however, concentrations currently appear to be decreasing. The decreasing VC trends are expected to continue as cDCE concentrations have decreased and VC is progressively transformed along the reductive dechlorination pathway. The pilot test was successful in reducing total CVOC concentrations in a limited area around the injection area; however, concentrations of VC in the injection area and downgradient continue to be up to two orders of magnitude above the SWQS in groundwater described in Section 3.0.

3.0 PROPOSED CLEANUP STANDARDS

Cleanup standards consist of three distinct components: 1) regulatory requirements that apply to the Site (applicable state and federal laws; WAC 173-340-700); 2) cleanup levels for hazardous substances present at the Site; and 3) the location where the cleanup levels must be met (POC). This section discusses the process to develop cleanup standards at the Site and the proposed cleanup standards including pCULs. The proposed cleanup standards were used in development and evaluation of cleanup alternatives that are presented in Sections 5.0 through 7.0 of this report. The cleanup standards discussed in this section are proposed for Ecology review. Final cleanup standards will be approved by Ecology through incorporation into the final cleanup action plan. In addition to cleanup standards, this section discusses the proposed use of remediation levels (RELs) as a tool to guide the use and transition of cleanup actions at the Site.

3.1 Regulatory Considerations

In accordance with MTCA, all cleanup actions must comply with applicable state and federal laws (WAC 173-340-710[1]). MTCA defines applicable state and federal laws to include applicable or relevant and appropriate requirements (ARARs). The MTCA cleanup regulation (WAC 173-340) outlines requirements for the development of cleanup standards and procedures for development and implementation of a cleanup. MTCA and the other ARARs that may be applicable to the development of cleanup standards or implementation of cleanup actions are presented in Table 3-1. For the purpose of developing pCULs, the following ARARS were considered in addition to MTCA:

- Federal Clean Water Act Water Quality Standards
- Washington State Surface Water Quality Standards
- Washington State Maximum Contaminant Levels in Drinking Water
- National Primary Drinking Water Regulations.

3.2 Proposed Cleanup Levels

In the RI, preliminary screening levels were developed for all evaluated constituents and used to determine IHSs[7] and COCs.[8] As part of the FS, pCULs have been developed for IHSs and other COCs identified in soil, groundwater, and surface water. The pCULs were revised from the preliminary screening levels established in the RI to account for migration pathways and new or revised ARARs as described below. The pCULs for soil, groundwater, and surface water are presented in Tables 3-2 through 3-4.

[7] Per WAC 173-340-200, IHS are defined as "the subset of hazardous substances present at a site selected under WAC 173-340-708 for monitoring and analysis during any phase of remedial action for the purpose of characterizing the site or establishing cleanup requirements for that site."

[8] COCs are those constituents that are analyzed to evaluate releases from each AOC that may or may not be identified as an IHS. IHS constituents were identified in the RI report (LAI 2017h).

3.2.1 Soil

Soil pCULs were developed for IHSs in soil (TCE, antimony, cadmium, cyanide, diesel-range organics [DRO], oil-range organics [ORO], and gasoline-range organics [GRO]) and other COCs analyzed during FS investigation activities (benzene, toluene, ethylbenzene, and xylene [BTEX]; copper; nickel).[9] In the RI, preliminary screening levels were based on Method B unrestricted cleanup levels to account for the most conservative exposure scenarios. In this FS, soil pCULs are developed based on industrial worker exposure scenarios (Method C) with the expectation that environmental covenant and institutional controls would be placed on the property to restrict future change in land use. All identified soil contamination at the Site is on the Boeing Auburn Facility and the Facility meets the applicability criteria identified in WAC 173-340-745(1)(a), so Method C industrial cleanup levels are appropriate. Under MTCA Method C, soil cleanup levels must be at least as stringent as all of the following:

- "Concentrations established under applicable state and federal laws."
- "Concentrations that result in no significant adverse effects on wildlife..." As demonstrated in the RI and approved by Ecology, establishing a soil concentration protective of terrestrial ecosystems is unnecessary at this Site.
- "For hazardous substances for which sufficiently protective, health-based, criteria or standards have not been established under applicable state and federal laws, those concentrations that protect human health as determined by evaluating the following exposure pathways:"
  - Groundwater protection; concentrations determined using methods described in WAC 173-340-747.
  - Soil direct contact; concentrations determined using MTCA Equations 745-1 or 745-2.
  - Soil vapors.

These criteria were considered during development of soil pCULs. Soil pCULs are based on protection of groundwater (where required) or direct-contact exposure of industrial workers. No ARARs are available for IHSs or COCs in soil.

For hazardous substances that do not exceed groundwater pCULs, current concentrations in soil are considered empirically protective of groundwater and, therefore, only Method C direct-contact pCULs were considered. As documented in WAC 173-340-747(3)(f), an empirical demonstration may be used to show that measured concentrations in soil would not cause an exceedance of groundwater pCULs. For constituents that exceed pCULs in groundwater, both Method C direct contact and protection of groundwater as drinking water (if available) were evaluated. Although a few constituents that exceed groundwater pCULs are also found in soil, Site cleanup is expected to reduce groundwater concentrations below the pCULs in the future; at that point soil concentrations would be considered

[9] Arsenic is sampled in groundwater as part of the interim groundwater monitoring program; however, arsenic is not associated with any of the AOCs identified for evaluation in the FS and was not detected above screening levels identified in the RI, so it is not included as a COC.

empirically protective of groundwater (soil would not be contributing to exceedances of groundwater pCULs). MTCA does not require cleanup levels to remain static in perpetuity as site conditions change; as such, the soil pCULs would revert to the Method C direct-contact concentration (WAC 173-340-747[3][f]) at the point where soil is no longer contributing to exceedance of the groundwater pCUL for that constituent.

Adjustments to pCULs were also made to account for natural background (WAC 173-340-740[5][c]), where appropriate. Only the pCUL for cadmium was adjusted upward to the natural background level published by Ecology (Ecology 1994). No COCs required adjustment for laboratory practical quantitation limits (PQLs; WAC 173-340-740[5][c]). Soil pCULs are provided in Table 3-2.

Antimony was listed as an IHS in soil in the RI report based on exceedances of the RI screening level; however, in the FS, it is eliminated as a COC in soil because there were no detections above the soil pCUL and no groundwater contamination. Antimony is shaded grey in Table 3-2 to identify that it is no longer being considered in the FS. Antimony is not associated with an AOC evaluated as part of the FS and is not discussed further.

Petroleum hydrocarbons are detected in soil at two separate locations (AOC A-01 and AOC A-13), both on the Boeing property. Groundwater pCULs were evaluated separately for AOC A-01 and AOC A-13 because of differences in petroleum hydrocarbon composition at the two locations.

AOC A-01

Soil impacts at AOC A-01 are related to releases from gasoline and diesel USTs. Petroleum hydrocarbon impacts are primarily GRO and small amounts of DRO. Method A industrial values are appropriate for this area and were used as the pCULs presented in Table 3-2. Method C values were not calculated since volatile petroleum hydrocarbons (VPH) and extractable petroleum hydrocarbons (EPH) analysis were not conducted on soil samples collected in this area.

AOC A-13

Soil impacts at AOC A-13 are related to a hydraulic oil release. Petroleum hydrocarbon impacts are primarily DRO and ORO. Often, establishing a site-specific petroleum hydrocarbon cleanup level is appropriate for sites with diesel and heavy oil releases (i.e., DRO and ORO; Ecology 2016). To calculate Method C values, samples must be analyzed for petroleum fractions (EPH).[10] EPH analysis provides results for aromatic and aliphatic hydrocarbons in specific carbon ranges (e.g., C10 to C12). EPH data are then entered into Ecology's total petroleum hydrocarbon (TPH) workbook tool (Ecology 2007) to calculate Method C values protective of direct contact and groundwater. The workbook provides a TPH value that reflects the combined DRO and ORO hydrocarbon ranges. Therefore, DRO and ORO

[10] VPH were not analyzed because samples on which the analysis was completed did not contain significant fractions of volatile hydrocarbons.

results from standard northwest total petroleum hydrocarbon diesel-range extended (NWTPH-Dx) analysis are combined for comparison to the Method C TPH value.

One soil sample (ASB0160R-17.5) was analyzed for EPH as part of the RI in the AOC A-13 release area. This soil sample is considered representative of the contamination in the area and has the highest petroleum hydrocarbon concentrations in soil detected at AOC A-13 (See Section 4.3). As shown in Table 3-2, the calculated Method C protection of direct-contact TPH concentration is 192,939 milligrams per kilogram (mg/kg). The calculated protection of groundwater (soil leaching) TPH concentration is 71,000 mg/kg (calculated 100 percent non-aqueous phase-liquid [NAPL] residual saturation value). The EPH results for ASB0160R-17.5 and the completed TPH workbook tool spreadsheets are provided in Appendix A.

3.2.2 Groundwater

Groundwater pCULs were developed for IHS in groundwater established in the RI (TCE, VC, cadmium, GRO, DRO, ORO) and other COCs analyzed during FS investigation activities (BTEX, arsenic, copper, nickel, and cyanide). For groundwater, the location and extent of contaminants factor into the development of pCULs. With the exception of TCE and VC, IHSs and COCs in groundwater are found only in localized areas on the Boeing property and are not migrating off site. TCE and VC are present site-wide and, therefore, were given additional consideration with respect to developing pCULs.

TCE and VC are detected in downgradient portions of the groundwater plumes and have been detected in some stormwater conveyance and treatment features that intercept shallow groundwater. Ecology has requested that Boeing develops cleanup levels for groundwater that are equal to the SWQS. Boeing has assessed the regulatory requirements under MTCA for developing groundwater cleanup levels and has concluded that, while the regulations stipulate that groundwater cleanup levels must be protective of surface water beneficial uses, they do not require that groundwater cleanup levels be equal to SWQS throughout the Site.[11]

When developing groundwater cleanup levels based on ARARs, MTCA regulations require that the technical and procedural requirements of the ARARs must be considered. Specifically, the pertinent technical and procedural requirements and limitations under the National Toxics Rule (NTR; 40 Code of Federal Regulations [CFR] 131.45) and WAC 173-201A (applicable ARARs for TCE and VC that the MTCA regulations state must be adhered to) are that “waters shall maintain a level of water quality **when entering downstream waters** [emphasis added] that provides for the attainment and maintenance of the water quality standards of those downstream waters...” Furthermore, a close reading of WAC 173-340-720(4) and 730 indicates that the interplay of those sections requires setting a groundwater cleanup level that is “in accordance with” the protection of surface water. This means

[11] WAC 173-340-720(1)(c) requires that “Ground water cleanup levels shall be established at concentrations that do not directly or indirectly cause violations of surface water, sediments, soil, or air cleanup standards established under this chapter or other applicable state and federal laws.” It does not require that groundwater cleanup levels be equal to SWQS.

setting a groundwater cleanup level protective of surface water, not simply applying the SWQS as the groundwater cleanup level itself, and particularly not significantly upgradient of the point where groundwater enters surface water.

Furthermore, WAC 173-340-355 requires that cleanup action alternatives must comply with cleanup standards (when complete) including the requirement that cleanup levels are met in all media at the applicable points of compliance. WAC 173-340-330 specifies requirements for a site to be delisted and specifies that a site may only be removed from the hazardous sites list when "…all remedial actions, except confirmational monitoring, have been completed and compliance with the cleanup standards has been achieved at the site." Because cleanup is not considered complete until both groundwater and surface water throughout the Site meet their respective cleanup standards, separate cleanup standards for groundwater and surface water would be protective of human health and the environment.

Despite clear regulatory direction that separate cleanup levels should apply to each media and compliance should be measured for each cleanup level in each respective media[12], Ecology has insisted that Boeing apply SWQS for TCE and VC as cleanup levels in groundwater throughout the Site in order to protect surface water beneficial uses at the surface water POC. However, applying the SWQS to groundwater throughout the Site is not consistent with the MTCA regulations and applicable ARARs. Groundwater does not need to meet SWQS throughout the Site in order to protect surface water beneficial uses because concentrations in upgradient groundwater do not make their way to the surface water unattenuated. As described in Section 2.2, significant attenuation (including degradation) of concentrations occurs as contaminants make their way through the aquifer. In particular, very high rates of contaminant degradation have been demonstrated in the shallow groundwater zone along the west side of the valley and in the hyporheic zone of Mill Creek. Additionally, the plume centers of mass have been evaluated and determined to be stable (meaning they are not moving toward surface water) and are located significantly upgradient of the surface water features (LAI 2017h, 2019d). As Site cleanup occurs in the future, the contaminant plumes are expected to shrink back toward the center of mass (see discussion in Section 2.2).

In addition to the regulatory requirements discussed above, it should also be noted that applying SWQS that are intended to be protective of fish consumption to groundwater throughout the Site, where fish cannot possibly live, is unnecessary to protect surface water beneficial uses. As long as groundwater is cleaned up to levels protective of drinking water and SWQS are met where groundwater flows into surface water, groundwater and surface water would be protective of all applicable groundwater and surface water beneficial uses, including drinking water and fish

[12] WAC 173-340-720(8) discusses cleanup level point of compliance for groundwater and WAC 173-340-730(6) discusses cleanup level point of compliance for surface water. Specifically, WAC 173-340-730(6)(a) states that "the point of compliance for the surface water cleanup levels shall be the point or points at which hazardous substances are released to surface waters of the state…" and WAC 173-340-720(8)(d)(ii) specifically states "the point or points where the groundwater flows into the surface water".

consumption. In other words, applying SWQS to groundwater does not increase protection of human health or the environment because there is already a requirement to achieve the applicable cleanup standards in surface water (the SWQS), regardless of the groundwater cleanup level. Achieving SWQS in the surface water fully protects surface water and its beneficial uses. Requiring that groundwater (particularly throughout the Site and up to a mile away from surface water features—i.e., Mill Creek) meet the SWQS provides no additional risk reduction.

The analysis above is consistent with MTCA and the Clean Water Act (authorizing law for the NTR). The following select references and excerpts further support the proper applicability of MTCA and the use of SWQS as groundwater cleanup levels:

- When it promulgated MTCA rules, Ecology rejected the concept of monitoring throughout an upland groundwater plume for compliance with surface water standards; as stated by Ecology "[W]here [groundwater] cleanup levels are based on protecting nearby surface water, compliance with [the surface water quality criteria,] **will generally be based on surface water monitoring performed as close as possible to the groundwater/surface water interface**..." (Ecology, Responsiveness Summary for the Amendments to MTCA Cleanup Regulation Chapter 173-340 WAC, 1991).
- With regard to remediating groundwater and determining compliance of groundwater entering surface water to meet federal surface water standards, EPA states: "[w]here groundwater flows naturally into surface water, the ground-water remediation should be designed so that the receiving surface water body will be able to meet any ambient water-quality standards (such as State WQS…) that may be ARARs for the surface water. This means that the [SWQS] should be considered when establishing cleanup levels for the ground water at those sites, but they are not necessarily ARARs for the cleanup of ground water" (US Environmental Protection Agency [EPA], ARARs Q's and A's: Compliance with Federal Water Quality Criteria, 1990).
- Regarding the applicability of the CWA, a clear distinction was defined and made between the point at which groundwater transitions to and may be considered surface water: "surface expressions of groundwater...where groundwater emerges on the surface and becomes base flow in streams or spring fed ponds" (Clean Water Rule, 80 Fed. Reg.); at that point, "when groundwater emerges on the surface, it is surface water, and the resulting water feature is potentially regulated under the Clean Water Act" (Clean Water Rule Response to Comments – Topic 7: Features and Waters Not Jurisdictional).

Additional information further demonstrating that the application of SWQS to groundwater is improper can be found in Appendix B.[13]

The sections below present pCULs for groundwater based on protection of drinking water, developed in accordance with the MTCA regulation WAC 173-340-720. At Ecology's request, the SWQS have also

[13] Also see Boeing's July 2017 Dispute Resolution Submittal to Ecology regarding the Boeing Everett Site and the attached legal analysis regarding Ecology's application of SWQS as groundwater cleanup levels for that Site.

been evaluated for use as groundwater cleanup levels in lieu of the drinking water standards. Section 3.2.3 presents pCULs for surface water.

3.2.2.1 Protection of Groundwater as Drinking Water

In this FS, groundwater pCULs are based on estimates of the highest beneficial use and the reasonable maximum exposure expected to occur under both current and potential future Site use conditions (WAC 173-340-720). Contaminated groundwater is not being used for drinking water at the Site, nor is groundwater within the area of the plumes expected to be used as a drinking water source in the future. However, based on the MTCA requirements under WAC 173-340-720(1), pCULs must be developed to protect drinking water. Under MTCA Method B, groundwater cleanup levels must be at least as stringent as all of the following:

- "Concentrations established under applicable state and federal laws."
- "Concentrations established in accordance with the methods specified in WAC 173-340-730 for protecting surface water beneficial uses, unless it can be demonstrated that hazardous substances are not likely to reach surface water." The applicability of protection of surface water beneficial uses is discussed above.
- "For hazardous substances for which sufficiently protective, health-based, criteria or standards have not been established under applicable state and federal laws, those concentrations that protect human health…" Concentrations are determined using MTCA Equations 720-1 or 720-2.

These criteria were used in development of groundwater pCULs.

Where appropriate, pCULs were also adjusted for natural background (WAC 173-340-720[7][c]). Only the pCUL for arsenic was adjusted upward to the natural background levels published by Ecology (PTI 1989). No COCs required adjustment for laboratory PQLs (WAC 173-340-720[7][c]). Groundwater pCULs are provided in Table 3-3.

MTCA requires that the combined risk of chemical mixtures be considered when developing cleanup standards (WAC 173-340-720[7][a]). Because natural attenuation is actively occurring at the Site and converting TCE to breakdown products, it does not make sense to adjust cleanup level concentrations based on the current chemical composition in groundwater when it would inevitably change over time. Instead, Boeing proposes to evaluate whether compliance points meet cleanup objectives by conducting routine assessments of combined chemical risks for both carcinogens and non-carcinogens based on constituents and concentrations present at that time. The procedures for conducting the evaluation are described in the FSWP (LAI 2017g) and will be presented in detail in the cleanup action plan.

Of the COCs evaluated during the FS, arsenic was eliminated because concentrations are below pCULs, there is no history of its use or release at the Site, and the concentrations found in groundwater are

consistent with background concentrations within the region. Arsenic is shaded grey in Table 3-3 and is not discussed further.

Petroleum hydrocarbons are detected in groundwater at two separate locations (AOC A-01 and AOC A-13), both on the Boeing property. Groundwater pCULs were evaluated separately for AOC A-01 and AOC A-13 because of differences in petroleum hydrocarbon composition at the two locations.

AOC A-01

Groundwater impacts at AOC A-01 are related to releases from gasoline and diesel USTs. Petroleum hydrocarbon impacts at AOC A-01 are primarily GRO and small amounts of DRO. The impacts to groundwater are localized and do not leave the Boeing Auburn property. Method A groundwater cleanup levels for unrestricted land uses were used for pCULs (presented in Table 3-3). Method B values were not calculated because Method A values are appropriate for this area and VPH and EPH analysis (required to calculate a Method B pCUL) were not conducted on groundwater samples collected in this area.

AOC A-13

Groundwater impacts at AOC A-13 are related to a hydraulic oil release. Petroleum hydrocarbon impacts are in the DRO and ORO hydrocarbon ranges. The impacts to groundwater are localized and do not leave the Boeing Auburn property. At AOC A-13, Method B was used to determine groundwater pCULs protective of drinking water. To calculate Method B values, samples must be analyzed for EPH.[14] EPH analysis provides results for aromatic and aliphatic hydrocarbons in specific carbon ranges (e.g., C10 to C12). EPH data are then entered into Ecology's TPH workbook tool (Ecology 2007) to calculate Method B values protective of groundwater as drinking water. The workbook provides a TPH value that reflects the combined DRO and ORO hydrocarbon ranges. Therefore, DRO and ORO results from standard NWTPH-Dx analysis are combined for comparison to the Method B TPH value.

Two groundwater samples representative of the area (AGW128 and AGW281), were collected as part of the FS at AOC A-13 and analyzed for EPH to determine a Method B pCUL. As described in the Ecology guidance for Method B Groundwater TPH cleanup level development (Ecology 2016), the median of the calculated Method B values from each sample is used as the pCUL. As shown in Table 3-3, the Method B groundwater pCUL (median calculated value rounded to two significant figures) is 20,000 µg/L. Groundwater EPH results and the completed TPH workbook tool spreadsheets for AGW128 and AGW281 are provided in Appendix A.

[14] VPHs were not analyzed because samples on which the analysis was completed did not contain significant fractions of volatile hydrocarbons.

3.2.2.2 Surface Water Quality Standards in Groundwater

In accordance with Ecology's request in its June 28, 2019 letter (Ecology 2019), Boeing is presenting SWQS applicable to Mill Creek. Though the application of surface water criteria to groundwater is unlawful, Ecology has requested that the SWQS protective of fish consumption and drinking water be used as groundwater cleanup standards for TCE and VC because they are present in downgradient portions of the plume. The SWQS proposed by Ecology (0.30 µg/L for TCE and 0.02 µg/L for VC) are found in the NTR and WAC 173-201A, respectively.

Boeing disagrees with Ecology's direction to impose SWQS on groundwater throughout the Site as discussed above, in Appendix B, and elsewhere. Additionally, achieving groundwater concentrations meeting the extremely low SWQS for TCE and VC Site-wide within a reasonable restoration time frame is technically impracticable because of the complex nature of a heterogeneous aquifer, the distribution of contaminants, and hydraulic and geochemical interactions of CVOCs with the saturated aquifer matrix (see Section 2.2). Further justification of this technical impracticability is presented in Section 3.2.2.3. Additionally, as described above, even if groundwater concentrations meeting the SWQS could be achieved throughout the Site, it would not result in additional risk reduction.

Groundwater pCULs provided in the FS are based on application of the drinking water standards throughout the Site. However, to comply with Ecology's directive, the FS evaluation also considers the application of the SWQS for TCE and VC in groundwater throughout the Site. Therefore, the remedial alternatives for groundwater discussed in Sections 5.0 through 7.0 include evaluation of cleanup of TCE and VC to groundwater pCULs (4.0 µg/L for TCE and 0.2 µg/L for VC) and the SWQS (0.3 µg/L [TCE] and 0.02 µg/L [VC], as shown in Table 3-3).

3.2.2.3 Practicability of Meeting the Surface Water Quality Standards in Groundwater

Determining the feasibility of remedial alternatives or components includes evaluation of whether they would be "technically possible at the site" (WAC 173-340-350[8][b][ii]) or disproportionately costly (see Section 6.0). Based on the current state of the science for remediation of CVOC sites (discussed below), no known current "active" [15] remedial technology (technology that is implemented beyond naturally occurring treatment) is capable of achieving extremely low cleanup levels, such as the SWQS for TCE of 0.3 µg/L and VC of 0.02 µg/L, in groundwater throughout the Site.

In order for the SWQS to be achieved in groundwater throughout the Site through an implemented technology, such as those described in Alternatives D2 through D5 (Section 5.5), concentrations would have to be reduced by that technology over an order of magnitude below the state or federal drinking

[15] The term "active" is only being used in this section in reference to the use of the technologies documented in the Environmental Security Technology Certification Program (ESTCP) study discussed below (such as EISB, *in situ* chemical oxidation (ISCO) sites, thermal treatment, chemical reduction, and surfactant flushing sites. However, note that per MTCA the Site has the appropriate conditions (WAC 173-340-370[7]), and monitored natural attenuation (MNA) is also considered an active remedial measure and is referred to as such in the rest of this document.

water maximum contaminant level (MCL; 5 µg/L) for TCE and 2 orders of magnitude below the state and federal drinking water MCL (2 µg/L) for VC. The available literature and data, as discussed below, indicate that achieving reductions to such low concentrations of CVOCs throughout the groundwater plumes is unachievable by any currently available "active" remedial technologies within a reasonable restoration time frame.

In a recent US Department of Defense (DOD) Environmental Security Technology Certification Program (ESTCP) publication (GSI Environmental 2016), a large data mining and evaluation exercise was completed to develop a comprehensive remediation performance database. In this study, data from 235 DOD CVOC cleanup sites were evaluated that used *in situ* remediation technologies, including 117 EISB sites, 70 *in situ* chemical oxidation (ISCO) sites, 23 thermal treatment sites, 21 chemical reduction sites, and four surfactant flushing sites.[16] The study evaluated parent CVOC concentrations at each site before and after cleanup, and the corresponding order of magnitude concentration reductions achieved at the site for the various remedial technologies. The results of the study identified that the mean concentration reduction for all 235 sites was 1.1 orders of magnitude (91 percent) for the parent compound in the treatment zone, and "Only 7% of 235 sites achieved MCLs (e.g., 5 µg/L for TCE) at every monitoring well…" within the treatment zone (GSI Environmental 2016). These performance results were reportedly statistically consistent regardless of the time frame of active remediation or the duration of monitoring following the active treatment period.[17] Only one site achieved a final parent CVOC concentration that was at or below 1 µg/L in the treatment zone (actual final concentration was not identified).[18] The results above evaluate only the reduction in parent CVOC concentration. One section of the study evaluated reduction in total CVOCs and results indicate considerably worse performance.

For technologies that could be applicable to the Site (EISB and chemical reduction), the mean reduction in total CVOCs was only between 0.4 and 0.6 orders of magnitude for total CVOCs. The distinction between parent compound reduction and total CVOC reduction is important because at the Site the parent TCE compound is converted to the VC daughter product and Site cleanup cannot be achieved until both TCE and VC meet cleanup levels. The analysis of total CVOC reduction provides insight into the difficulty of reducing concentrations of daughter products. Additionally, it is important to point out that the study focused exclusively on measurements at monitoring points within the treatment zone. So, while a few sites did achieve MCLs within the treatment zone, they did not necessarily achieve MCLs outside of the treatment zone. This is an important consideration when making a comparison to the Boeing Auburn Site because the large diffuse nature of the groundwater

[16] DOD cleanup sites provide a particularly relevant sample for consideration here because of the number of DOD sites that historically used solvents, particularly TCE, and that have dispersed, mature TCE groundwater plumes. (*See generally* GSI Environmental 2016.)

[17] Active treatment durations for these projects ranged from less than 1 year to more than 13 years and monitoring periods after completion of active treatment ranged from less than 1 year to more than 18 years.

[18] The specific identification of the hydrogeologic conditions, history, and nature and extent of contamination at this site were not reported, so direct comparisons to conditions at the Site were not possible.

plume makes active treatment of all areas of the plume impractical. Note that this study focused on sites meeting MCLs, not levels as low as SWQS in groundwater.

The ESTCP study also compared the results of 45 site where MNA (proposed as the only remedial technology under Alternative D1, and as a supplemental technology under the other Alternatives) has been applied against the results of the other 235 sites where other "active" technologies were applied. The study concluded that MNA was as successful as more "active" technologies as described below.

- The application of MNA achieved median order of magnitude reductions of the parent CVOC concentrations slightly lower that of the other technologies.
- MNA sites generally had lower starting concentrations than the other sites.
- The extrapolated median reduction in restoration time frames of the other remedial technologies compared to MNA was about 13.5 years (assuming no rebound after completing implementation of the other technologies).
- A data chart in the study report indicated that 6 of the 45 sites (13.3 percent) where MNA was applied reached parent CVOC concentrations at or below the MCL, with 2 of the sites apparently reaching a final concentration as low as 1 µg/L (the parent CVOC was not identified nor were the results for daughter products).

These findings indicate that MNA did reach drinking water standards in a small proportion of sites, but did not achieve concentrations as low as the SWQS for TCE and VC; however, the longest MNA monitoring period identified in the study was 15 years. It is possible that, given sufficient time, MNA could eventually reach the cleanup standards for all CVOCs at sites where natural attenuation processes result in complete reductive dechlorination.

The ESTCP study builds on previous studies (e.g., ITRC 2011; NRC 2005, 2013) that reached similar conclusions regarding the impracticability of achieving typical cleanup levels (e.g., MCLs) in a reasonable restoration time frame in aquifers impacted by CVOC contaminants. It is widely understood and accepted, based on numerous studies and publications (e.g., Ball et al.1998; Chapman and Parker 2005; Mackay and Cherry 1989; Sale et al. 2008), that the primary factor that limits an *in situ* remedial action's ability to achieve very low cleanup levels is matrix diffusion (back diffusion and desorption) related to low-permeability soils such as silts and clays, which can be a very slow process and result in the cleanup of groundwater taking many decades or centuries. The findings in these studies are directly applicable to the Boeing Auburn Site because back diffusion is an actively occurring process at the Site and calculated restoration time frames for the Site are consistent with the findings in the cited literature. Specifically, the matrix diffusion effects for TCE adsorbed to silts in the aquifer may result in the ongoing presence of TCE and VC in groundwater above the SWQS that may persist for many decades or centuries.

Based on these data and studies, it appears that it is not technically possible using any "active" remedial technology or combination of technologies to achieve the SWQS at the groundwater

standard POC (throughout the Site). Pursuant to WAC 173-340-350(8)(b)(ii), application of SWQS as groundwater cleanup levels for the Site would screen out all applicable remedial technologies because it is not technically possible to achieve SWQS in groundwater. However, to satisfy Ecology's request to perform and evaluation of the remedial alternatives assuming SWQS must be met in groundwater throughout the Site, the analysis provided in the remainder of this FS assumes that with the inclusion of MNA, each of the Alternatives would eventually reach the SWQS in groundwater.

3.2.3 Stormwater and Surface Water Features

Surface water screening levels in the RI were established and approved by Ecology based on highest beneficial use and reasonable maximum exposure for the various types of stormwater and surface water. For example, Washington State water quality criteria protective of drinking water and fish consumption were used for Mill Creek, but Site-specific health risk-based criteria were developed for stormwater conveyance, treatment, and control structures (e.g., Chicago Avenue ditch) because these structures are not expected to be used for drinking water at any point in the future and individuals are not expected to consume aquatic organisms from these structures at any time in the future because the stormwater structures do not support adequate adult fish/shellfish habitat. Health risk-based screening levels for stormwater conveyance, treatment, and control structures were developed based on reasonable maximum exposure scenarios that included direct human contact, incidental ingestion, and inhalation. The reasonable maximum exposure scenarios were reviewed and approved by both Ecology and WDOH (LAI 2013; WDOH 2013, 2014). In developing Site-specific health risk-based criteria for stormwater features, Ecology and WDOH recognized that the exposure scenarios for these types of structure are unique and that applying SWQS criteria based on drinking water and fish consumption was not appropriate for setting Site screening levels. However, Ecology noted that these screening levels could not be applied as cleanup levels. Boeing does not believe that pCULs are necessary for stormwater features because contaminant concentrations are below risk-based human health screening levels (as described in Section 2.3).

Additionally, the SWQS regulation specifically indicates that it is not intended for application to human-created waters managed primarily for the removal or containment of pollution (WAC 173-201A-260[3]). Numerous examples of how SWQS should be applied can be found in regulation and policy documents that utilize the SWQS (e.g., Stormwater Management Manual for Western Washington, Washington State National Pollution Discharge and Elimination System permits, Ecology's Stormwater Sampling Manual, Ecology's Water Quality Program Permit Writer's Manual). Additional discussion on the application of SWQS to these types of waters is provided in Appendix B.

Boeing agrees with Ecology that the SWQS apply to surface water features such as Mill Creek and the applicable SWQS for Mill Creek are discussed below. However, Boeing disagrees with Ecology's directive to apply cleanup levels equal to SWQS criteria protective of drinking water and fish consumption to all stormwater conveyance, treatment, and control structures and provides further justification in Appendix B.

For the purpose of establishing pCULs for surface water in Mill Creek, WAC 173-340-730 provides direction on determining surface water cleanup levels. Under Method B, surface water cleanup levels must be at least as stringent as the following:

- "Concentrations established under applicable state and federal laws, including the following requirements:"
  - "All water quality criteria published in the water quality standards for surface water of the state of Washington, chapter 173-201A WAC"
  - "Water quality criteria based on the protection of aquatic organisms (acute and chronic criteria) and human health published under section 304 of the Clean Water Act unless it can be demonstrated that such criteria are not relevant and appropriate for a specific surface water body or hazardous substance"
  - "National toxic rule (40 C.F.R. Part 131)"
- "For hazardous substances for which environmental effects-based concentrations have not been established under applicable state or federal laws, concentrations that are estimate to results in no adverse effects on the protection and propagation of wildlife, fish, and other aquatic life…"
- "For hazardous substances for which sufficiently protective, health-based, criteria or standards have not been established under applicable state and federal laws, those concentrations that protect human health….". Concentrations determined using MTCA Method B Equations 730-1 or 730-2.

Although no COCs in surface water exceeded screening levels in the RI, surface water pCULs are developed for TCE and VC as part of the FS.[19] No aquatic life criteria are available for TCE or VC; however, both compounds have SWQS established under WAC 173-201A and the NTR.[20] Surface water pCULs for Mill Creek were set at the SWQS. Surface water pCULs are presented in Table 3-4.

3.3 Points of Compliance

This section discusses the process used to establish POCs as part of the development of proposed cleanup standards, and for use in the FS evaluation. Proposed POCs will be finalized in the cleanup action plan.

3.3.1 Soil Point of Compliance

The standard POC where soil cleanup levels protective of direct human contact must be met is throughout a site from the ground surface to 15 ft bgs, in accordance with WAC 173-340-740(6)(d). The standard POC where soil cleanup levels protective of groundwater must be met is throughout a

[19] No state or federal criteria are available for cDCE because insufficient toxicity information is available. Detections of cDCE in stormwater are well below drinking water criteria. No surface water pCUL for cDCE has been developed.

[20] State water quality criteria from WAC 173-201A were partially revised by the US Environmental Protection Agency (EPA) as part of the approval process that substituted the NTR criteria established under 40 CFR 131.45 for some COCs. However, EPA has proposed rulemaking to withdraw most of the human health criteria for Washington found in the NTR. The rulemaking process is still underway as of submittal date of this report.

site, in accordance with WAC 173-340-740(6)(b). For the Site, where certain IHSs in groundwater are the result of leaching from soil; the proposed soil POC for COCs required to be protective of groundwater (shown in Table 3-2) would be throughout the Site. For all other COCs, or when groundwater is sufficiently cleaned up and the soil cleanup levels revert to protection of direct contact, as described in Section 3.2.1, the soil POC throughout the Site would be from the ground surface to 15 ft bgs.

MTCA also recognizes that when cleanup actions involve containment of hazardous substances, the soil cleanup levels would typically not be met at the POCs specified above. MTCA establishes conditions that must be met for the cleanup action to comply with the cleanup standards (WAC 173-340-740[6][f]). Some of the alternatives discussed in Section 5.0 include containment remedies; therefore, cleanup actions would comply with WAC173-340-740[6][f] for these remedies.

3.3.2 Groundwater Point of Compliance

For the purposes of evaluating cleanup alternatives in this FS, a standard POC was used for groundwater. Additionally, conditional points of compliance (CPOCs) were considered because achieving the pCUL based on protection of drinking water and specifically achieving the SWQS in groundwater, as required by Ecology and discussed above, cannot be achieved in a reasonable restoration time frame.

The standard POC for groundwater is throughout groundwater at the Site, in accordance with WAC 173-340-720(8). A CPOC is an alternative point or points (typically downgradient of the contaminant source) where compliance with the cleanup standards must be demonstrated. A CPOC may be used for a site (in accordance with WAC 173-340-720[8][c,d]) if it can be demonstrated that it is not practicable to meet the cleanup levels throughout the site in a reasonable restoration time frame, and that all practicable methods of treatment are to be used in the site cleanup.[21] Boeing may pursue use of a CPOC downgradient of the release areas and possibly within the transition zone near Mill Creek. If Ecology requires the use of SWQS as the cleanup level for groundwater, Boeing is unaware of any other method (other than a CPOC at the transition zone or an area-wide CPOC) to meet MTCA's requirement that cleanup levels be achieved in a reasonable restoration time frame. There are two possible options for an off property (off-Facility CPOC) under MTCA (WAC 173-340-720[8][d][ii, iii]), described in Sections 3.3.2.1 and 3.3.2.2 below. Alternately, Boeing may pursue one or more on-Facility CPOCs; MTCA specifically allows multiple points of compliance to address multiple sources and types of contamination (WAC 173-340-720[8][d][iii]). Use of on-Facility CPOCs are discussed in Section 3.3.2.3 below. The final determination for a CPOC can be made during the development of the cleanup action plan.

[21] The MTCA definition for practicable is "capable of being designed, constructed, and implemented in a reliable and effective manner including consideration of cost" (WAC 173-340-200). This means that the disproportionate cost analysis as described in Section 6.0 will be included in defining if the methods of treatment are practicable.

3.3.2.1 Off-Facility CPOC in Groundwater Near Surface Water

The Site meets the allowable criteria for use of an off-Facility CPOC under WAC 173-340-720(8)(d)(ii) for a property near, but not abutting, surface water because there is not a practicable means to meet cleanup levels throughout the Site in a reasonable restoration time frame (see discussion in Section 6.0). Use of this type of CPOC typically requires approval from "affected" property owners between the Facility and the CPOC (WAC 173-340-720[8][d][ii]). Obtaining approval from the large number of off-Facility property owners at the Site would be prohibitive and impractical; Ecology acknowledged this in its June 28, 2019 letter (Ecology 2019). However, approval from intervening property owners may not be required if the CPOC is used only to determine where SWQS would apply and drinking water criteria in groundwater are met throughout the Site. This is because meeting drinking water standards in groundwater throughout the Site is the expected outcome in order to allow the "highest beneficial use" of groundwater under "reasonable maximum exposure" scenarios (WAC 173-340-720[1][a]), so use of groundwater beneath off-Facility properties would not need to be restricted in any way. Once, groundwater is returned to beneficial use (as drinking water), intervening property owners would not be "affected" since groundwater beneath their property could be used for drinking water (the highest beneficial use). As written in MTCA, if a CPOC is used, there is not a requirement for a cleanup level upgradient of the CPOC location. Under that scenario, it would makes sense that the property owners would be "affected" because groundwater would not necessarily meet drinking water standards and may not be suitable for drinking. However, under the scenario Boeing is proposing, a cleanup level would apply upgradient of the CPOC, eliminating the requirement of the property owners to approve the CPOCs, since groundwater would meet drinking water standards beneath their property once cleanup is complete. If Ecology continues to require that Boeing apply SWQS to groundwater, Boeing could pursue an off-Facility CPOC for SWQS, but still propose that drinking water standards be met throughout the Site.

3.3.2.2 Off-Facility Area-wide CPOC

The Site also meets the allowable criteria for an area-wide CPOC under WAC 173-340-720(8)(d)(iii). An area-wide CPOC may be applied for "areas that are affected by hazardous substances released from multiple sources that have resulted in comingled plumes of contaminated groundwater that are not practicable to address separately." At the Facility, multiple releases from different sources at the Facility have resulted in large plumes (Western Plume and Area 1 Plume) that have commingled. Additionally, the Area 1 Plume is comingled with an off-Facility VOC source that originates upgradient and east of the Facility. For an area-wide CPOC, there is no requirement that the comingled sources originate from more than one Facility. Regardless, the RI demonstrated that there were several different sources of releases at the Site, and that there is at least one off-Facility source contributing to the plumes downgradient of the Facility. The Site is therefore also eligible for an Area-wide CPOC.

To apply an area-wide CPOC, the following conditions must be met:

- Demonstrate that it is not practicable to meet the cleanup levels throughout the site in a reasonable restoration time frame, and that all practicable methods of treatment are to be used in the site cleanup.[22]
- Develop a plan for implementation of cleanup action, including a description of obtaining access to affected properties.
- Demonstrate the public water systems have sufficient capacity to serve future development in these areas.
- Provide a mailed notice-of-proposal to establish an area-wide CPOC to property owners, tribes, local governments, and water purveyors with jurisdiction in the area and provide an opportunity to comment.

Section 6.0 of this FS provides the demonstration that it is not practicable to meet the cleanup levels throughout the site in a reasonable restoration time frame, and that all practicable methods of treatment are to be used in the site cleanup. Boeing will develop plans for bullets 2, 3, and 4 as part of the cleanup action plan, in conjunction with Ecology. An area-wide CPOC could be established for application of the surface water criteria to groundwater. Under this scenario, groundwater would meet drinking water standards throughout the Site, so there would be no concern about meeting drinking water needs with future development. Nonetheless, Boeing will consult with the City of Auburn, the sole drinking water provider within the downgradient area of both plumes, regarding future development and drinking water needs.

3.3.2.3 Facility Boundary CPOC

The Site is also eligible for a CPOC at the Facility boundary as provided in WAC 173-360-720(8)(c). A Facility boundary CPOC is allowable because it is not possible to meet SWQS in groundwater at the Site in a reasonable restoration time frame for CVOCs as discussed above.

3.4 Remediation Levels

When a cleanup involves multiple actions or components, REL concentrations or other qualitative or quantitative methods of identification of hazardous substances are used to determine when the cleanup actions would be modified or changed based on the progress of the cleanup. The use of RELs for cleanup of TCE and VC in groundwater (WAC 173-340-355) is appropriate at the Site.[23] Use of RELs would allow the remedy to progress and use appropriate, efficient, and effective technologies based on current conditions and performance of various cleanup action components. Boeing envisions RELs would be used to determine when certain remedial actions are complete including monitored natural attenuation (MNA) monitoring requirements at various locations. Because it is difficult to determine the exact timing of when a remedy would be sufficiently complete in a given area and because the

[22] The MTCA definition for practicable is "capable of being designed, constructed and implemented in a reliable and effective manner including consideration of cost." This means that the disproportionate cost analysis as described in Section 6.0 must be included in determining whether the methods of treatment are practicable.

[23] The use of RELs was recommended by Ecology in a letter dated February 28, 2019 (Ecology 2019).

RELs are expected to be similar for each alternative, RELs are not included in costs and comparative evaluations in Section 6.0. Depending on the final cleanup alternatives selected, RELs may be used at other AOCs in addition to AOC A-14. A detailed description of RELs, will be presented in the cleanup action plan.

4.0 CURRENT CONDITIONS

This section presents current conditions at each AOC evaluated as part of the FS. Current conditions include a summary of previous investigation results (data through the end of 2015) described in the RI Report (LAI 2017h) and updates the results to include FS investigation activities (2016 through the end of 2018).[24] FS investigation activities were conducted under the FSWP (LAI 2017g) and presented in a series of FS data submittals (discussed below). This section also provides estimates of the quantities of contaminated media that require cleanup at each AOC and describes the locations of the media requiring cleanup based on the pCULs described in Section 3.0.

4.1 AOC A-01: Building 17-06 Former USTs TAU-01 and TAU-02

AOC A-01 (A-01) consists of two former 10,000-gallon fuel USTs that were installed near the northwest corner of Building 17-06 in 1967. UST TAU-01 was a diesel tank used to power emergency generators and UST TAU-02 was a gasoline tank. Historical releases from the A-01 USTs resulted in soil and groundwater petroleum hydrocarbon contamination downgradient (north and northwest) of the USTs. Both tanks and a fuel island were removed in 1990 and approximately 500 cubic yards (yd^3) of contaminated soil was excavated from the former tank areas (Geomatrix 2003). In 2004, an additional 10 yd^3 of soil was also removed (LAI 2004d). Subsequent investigations indicate that some soil contamination was left in place and low-level groundwater contamination is still present in a limited area at A-01. COCs at this AOC include petroleum hydrocarbons (GRO, DRO, and ORO) and associated VOCs: BTEX. The extent of AOC A-01 and all exploration locations are presented on Figure 4-1. A cross-section of AOC A-01 including depths of the 1990 and 2004 excavations is presented on Figure 4-2.

4.1.1 Summary of Investigation Activities

RI investigations included collecting soil samples at 14 boring locations,[25] nine of which were converted to groundwater monitoring wells (AGW009 through AGW017). Groundwater samples were collected at all nine wells. One well, AGW010, is currently sampled as part of the interim Site-wide groundwater monitoring for petroleum hydrocarbons (GRO, DRO, and ORO) and BTEX. A complete summary of RI investigation activities is provided in the RI Report (LAI 2017h).

FS investigations were completed to refine the extent of remaining petroleum hydrocarbon contamination in soil and groundwater. Two subsurface drilling investigations included advancing nine soil borings (ASB0264 through ASB0270, ASB0280, and ASB0281) and the collection of soil and groundwater grab samples. One-time groundwater sampling was conducted at six existing groundwater monitoring wells (AGW009, AGW010, AGW011, AGW014, AGW015, and AGW016). Groundwater samples were collected from wells and borings screened across the water table and analyzed for GRO, DRO, ORO, and BTEX. Additionally, sampling for aquifer redox parameters was

[24] Additionally, EPH data was collected in July 2019 and is included in Appendix A.

[25] AGW009 was only analyzed for TPH. Because pCULs are presented for individual petroleum hydrocarbon constituents (GRO, DRO, ORO), these results are not presented as part of the FS report.

conducted at five existing groundwater monitoring wells and analyzed for field parameters (dissolved oxygen [DO], oxidation reduction potential [ORP], and ferrous iron) and laboratory analysis (nitrate, sulfate, and TOC) to evaluate potential effectiveness of MNA or *in situ* treatment technologies. Additional information about the FS investigations is provided in the 2017 FS Data Submittals (LAI 2017b, c).

4.1.2 Geochemistry at AOC A-01

Aquifer redox parameters indicate that conditions in the general AOC A-01 area are aerobic to mildly reducing. The area impacted by petroleum hydrocarbons (AGW010) is more moderately reducing (iron- to sulfate-reducing) as would be expected in an area impacted by hydrocarbons.[26] Well AGW016 downgradient to the northwest of the petroleum hydrocarbon contamination exhibited mixed conditions (aerobic to sulfate-reducing), indicative of a mix of natural aerobic to mildly reducing conditions mixing with upgradient moderately reducing conditions (caused by the petroleum hydrocarbon impacts). These redox parameters indicate that application of oxidative *in situ* treatment strategy could be appropriate for this AOC (like the Oxygen Release Compound [ORC®] presented in Section 5.2). Aquifer redox parameters are presented in Table 4-1.

4.1.3 Quantities and Location of Environmental Media Requiring Cleanup

Based on the RI and FS investigation data, petroleum hydrocarbon contamination at AOC A-01 is present above pCULs in soil and groundwater as summarized in the following sections.

4.1.3.1 Soil Contamination

Current conditions at AOC A-01 indicate that the soil contamination is limited in depth and lateral extent. COCs detected in soil above pCULs include GRO, ethylbenzene, and total xylenes. Soil contamination above pCULs was detected at three site borings (B-4, ASB0265, and ASB0268). Contaminated soil is located northwest of the former tanks in an area measuring approximately 15 ft by 30 ft. The depth of impacted soil ranges from about 10 to 23 ft bgs at boring ASB0265, and is 13 ft bgs at borings B-4 and ASB0268. The approximate vertical extent of soil contamination is shown on Figure 4-2. Soil results are shown on Figure 4-3 and presented in Table 4-2.

4.1.3.2 Groundwater Contamination

Current conditions at AOC A-01 indicate that groundwater contamination is also limited in lateral extent. COCs detected in groundwater above pCULs include GRO, DRO, benzene, ethylbenzene, and total xylenes. Groundwater contamination above pCULs is detected at only one site monitoring well (AGW010); concentrations in upgradient and downgradient bounding wells are not detected or are below pCULs. During the FS investigation boring grab samples were collected to inform further investigation. Groundwater concentrations from temporary boring grab samples are for screening

[26] Petroleum hydrocarbons are utilized as electron donor by native aquifer bacteria. This results in the consumption of available dissolved oxygen and transition to an anaerobic and reduced aquifer redox condition.

purposes only and not considered a reliable estimate of actual groundwater concentrations; grab samples typically overestimate actual concentrations because of disturbance during drilling and samples collected from an undeveloped temporary well without a sand pack. Groundwater contamination is present at the water table, which fluctuates from about 10 to 16 ft bgs. The groundwater contamination is associated with soil contamination, the groundwater contamination is distributed over a small area (approximately 30 ft by 30 ft) and is stable (not moving downgradient). The investigation locations where sampling results exceed groundwater pCULs are presented on Figure 4-4. Groundwater results collected during the FS (2016 through 2018) and most recent results for locations sampled prior to the FS are presented in Table 4-3.

Exceedances of pCULs in groundwater monitoring wells are limited to one well (AGW010) out of nine groundwater monitoring wells. COCs exceeding pCULs at this well are GRO, DRO, ethylbenzene, and total xylenes. Concentrations of these COCs at this well have shown a declining trend consistent with natural attenuation processes. A concentration time series plot for AGW010 is shown on Figure 4-5.

4.2 AOC A-09: Building 17-07 Acid Scrubber Drain Line Leak

AOC A-09 (A-09) is defined as contamination associated with a leak from the acid scrubber drain line located on the south side of Building 17-07 near column C11 (outside of the building). The leak was discovered in 1996 during closure and removal of two waste holding tanks. During excavation activities to remove the waste holding tanks outside the building between scrubbers No. 2 and No. 3, seepage from the acid scrubber drain pipe was noted at about 5 ft bgs near a structural pier along the south wall of Building 17-07. A partial remedial excavation was completed in 1996 to the extent practicable; however, contamination was left in place under the footprint of the building and adjacent scrubber No. 3 pad foundation, because of structural concerns. COCs from AOC A-09 are metals (cadmium, copper, and nickel) and cyanide. The 1996 excavation area and exploration locations associated with AOC A-09 are shown on Figure 4-6. A cross-section of AOC A-09, including the depth of the 1996 excavation, is presented on Figure 4-7.

4.2.1 Summary of Investigations

Prior to backfilling the 1996 excavation, 20 soil samples were collected from the base and sidewalls of the northeast corner of the excavation (AGI 1996). Some of these samples were collected from hand-augured borings that were advanced through the shored sidewalls of the excavation. Soil analytical results from 13 of the 20 samples indicated concentrations of cadmium, copper, nickel, and/or cyanide exceeded soil screening levels. Further assessment activities took place after backfilling. In September 1996, five monitoring wells (AGW046 through AGW050) were installed, and soil and groundwater samples were collected. Additionally, three hand-augured borings (HA1 to HA3) were advanced for collection of soil samples.

FS investigations included additional groundwater sampling for copper and cyanide and continued semiannual groundwater sampling as part of the interim groundwater monitoring program. The

interim groundwater monitoring program includes analysis of cadmium and nickel at AGW048 annually and AGW049 and AGW050 semiannually. Groundwater sampling for additional COCs was started in June 2017 because Site screening levels changed (as indicated in the RI report; LAI 2017h). Copper was detected above the RI screening level in the sample from AGW049 and was subsequently added to the analyte list for semiannual sampling at this well. Groundwater samples from monitoring wells AGW037, AGW047 through AGW050, and AGW278-1 were analyzed for cyanide. Cyanide compounds are classified into three categories: total cyanide, available or weak acid dissociable cyanide, and free cyanide (OI Analytical 2009). Total cyanide refers to the sum of all cyanide species (free cyanide, weak to moderately strong metal complexes, and strong metal complexes). Available cyanide includes free cyanide and also includes weak to moderately strong metal complexes. These are compounds that dissociate and release hydrogen cyanide under mildly acidic conditions (pH 3–6). Free cyanide is the sum of hydrogen cyanide and cyanide ions present in a sample. Groundwater samples at the Site have been analyzed for total, available, and free cyanide.

While cyanide was apparently detected above screening levels at all wells except AGW037, free cyanide analysis results show fewer and lower level detections. Cyanide sampling and laboratory analysis is inherently difficult because cyanide has the ability to complex with numerous metals and is subject to a wide variety of possible matrix interferences. To determine the most appropriate analytical and preparation methods for the Site, a number of cyanide sampling, analysis, and interference studies were completed as part of the FS; these studies are presented in a series of FS data submittals (LAI 2017f, 2019b). Ecology guidance for cleanup levels (Cleanup Levels and Risk Calculation [CLARC]) was updated in May 2019; these updates included allowance of free cyanide analysis for comparison to cyanide cleanup levels. Therefore, free cyanide analysis will be used to monitor cyanide concentrations at wells AGW047 through AGW050 and AGW278-1 going forward.

4.2.2 Quantities and Location of Environmental Media Requiring Cleanup

Based on the RI and FS investigation data, metals and cyanide contamination at AOC A-09 are still present above pCULs in soil and groundwater in a small contained area as summarized in the following sections. Remaining contamination, both soil and groundwater, is currently contained under existing asphalt/concrete that acts as a cap and prevents both exposure and infiltration of precipitation. Groundwater contamination is in a limited area and stable (not migrating downgradient).

4.2.2.1 Soil Contamination

The extent of existing soil contamination is based on the results of the 1996 investigations. No additional soil investigations were completed during the FS. During the 1996 investigations, soil samples were analyzed for a variety of metals and cyanide .[27,] Soil contamination was detected at

[27] Soil samples were analyzed for the following list of total metals: aluminum, cadmium, chromium, hexavalent chromium, copper, lead, manganese, nickel, titanium, and zinc. Soil samples were analyzed for the following cyanide analyses: total cyanide, amenable cyanide, and post-chlorination cyanide

concentrations exceeding pCULs for cadmium and copper.[28] Soil contamination above pCULs was detected at 16 locations both inside Building 17-07 (currently contains an active tank line and below-ground containment area) and outside the building to the south. This area of soil contamination is limited to an area approximately 40 ft by 25 ft. The depth of impacted soils is approximately 4 to 12 ft bgs inside the building, and from about 6 to 12 ft bgs outside the building. The investigation locations where sampling results exceeded soil pCULs are presented on Figure 4-8. Soil results are presented in Table 4-4.

4.2.2.2 Groundwater Contamination

The extent of existing groundwater contamination is relatively limited in lateral extent. Cadmium, copper, nickel, and cyanide were detected in groundwater samples at concentrations above pCULs during the FS investigation. Nickel concentrations exceeded the pCUL only once out of six sampling events during the FS and only at AGW050. Nickel concentrations are decreasing, and concentrations have not been detected above the pCUL since June 2017; therefore, nickel is removed as a COC. Cadmium was detected above pCULs at AGW049 and AGW050. Copper was detected above pCULs at AGW049.

During the recent updates to the CLARC tables, Ecology clarified that the cyanide cleanup level in CLARC is for free cyanide. Total cyanide analysis can also be used; however, the CLARC guidance discusses the difference between the total and free cyanide analyses as follows: "A total cyanide measurement is also acceptable, but the measured concentration of total cyanide in a sample may be higher than the concentration quantified with a free cyanide analysis, potentially leading to unnecessary cleanup." Free cyanide was analyzed at all locations where total cyanide exceeded the pCUL (AGW047, AGW048, AGW049, AGW050, and AGW278-1). Well AGW050 had groundwater sample results exceeding the free cyanide pCUL during the June 2018 sampling event, but not during the following September 2018 sampling event. Free cyanide results at AGW278-1 were above pCULs during both the June and December 2018 sampling events; however, the free cyanide concentrations were higher than the total cyanide concentration (not technically possible) during both sampling events, indicating a matrix interference causing false positives.[29] Additional sampling during finalization of the FS and preparation of the cleanup action plan would need to be conducted to determine if free cyanide concentrations exceed pCULs at AOC A-09. The investigation locations where sampling results exceed groundwater pCULs are presented on Figure 4-9. Groundwater results collected during the FS (2016 through 2018) and most recent results for locations or analyses prior to the FS are presented in Table 4-5.

Based on the results of the investigation activities discussed above, groundwater contamination above pCULs remains in at least two (and up to three) monitoring wells at AOC A-09: AGW049

[28] Only one soil sample out of 40 samples exceeded screening levels from the RI for lead; therefore, lead is not considered a COC for A-09.

[29] Total cyanide includes free cyanide and metals complexed cyanide; therefore, total cyanide concentrations should be equal to or higher than free cyanide concentrations.

(cadmium and copper) and AGW050 (cadmium), and possibly AGW278-1 (cyanide). As discussed above, additional evaluation would need to be completed to determine if cyanide contamination remains at AGW050 and AGW278-1. Concentrations of metals appear to be decreasing over time. Time series plots of metals concentrations at AGW049 and AGW050 are shown on Figure 4-10.[30]

4.3 AOC A-13: Building 17-06 Petroleum Hydrocarbon Contamination

AOC A-13 (A-13) was designated to address petroleum hydrocarbon (hydraulic oil) contamination in soil and groundwater on the east side of Building 17-06. This AOC encompasses the areas investigated for SWMUs S-15a and S-16 in the RI report (LAI 2017h). Investigations indicate that the source or sources of the hydraulic oil contamination are related to historical releases from an individual spar mill (Former Mill No. 144; this mill has been removed) in Building 17-06. Releases do not appear to be from the chip collection system, associated sumps, nor the aluminum briquetter (SWMU S-15a/S-16); therefore, these SWMUs were not investigated further as part of the FS. FS investigations focused on the area surrounding well AGW128, which has small amounts of seasonally present light non-aqueous phase liquid (LNAPL) hydraulic oil. The extent of AOC A-13 is shown on Figure 4-11. The FS investigation focus area and exploration locations are shown on Figure 4-12. A cross-section of AOC A-13 focus area is presented on Figure 4-13.

4.3.1 Summary of Investigations

In 1996, an investigation was conducted to assess soil and groundwater near the Building 17-06 east side chip collection system and briquetter (SECOR 1996). Fifteen soil borings were advanced: 10 were immediately decommissioned (ASB0022 through ASB0031), and five were converted to monitoring wells (AGW041 through AGW045). In 2004, seven soil borings were advanced (ASB0159, ASB0160R, ASB0167, ASB0168, ASB0169, ASB0170, and ABS0171) and four monitoring wells were installed (AGW115 through AGW118) along the east side of the building near the chip collection system. In 2008, four additional wells (AGW127 through AGW130) were installed along the east side chip collection system and adjacent to the briquetter and crossover area.

FS investigations included two drilling investigations (August and December 2017), continued groundwater sampling as part of the interim groundwater monitoring program, monthly LNAPL thickness measurements at monitoring well AGW128, LNAPL physical testing, and a bench-scale treatability study. FS investigations were completed to refine the extent of remaining petroleum hydrocarbon contamination in soil and groundwater. The drilling investigations included advancing eight borings (ASB0271, ASB0272, ASB0274, ASB0275, and ASB0286 through ASB0289) and installation of five monitoring wells (AGW277, and AGW279 through AGW282) for the collection of soil and groundwater samples. Groundwater and soil samples were analyzed for DRO and ORO. Additional details of the FS investigations are available in the 2017 and 2018 data submittals (LAI 2017i, 2019a).

[30] The other wells do not have concentrations detected above pCULs so are not presented.

Additionally, two groundwater samples from AGW128 and AGW281 were collected in July 2019 for EPH analysis and used to calculate Method B pCULs as described in Section 3.0.

4.3.1.1 Free-Phase Product Thickness and Testing

Free-phase hydraulic oil product, or LNAPL, is detected at AGW128 intermittently during periods when the water table is decreasing or is at its low point. During the FS, the presence and thickness of LNAPL at AGW128 has been measured approximately monthly. There is no evidence that LNAPL thickness is increasing over time; rather fluctuations in presence and thickness are driven by changes in the water table. In general, LNAPL thickness is greatest at the end of the dry season when water levels in the aquifer are lowest. During the wet season, the LNAPL layer is very thin (generally less than 1 centimeter) or not present. LNAPL thickness ranged from not present to 0.26 ft (3.1 inches) at AGW128 during the FS investigation. Free-phase product has never been detected in any other AOC A-13 monitoring wells.

LNAPL physical testing was conducted on product extracted from AGW128 in October 2018. This data was used to evaluate LNAPL transmissivity and recoverability as described in the following paragraph. The LNAPL was determined to have a high viscosity and is classified as a medium oil that floats on water. Additional details of the physical testing were provided in the FS data submittal (LAI 2019a).

The LNAPL physical characteristics along with site-specific aquifer information and product thickness were used to calculate LNAPL transmissivity using a simplified Darcy's law calculation (ITRC 2018). The calculated LNAPL transmissivity near well AGW128 is 0.03 square feet per day (ft^2/day). Acceptable LNAPL transmissivity for active product recovery is greater than 0.8 ft^2/day (ITRC 2018), more than an order of magnitude greater than the estimated LNAPL transmissivity at AOC A-13. These calculations indicate that the hydraulic oil LNAPL at well AGW128 is not practicable to recover. Sorbent sock mass removal was measured from September 2016 through September 2018. Over the 2-year period, approximately 1.4 gallons of LNAPL was removed using the sorbent sock. Additional information about the free-phase product and transmissivity calculations is provided in Appendix C.

4.3.1.2 Treatability Study

As part of 2018 FS investigations, a bench-scale treatability study was conducted to determine if chemical oxidation is a feasible cleanup technology for the hydraulic oil contamination in soil and groundwater at A-13. Soil samples collected during the drilling conducted as part of the FS were used to determine if overall mass reduction of DRO and ORO could be achieved through chemical oxidation using alkaline-activated or iron-activated persulfate. Samples of contaminated soil were collected from borings and homogenized before being placed into four separate jars; groundwater samples were collected from the same locations. One of the four soil jars was sent immediately for analytical testing to verify adequate TPH concentrations for bench testing, the other three jars were sent to Peroxychem for bench testing. The bench test jars were treated as follows: 1) control (no treatment), 2) iron-activated persulfate; 3) alkaline-activated persulfate. For the persulfate treatment, Site

groundwater samples were used to mix the persulfate into liquid form for treatment; the untreated groundwater was added to the control at the same volume as the treated samples. The treated test samples and control were allowed to stand for 20 days before being shipped to the analytical laboratory for analysis. Analytical results showed no decrease in the soil concentration or in some cases higher concentrations than the control sample. The results of the study indicate that no mass reduction was achieved using either persulfate mixture compared to the control sample. Hydraulic oil is an engineered product designed for stability under extreme pressure and temperatures, so the results indicating that chemical oxidation treatment does not result in mass reduction were not unexpected (Hydraulics & Pneumatics undated; accessed 2019). Additional details of the treatability study are available in the FS data submittal (LAI 2019a).

4.3.2 Quantities and Location of Environmental Media Requiring Cleanup

AOC A-13 was carried forward to the FS because of exceedances of screening levels based on MTCA Method A criteria in soil and groundwater. However, because pCULs used in the FS are based on Method C (soil) and Method B (groundwater) criteria (Section 3.2, Tables 3-2 and 3-3), there are no exceedances of soil or groundwater pCULs and thus no environmental media requiring cleanup. DRO and ORO results are summed and presented as TPH for comparison to Method B pCULs in Tables 4-6 and 4-7, for soil and groundwater, respectively.

There is no soil contamination above the TPH (total DRO/ORO) pCUL at any AOC A-13 borings or wells. Locations where TPH has been detected in soil (below the pCUL) are presented on Figure 4-14. Soil results are presented in Table 4-6. There is no groundwater contamination above the TPH pCUL at AOC A-13 groundwater monitoring wells. During the FS investigation, boring grab samples were collected to inform further investigation. Groundwater concentrations from temporary boring grab samples are for screening purposes only and are not considered a reliable estimate of actual groundwater concentrations; grab samples typically overestimate actual concentrations because of disturbance during drilling and samples were collected from an undeveloped temporary well without a sand pack. Subsequent sampling of monitoring well AGW277 compared to initial borehole sampling (AGW277-20) confirmed that groundwater COC concentrations are below the pCULs. It should also be noted that minimal quantities (maximum of approximately 3 inches; typically less than 1 inch) of LNAPL present at well AGW128 are not indicative of soil concentrations above residual saturation (i.e., does not indicate the presence of mobile LNAPL; WAC 173-340-747[10]). The temporal nature of the observed LNAPL and its presence at only one monitoring well location indicate that hydraulic forces (e.g., buoyancy and capillary forces) resulting from seasonal groundwater elevation changes drive small quantities of LNAPL out of pore spaces, where LNAPL would otherwise be trapped under equilibrium conditions, and into the well casing (which can be thought of as one very large pore space). MTCA requires LNAPL removal only to the extent practicable and to prevent migration of free product (WAC 173-340-360[2][c][ii][A] and WAC 173-340-450[4][a]). As indicated above, the transmissivity evaluation indicates that LNAPL is not recoverable with active methods (using normally accepted engineering practices) at this well. Additionally, a demonstration has been made that LNAPL

is not migrating. Therefore, no additional LNAPL removal/cleanup is required. Groundwater sampling results are presented on Figure 4-15. Groundwater results collected during the FS (2016 through 2018) and most recent results for locations sampled prior to the FS are presented in Table 4-7. A time series plot showing TPH concentrations at AGW128[31] is provided on Figure 4-16.

The soil and monitoring well groundwater results at AOC A-13 indicate TPH concentrations do not exceed the Site-specific pCUL at this AOC. Based on the current conditions at AOC A-13, no cleanup at this location is required and, therefore, this AOC is not carried forward for further cleanup evaluation in Section 5.0.

4.4 AOC A-14: Site-Wide Soil and Groundwater Trichloroethene and Vinyl Chloride Contamination

Multiple TCE release areas have resulted in comingled groundwater plumes at the Site that are not practical to address individually. As a result, the groundwater plumes and the contributing release areas were designated as AOC A-14 (A-14) during the RI to address Site-wide groundwater contaminated with TCE and VC and the associated release areas on the Facility.[32] During FS investigations, soil TCE contamination was added for evaluation of cleanup alternatives of soil above pCULs protective of groundwater (VC is not detected in soil at the Site). Soil TCE contamination was added to the AOC based on FS investigation described in Sections 4.4.1.

Releases of TCE from the Facility have resulted in two comingled groundwater plumes that extend from the release areas more than 1 mile northwest of the Facility. The two groundwater plumes are defined based on their release areas: the Western Plume originating from or near Building 17-07, and the Area 1 Plume originating at former Area 1 from former Building 17-03 and former Building 17-05. A-14 comprises the two groundwater plumes and the three associated release areas, as well as low-level groundwater contamination upgradient or crossgradient of the release areas. It is also important to understand that portions of the upgradient and cross-gradient contamination as well as downgradient areas along the eastern and northern edge of the Area 1 plume appear to be caused by other sources not associated with the Boeing Auburn Facility (LAI 2014, 2017h). There is indication that VOC contamination from an upgradient source south to southeast of the Site has contributed, in particular, to upgradient areas and the eastern and northern extent of the Area 1 plume. Data from public water systems east and southeast of the Facility (cross gradient and upgradient of Facility release areas) have historically shown low concentrations of TCE, below the drinking water MCL of 5 µg/L (LAI 2014). Concentrations found in the public water system wells are consistent with concentrations found in monitoring wells along the eastern and northern portions of the Area 1 plume and particle tracking with the numerical groundwater flow model indicates that the source of

[31] The time series plot is provided for AGW128 since this is the groundwater monitoring well with the highest petroleum hydrocarbon concentrations at AOC A-13 (through all concentrations measured during the FS are below pCULs).

[32] A portion of the groundwater plumes are believed to be from releases not associated with the Facility as described in the RI Report (LAI 2017h).

groundwater in these areas is not from the Facility, but rather originates southeast of the Facility. Additionally, a property northwest of the Boeing Auburn Facility known as McKessen/DS Waters appears to have contributed to the northern portion of the Area 1 plume (G-Logics 2009a, b).

Because of their prevalence and relative toxicity (i.e., resulting in lower pCULs compared to other CVOCs), TCE and VC are the primary COCs and IHSs in Site-wide groundwater. Concentrations of the breakdown products cDCE, trans-1-2-dichloroethene (tDCE), and 1,1-dichloroethene (1,1-DCE) are well below screening levels, as presented in the RI report (LAI 2017h), but are mentioned here because they are intermediate breakdown products between TCE and VC. The current extent of A-14 (exceedances of pCULs protective of drinking water and concentrations above SWQS in groundwater) is provided on Figure 4-17.

Additional investigations during the FS were completed to further evaluate the Western Plume and Area 1 Plume release areas and groundwater before reaching Mill Creek as described in Section 4.4.1. Groundwater geochemistry relating to the natural breakdown and reduction of CVOCs in Site-wide groundwater is presented in Section 4.4.2. Quantities of soil and groundwater TCE and VC contamination requiring cleanup at the Site are presented in Section 4.4.3.

4.4.1 Summary of AOC A-14 Investigations

RI investigation activities included identification of release areas on the Facility, defining the nature and extent of the CVOC plumes horizontally and vertically throughout the aquifer and defining the plume stability and mass. SWMUs and AOCs that contribute to the groundwater TCE and VC contamination are incorporated into AOC A-14 to allow for a Site-wide strategy for addressing the contamination. A full description of the site-wide groundwater quality evaluation is presented in the Final RI report (LAI 2017h).

FS investigation activities added to the understanding of the nature and extent of Site-wide groundwater contamination and included additional release area investigation and additional investigation of the downgradient extent of contamination. Investigation activities included regular ongoing Site-wide CVOC groundwater sampling as part of the interim groundwater monitoring program (currently Phase 9; [LAI 2019c]); soil gas sampling, borehole and well drilling for additional evaluation of the release areas; and installation and sampling of pore water piezometers to monitor groundwater concentrations prior to entering Mill Creek. The Site-wide groundwater monitoring program includes sampling of 214 wells and 260 active sampling points (i.e., well screens) as part of the interim Site-wide groundwater monitoring program for six CVOCs (tetrachloroethene [PCE], TCE, cDCE, tDCE, 1,1-DCE, cDCE, and VC) on a semiannual or annual basis. Most recent (as of December 2018) groundwater results are presented in Table 4-8. The FS investigation activities related to the Western Plume release area, the Area 1 plume release area, and sediment pore water investigations are discussed in more detail below.

4.4.1.1 Western Plume Release Area

The Western Plume release area is defined as an area inside or near Building 17-07. A description of the release area, is provided in the RI Report (LAI 2017h). The source of the Western Plume is complex, but appears to be mainly attributed to a former TCE vapor degreaser located in the Building 17-07 tank line area at the south end of the building (referred to herein as the Western Plume release area).

Building 17-07 Release Area—Summary of Investigations

FS investigation activities focused on further evaluation of potential sources in Building 17-07. Sub-slab soil vapor sampling was completed in order to better identify release areas and locations for installation of monitoring wells. FS sub-slab soil gas sampling included installation of 17 permanent and two temporary soil gas sampling locations. Areas of sub-slab soil gas sampling investigation included:

- Building 17-07 vapor degreaser tank line area (columns B9 to D9),
- Building 17-07 column E2 area (identified as a possible source during 2011 sub-slab voil vapor sampling [LAI 2012]), and
- Building 17-07 column B4 area (identified as another possible location of a TCE degreaser based on historical information).

Sub-slab soil gas results did not indicate VOC sources at either the column B4 or column E2 areas. The highest soil gas concentrations were detected in the tank line area adjacent to the east of the former vapor degreaser at column B9. A continuous multi-channel tubing (CMT) well (AGW278) was installed at this location in August 2017 to collect soil and groundwater samples. Other area wells were also monitored for TCE and VC as part of the interim groundwater monitoring program. The Western Plume release area investigation explorations for the tank line area are shown on Figure 4-18. FS investigation results were presented in a series of data submittals (LAI 2017a, d).

Building 17-07 Release Area—Soil and Soil Gas Contamination

Soil samples were collected during the FS when drilling AGW278 in August 2017. Three soil samples were collected in the vadose zone. Only one sample (7.5 ft bgs) had a detection of TCE, but concentrations are below the pCUL. Other soil samples were collected during investigation and removal of the degreaser in 1996 (Kennedy/Jenks 1996). There were no detections of TCE in the soil during the investigations of the degreaser. Soil results are shown on Figure 4-19 and presented in Table 4-9.

Sub-slab soil gas sampling was completed during the RI and the FS to identify possible release areas by identifying elevated levels of CVOCs in soil gas. Indoor air evaluations were completed in Building 17-07 as part of the RI; concentrations in soil gas are not causing concentrations of TCE in indoor air; thus, vapor intrusion is not a complete pathway (LAI 2017h). Soil gas concentrations are

not compared to vapor intrusion screening levels (because vapor intrusion is an incomplete pathway) and are only used as a tool to identify potential release areas. The highest soil gas concentrations were detected beneath the tank line area east of the former degreaser at column B9 (SSV082), in the same location where the highest concentrations were detected during sampling in 2011 (SSV-29). Generally, elevated TCE soil gas concentrations were detected on the north side of the tank line between columns B9 and C9, consistent with a former release area. If TCE concentrations in soil gas were the result of groundwater contamination, the theoretical maximum TCE concentrations would be less than 5 micrograms per cubic meter ($\mu g/m^3$) based on the current groundwater concentrations near the water table surface. However, the measured TCE soil gas concentration was 1,010 $\mu g/m^3$ and is indicative of residual mass in the vadose zone and a likely release in the area. Soil gas results are shown on Figure 4-19 and presented in Table 4-10.

Building 17-07 Release Area—Groundwater Contamination

Groundwater results indicate low concentrations of TCE and VC in the Western Plume release area. This is consistent with the subsurface contaminant fate and transport conceptual model presented in Section 2.2, where high seepage velocities in the aquifer result in rapid flushing and dissolution of DNAPL and persistent low-level concentrations at the plume source areas are the result of matrix desorption and back diffusion processes. During the initial investigation during the removal of the degreaser in 1995, the highest TCE concentration was 1.7 µg/L and the highest VC concentration was 7.2 µg/L.[33] TCE does not exceed pCULs protective of drinking water at any monitoring wells in this area. VC exceeded pCULs protective of drinking water during the 2018 sampling only at AGW278-1 and AGW278-4. TCE and VC concentrations are greater than SWQS in groundwater in the shallow and intermediate groundwater zones at locations in and around the Building 17-07 tank line area. The locations of groundwater monitoring wells where TCE and/or VC were identified above pCULs and SWQS are shown on Figure 4-20. Western Plume release area groundwater results collected during the FS (2016 through 2018) and most recent results for locations or analyses prior to the FS are presented in Table 4-11.

4.4.1.2 Area 1 Plume Release Area

The AOC A-14 Area 1 Plume release area was identified in the RI report as the former Building 17-05 degreaser and associated tank line. Boeing conducted an IRA to clean up the Area 1 Plume release area in 2004 and 2005 (see Section 2.3). The IRA addressed TCE and VC in groundwater near the former vapor degreaser and this area does not warrant further investigation or evaluation of remedial alternatives.

Although TCE and VC concentrations decreased substantially at Area 1 wells in the immediate vicinity of the former Building 17-05 degreaser following the IRA, concentrations at monitoring wells installed to the north of the former building (AGW125 and AGW126) were not impacted by the IRA. The

[33] The removal of the degreaser in 1995 was 20 years after Boeing discontinued use of TCE in vapor degreasing. The low concentrations found during the initial investigation further support the contaminant fate and transport CSM.

numerical groundwater model developed for the Site was used to trace particles from the vicinity of AGW125 and AGW126 upgradient to potential release areas (a process called reverse particle tracking). The modeling analysis indicated another possible source at the former Building 17-03 TCE degreaser (previously SWMU S-12a) and associated piping. The former degreaser was investigated as part of the expedited Area 1 RI (LAI 2004b), and did not indicate significant release to soil or groundwater and the SWMU was closed (Ecology 2004). Based on the results of the reverse particle tracking, a review of historical documents was completed to further investigate a possible release area. A 1996 soil gas investigation (Kennedy/Jenks 1997b) indicated significant concentrations of TCE in soil gas near the former degreaser and associated waste piping west of the former degreaser. Discovery of the historical soil gas results prompted additional investigation of the former Building 17-03 degreaser area during the FS (LAI 2018c).

Former Building 17-03 Release Area—Summary of Investigations

An historical investigation of soil and groundwater was completed around the former Building 17-03 degreaser during building demolition in 1992 (Kennedy/Jenks 1993). During the degreaser decommissioning in November and December 1992, four soil samples were collected directly beneath or adjacent to the degreaser pit (SS-26 through SS-29) at a depth of approximately 8.5 ft bgs, and a groundwater grab sample (SS-33) was collected adjacent to the pit at a depth of 25 ft bgs (Kennedy/Jenks 1993). A shallow monitoring well (AGW001) was installed at the location of the former vapor degreaser after building demolition. Additional soil and groundwater investigations of the former degreaser area took place during the Area 1 property transfer in 2003 and 2004 (LAI 2004c), during which intermediate and deep monitoring wells (AGW097 and AGW099, respectively) were installed near AGW001. Shallow soil samples were collected from just above the water table (16 ft bgs) in the borings for each well. An investigation of the Building 17-03 and Building 17-05 adjacent chrome waste piping occurred in December 1996 (Kennedy/Jenks 1997a). Soil and soil gas samples were collected from 106 locations and analyzed for select VOCs and metals.

Additional investigation activities were completed at former Building 17-03 during the FS in 2017 and 2018 to further define the extent of VOC contamination in soil and groundwater. Soil gas measurements were used as a tool to identify the release area and direct additional soil and groundwater investigation. In June 2017, six temporary soil gas sampling locations (ASG001 through ASG006) were installed. In August and September 2017, eight borings (ASB0276, ASB0277, ASB0278, ASB0279, ASB0282, ASB0283, ASB0284, and ASB0285) were drilled for the collection of soil and groundwater samples. In December 2018, an additional four borings (ASB0290, ASB0291, ASB0292, and ASB0293) were drilled. Former Building 17-03 release area investigation explorations are shown on Figure 4-21. A cross-section is presented on Figure 4-22. Based on the FS investigation results, it appears that the releases associated with the degreaser may have been from piping and a sump associated with the degreaser and to a lesser extent from the degreaser pit itself. As a result, the previous wells (AGW001, AGW097, and AGW099) were installed slightly to the east of the release areas.

Former Building 17-03 Release Area—Soil and Soil Gas Contamination

Soil contamination is present slightly above the TCE pCUL for protection of groundwater (via leaching from soil) at one FS boring location (ASB0290) in samples collected from a depth of 12 and 16 ft bgs. ASB0290 is located directly west of the former vapor degreaser tank pit. There were no detections of TCE, trichloroethane (TCA), or their breakdown products in the soil samples collected from soil borings for monitoring wells AGW097 and AGW099, or from other pre-RI investigations (Kennedy/Jenks 1992). Soil results are shown on Figure 4-23 and presented in Table 4-12.

Soil gas sampling was completed during the FS to identify possible release areas indicated by elevated levels of CVOCs in soil gas. Indoor air evaluations were completed at the Prologis building as part of the RI; concentrations in soil gas did not result in detectable concentrations in indoor air; thus, vapor intrusion is not a complete pathway (LAI 2017h). Because vapor intrusion is not a complete pathway, soil gas concentrations are not compared to vapor intrusion screening levels and are only used as a tool to identify release areas as described in the Ecology-approved FSWP (LAI 2018c). FS soil gas results show concentrations generally higher near the south end of former Building 17-03 and within the former tank line area, and lower downgradient (northwest) of the former tank line area. The FS soil gas sample with the highest TCE concentration was collected at ASG003, directly south of the former sump. If TCE in soil gas were the result of groundwater contamination, the theoretical maximum TCE concentrations would be lower than those detected in soil gas (less than 57 µg/m^3 based on the current groundwater concentrations near the water table surface). However, the maximum measured TCE soil gas concentration (1,700 µg/m^3) is indicative of residual mass in the vadose zone and a former TCE release area. Soil gas results are shown on Figure 4-23 and presented in Table 4-13.

Former Building 17-03 Release Area—Groundwater Contamination

Groundwater results indicate low concentrations of TCE and VC in the former Building 17-03 release area for the Area 1 Plume. This is consistent with the subsurface contaminant fate and transport conceptual model presented in Section 2.2, where high seepage velocities in the aquifer result in rapid flushing and dissolution of DNAPL and persistent low-level concentrations at the plume source areas are the result of desorption and back diffusion processes. TCE concentrations exceed groundwater pCULs protective of drinking water at two locations (ASB0277-40 and ASB0290-20). TCE concentrations are above SWQS in groundwater at the one current monitoring well (AGW001R) and at grab samples from all 12 FS borings (ASB0276 through ASB0279; ASB0282 through ASB0285; and ASB0290 through ASB0293) in the former Building 17-03 area. VC is not detected in the former 17-03 release area. The locations with the highest detections of TCE are just west of the former tank line area approximately in line with the chrome waste line that left the former Building 17-03 to the south. The highest TCE detection (11 µg/L) was found at 40 ft bgs (ASB0277-40). The locations of groundwater monitoring wells where TCE concentrations were identified above pCULs and SWQS are shown on Figure 4-24. Former Building 17-03 release area groundwater results collected during the FS

(2016 through 2018) and most recent results for locations sampled prior to the FS are presented in Table 4-14.

4.4.1.3 Sediment Pore Water Investigations

Sediment pore water sampling investigations were conducted along Mill Creek during the RI and FS to verify that VOC concentrations in groundwater were not impacting surface water in Mill Creek. RI pore water investigation included one-time sampling at three locations (PW-23 through PW-25) in 2015 (LAI 2017a). FS pore water investigation included installation of permanent pore water piezometers (PW-18a, PW-18b, and PW-27a; installed at 2.5 and 5 ft bgs) in 2017 and 2018. Groundwater samples collected from the pore water samplers were analyzed for VOCs and MNA parameters. Pore water TCE and VC results are presented with the groundwater monitoring well results in Table 4-8. Soil samples were also collected from the borehole at each location and analyzed for TOC to evaluate VOC retardation factors in the hyporheic zone of Mill Creek. Analysis of geochemistry and TOC concentrations in the sediments beneath Mill Creek are discussed in Section 4.4.2. Additional information about the FS investigations are provided in the 2017 and 2018 FS data submittals (LAI 2018a, d).

4.4.2 Site-Wide Groundwater Geochemistry

Groundwater geochemistry parameters were evaluated during the RI and additional evaluation was completed during the FS. Groundwater geochemistry is important in understanding contributions of contaminants from release areas to Site-wide groundwater and contaminant fate and transport processes. Natural attenuation indicators evaluated at the Site include aquifer redox parameters: nitrate, ferrous iron (iron [II]), sulfate, and methane;[34] and evidence of natural electron donor indicators (TOC). There is strong evidence that natural attenuation is occurring throughout the plumes and that anaerobic biodegradation via reductive dechlorination is the primary mechanism of natural attenuation.

Lines of evidence to document that natural attenuation is occurring at the Site were presented in the Site-wide natural attenuation report (LAI 2019d). Breakdown and end products are present along the flow paths from sources to distal edges of the plumes, and overall historical trends in contaminant concentrations are decreasing. There are a few areas of the plumes (both spatially and with depth) where indicators of reductive dechlorination are less prevalent; although potential for reductive dechlorination may be lower in some distinct areas, it is occurring at multiple points along the groundwater flow paths. CVOC degradation occurs along horizontal flow paths extending from the release areas to the distal ends of the Western and Area 1 plumes, as groundwater flows through areas with TOC and reduced aquifer redox conditions. The concentration and distribution of TOC

[34] Other indicators of aquifer redox conditions include DO and ORP; however, DO and ORP are less reliable due to difficulty in measuring these parameters consistently and accurately.

increases and the redox condition becomes more reducing as groundwater moves from the deep zone, through the intermediate zone, and into the shallow zone.

It is significant and beneficial that degradation is most pronounced and widespread in the shallow zone. There is currently no drinking water use of the groundwater within the plumes and the only route of potential exposure would be at the ground surface, which would require movement of groundwater contaminants through the shallow zone where natural attenuation is demonstrated to be prevalent and effective. Pore water geochemistry, collected from the hyporheic zone below Mill Creek, demonstrates that this area has some of the greatest capacity for reductive dechlorination anywhere at the Site. The high rates of degradation near Mill Creek result in attenuation of CVOCs before they can reach surface water. Pore water sample results show that aquifer redox conditions beneath Mill Creek are highly reducing (sulfate reducing to methanogenic). Concentrations of TOC (greater than 20 milligrams per liter [mg/L]) are present in pore water samples in the hyporheic zone of Mill Creek, indicating adequate electron donor for breakdown of chlorinated ethenes. These conditions indicate that aquifer conditions in the hyporheic zone are conducive to complete reduction of VOC contamination to non-toxic end products. If contaminants were to reach the hyporheic zone, CVOCs would be significantly degraded before reaching the surface water. Substantial additional degradation is expected to occur at the distal ends of both plumes where groundwater flows upward through a biologically active zone with organic-rich soils and sediment before it enters Mill Creek. The substantial degradation occurring in the hyporheic zone of Mill Creek is consistent with the absence of cVOCs in Mill Creek.[35]

In addition to geochemical indicators of natural attenuation, analysis of historical trends in CVOC data show that concentrations are decreasing or stable and the groundwater plumes are decreasing or stable (LAI 2019d). Historical trends in contaminant concentrations were evaluated by analyzing concentrations over time at individual wells and analyzing overall plume stability. The analysis indicates that the majority of wells have a decreasing or stable CVOC concentration trend (or are non-detect). Analysis of TCE, VC, and total CVOC concentrations throughout the plume also indicate decreasing or stable total dissolved mass and a stable center of mass (stable plume). The stable or decreasing trends at individual wells and in overall dissolved plume mass substantiates the conclusion that natural attenuation is resulting in declining concentrations over time. The stability of the center of mass indicates that the plumes are not migrating downgradient. Degradation rates for CVOC trends over time were initially provided in the Site-wide natural attenuation report (LAI 2019d) and are updated to determine restoration time frames for the Site in Appendix D.

4.4.3 Quantities of Media Requiring Cleanup at AOC A-14

TCE soil contamination at the Facility and groundwater TCE and VC contamination Site-wide exceed pCULs as summarized in the following sections.

[35] With the exception of sampling conducted at surface water location SW-18 in the third quarter of 2016 with results indicating VC concentration detected just above the reporting limit.

4.4.3.1 Extent of Soil Contamination

The extent of soil TCE contamination is limited to a small area at the Facility at former Building 17-03. VC is not detected in soil at any of the soil sampling locations. TCE concentrations are present above pCULs protective of groundwater (via leaching from soil) in the release area associated with the former Building 17-03 vapor degreaser as discussed in Section 4.4.2.2. However, concentrations are well below pCULs protective of direct contact for industrial workers. Because of the limited extent of soil contamination exceeding pCULs at AOC A-14, evaluation of remedial alternatives for soil is not necessary. However, soil gas concentrations detected in the Building 17-07 release area and the former Building 17-03 release area indicate possible ongoing inputs of mass from soil gas to groundwater.[36]

4.4.3.2 Extent of Groundwater Contamination

Groundwater contamination consists of two groundwater plumes and upgradient and cross-gradient concentrations of TCE and VC exceeding pCULs protective of drinking water or are greater than SWQS in groundwater. The two plumes originate from the Facility (the Area 1 Plume and the Western Plume) and extend approximately 1 mile northwest of the Facility. Areas in all three groundwater zones where 2018 groundwater concentrations exceed pCULs protective of drinking water or are above SWQS in groundwater are shown on Figure 4-17. Site-wide groundwater results (2018) are presented in Table 4-8. There are 68 wells that exceed pCULs protective of drinking water. There are 168 wells that have concentrations greater than SWQS in groundwater.

The current horizontal extent of the Area 1 plume and Western Plume is due to dissolution of TCE at the release areas and advective migration of dissolved TCE and degradation products (cDCE and VC) downgradient with the bulk motion of flowing groundwater. The resulting spatial distribution of the plumes is affected by aquifer heterogeneity, contaminant transport process such as sorption, dispersion, and contaminant degradation. Other factors that affect the distribution of the plume are the release history, slight changes in groundwater flow directions over time, and the presence of complex boundary conditions that include an array of surface water and stormwater control and conveyance structures (e.g., the Chicago Avenue ditch, the Auburn 400 stormwater retention basins, and Mill Creek) that intercept the shallow groundwater. The combination of these factors along with contribution from CVOCs from release areas not associated with the Facility has resulted in complex plume geometries in the shallow, intermediate, and deep zones. Plume maps for the shallow, intermediate, and deep groundwater zones for TCE and VC are presented on Figures 4-25 through 4-30. Plume maps for the shallow, intermediate, and deep groundwater zones for total CVOCs (sum of all chlorinated VOCs: TCE, DCE,[37] and VC) are presented on Figures 4-31 through 4-33. Additionally, a geologic and total CVOC cross-section along the general centerline of the plume for both the Western

[36] As discussed in Section 5.0, soil vapor extraction (SVE) is a remedial alternative evaluated to address soil gas (and residual soil contamination) in the release areas to deplete residual mass inputs to groundwater from the vadose zone.
[37] Includes cDCE, tDCE, and 1,1-DCE.

and Area 1 Plumes (see alignment on Figure 4-34) are provided on Figure 4-35a and 4-35b, respectively.

Nature and Extent of Western Plume

The Western Plume extends from the release area (at or near Building 17-07) to the distal end of the plume approximately 6,000 ft downgradient. Because of the high groundwater flux rates in the aquifer, the former release areas no longer have high concentrations of TCE typical of a CVOC release area, and the highest TCE concentrations are downgradient of the release area. As discussed in Section 2.2, the Western Plume release area now has the characteristics of a later stage release (Stage 5) where DNAPL has been depleted and persistent low concentrations at the release area are dominated by desorption and back diffusion (Kueper et al. 2014). The low historical and current observed concentrations may be related to a number of factors including the original release or releases were probably not extensive, the coarse-grained nature of soil texture likely resulted in low pore-entry pressures and low DNAPL residual saturation. This would allow the release to move downward to the deep zone easily without an accumulation of significant mass. The high groundwater velocities would also result in rapid dissolution and deplete residual DNAPL quickly. Given that the most recent release would have occurred at the Site approximately 40 years ago (mid-1970s), the high degree of aquifer flushing has depleted the contaminant mass in the release area causing the resultant low concentrations.

The highest TCE concentrations in the Western Plume are downgradient of the release area, north of Building 17-07, in the deep zone (AGW201-6; TCE concentration of 6.4 µg/L), at the Facility boundary in the intermediate zone (AGW145; TCE concentration of 6.2 µg/L), and in commercial Algona (AGW167 and AGW169; TCE concentration of 5.1 and 5.0, respectively). The Western Plume is generally conducive to reductive dechlorination of TCE. VC concentrations are detected above pCULs at the Facility and downgradient in the Western Plume. The highest concentrations of VC in the Western Plume are downgradient of the release area, west of Building 17-07, in the intermediate zone (AGW155; VC concentration of 4.8 µg/L), in commercial Algona in the intermediate zone (AGW251-3; VC concentration of 4.3 µg/L), and at the area of the Algona Enhanced Natural Attenuation Pilot Test in the shallow zone (AGW270; VC concentration of 4.1 µg/L). The highest total CVOC concentration (100 nanomole per liter [nmol/L]) is in the deep zone well downgradient of the release area, north of Building 17-07 at AGW201-6. Concentrations of CVOCs in the distal end of the Western Plume deep zone decrease to non-detect as flow paths move to shallower groundwater zones and concentrations attenuate (See Figure 4-35a). The highest CVOC concentrations in the distal end of the Western Plume are in the shallow and intermediate zones at AGW235 and are due primarily to degradation products (AGW235-2; VC concentration of 3.4 µg/L).

Nature and Extent of Area 1 Plume

The Area 1 Plume extends from the release areas (former Buildings 17-03 and 17-05) to the distal end of the plume approximately 8,000 ft downgradient. The former release area at 17-05 was identified as

SWMU S-12b (former TCE degreaser) and AOC A-08 (former tank line adjacent to the degreaser) in former Building 17-05 (currently the Prologis warehouse). The degreaser was removed in 1979 and the tank line was decommissioned in 1994. Maximum historical TCE concentrations in groundwater near the degreaser and tank line were 5,460 µg/L detected from borehole sample 17-05-GW-4 in 1994 (Kennedy/Jenks 1995) and 1,433 µg/L at monitoring well AGW002 drilled in the same location later in 1994. The TCE concentration at AGW002 was 4.6 µg/L in 1996. The large reduction in concentrations over a period of 2 years demonstrates evidence of rapid dissolution and depletion of TCE that occurs as a result of high groundwater velocities and aquifer flushing (See Section 2.2). Following the rapid decline, concentrations in the release area remained relatively steady, concentrations were greater than 100 µg/L at nearby monitoring locations, until the IRA began in 2004 (see Section 2.4.1). The persistent low concentrations of TCE observed prior to the IRA are indicative of matrix desorption and back diffusion processes.

The release from the former Building 17-03 does not have the high current or historical concentrations found at the former Building 17-05 release area. The highest concentration of TCE detected at the former Building 17-03 release area is in the intermediate zone at ASB0277 (TCE concentration of 11 µg/L). The lower concentrations observed at the former Building 17-03 release area may be related to a number of factors including the original release, or releases may have been less extensive, the timeline of TCE use and subsequent investigation allowed more time for dissolution of DNAPL and attenuation of release area concentrations prior to the initial investigation activities. The former Building 17-03 release area continues to have persistent low concentrations of TCE at AGW001 that are indicative of matrix desorption and back diffusion processes.

The highest concentration of TCE detected at the former Building 17-03 release area correlates with the next highest TCE concentrations downgradient in the shallow and intermediate zones (AGW125; TCE concentration of 5.5 µg/L and AGW126; TCE concentration of 6.7 µg/L). The next highest TCE concentrations in the Area 1 Plume are found downgradient near The Outlet Collection in the intermediate zone (AGW196) and deep zones (AGW195, AGW197 and AGW234). Concentrations in the distal end of the Area 1 Plume in all groundwater zones decrease to non-detect before groundwater enters Mill Creek downgradient. VC concentrations are not as prevalent in the former Building 17-03 release area, indicative of more mildly reducing aquifer conditions in this area. The highest VC concentrations in the Area 1 plume are downgradient in the shallow zone (AGW232; VC concentration of 4.3 µg/L) and intermediate zone (AGW196; VC concentration of 2.5 µg/L). The conversion of concentrations from TCE to VC is indicative of the natural biodegradation of contaminants along the Area 1 Plume flow path. Concentrations of CVOCs in the distal end of the Area 1 plume decrease to non-detect as flow paths move to shallower groundwater zones and concentrations degrade (See Figure 4-35b). There were no detections of TCE or VC in the shallow pore water samples (2.5 ft below the creek bottom) collected during the FS. There were no detections of TCE or VC in the deeper pore water samples (5 ft below the creek bottom) with the exception of one sample in 2018 from (PW-18a-5), which had a low concentration of VC (0.061 µg/L). Pore water

results verify that, though groundwater is entering Mill Creek, concentrations of TCE and VC are degrading before reaching surface water. The concentrations currently in groundwater are already protective of surface water at Mill Creek; therefore, meeting pCULs in groundwater protective of drinking water are appropriate for AOC A-14.

4.5 AOC A-15: Site-Wide Trichloroethene and Vinyl Chloride in Stormwater and/or Surface Water

AOC A-15 was designated to address TCE and VC contamination in stormwater and/or surface water features. AOC A-15 is defined as the areas within the Cities of Auburn and Algona where concentrations of TCE and VC are monitored in surface water (Mill Creek) or stormwater features (Chicago Avenue ditch, Auburn 400 north and south stormwater detention basins).

4.5.1 Summary of Investigations

Sampling of stormwater and surface water features has been conducted at the Site since 2012. During the RI, Boeing conducted sampling in various surface water, wetland, and stormwater features present near the Site. These features include Government Canal, stormwater collection ditches in Algona including the Chicago Avenue ditch, the O Street wetland, The Outlet Collection stormwater basins and stormwater collection ditch, the Auburn 400 stormwater retention basins (north and south), Mill Creek, and various wetlands associated with Mill Creek including the Auburn Environmental Park. The objective of these investigations was to determine if groundwater contaminated with CVOCs associated with the Facility was entering these various stormwater and surface water features. Although CVOCs were detected in some stormwater features, concentrations were not greater than screening levels presented in the RI Report anywhere at the Site. No COCs were detected in surface water samples collected from wetlands or Mill Creek during the RI, with the exception of one sample location, SW-17, which is collected where the Auburn 400 north retention basin flows into the wetland and is not necessarily representative of surface water conditions. VC concentrations at SW-17 have been sporadically detected, below RI screening levels, and just above the detection limit. Results are presented in the RI Report (LAI 2017h).

During FS investigations, stormwater and surface water sampling was conducted annually during the dry season at six locations and semiannually at one location in the wet season. Samples were collected from stormwater features at the Chicago Avenue ditch (SW-CD4), the Auburn 400 south stormwater retention basin (SW-14), the Auburn 400 north stormwater retention basin (SW-16), and where the Auburn 400 north retention basin flows into the wetland that drains into Mill Creek (SW-17). Samples were collected from the wetland before convergence with Mill Creek (SW-20), and two downstream locations at Mill Creek (SW-18 and SW-27). Stormwater and surface water features and sampling locations are shown on Figure 4-34 and results are discussed in Section 4.5.2.

4.5.2 Quantities and Location of Environmental Media Requiring Cleanup

CVOCs from groundwater are entering into three stormwater features at the Site (Chicago Avenue Ditch, Auburn 400 North retention basin, and Auburn 400 South retention basin) causing detections of TCE (September 2018 concentrations less than 2 µg/L) and VC (September 2018 concentrations less than 0.35 µg/L). Cleanup levels are not applicable to stormwater features as described in Section 3.2.3 and Appendix B. The detections of TCE and VC in stormwater features do not pose a risk to human health. Stormwater feature sampling results collected during the FS (2016 through 2018) and most recent results for locations sampled prior to the FS are presented in Table 4-15.[38] Most recent detected concentrations of TCE and VC in stormwater are shown on Figure 4-36.

In 2016, there were concentrations of VC detected just above the surface water pCUL (concentration less than 0.03 µg/L) in water collected and from one location at Mill Creek (SW-18). There was also a detection of VC from where the Auburn 400 north retention basin flows into the wetland that drains into Mill Creek (SW-17). The detected concentrations were close to the detection limits and VC was not detected during more recent sampling events in 2017 and 2018. Surface water results collected during the FS (2016 through 2018) and most recent results for locations sampled prior to the FS are presented in are presented in Table 4-16. Most recent surface water sampling results have not had detections of TCE of VC as shown on Figure 4-36.

The concentrations detected in surface water are much lower than the concentrations detected in groundwater. Once groundwater concentrations have been remediated to pCULs protective of drinking water, storm water concentrations would also decrease accordingly and surface water concentrations would remain below the surface water pCULs (SWQS). Concentrations of TCE and VC in stormwater and surface water are evaluated for remediation with AOC A-14.

[38] Algona residential yard and ditch sampling results are not included in this table.

5.0 DEVELOPMENT OF CLEANUP ACTION ALTERNATIVES

This section describes a set of cleanup action alternatives developed for each AOC. For the purposes of this FS, the cleanup action alternatives for each AOC are designated with distinct alphanumeric values. For example, remedial alternatives for AOC A-01 have designations beginning with "A" (e.g., Alternative A1); and remedial alternatives for AOC A-14 have designations beginning with "D" (e.g., Alternative D1) to avoid confusion between numbered alternatives for each AOC).

5.1 Identification and Screening of Technologies

Alternatives for each AOC were developed based on the results for the technology screening performed in the Ecology-approved FSWP and following the screening criteria in WAC 173-340-350(8)(b). Technologies were evaluated based on their applicability and suitability in a given area, their presumed effectiveness based on site conditions, location constraints, and relative cost. The final technology screening table, updated with Ecology requests for additional technology evaluations and modifications that occurred during the FS evaluation process, is provided in Table 5-1.

5.2 AOC A-01 Description of Selected Cleanup Action Alternative

AOC A-01 consists of petroleum hydrocarbon contamination in soil and groundwater associated with releases from the former USTs northeast of Building 17-06. Ecology has developed model remedies for sites with petroleum impacts to soil and groundwater (Ecology 2017b, c). A Model remedy is a set of technologies, procedures, and monitoring protocols identified by Ecology for use in routine types of cleanup projects that have common features and lower risk to human health and the environment. Model remedies are developed in accordance with MTCA 173-340-390 and where a model remedy is chosen as the cleanup action, an analysis of the feasibility of alternative remedies is not required (Revised Code of Washington [RCW] 70.105D.030[k][i][C][iii]). A model remedy was chosen for AOC A-01 (Alternative A1) and consists of excavation of the petroleum hydrocarbon soil contamination and ORC, or other equivalent oxidant, emplacement in the saturated/seasonally saturated portion of the excavation backfill (and supplemental MNA as necessary) for the treatment of residual petroleum hydrocarbon contamination in groundwater. The conceptual excavation area is presented on Figure 5-1.

5.3 AOC A-09 Description of Cleanup Action Alternatives

The cleanup action alternatives evaluated at AOC A-09 have been assembled into a reasonable number of the most viable alternatives following the guidelines provided in MTCA (WAC 173-340-350[8][c]). AOC A-09 consists of cadmium, copper, and cyanide contamination in soil and groundwater associated with the former acid scrubber drain line leak at Building 17-07. The area is currently contained under pavement and by the building slab; groundwater impacts are localized in a relatively small area, are not migrating downgradient, and concentrations of COCs in groundwater are generally declining (Section 4.2). The cleanup action alternatives evaluated as part of the FS for AOC A-09

include: monitored containment and MNA; *in situ* groundwater treatment; and future excavation (including monitored containment until the excavation occurs). A brief description of each remedial alternative is provided below. A summary and conceptual description of each remedial alternative is provided in Table 5-2.

5.3.1 Alternative B1: Monitored Containment and MNA

This alternative includes containment of COCs in soil and MNA for cleanup of metals and cyanide (if necessary) in groundwater. Soil is currently contained under pavement and the building slab, the remedy would include periodic inspections of the containment area, asphalt or concrete maintenance as necessary inside and outside Building 17-07, and institutional controls with a restrictive covenant to maintain the existing asphalt/concrete that acts as a cap and prevents infiltration. MNA would include routine monitoring of the groundwater contamination and ongoing evaluation of the attenuation processes (microbial, chemical, or physical) that is causing degradation of the inorganic contaminants at A-09 (EPA 2007, 2015). Once groundwater concentrations meet pCULs, it would be considered an empirical demonstration that soil concentrations are protective of groundwater and the soil pCUL would revert to the concentration protective of direct contact (soil concentrations at A-09 are currently below pCULs protective of direct contact). Once it has been empirically demonstrated that groundwater concentrations are below pCULs without further treatment, cleanup would be complete because residual contamination in soil already meets the soil direct contact pCULs. A figure showing proposed groundwater monitoring wells selected for routine sampling is presented on Figure 5-2.

5.3.2 Alternative B2: *In Situ* Groundwater Treatment

In situ groundwater treatment would consist of sorbing, complexing, and/or precipitating dissolved metals and cyanide in groundwater with an injected substrate (e.g., conceptual design is injection of colloidal sulfidated zero-valent iron [ZVI]) to remediate elevated concentrations of COCs in groundwater. Groundwater treatment would also provide treatment for saturated soils. Testing (either bench testing or *in situ* pilot testing) to determine the effectiveness of *in situ* groundwater remediation remedies has not been completed to date and would need to be completed prior to design. Additional design consideration, particularly with respect to pH, would need to be given to the impacts of *in situ* treatment on the downgradient A-14 VOC release area (former 17-07 degreaser). Injected treatment at AOC A-09 would be expected to impact the former 17-07 degreaser area. Residual soil contamination in the vadose zone is minimal and below direct contact pCULs. Once it has been empirically demonstrated that groundwater concentrations are below pCULs without further treatment, cleanup would be complete because residual contamination in soil already meets the soil direct contact pCULs. The conceptual layout for the injection system at Building 17-07 is shown on Figure 5-3.

5.3.3 Alternative B3: Future Excavation (and Monitored Containment)

Future excavation at AOC A-09 would include institutional controls to maintain the asphalt/concrete cap and continued monitoring of the groundwater contamination (monitored containment) until such a time that Building 17-07 and the associated structures are removed or accessible without impact to operations. If groundwater concentrations exceed pCULs at the time of building demolition, soil excavation would occur. The soil contamination that is currently under structures at AOC A-09 is assumed to be the source of ongoing low-level concentrations of contaminants in groundwater. The contaminated soil would be removed and transported to an appropriate, licensed, offsite disposal facility. Compliance groundwater monitoring would then be conducted to demonstrate that the removal action has resulted in groundwater COC concentrations being reduced below the pCULs. The conceptual excavation area is presented on Figure 5-4.

5.4 AOC A-13 Description of Cleanup Action Alternatives

AOC A-13 consists of petroleum hydrocarbon contamination in soil and groundwater at the east side of Building 17-06. Soil and groundwater concentrations exceeded screening levels presented in the RI report; however, concentrations of TPH do not currently exceed the pCULs developed as part of the FS report. No cleanup action is warranted for AOC A-13.

5.5 AOC A-14 Description of Cleanup Action Alternatives

Cleanup action alternatives evaluated for cleanup of TCE and VC in Site-wide groundwater and TCE in Facility soil have been assembled into a reasonable number of the most viable alternatives, including those requested by Ecology. A summary of each remedial alternative is provided in Table 5-3.

Because there is no known remedial technology or combination of technologies that result in cleanup of the entire plume down to pCULs or SWQS, MNA is a component of each alternative described for AOC A-14 (See Section 3.2.2.3). Natural attenuation is considered an active remedy under the MTCA regulation (WAC 173-340-200) at sites meeting the necessary requirements (WAC 173-340-370[7]) and a permanent remedy. Additionally, natural attenuation has been proven to be occurring at the Site (LAI 2019d). Natural attenuation is an appropriate remedy (either solely or in conjunction with other remediation technologies) at the Site and the remedial alternatives for the Site meet or would meet the requirements for the appropriate use of natural attenuation remedies set forth in WAC 173-340-370(7):

- “Source control (including removal and/or treatment of hazardous substances) has been conducted to the maximum extent practicable”
- “Leaving contaminants on-site during the restoration time frame does not pose an unacceptable threat to human health or the environment”
- “There is evidence that natural biodegradation or chemical degradation is occurring and will continue to occur at a reasonable rate at the site”

- "Appropriate monitoring requirements are conducted to ensure that the natural attenuation process is taking place and that human health and the environment are protected".

5.5.1 Alternative D1: MNA

This alternative includes containment of COCs in soil and MNA for cleanup of Site-wide groundwater. Release areas are already contained under either pavement or building slabs. Containment of the soil would be completed by periodic inspections, maintenance as necessary, and institutional controls and a restrictive covenant to maintain asphalt/concrete and buildings overlying contaminated soil. Once groundwater concentrations meet pCULs, it would be considered an empirical demonstration that soil concentrations are protective of groundwater and the soil pCUL would revert to the concentration protective of direct contact. Once it has been empirically demonstrated that groundwater concentrations are below pCULs without further treatment, soil cleanup would be complete because residual contamination in soil is already at concentrations below the soil direct contact pCULs. Routine sampling and analysis for MNA parameters and CVOCs would be conducted at wells with TCE and VC concentrations above pCULs and at a series of boundary wells. The data would be evaluated to monitor the progress and effectiveness of the naturally occurring reductive dechlorination processes at the Site. Natural attenuation has already been evaluated and is demonstrated to be in effect at the Site (LAI 2019d). Additionally, current risks to human health and the environment are negligible (Section 2.3). Based on predictive modeling and statistical evaluation of restoration time frames at Site monitoring wells, MNA is estimated to require approximately 95 years to reach pCULs protective of drinking water and 233 years to reach the SWQS in groundwater Site-wide. Evaluation of restoration time frames is presented in Appendix D. Wells proposed for ongoing monitoring (based on exceedance of pCULs or concentrations greater than SWQS) and possible proposed boundary wells are presented on Figures 5-5a (pCULs) and 5-5b (SWQS).

5.5.2 Alternative D2: Soil Vapor Extraction and Enhanced *In Situ* Bioremediation at Release Areas and MNA

There are two release areas described in Section 4.0 that have not been treated with prior interim actions (i.e., release areas in the vicinity of the former degreasers at Building 17-07 and former Building 17-03). Although the remaining CVOC contamination in these release areas is at relatively low concentrations (e.g., TCE concentrations less than 3 µg/L at Building 17-07 and less than 12 µg/L at former Building 17-03) and can be cleaned up through MNA, as described in alternative D1, treatment of the release areas is evaluated to complete the analysis of source cleanup to the maximum extent practicable and to support alternatives evaluation in the disproportionate cost analysis in Section 6.3. This alternative would provide treatment of release areas in an effort to decrease residual mass within the groundwater plumes. Additionally, treatment of the release areas would remove residual mass in soil gas that could be contributing to groundwater contamination through diffusion and would provide treatment to the small areas of soil that exceed pCULs protective of leaching to groundwater. The release area treatment would consist of multiple technologies to address soil/soil gas and groundwater: soil vapor extraction (SVE) to remove VOCs from soil and soil gas, and EISB to increase

the rate of VOC degradation in groundwater. The downgradient portions of the groundwater plumes would be treated by MNA in a similar manner to Alternative D1.

Soil Vapor Extraction

SVE physically removes vapor-phase VOCs and volatilizes and removes adsorbed VOCs from vadose zone soil through vacuum extraction. SVE also functions to remove contaminant mass from saturated zone soils exposed during seasonal periods of lower water table elevations. SVE would be accomplished by applying a vacuum to wells screened within the vadose zone. Extracted vapor would be treated using vapor-phase granular activated carbon (GAC) vessels. SVE reduces future potential vapor intrusion and removes contaminant mass from the subsurface vadose zone that could potentially diffuse to groundwater.

SVE treatment would be targeted in areas with elevated TCE soil gas values. A pre-remedial design pilot study would be conducted in each treatment area to determine key design parameters including, subsurface air permeability and typical extraction well radius of influence (ROI). ROI is defined as the approximate distance away from an extraction point at which a vacuum pressure is still apparent. ROI would be used to determine effective well spacing that provides vapor capture throughout the targeted treatment area. Soil permeability and air extraction rates would be used to design treatment system elements (blower, knockout tank, GAC vessels). Conceptual design figures are provided for each SVE treatment area, but are not representative of Site-specific requirements. SVE would occur in both the Building 17-07 and former Building 17-03 release areas.

- **Building 17-07:** The construction of the SVE system inside Building 17-07 is anticipated to be technically and logistically challenging given the active building operations and many permanent above- and below-grade structures/equipment that may impede the placement of SVE wells or piping. The placement of SVE wells would also be constrained by the sub grade tank line containment area. The tank line containment area is a recessed portion of the Building 17-07 foundation (approximately 10 ft deep) adjacent to the former TCE degreaser; additionally a subgrade containment pit is present below the location of the former TCE degreaser. Groundwater has been observed in contact with the containment area foundation at certain times of the year, which makes SVE implementation beneath the containment area or degreaser pit impractical. Therefore, for conceptual design, SVE wells would be placed outside the degreaser pit, but still inside Building 17-07. SVE system activities would need to be conducted without impacting operations at the Boeing Auburn Plant. The conceptual layout for an SVE system in Building 17-07 is shown on Figure 5-6.
- **Former Building 17-03:** The construction of SVE in the former Building 17-03 area would require coordination with the current property owner, Prologis, and its tenants. The treatment area is located outside the Prologis warehouse in a current storage/parking area in the southeast corner of the property. To minimize impacts to Prologis, the conceptual design assumes vapor conveyance piping would be installed underground and extraction wellhead vaults would be flush with the ground. Good spatial coverage of the TCE release area is anticipated, because this area is clear of buildings and other permanent structures. The conceptual layout for the SVE system at former Building 17-03 is shown on Figure 5-7.

It is anticipated that the SVE systems would each operate for 5 years, based on the typical useful lifespan of SVE for effectively removing CVOCs from the subsurface. Typically, after 3 to 5 years of operations, the rate of SVE mass removal decreases to a relatively low rate, and the limited benefit of additional treatment typically makes further continuous SVE operation impractical. Switching to a pulsing operational regime for a short period of time can sometimes be used to maximize short-term mass removal rates toward the end of SVE system operations. While operating, the system performance and mass removal rates would be routinely monitored by sampling influent and effluent concentrations at each treatment system. It is assumed that monthly monitoring would be conducted for the first year of operation followed by quarterly monitoring in years 2 through 5. Monitoring results would be reported on an annual basis along with an evaluation of the treatment performance and progress.

Enhanced In Situ Bioremediation

EISB consists of supplying electron donor to the groundwater to stimulate and enhance reductive dechlorination. EISB was demonstrated to be effective at reducing release area mass during the IRA at former Building 17-05 (see Section 2.4). For the purpose of conceptual design, the electron donor would be delivered via active injection of aqueous solution. A fermentable substrate (conceptual design uses as LactOil® for cost-estimating purposes), would be selected for EISB implementation. The chosen substrate would contain both fast-release (soluble) and slow-release substrate to provide lasting treatment after injection. The fast-release substrate (e.g., ethyl lactate) would immediately begin to ferment, creating an area of active treatment at the location of injection and downgradient of the injection row as groundwater transports the fermentation by-products necessary to stimulate reductive dechlorination. The slow-release substrate (e.g., soybean oil) provides lasting treatment as it is more slowly fermented within the aquifer. The substrate would be mixed with extracted groundwater on Site to create an injection solution. EISB would be implemented at the Building 17-07 and former Building 17-03 release areas.

- **Building 17-07:** The EISB conceptual design consists of two injection rows to target the shallow, intermediate, and deep groundwater zones. The first injection row would be approximately 60 ft long with five injection well clusters (three-well clusters) installed on 15-ft centers, and located 20 feet upgradient of the former vapor degreaser near column B9. The second injection row, located 60 ft upgradient of the former vapor degreaser near columns C9 and C10, would be approximately 75 ft long with six injection well clusters (three-well clusters) installed on 15-ft centers. New monitoring wells would also be installed in the vicinity of the new injection rows in order to monitor treatment progress. The installation of injection rows and performing each injection event is anticipated to be technically difficult given the placement within an active chemical tank line area. Building operations and many permanent structures/equipment are present would likely impede drilling access, and the running of injection hoses. The placement of injection wells could also be constrained by the sub floor tank line area. The tank line area is a recessed portion of the Building 17-07 building slab; installing wells within this area is not possible. Injection activities must be conducted without impacting operations at the Boeing Auburn Plant. The conceptual layout for the EISB system at Building 17-07 is shown on Figure 5-8.

- **Former Building 17-03:** The EISB conceptual design for former Building 17-03 consists of two approximately 75-ft-long injection rows situated perpendicular to the local groundwater flow direction. Each injection row would have six wells installed on 15-ft centers to target the shallow groundwater zone. The first injection row would be located upgradient of the former tank line area and the second row would be located within the former tank line area. Only one monitoring well exists downgradient of the targeted treatment area; therefore, new monitoring wells would be installed in the vicinity of the injection rows to provide additional treatment progress monitoring points. The installation of injection rows would be constrained by the active road and fence that surrounds the parking lot that now occupies the former Building 17-03 area. Several sampling locations with TCE concentrations above the screening levels are located along the fence line; injection rows would be situated as close to the fence as is feasible. Injection wells cannot be located in the adjacent road because the road is used 24 hours a day, every day for truck access to the distribution warehouse. The conceptual layout for the EISB system at former Building 17-03 is shown on Figure 5-9.

The conceptual design for the injection solution at both release areas includes 5 percent LactOil by volume and yeast extract as a source of micronutrients for enhanced reductive dechlorination. For the purposes of this FS, it is assumed that three injection events would be performed over a span of approximately 10 years, with each injection event lasting approximately 2 weeks. Quarterly groundwater monitoring would be performed for the first 4 years of active treatment and transition to semiannual monitoring for the remaining 6 years of active treatment. Semiannual monitoring would continue for 3 years after treatment ends.

Monitored Natural Attenuation

Upon completion of the release area SVE and EISB remedial actions, MNA would be implemented for cleanup of Site-wide groundwater remaining above pCULs. Routine sampling and analysis for MNA parameters and CVOCs would be conducted at wells with TCE and VC concentrations above pCULs and at a series of bounding wells, as discussed in Alternative D1. The predictive transport modeling described in Appendix E, indicates that the treatments of SVE and EISB in the release areas would decrease the restoration time frame for Alternative D1 (MNA for AOC A-14) by only about 1.3 percent; the resulting MNA implementation time frame would be slightly reduced to approximately 94 years to meet pCULs protective of drinking water or 230 years to meet SWQS in groundwater. Remediation of the release areas results in very minimal reductions to the overall restoration time frames because most of the contaminant mass has been redistributed downgradient of the release areas (see Section 2.2). Evaluation of restoration time frames is presented in Appendix D. Wells proposed for ongoing monitoring are assumed not to change from Alternative D1, for the purposes of cost estimation, and are presented on Figure 5-5a (pCULs) and Figure 5-5b (SWQS).

5.5.3 Alternative D3: Soil Vapor Extraction and Dynamic Groundwater Recirculation at Release Areas and MNA

This alternative includes soil vapor extraction at the release areas (as described in Alternative D2), dynamic groundwater recirculation (DGR) targeting the former release areas at Building 17-07 and

former Buildings 17-03 and 17-05, and MNA. DGR consists of extraction and re-injection of treated groundwater through a network of injection and extraction wells to create a dynamic groundwater flushing and contaminant recovery system. DGR systems increase contaminant mass recovery rates by inducing gradients that alter groundwater flow paths to provide flushing of pore spaces not readily or as quickly accessed under natural groundwater flow regimes or traditional pump-and-treat or groundwater recirculation system flow conditions and accelerate the clean-up time frame through overall increased aquifer flushing rates. This is accomplished through frequent selective changes to the operation of and/or pumping rates at injection and extraction wells in specific areas of the contaminant plume. MNA would be utilized for downgradient portions of the plume that would not be actively treated by DGR.

Soil Vapor Extraction

The conceptual design for the soil vapor extraction system is the same as described in Alternative D2 for the release areas at Building 17-07 and former Building 17-03.

Dynamic Groundwater Recirculation

The conceptual layout for the DGR system is shown on Figure 5-10. DGR wells would be located to provide treatment for groundwater at the Building 17-07 and former Building 17-03 TCE release areas. Extraction and injection well clusters shown on Figure 5-10 are conceptual and actual locations would be developed during the engineering design phase. To provide adaptive DGR operation and treatment optimization, each extraction well cluster would include an extraction well screened across each of the shallow, intermediate, and deep zones; each injection well cluster would include an injection well screened across each of the shallow and deep zones. Different pumping and injecting configurations of extraction and injection would be used to shift groundwater flow to the extent possible, including in the vertical dimension (for example, operation of a deep zone injection well and a nearby shallow zone extraction well, without the intermediate and deep zone extractions wells at a given well cluster, to create a net upward gradient in this area). Based on modeled pumping rates using the Ecology-reviewed numerical groundwater flow model (LAI 2016), extraction rates would need to be approximately 125 gallons per minute (GPM) per well to have a sufficient effect on overcoming natural groundwater flow directions. The conceptual design assumes up to 11 active extraction wells operating at one time for a total of 1,375 GPM of water that would require treatment. Extracted water would be conveyed to a central treatment building in each area (Western Plume release area and Area 1 release area) and treated with air stripper units for CVOC removal. Treated water would be pumped from each treatment building to operating injection wells.

Additional monitoring wells in the shallow, intermediate, and deep zones would be necessary to provide groundwater flow/gradient data. Because the DGR system could be operated in various configurations, it would be imperative to understand the effects of the system on hydraulic gradients during operation under each configuration. DGR monitoring wells or piezometers would be installed with pressure transducer data loggers to record groundwater elevation data so that hydraulic gradient

information can be evaluated over time. Because of the aquifer heterogeneity and relatively high seepage velocities within the upper alluvial aquifer, DGR may not be possible or practical. Additionally, reducing aquifer conditions and significant dissolved ferrous iron in the groundwater have the potential to cause significant biofouling and/or mineral fouling of the well pumps and treatment system as oxidation of the groundwater causes iron bacterial colony growth and/or iron precipitation that clogs the wells and treatment system. Fouling can significantly reduce the effectiveness of a treatment system by reducing pumping rates, treatment efficiency, and requiring frequent shut downs for maintenance. A DGR pilot study would be necessary to demonstrate whether natural groundwater flow directions and gradients could be overcome by DGR, demonstrate the feasibility of maintaining the treatment system, and to provide additional information needed for full-scale DGR design and implementation. For the purposes of the DGR cost estimate, it is assumed that a pilot study would be conducted for 6 months with four extraction wells (two in the shallow zone and two in the deep zone) and four injection wells (two in the shallow zone and two in the deep zone).

Batch flush modeling was used to evaluate an effective treatment time frame for DGR. Results indicate that DGR would need to be operated for 17 years for the system around the Building 17-07 release area and 29 years for the system around the former Building 17-03 release area to meet pCULs for TCE and VC. It should be noted that the batch flush model does not account for matrix desorption and back diffusion processes and may significantly underestimate the restoration time frame; however, the batch flush model is still the best available tool for estimating DGR system performance. Batch flush model results and rationale for using the batch flush model for DGR restoration time frames are documented in Appendix F.

Monitored Natural Attenuation

Upon completion of the release area SVE and DGR remedial actions, MNA would be implemented for cleanup of Site-wide groundwater remaining above pCULs. Routine sampling and analysis for MNA parameters and CVOCs would be conducted at wells with TCE and VC concentrations above pCULs and at a series of boundary wells, as discussed in Alternative D1. The predictive transport modeling described in Appendix E indicates that the treatments of SVE and DGR in the release areas would decrease the restoration time frame for AOC A-14 by approximately 10.5 percent; the resulting MNA implementation time frame would be reduced to approximately 85 years to meet pCULs protective of drinking water and 208 years to meet SWQS in groundwater. Remediation of the release areas results in very minimal reductions to the overall restoration time frames because most of the contaminant mass has been redistributed downgradient of the release areas (see Section 2.2). Evaluation of restoration time frames is presented in Appendix D. Wells proposed for ongoing monitoring are assumed not to change from Alternative D1 for the purposes of cost estimation and are presented on Figure 5-5a (pCULs) and Figure 5-5b (SWQS).

5.5.4 Alternative D4: Permeable Reactive Barriers at the Facility Boundary and MNA

Alternative D4 includes installation of permeable reactive barriers (PRBs) along the facility boundary and MNA for the rest of the Site. Two possible technologies for the PRBs are:

- **Alternative D4A:** EISB injections
- **Alternative D4B:** Injected colloidal ZVI (conceptual design with colloidal sulfidated ZVI).

The conceptual design for the PRB at the Facility boundary is shown on Figure 5-11.

In PRB applications, conditions for effective bioremediation must be maintained until contaminant concentrations have been sufficiently attenuated in the release areas located hydraulically upgradient of the PRB. PRB implementation does not enhance or speed the treatment of contaminant mass in the release area, but instead treats the flux of contamination that extends downgradient from the release area that would otherwise migrate off the Facility. Based on estimated remediation time frames for the release area (and model runs of the predictive groundwater transport model, see Appendix E), the FS assumes that PRBs would need to maintain effectiveness for approximately 20 years.

Alternative D4A: EISB PRB

The EISB conceptual design for the Facility boundary PRB consists of two approximately 1,120-ft-long injection rows with 33 injection well clusters (three-well clusters) each installed on 35-ft centers to target the shallow, intermediate, and deep groundwater zones. The injection solution for the Facility boundary injection rows would include 5 percent LactOil by volume and yeast extract as a source of micronutrients for enhanced reductive dechlorination. Based on the observed longevity of bioremediation treatment in the former Building 17-05 release area (see Section 2.4), five injections of electron donor to the PRB are assumed over a 10–12-year period (each injection event lasting approximately 18 weeks), followed by 8–10 years of sustained treatment due to endongenous decay and donor back diffusion. Sustained treatment following bioremediation injections was demonstrated with the Area 1 IRA and is documented in literature (Adamson and Newell 2009; Sleep et al. 2005) as a significant benefit of bioremediation over other technologies. It is assumed that a total of 20 years of treatment would be sufficient to address continued advection of upgradient concentrations into the treatment area. Quarterly groundwater monitoring would be performed for the first 4 years of active treatment and transition to semiannual monitoring for the remaining six years of active treatment. Semiannual monitoring would continue for 10 years after active treatment ends (during the sustained treatment period).

Alternative D4B: ZVI PRB

A PRB consisting of injected ZVI is a passive way to treat the flux of TCE-contaminated groundwater at the property boundary; the groundwater can flow through the PRB without mechanical assistance, allowing the target contaminants to come in contact with the reactive ZVI particles. For the purpose

of conceptual design, a colloidal sulfidated ZVI product, such as S-MicroZVI™, would be used to create the ZVI PRB at the property boundary. S-MicroZVI is composed of colloidal ZVI particles suspended in glycerol using proprietary environmentally-acceptable dispersants. The particles are sulfidated, meaning they are surface-treated with a reduced sulfur species. Sulfidation minimizes passivation of the ZVI caused by water reacting with the ZVI surface and increases the longevity of the reactive particle. Sulfidation can also enhance the rate of reduction for chlorinated contaminants, like TCE (Fan et al. 2017).

The PRB would be installed via injection to clustered injection wells screened in the shallow, intermediate, and deep zones. Each injection row would be approximately 1,120 ft long with 94 injection well clusters (two-well clusters) installed on 12-ft centers. The injection solution would contain 1.3 percent S-MicroZVI by volume; the longevity of each injection is conservatively estimated to be approximately 2 years. Ten injection events (each lasting approximately 8 weeks) would be performed on a 2-year cycle to provide 20 years of continuous treatment. The ZVI injection is not expected to have the extended sustained treatment period assumed for EISB injection in Alternative D4A.

Monitored Natural Attenuation

Upon completion of the PRB remedial actions, MNA would be implemented for cleanup of Site-wide groundwater remaining above pCULs. Routine sampling and analysis for MNA parameters and CVOCs would be conducted at wells with TCE and VC concentrations above pCULs and at a series of boundary wells, as discussed in Alternative D1. The predictive transport modeling described in Appendix E, indicates that the PRB treatments (either EISB or ZVI) along the Facility boundary would decrease the restoration time frame for AOC A-14 by approximately 9.2 percent; the resulting MNA implementation time frame would be reduced to approximately 86 years to meet pCULs protective of drinking water and 212 years to meet SWQS in groundwater. PRB implementation at the Facility boundary results in very minimal reductions to the overall restoration time frames because most of the contaminant mass has been redistributed downgradient of the Facility boundary (see Section 2.2). Evaluation of restoration time frames is presented in Appendix D. Wells proposed for ongoing MNA monitoring are assumed not to change from Alternative D1 for the purposes of cost estimation and are presented on Figure 5-5a (pCULs) and Figure 5-5b (SWQS).

5.5.5 Alternative D5: Soil Vapor Extraction and Enhanced *In Situ* Bioremediation at Release Areas, Enhanced *In Situ* Bioremediation at Focus Areas, and MNA

Alternative D5 includes the SVE and EISB release area treatments described in Alternative D2, EISB at three additional focus areas of the Site, and MNA for the remainder of the Site. SVE and EISB treatment at the release areas are described in Section 5.5.2; the three additional focus areas are described below.

Because the plumes are so large, three separate areas would be targeted with EISB to provide additional downgradient plume treatment to areas with higher CVOC concentrations, areas that have longer projected restoration time frames, or areas that warrant special attention because of consideration of public concerns. The three areas include:

- An area of Algona along Milwaukee Avenue (upgradient of the Chicago Avenue ditch and northeastern residential neighborhood; an expansion of the Algona Enhanced *In Situ* Bioremediation pilot test [Section 2.3.2]).
- An area along the Boeing property boundary to target one of the highest TCE concentrations (AGW145).
- The Outlet Collection mall parking lot to target the area with some of the highest CVOC concentrations and longer restoration time frames.

All injections in the downgradient focus areas would employ the concurrent extraction/injection method and would be performed approximately every 2 years for 10 years (five events anticipated) at each of the focus areas. Conditions for effective bioremediation must be maintained until contaminant concentrations have been sufficiently attenuated in the release areas located hydraulically upgradient of the focus areas. EISB implementation in focus areas does not enhance or speed the treatment of contaminant mass in the release areas, but instead treats the flux of contamination that extends downgradient from the release area. The FS assumes that the EISB injections would need to maintain effectiveness for 20 years (10 years of active treatment followed by 10 years of sustained treatment due to endongenous decay and donor back diffusion). Sustained treatment following bioremediation injections was demonstrated with the Area 1 IRA and is documented in literature (Adamson and Newell 2009; Sleep et al. 2005) as a significant benefit of bioremediation over other technologies. It is assumed that a total of 20 years of treatment would be sufficient to address continued advection of upgradient concentrations into the treatment area. No additional monitoring wells are proposed to be added to the extensive existing well network for the downgradient plume as part of EISB implementation. Quarterly groundwater monitoring would be performed for the first 4 years of active treatment and transition to semiannual monitoring for the remaining 6 years of active treatment. Semiannual monitoring would continue for the 10 years of sustained treatment after active treatment ends. The conceptual layout for EISB at the focus areas is shown on Figure 5-12.

17-07 Property Boundary

The EISB design for the property boundary consists of a 1,120-ft-long injection row with 33 injection well clusters (three-well clusters) installed on 35-ft centers to target the shallow, intermediate, and deep groundwater zones. The injection solution for the property boundary injection row would include 5 percent LactOil by volume and yeast extract as a source of micronutrients for enhanced reductive dechlorination. Each injection event would last approximately 18 weeks.

Algona

The EISB conceptual design for the Algona neighborhood would extend the existing pilot test injection row to the north to create an approximately 980-ft-long injection row with 29 single injection wells installed on 35-ft centers to target the shallow groundwater zone. Five of the injection wells were already installed during the pilot test, but an additional 24 wells would be installed for full-scale implementation. The injection solution for the Algona neighborhood would include 5 percent LactOil by volume and yeast extract as a source of micronutrients for enhanced reductive dechlorination. Because the injection would target only the shallow zone and requires fewer wells than the property boundary, each injection event would last approximately 6 weeks.

The Outlet Collection

The EISB conceptual design for The Outlet Collection consists of six injection rows on several sides of the mall buildings. Each injection row would target the shallow, intermediate, and deep groundwater zones. One approximately 385-ft-long injection row would be located on the west side of the mall and include 12 clusters of three wells (36 wells total) installed on 35-ft centers. Three approximately 98-ft-long injection rows would be located on the south side of the mall and include 29 clusters of three wells (87 wells total per row) installed on 35-ft centers. The three southern rows would be installed approximately 200 ft apart. Two more injection rows would be installed on the north side of the mall. The two northern rows would be approximately 700 ft long, include 21 clusters of three wells (63 wells total per row) installed on 35-ft centers, and be spaced approximately 200 ft apart. In all, The Outlet Collection injection area would have 423 injection wells. The injection solution for The Outlet Collection injection rows would include 5 percent LactOil by volume and yeast extract as a source of micronutrients for enhanced reductive dechlorination. Each injection event would last approximately 74 weeks (about 1.5 years). This length of injection is likely not practical in this location because of impacts to parking and business operations at The Outlet Collection.

Monitored Natural Attenuation

Upon completion of the SVE and EISB remedial actions, MNA would be implemented for cleanup of Site-wide groundwater remaining above pCULs. Routine sampling and analysis for MNA parameters and CVOCs would be conducted at wells with TCE and VC concentrations above pCULs and at a series of boundary wells, as discussed in Alternative D1. The predictive transport modeling described in Appendix E, indicates that treatments of SVE and EISB in the release areas, and EISB in the focus areas (Facility boundary near Building 17-07; expanding and re-injection at the former Pilot Test area at Milwaukee Avenue in Algona, and around The Outlet Collection) would decrease the restoration time frame for AOC A-14 by approximately 9.9 percent; the resulting MNA implementation time frame would be reduced to approximately 86 years to meet pCULs protective of drinking water and 210 years to meet SWQS in groundwater. Although Alternative D5 targets additional downgradient focus areas as well as the release areas, the resulting reduction in restoration time frames is still minimal because of the diffuse nature of the downgradient plumes (See Section 2.2). Even when the

primary focus areas are cleaned up, various other areas spread throughout the plumes drive the long restoration time frames. Because of the widespread nature of the plumes, it is not possible or practical to complete EISB remediation throughout the plumes. Evaluation of restoration time frames is presented in Appendix D. Wells proposed for ongoing monitoring are assumed not to change from Alternative D1 for the purposes of cost estimation and are presented on Figure 5-5a (pCULs) and Figure 5-5b (SWQS).

5.6 AOC A-15: Site-Wide Trichloroethene and Vinyl Chloride Stormwater and Surface Water Contamination

AOC A-15 was designated to address CVOC contamination in stormwater features and surface water, specifically TCE and VC from groundwater. AOC A-15 is defined as the features under investigation within the Cities of Auburn and Algona where groundwater enters stormwater or surface water (Chicago Avenue ditch, Auburn 400 north and south stormwater retention basins, and Mill Creek). Because of Ecology's direction that groundwater cleanup levels should be equal to SWQS in groundwater, there are no alternatives evaluated for AOC A-15 because under this scenario remediation of Site-wide groundwater (AOC A-14, described in Section 5.5) would result in remediation of surface water to the SWQS. Additionally, if pCULs protective of drinking water are met in Site-wide groundwater, it is anticipated that surface water features would meet surface water pCULs because the plume is expected to recede from the surface water (and stormwater) features with time and there is significant attenuation of contaminants that occurs in the hyporheic zone within and immediately below the sediments. Therefore, the alternatives evaluated for AOC A-14 would also provide cleanup for AOC A-15. If once groundwater pCULs are met Site-wide, surface water concentrations do not meet the surface water pCULs (not expected to occur) and shown to be associated with releases from the Facility, supplemental remedial alternatives for remediation of surface water would be evaluated.

6.0 ANALYSIS OF CLEANUP ACTION ALTERNATIVES

This section evaluates each of the cleanup action alternatives developed for each AOC in Section 5.0 individually, using applicable MTCA evaluation criteria. A preferred alternative is selected based on the evaluation and comparison of the alternatives. This section includes:

- An explanation of evaluation criteria to compare cleanup action alternatives.
- A comparison of cleanup action alternatives using the criteria under WAC 173-340-360(2).
- An evaluation of the financial costs associated with each cleanup action alternative and a relative cost-benefit analysis to determine whether the cleanup action is permanent to the maximum extent practicable using the criteria under WAC 173-340-360(3).
- An evaluation of determining if the cleanup action provides for a reasonable restoration time frame using criteria under WAC 173-340-360(4).

6.1 Minimum Requirements for Cleanup Action

MTCA regulations require that cleanup action alternatives meet certain minimum requirements as provided in WAC 173-340-360(2) Cleanup alternatives must also be compared to evaluate the benefits of the alternatives relative to their costs as provided in WAC 173-340-360(3). Consistent with MTCA, the alternatives described in Section 5.0 were evaluated with respect to the threshold requirements, and the other requirements (using permanent solutions to the maximum extent practicable, restoration time frame, and consideration of public concerns). The following sections briefly summarize the MTCA threshold and other requirements that must be met by the alternatives under consideration. Sections 6.2 and 6.3 describe how the remedial alternatives for AOC A-09 and AOC A-14 (i.e., those AOCs where multiple alternatives are considered) meet these evaluation criteria.

6.1.1 Threshold Requirements

WAC 173-340-360(2) requires first that all alternatives evaluated meet the following four threshold requirements:

- “Protect human health and the environment”
- “Comply with cleanup standards (see WAC 173-340-700 through WAC 173-340-760)”
- “Comply with applicable state and federal laws (see WAC 173-340-710)”
- “Provide for compliance monitoring (see WAC 173-340-410 and 173-340-720 through 173-340-760)”.

6.1.2 Other Requirements

In addition to the threshold requirements described in Section 6.1.1, WAC 173-340-360(2)(b) requires that cleanup actions meet certain other requirements:

- "Use permanent solutions to the maximum extent practicable…"
- "Provide for a reasonable restoration time frame…"
- "Consider public concerns (see WAC 173-340-600)".

6.1.2.1 Requirements for a Permanent Solution to the Maximum Extent Practicable

Steps to determining whether cleanup action uses permanent solutions to the maximum extent practicable are provided in WAC 173-340-360(3). WAC 173-340-200 defines a permanent solution as one in which cleanup standards "can be met without further action being required at the site being cleaned up or any other site involved with the cleanup action, other than the approved disposal site of any residue from the treatment of hazardous substances." MTCA recognizes that completely permanent solutions may not be practicable for all sites and provides a procedure referred to as a disproportionate cost analysis (DCA; WAC 173-340-360[3][e]) to determine whether a cleanup action is permanent to the maximum extent practicable.

As part of the analysis of whether an alternative uses permanent solutions to the maximum extent practicable, the DCA is performed to determine, whether the incremental increase in costs of a cleanup alternative over that of a lower cost alternative is justified by providing a corresponding incremental increase in human health and environmental benefits (WAC 173-340-360[3][e][i]). The relative benefits of a cleanup alternative are based on evaluation criteria provided in WAC 173-340-360(3)(f). These criteria are:

- ***Protectiveness.*** Overall protectiveness of human health and the environment, including the degree to which site risks are reduced, time required to reduce risk at the facility and attain cleanup standards, risks during implementation, and improvement of overall environmental quality.
- ***Permanence.*** The degree of reduction in toxicity, mobility, and volume of hazardous substances, including the reduction or elimination of hazardous substance releases and sources of releases.
- ***Cost.*** The cost to implement the remedy including capital costs and operation and maintenance costs.
- ***Effectiveness over the long term.*** Long-term effectiveness, including the degree of certainty that the alternative would be successful, long-term reliability, the magnitude of residual risk, and the effectiveness of controls required to manage treatment residues and remaining waste. The following types of cleanup action components may be used as a guide, in descending order, when assessing the relative degree of long-term effectiveness: reuse or recycling; destruction or detoxification; immobilization or solidification; onsite or offsite disposal in an engineered, lined, and monitored facility; onsite isolation or containment with attendant engineering controls; and institutional controls and monitoring.

- ***Management of short-term risks*.** The risk to human health and the environment during construction and implementation, and the effectiveness of measures to manage the risk.
- ***Technical and administrative implementability.*** Implementability, including consideration of whether the alternative is technically possible; the availability of necessary offsite facilities, services, and materials; administrative and regulatory requirements; scheduling, size, and complexity of construction; monitoring requirements; access for construction, operations, and monitoring; and integration with existing facility operations.
- ***Consideration of public concerns.*** Whether the community has concerns and the extent to which those concerns are addressed.

If the incremental increase in costs is determined to be disproportionate to the benefits, the more expensive alternative is considered impracticable and the lower cost alternative is determined to be permanent to the maximum extent practicable (WAC 173-340-360[3]). This process provides a mechanism for balancing the permanence of the cleanup action with its costs, while ensuring that human health and the environment are adequately protected. If alternatives are equal in benefits, the less costly alternative is selected (WAC 173-340-360[3][e][ii][C]).

6.1.2.2 Requirements for a Reasonable Restoration Time Frame

WAC 173-340-360(4)(b) specifies that the following factors be considered when determining whether a cleanup action provides for a reasonable restoration time frame:

- Potential risks to human health and the environment.
- Practicability of achieving a shorter restoration time frame.
- Current and potential future use of the Site, surrounding areas, and associated resources that are, or may be, affected by releases from the Site.
- Availability of alternative water supplies.
- Likely effectiveness and reliability of institutional controls.
- Ability to control and monitor migration of hazardous substances from the Site.
- Toxicity of the hazardous substances at the Site.
- Natural processes that reduce concentrations of hazardous substances and have been documented to occur at the Site or under similar Site conditions.

6.1.2.3 Requirement for Consideration of Public Concerns

Consideration of public concerns is an inherent part of the cleanup process under MTCA (WAC 173-340-600). A draft of this FS report will be issued for public comment and the comments will be considered prior to finalizing this report. A public comment period will also occur for the draft cleanup action plan report, prior to the selection of the final cleanup action, as specified in WAC 173-340-380. Public concerns will be considered when finalizing cleanup alternatives and the final cleanup action plan, as applicable. Further discussion of public concerns is incorporated into the disproportionate

cost analysis section for each AOC (Sections 6.2.2 and 6.3.2) as required under WAC 173-340-360(3)(e)(ii)(C)(vii).

6.2 Evaluation and Comparison of Alternatives—AOC A-09

This section evaluates and compares the adequacy of each alternative for AOC A-09 relative to the criteria discussed in Section 6.1. The comparative analysis of the alternatives is organized by comparison to threshold requirements in Section 6.2.1 and other requirements in Sections 6.2.2, 6.2.3, and 6.2.4.

6.2.1 Threshold Requirements

For an alternative to achieve the threshold requirements, it must adequately protect human health and the environment, comply with cleanup standards, comply with state and federal laws, and provide for compliance monitoring. Threshold requirements are evaluated for Alternatives B1 through B3 in Table 6-1 and summarized below:

- Protection of human health and the environment: Each of the remedial alternatives is protective of human health and the environment by reducing Site risks, addressing potential future exposure pathways, protecting human and ecological receptors, and improving overall environmental quality.
- Compliance with cleanup standards:
  - Alternative B1 complies with applicable cleanup standards by meeting the criteria in WAC 173-340-740(6)(f) through containment and institutional controls for soil contamination (per WAC 173-340-440). Groundwater would comply with cleanup standards at the standard POC after the MNA remedy is completed. Once groundwater quality standards are met, residual concentrations in soils would be shown to be empirically protective of groundwater. Remaining soil concentrations are protective of direct contact and, therefore, meet cleanup standards.
  - Alternative B2 complies with cleanup standards at the standard POC by treatment of groundwater to stabilize contamination and reduce dissolved concentrations; once groundwater quality standards are met, residual concentrations in soils would be shown to be empirically protective of groundwater. Remaining soil concentrations are protective of direct contact and, therefore, would meet cleanup standards.
  - Alternative B3 complies with cleanup standards at the standard POC by removal of contaminated soil followed by MNA resulting in restoration of groundwater quality at the Site.
- Compliance with applicable state and federal laws: Each of the remedial alternatives would comply with applicable state and federal laws as described in Section 3.1 or as otherwise applicable through proper development of cleanup levels (Section 3.0).
- Provisions for compliance monitoring: Alternatives B1 through B3 include compliance monitoring (protection monitoring, performance monitoring, and confirmation monitoring) as required under WAC 173-340-410 and compliance monitoring required by the cleanup standards (WAC 173-340-720 through -760).

Cleanup action alternatives B1, B2, and B3 for AOC A-09 meet all of the MTCA threshold requirements and are viable and appropriate cleanup alternatives under MTCA.

6.2.2 Permanent to the Maximum Extent Practicable

As described in Section 6.1.2, a DCA is performed to determine whether a cleanup alternative is permanent to the maximum extent practicable. The purpose of the DCA is to determine if the costs of a cleanup alternative are disproportionate to the human health and environmental benefits achieved by the cleanup action, thus rendering the alternative impracticable. Each of the remedial alternatives is evaluated using the DCA criteria and results of the evaluation are summarized in Tables 6-2 and 6-3 and on Figure 6-1. A summary of the costs is presented in Table 6-4. A breakdown of these costs is presented in Appendix G. These costs are further evaluated against the relative environmental benefit described in Section 6.2.3.

The following provides a brief summary of the rankings for each alternative for each qualitative DCA criteria. The summary below is intended to be used in conjunction with Table 6-2, which provides a complete summary of the rankings and considerations for each criteria and alternative.

- ***Protectiveness.*** All alternatives scored highly because current risks to human health and the environment are negligible. Alternative B3 received the highest benefit ranking for the protectiveness criteria because it reduces potential current and future risks through complete removal of contaminated soil, which results in groundwater restoration.
- ***Permanence.*** Alternatives B2 and B3 received the highest benefit ranking for the permanence criteria because they each permanently treat or remove soil and groundwater contamination.
- ***Effectiveness over the long term***. Alternative B3 received the highest benefit ranking for the long-term effectiveness criteria because it has the highest degree of certainty that it would be successful in achieving cleanup standards and provides adequate protection in the near term while contaminant concentrations are above pCULs.
- ***Management of short-term risks.*** Alternative B1 received the highest benefit ranking for the management of short-term risks (risks incurred during construction or implementation) criteria because it includes no soil excavation, hauling, or construction activities that could pose a risk to Site workers and minimizes potential exposure to contaminated media.
- ***Technical and administrative implementability.*** Alternative B1 received the highest benefit ranking for technical and administrative implementability criteria because it includes no additional construction or implementation and no permitting or other administrative challenges.
- ***Consideration of public concerns.*** Alternatives B1, B2, and B3 are ranked equally for the consideration of public concerns criteria. Each of these alternatives is protective of human health and the environment. Public concerns related to all the alternatives will be considered and addressed in the same manner by responding to comments received during the required public comment period for the RI/FS (and possibly the cleanup action plan), as part of the cleanup process under MTCA. Additionally, because this AOC and the impacts are contained within the Facility and are not expected to result in off-Facility impacts in the future; substantive public concern comments are not expected.

Based on these benefit rankings for each criteria and the assigned weighting factors,[39] the overall weighted benefit score for each alternative is as follows (from highest to lowest):

- Alternative B3: 8.5
- Alternative B1: 7.5
- Alternative B2: 6.9.

The final DCA criterion to be evaluated is the cost of each alternative:

- Cost: Alternative B1 is the least expensive alternative and Alternative B3 is the most expensive as summarized below with present value costs (assuming a 1.5 percent discount rate).[40] Present values and undiscounted costs are presented in Table 6-4.

Alternative	Cost Summary
Alternative B1	$187,000
Alternative B2	$652,000
Alternative B3	$718,000

6.2.3 Conclusion of Disproportionate Cost Analysis

To provide a direct quantitative metric for comparison of the costs and benefits of each alternative (WAC 173-340-360[3][e][ii][C]), a benefit-to-cost ratio was calculated for each. The overall benefit score for each alternative was divided by the overall cost, then multiplied by the cost of the lowest cost alternative to normalize and scale the data to fit on the chart shown on Figure 6-1. This benefit-to-cost ratio provides a metric to evaluate whether the cost of each alternative is commensurate with its benefits. The most permanent alternative is considered "permanent to the maximum extent practicable," so long as its benefits are not disproportionate to its costs as determined by comparison to other alternatives with higher benefit-to-cost ratios.

[39] Note that the use of weighting factors is not specifically included under MTCA; however, it has become a widely used and accepted practice by the regulated community and Ecology to assign weighting to the DCA criteria (for example see Whatcom County Superior Court 2007 and Ecology 2008). The weighting factors identified herein are typical for FS DCA evaluations performed under MTCA; protectiveness, permanence, and long-term effectiveness criteria are typically weighted more heavily "since they are core to protecting human health and the environment" (Ecology 2017d). Ecology guidance accepts and authorizes the use of alternative ranking and DCA criteria weighting. Boeing used the weights provided in Appendix H, Section H.1.4 (Ecology 2017d) in this FS DCA.

[40] Present value costs are required to be used for cost estimating per WAC 173-340-360(3)(f)(iii). EPA recommendations include a present value cost-estimating discount rate that is significantly out of date (October 1992). It is more appropriate and realistic to use applicable updated Office of Management and Budget (OMB)-published discount rates (i.e., OMB Circular A-94 Appendix C, revised November 2018) for the FS evaluation. The current real discount rate for a 30-year note is 1.5 percent (OMB Circular A-94 Appendix C, revised November 2018).

Using this methodology, the benefit-to-cost ratio for each of the alternatives was calculated to be:

- Alternative B1: 7.5
- Alternative B3: 2.2
- Alternative B2: 2.0.

Alternative B3 is considered the most permanent alternative developed in this FS (WAC 173-340-360[3][e][ii][B]). Alternative B3 consists of excavation of contaminated soil at a future time when access does not impact operations, most likely during demolition of Building 17-07, but the DCA shows that the cost of Alternative B3 is significantly disproportionate to the benefit. The results of the relative cost and benefit analysis are provided in graphical format on Figure 6-1, which compares the costs and benefits of each alternative. Alternative B1 has the highest cost-to-benefit ratio over both higher and lower cost alternatives (as illustrated on Figure 6-1, which shows a peak in the benefit-to-cost ratio at Alternative B1). This benefit-to-cost ratio indicates that more expensive alternatives are disproportionately costly compared to their incremental increase in benefits. Therefore, based on the DCA, Alternative B1 (monitored containment, which includes containment of contaminants under a permanent asphalt or concrete cap as well as institutional controls and periodic groundwater sampling to monitor MNA of inorganic contaminants) is permanent to the maximum extent practicable.

6.2.4 Restoration Time Frame

This section evaluates and compares the restoration time frame associated with each of the remedial alternatives. The restoration time frame is defined in MTCA as "the period of time needed to achieve the required cleanup levels at the points of compliance established for the site" (WAC 173-340-200). Per WAC 173-340-360(4)(b), the selected alternative must meet the cleanup levels within a reasonable time frame as determined based on the eight factors identified in Section 6.1.3 and WAC 173-340-360(4)(b)(i) through (ix). A summary of the estimated restoration time frames for each remedial alternative and how each of the associated factors relates to "reasonableness" is summarized in Table 6-1. The estimated restoration time frame for each alternative is estimated to be as follows:

- Alternative B1: Estimated restoration time frame for cadmium and copper in groundwater is approximately 8 years based on evaluation of concentrations over time (See Appendix D). Additional data collection would be required to determine the cyanide in groundwater restoration time frame because testing requirements recently changed and insufficient data is available. For purposes of cost estimation, 30 years is assumed.
- Alternative B2: The estimated restoration time frame for this alternative to reduce groundwater concentrations is approximately 10 years for design, construction, implementation, and groundwater compliance monitoring.

- Alternative B3: The estimated restoration time frame for this alternative is 2 years from when excavation occurs (in the future) to demonstrate that groundwater pCULs are met. Institutional controls would be implemented and periodic monitoring of groundwater would be performed to confirm Site conditions are adequately protective until future excavation occurs.

For each of the alternatives, it is assumed that the remedy described in Section 5.3 would be successful in achieving the pCULs as planned/designed and that contingent actions are not required. Achievement of the cleanup standards for each alternative is considered to be within a reasonable restoration time frame after implementation.

6.3 Evaluation and Comparison of Alternatives—AOC A-14

This section evaluates and compares the adequacy of each alternative for AOC A-14 relative to the criteria discussed in Section 6.1. The comparative analysis of the alternatives is organized by comparison to threshold requirements in Section 6.3.1 and other requirements in Sections 6.3.2, 6.3.3, and 6.3.4.

6.3.1 Threshold Requirements

For an alternative to achieve the threshold requirements, it must adequately protect human health and the environment, comply with cleanup standards, comply with state and federal laws, and provide for compliance monitoring. Threshold requirements are evaluated for remedial alternatives D1 through D5 in Table 6-5 and summarized below:

- Protection of human health and the environment: Each of the remedial alternatives is protective of human health and the environment by reducing Site risks, addressing potential future exposure pathways, protecting human and ecological receptors, and improving overall environmental quality.
- Compliance with cleanup standards: Each of the remedial alternatives complies with the cleanup standards. Alternatives D1 and D4 (A and B) comply with applicable soil pCULs by meeting the criteria in WAC 173-340-740(6)(f) through containment and institutional controls (per WAC 173-340-440), and complies with groundwater standards once the MNA portion of the remedy is completed. Additionally, once groundwater pCULs have been met, soil would have been empirically demonstrated to be protective of groundwater. Remaining concentrations are protective of soil direct contact pCULs. Alternatives D2, D3, and D5 comply with soil and groundwater pCULs once SVE for soil treatment and the groundwater MNA remedy are completed.
- Compliance with applicable state and federal laws: Each of the remedial alternatives would comply with applicable state and federal laws as described in Section 3.1 or as otherwise applicable through proper development of cleanup levels (Section 3.0).
- Provisions for compliance monitoring: Alternatives D1 through D5 include compliance monitoring (protection monitoring, performance monitoring, and confirmation monitoring) as required under WAC 173-340-410 and WAC 173-340-720 through -760.

As demonstrated, each of the cleanup action alternatives meets all of the MTCA threshold requirements. Each alternative is a viable and appropriate cleanup alternatives under MTCA.

6.3.2 Permanent Solutions to the Maximum Extent Practicable

Alternatives that meet threshold requirements must also meet the other requirements provided in WAC 173-340-360(2)(b). One of these requirements is evaluate whether a cleanup alternative is permanent to the maximum extent practicable (WAC 173-340-360[2][b][i]). As described in Section 6.1.2, a DCA is performed to determine whether a cleanup alternative is permanent to the maximum extent practicable (WAC 173-340-360[3][b]). The DCA is performed to determine whether the incremental costs of a cleanup alternative over that of a lower cost alternative exceeds the incremental degree of human health and environmental benefits achieved by the alternative over that of the lower cost alternative, in which case the costs of that alternative are considered disproportionate to the benefits. In accordance with WAC 173-340-360(3)(f), each of the remedial alternatives is evaluated using the DCA criteria listed in the bullets below; results are presented in Tables 6-6 and 6-7 and Figures 6-2 and 6-3. A summary of the costs is presented in Table 6-8. A breakdown of these costs is presented in Appendix G. These costs are further evaluated against the relative environmental benefit described in Section 6.3.3.

A brief summary of the rankings for each alternative for each qualitative DCA criteria are provided below. The summary below is intended to be used in conjunction with Table 6-6, which provides a complete summary of the rankings and considerations for each criteria and alternative.

- ***Protectiveness.*** Alternatives D1 through D5 are ranked equally for protectiveness. Risks to human health and the environment are negligible as described in Section 2.3 and all five alternative rely on a long period of MNA for some portion of the remedy. The time required to reduce the risk at the Site does not change significantly (only up to an estimated 10 percent decrease restoration time frame) no matter which alternative is selected, as described in Section 6.3.4. After completion of implementation of any of the alternatives, the risks and improvement of overall environmental quality would be the same (the same cleanup standards would be met no matter which alternative is implemented).
- ***Permanence.*** Alternatives D1, D2, D4 and D5 all received relatively high rankings for permanence because all permanently treat soil and groundwater contamination. D2 and D5 were given slightly higher rankings than D1 and D4 because D2 and D5 include additional mass reduction in vadose zone soil through SVE. While permanently treating groundwater, Alternative D3 receives the lowest benefit ranking for permanence criteria because *ex situ* treatment of groundwater from the DGR system would generate residual wastes (granular activated carbon) that need to be treated or disposed of off-site.
- ***Effectiveness over the long term.*** Alternatives D1 through D5 are ranked equally for long-term effectiveness. The long-term groundwater treatment effectiveness for each remedy relies primarily on natural degradation processes to provide *in situ* destruction and detoxification and to reach the groundwater pCULs. Implementation of additional technologies provides no additional certainty that the alternatives would be successful. The risks to human health and the environment, would also remain negligible throughout the duration of cleanup under any

of the alternatives. It is also unlikely that implementation of any currently available treatment technology can meet SWQS in groundwater site-wide because of the heterogeneity of the aquifer, the diffuse nature and extent of the CVOC plumes, and the potential to reach asymptotic concentration thresholds (see Section 3.2.2.3).

- ***Management of short-term risks.*** Alternative D1 received the highest benefit ranking for the management of short-term risk criteria because it includes no construction or operations and monitoring activities that could pose a risk to Site workers. Alternatives D3 and D5 received the lowest benefit ranking for short-term risks because of significant risk potential to both Site workers and Site infrastructure during implementation (i.e., potential for ground settlement and structure damage for Alternative D3 and impacts to stormwater or surface water features based on location of injection activities for Alternative D5).
- ***Technical and administrative implementability.*** Alternative D1 received the highest benefit ranking for technical and administrative implementability criteria because it includes no additional construction or implementation and no permitting or other administrative challenges. Alternatives D3 and D5 received the lowest benefit ranking for technical and administrative implementability criteria. Both alternatives present access constraints because of the large number of required well installations. Alternative D3 is technically difficult to implement because of the likelihood of iron fouling requiring frequent maintenance and well rehabilitation.[41] Alternative D5 is difficult to implement technically because of the injections closer to stormwater or surface water features that could cause water quality impacts and because of the excessive timeline required to complete injection at The Outlet Collection (more than 1.5 years per injection event).
- ***Consideration of public concerns.***[42] Alternatives D4 and D5 are ranked the highest because the remedial actions off-Facility or at the property boundary would have more immediate impacts on reducing contaminant concentrations in the individual focus areas. However, Alternative D5 would also have negative impacts to offsite property use and operations that would likely increase public concern.[43] The duration of treatment activities in public areas may create concerns related to lost revenue for commercial businesses, impact of additional traffic on roadways and noise, and concern about use of injection solution (can be perceived as chemicals, even though injection solution is non-toxic) in public areas around The Outlet Collection. Because it is unclear how the negative and positive aspects of Alternative D5 would offset one another from the public's point of view, the positive benefits were given higher priority and the alternative was given the same high score as D4. Alternative D1 and D3 are ranked lowest. For Alternative D1, the public may have more concerns about this alternative because of difficulty understanding that MNA is considered an active treatment, difficulty understanding the treatment mechanisms that occur as part of MNA, and an inaccurate perception that it is less protective. For Alternative D3, the low score is based on the potential

[41] Ferrous iron would be converted to ferric iron as it is oxidized in the air stripper before reinjection. This would result in a large amount of iron precipitation in the air stripper and in the injection well screens. Extraction well screens are likely to be impacted as well.

[42] For consideration of public concerns a high ranking means that it is assumed the public would not have as many concerns about this alternative. A low ranking means that it is assume that public would have more concerns about this alternative.

[43] Alternative D5 includes injection activities on commercial properties in Algona and in Auburn (at The Outlet Collection). The duration of each injection event at the commercial area in Algona would each last approximately 6 weeks. Due to the amount of injection solution and size of the injection area needed at The Outlet Collection, each injection event would last approximately one and a half years. This length of injection activities would have a considerable impact on the business activities in both commercial Algona and at The Outlet Collection.

for public concerns related to ground settlement and infrastructure damage during implementation of DGR[44] and potential for redistribution of contaminants to areas with previously lower or non-detect concentrations because of the shifting of groundwater flow directions.[45] Alternatives D1 through D5 are all protective of human health and the environment. Public concerns related to all the alternatives will be considered and addressed in the same manner by responding to comments received during the required public comment period for the RI/FS (and possibly the cleanup action plan), as part of the cleanup process under MTCA.

Based on these benefit rankings for each criteria and the assigned weighting factors,[46] the overall weighted benefit score for each alternative is as follows (from highest to lowest):

- Alternative D1: 6.1
- Alternative D2: 5.6
- Alternative D4: 5.3
- Alternative D5: 4.9
- Alternative D3: 4.0.

The above benefit rankings do not consider cost. The final DCA criterion to be evaluated is the cost of each alternative [WAC 173-340-360(3)(f)(iii)].[47] As summarized below, Alternative D1 is the least expensive alternative and Alternative D5 is the most expensive. Cost breakdowns for the alternatives are provided in Table 6-8.

[44] Historical construction dewatering activities at the site resulted in complaints from nearby property owners about ground settlement and damage to building foundations. The concerns resulted in litigation.

[45] Appendix E shows examples of possible contaminant locations during implementation of DGR activities.

[46] Note that the use of weighting factors is not specifically included under MTCA; however, it has become a widely used and accepted practice by the regulated community and Ecology to assign weighting to the DCA criteria (for example see Whatcom County Superior Court 2007 and Ecology 2008). The weighting factors identified herein are typical for FS DCA evaluations performed under MTCA; protectiveness, permanence, and long-term effectiveness criteria are typically weighted more heavily "since they are core to protecting human health and the environment" (Ecology 2017d). Ecology guidance accepts and authorizes the use of alternative ranking and DCA criteria weighting. Boeing used the weights provided in Appendix H, Section H.1.4 (Ecology 2017d) in this FS DCA.

[47] Present value costs are required to be used for cost estimating per WAC 173-340-360(3)(f)(iii). EPA recommendations include a present value cost-estimating discount rate that is significantly out of date (October 1992). It is more appropriate and realistic to use applicable updated Office of Management and Budget (OMB)-published discount rates (i.e., OMB Circular A-94 Appendix C, revised November 2018) for the FS evaluation. The current real discount rate for a 30-year note is 1.5 percent (OMB Circular A-94 Appendix C, revised November 2018).

Cost:

Alternative	Cost Summary	
	Remedy to Meet GW pCULs	**Remedy to Meet SWQS in GW**
Alternative D1	$3.90M present value ($7.03M undiscounted)	$7.70M present value ($26.9M undiscounted costs)
Alternative D2	$8.41M present value ($11.7M undiscounted)	$12.1M present value ($31.1M undiscounted)
Alternative D3	$25.8M present value ($29.3M undiscounted)	$39.0M present value ($57.8M undiscounted costs)
Alternative D4A	$17.1M present value ($20.7M undiscounted)	$20.8M present value ($34.9M undiscounted costs)
Alternative D4B	$38.2M present value ($44.4M undiscounted)	$41.8M present value ($58.6M undiscounted costs)
Alternative D5	$44.8M present value ($50.6M undiscounted)	$48.5M present value ($68.3M undiscounted costs)

GW = groundwater
M = million
pCULs = proposed cleanup levels
SWQS = surface water quality standards

6.3.3 Conclusion of Disproportionate Cost Analysis

To provide a direct quantitative metric for comparison of the costs and benefits of each alternative (WAC 173-340-360[3][e][ii][C]), a benefit-to-cost ratio was calculated for each. The overall benefit score for each alternative (as provided above) was divided by the overall cost, then multiplied by the cost of the lowest cost alternative to normalize and scale the data to fit on the chart shown on Figures 6-2 and 6-3. This benefit-to-cost ratio provides a metric to evaluate whether the cost of each alternative is commensurate with its benefits. The most permanent alternative is considered "permanent to the maximum extent practicable," so long as its benefits are not disproportionate to its costs as determined by comparison to other alternatives with higher benefit-to-cost ratios.

Using this methodology, the benefit-to-cost ratio for each of the alternatives was calculated to be:

Alternative	Benefit-to-Cost Ratio	
	Remedy to Meet GW pCULs	**Remedy to Meet SWQS in GW**
Alternative D1	6.1	6.1
Alternative D2	2.6	3.6
Alternative D3	0.5	0.8
Alternative D4A	1.2	2.0
Alternative D4B	0.6	1.0
Alternative D5	0.4	0.8

GW = groundwater
pCULs = proposed cleanup levels
SWQS = surface water quality standards

Alternative D1 is considered the alternative developed in this FS that is permanent to the maximum extent practicable per WAC 173-340-360(3)(e)(ii)(B). Alternative D1 consists of MNA for Site-wide groundwater and containment and institutional controls for Facility soil. The complete DCA analysis is presented in Table 6-7 and the rankings and associated rationale for the various rankings are presented in Table 6-6. A relative cost and relative benefit analysis was also performed as part of the DCA. The results of the relative cost and benefit analysis are provided in graphical format on Figures 6-2 and 6-3, which compares the costs and benefits of each alternative. Alternative D1 has the highest cost-to-benefit ratio over both higher and lower cost alternatives (as illustrated on Figures 6-2 and 6-3, which shows a peak in the benefit-to-cost ratio at Alternative 1). This indicates that more expensive alternatives are disproportionately costly to their incremental increase in benefits, if any. Based on these DCA results, and because Alternative D1 uses and takes advantage of active and naturally occurring contaminant degradation and treatment processes (that are also required in order to meet the cleanup standards under any of the alternatives), is permanent and protective of human health and the environment, and minimizes potential implementation risks to workers and public/commercial areas in the vicinity, Alternative D1 is permanent to the maximum extent practicable.

6.3.4 Restoration Time Frame

This section evaluates and compares the restoration time frame associated with each of the remedial alternatives. The restoration time frame is defined in MTCA as “the period of time needed to achieve the required cleanup levels at the points of compliance established for the site” (WAC 173-340-200). Per WAC 173-340-360(4)(b), the selected alternative must meet the cleanup levels within a reasonable time frame based on the eight factors identified in Section 6.1.3 and WAC 173-340-360(4)(b)(i) through (ix). None of the alternatives can achieve a reasonable restoration timeframe and there are no available remedial technologies that can achieve a reasonable restoration timeframe (see discussion in Section 3.2.2.3). A summary of the estimated restoration time frames for each remedial alternative and how each of the associated factors relates to “reasonableness” is summarized in Table 6-5.

Restoration time frames were calculated based on individual well points throughout the Site from individual well point attenuation rates from total CVOC time series plots (data from 2011 through 2018). The specific methodology for the restoration time frame calculations is described in Appendix D. The reduction of overall restoration time frames for the different remediation alternatives was determined using the predictive numerical groundwater transport model as described in Appendix E. The estimated approximate restoration time frames for each alternative are as follows:

Alternative	Estimated Restoration Time Frame	
	Years to Meet pCULs Protective of Drinking waters	Years to Meet SWQS in GW
Alternative D1	95	233
Alternative D2	94	230
Alternative D3	85	208
Alternative D4 (A and B)	86	212
Alternative D5	86	210

GW = groundwater
pCULs = proposed cleanup levels
SWQS = surface water quality standards

The calculations and the modeling demonstrate that restoration time frames for AOC A-14 are estimated to be 85–95 years to meet pCULs protective of drinking water and 210–233 years to meet SWQS in groundwater, regardless of what remedial action alternative is selected.

The long restoration time frames for all of the alternatives are a function of the low cleanup levels, the nature of the contaminant distribution within the aquifer, and the size and heterogeneity of the aquifer itself. As discussed in Section 2.2, persistent low concentrations in groundwater are driven by desorption and back diffusion processes from low permeability layers within the aquifer. This late-stage plume concept is well documented and known to sustain low contaminant concentrations for long periods of time (Kueper et al. 2014). When combined with very low cleanup levels, the resulting restoration time frames are extensive. Currently available remedial technologies provide little benefit with respect to back diffusion (Kueper et al. 2014; Seyedabbasi et al. 2012). This lack of effectiveness is related to the technical difficulty of accessing the sequestered mass in lower permeability portions of the aquifer. In aquifers dominated by back diffusion, the decline in concentration exhibits a tailing effect that results in slower and slower rates of reduction in concentration as concentrations become lower. This type of tailing effect magnifies the difficulty of achieving very low concentration cleanup levels in short periods of time. This type of tailing effect also explains why it is so much more difficult to achieve SWQS than drinking water standards in groundwater in any reasonable time frame, if ever. Though still considered technically difficult to achieve, the practicability and likelihood of achieving the pCULs protective of drinking water standards Site-wide is far greater than that of achieving SWQS in groundwater. PCULs protective of drinking water can likely be met in less than 50 percent of the time required to meet the SWQS. For example, as shown above, preferred alternative D1 is likely to achieve drinking water pCULs in 95 years while it would take 233 years (an additional 138 years) to meet SWQS in groundwater.

7.0 RECOMMENDATION OF PREFERRED CLEANUP ACTION ALTERNATIVE AND CONCLUSIONS

This section recommends a cleanup action alternative for each AOC, where appropriate, and summarizes activities required for AOCs that do not require cleanup action evaluations. Selected alternatives for each AOC are presented in Table 7-1.

7.1 AOC A-01

A remedial excavation (which is a model remedy) would be completed and is the most permanent remedy for petroleum hydrocarbon contamination in soil and groundwater from the former USTs northeast of Building 17-06 (AOC A-01). Cleanup action Alternative A1 consists of excavation of the petroleum hydrocarbon soil contamination and ORC, or other equivalent oxidant, emplacement in the saturated/seasonally saturated portion of the excavation backfill (and supplemental MNA as necessary) for the treatment of residual petroleum hydrocarbon contamination in groundwater.

7.2 AOC A-09

For AOC A-09, Boeing has selected Alternative B3 as the preferred remedial action alternative. Alternative B3includes future excavation of soil contamination when the area is accessible without disrupting operations, likely when Building 17-07 is demolished and monitored containment until that time. The results of the DCA analysis in Section 6.2.3 indicate that alternative B1 is the alternative that is permanent to the maximum extent practicable; however, Boeing is choosing B3 instead because overall it is a more permanent remedy. Selection of Alternative B3 over Alternatives B1 and B2 is primarily based on the following:

- Alternative B3 achieves each of the threshold requirements as described in Section 6.2.1.
- Even though Alternative B1 is permanent to the maximum extent practicable, as described in Section 6.2.3, Boeing is choosing to select a more permanent but still technically possible solution (excavation) at a future time when excavation would not impact operations (most likely at the time of building demolition).
- Alternative B3 provides for a reasonable restoration time frame as described in Section 6.2.4.
- Groundwater contamination is contained to a small area and is not migrating off the Facility. Contaminated soil is limited to a small area underneath pavement or buildings and does not exceed direct contact cleanup levels. There is negligible risk to human health or the environment from the contamination present at AOC A-09 and the current containment is expected to be protective until excavation can be completed in the future.
- Contamination would be contained with institutional controls until excavation can be completed. Once excavation occurs, it is expected that groundwater concentrations would decrease because of source removal and would meet pCULs.

7.3 AOC A-13

As stated in Section 4.0, concentrations of TPH in soil and groundwater at AOC A-13 do not currently exceed the pCULs, and no cleanup action is required. Boeing requests that Ecology provide approval of closure of this AOC.

7.4 AOC A-14

Based on the FS evaluation, including the DCA discussed in Section 6.3.3, the preferred remedial action alternative for the Site is Alternative D1, which includes Site-wide MNA. Selection of this alternative over Alternatives D2, D3, D4 (A and B), and D5 is primarily based on the following:

- Alternative D1 achieves each of the threshold requirements as described in Section 6.3.1.
- The results of the DCA in Section 6.3.3 demonstrate that Alternative D1 uses permanent solutions to the maximum extent practicable. Alternative D1 received both the highest benefit score and received the highest benefit to cost score.
- Alternative D1 uses and takes advantage of active and naturally occurring contaminant degradation and treatment processes (that would be required to meet the cleanup standards under any of the alternatives).
- Alternative D1 is permanent and protective of human health and the environment; current Site risks to human health and the environment are negligible and any potential future Site risks would be completely eliminated through the eventual cleanup of groundwater and surface water.
- Alternative D1 provides the lowest potential implementation risks to workers and public/commercial areas in the vicinity of each of the alternatives.
- Contaminated soil is limited to a small area underneath pavement or buildings and does not exceed Method C direct contact cleanup levels. Surface water downgradient of the Site and contaminated groundwater are not being used as drinking water. Risks to human health and the environmental are negligible from the contamination present at AOC A-14.

Although the evaluation of cleanup alternatives in Sections 5.0 and 6.0 included the standard POC; Boeing is requesting a CPOC for AOC A-14 (either an off-Facility area-wide CPOC or a CPOC at the Facility Boundary). As demonstrated in Section 3.0, a CPOC for AOC A-14 may be authorized by Ecology. No alternative can meet groundwater pCULs protective of drinking water as described in Section 6.3.4 sooner than approximately 86 years. Achieving SWQS in groundwater Site-wide would increase the restoration time frames by more than 50 percent, to well over 200 years, and thus cannot be accomplished in a reasonable time frame, if ever. In addition, RELs may be used at the Site as discussed in Section 3.4. Details of how RELs will be used will be presented in the cleanup action plan.

7.5 AOC A-15

The remediation of Site-wide groundwater (AOC A-14) would result in remediation of AOC A-15. If pCULs protective of drinking water are met in Site-wide groundwater, it is expected that surface water features would meet surface water pCULs once groundwater cleanup is complete. If once groundwater pCULs are met Site-wide, surface water concentrations exceed surface water pCULs and are shown to be associated with releases from the Facility, supplemental remedial alternatives for remediation of surface water would be evaluated. If Ecology continues to require that groundwater TCE and VC concentrations meet SWQS in groundwater, the remediation of AOC A-14 by Alternative D1 would meet SWQS in groundwater and therefore; concentrations in surface water would also meet SWQS.

8.0 USE OF THIS REPORT

This report has been prepared for the exclusive use of The Boeing Company and applicable regulatory agencies for specific application to the Boeing Auburn project. No other party is entitled to rely on the information, conclusions, and recommendations included in this document without the express written consent of LAI. Further, the reuse of information, conclusions, and recommendations provided herein for extensions of the project or for any other project, without review and authorization by LAI, shall be at the user's sole risk. LAI warrants that within the limitations of scope, schedule, and budget, our services have been provided in a manner consistent with that level of care and skill ordinarily exercised by members of the profession currently practicing in the same locality under similar conditions as this project. We make no other warranty, either express or implied.

9.0 REFERENCES

Adamson, D.T., and C.J. Newell. 2009. "Support of Source Zone Bioremediation through Endogenous Biomass Decay and Electron Donor Recycling." *Bioremediation Journal* 13 (1):29-40.

AGI. 1996. Report: Soil and Groundwater Assessment, Acid Scrubber Drain Line Leak, 17-07 Building, BCAG - Fabrication Division, Auburn, Washington. AGI Technologies. November 8.

Ball, W.P., C. Liu, R.D. Wilson, and D.M. Mackay. 1998. Studies of Contaminant Diffusion in an Aquitard and Groundwater Remediation by Reactive Metals at Dover Air Force Base, Delaware. Publication No. AFRL-ML-TY-TR-1998-4518. Airforce Research Laboratories. January 23.

Chapman, S.W. and B.L. Parker. 2005. "Plume persistence due to aquitard back diffusion following dense nonaqueous phase liquid source removal or isolation." *Water Resources Research* 41 (No. 12).

Ecology. 1994. Natural Background Soil Metals Concentrations in Washington State. Publication No. 94-115. Washington State Department of Ecology. October. https://fortress.wa.gov/ecy/publications/documents/94115.pdf.

Ecology. 2002. Agreed Order No. 01HWTRNR-3345. Washington State Department of Ecology. August 14.

Ecology. 2004. Letter: Letter of Determination for SWMUs and AOCs Within or Near the Area 1 Property Boundary Based on Ecology Review of the Expedited Area 1 Remedial Investigation Report and Supplemental Area 1 Remedial Investigation Report, Boeing Commercial Airplanes Group, Fabrication Division - Auburn Plant, WAD041337130. From PG Robin Harrover, PHg, to Environmental Affairs, The Boeing Company. April 29.

Ecology. 2006. First Amended Agreed Order No. 01HWTRNR-3345; In the Matter of Remedial Action by: The Boeing Company and AMB Property Corporation, to The Potentially Liable Parties. State of Washington Department of Ecology. April 7.

Ecology. 2007. "Toxics Cleanup Program Tools & Resources, Assessing Risk/Establishing Cleanup Levels, Workbook Tools for Calculating Cleanup Levels for Individual Substances and TPH." Washington State Department of Ecology. http://www.ecy.wa.gov/programs/tcp/tools/toolmain.html.

Ecology. 2008. Annotated Outline for RI/FS Documents. Washington State Department of Ecology. July 24.

Ecology. 2016. Guidance for Remediation of Petroleum Contaminated Sites. Publication No. 10-09-057. Washington State Department of Ecology. Revised June. https://fortress.wa.gov/ecy/publications/documents/1009057.pdf.

Ecology. 2017a. Letter: Ecology Approval of the Draft Remedial Investigation Report, Boeing Auburn Facility, Landau Associates, Inc. for the Boeing Co; February 9, 2017; FS #2018; CS #5049; EPA ID: WAD041337130. From LHG Robin Harrover, Hazardous Waste and Toxics Reduction Program, Washington State Department of Ecology, to Carl M. Bach, EH&S Remediation Project Manager, The Boeing Company. September 12.

Ecology. 2017b. Model Remedies for Sites with Petroleum Contaminated Soils. Publication No. 15-09-043. Toxics Cleanup Program, Washington State Department of Ecology. December.

Ecology. 2017c. Model Remedies for Sites with Petroleum Impacts to Groundwater. Publication No. Publication No. 16-09-057. Toxics Cleanup Program, Washington State Department of Ecology. December.

Ecology. 2017d. Sediment Cleanup User's Manual II: Guidance for Implementing the Cleanup Provisions of the Sediment Management Standards, Chapter 173-204 WAC. Publication No. 12-09-057. Washington State Department of Ecology. Revised December. https://fortress.wa.gov/ecy/publications/documents/1209057.pdf.

Ecology. 2018. Second Amended Agreed Order No. 01HWTRNR-3345. In the Matter of Remedial Action by The Boeing Company and Prologis to The Potentially Liable Person(s). Washington State Department of Ecology. November 1.

Ecology. 2019. Letter: Ecology's Cleanup Standards Based on the Model Toxics Control Act Specific to the Boeing Auburn Site; FS #2018; CS #5049; EPA WAD041337130. From Robin Harrover LHg, Hazardous Waste and Toxics Reduction Program, Washington State Department of Ecology, to Debbie Taege, The Boeing Company. June 28.

EPA. 2007. Monitored Natural Attenuation of Inorganic Contaminants in Ground Water Volume 2: Assessment for Non-Radionuclides Including Arsenic, Cadmium, Chromium, Copper, Lead, Nickel, Nitrate, Perchlorate, and Selenium. Publication No. EPA/600/R-07/140. Office of Research and Development National Risk Management Research Laboratory, US Environmental Protection Agency. October.

EPA. 2015. Use of Monitored Natural Attenuation for Inorganic Contaminants in Groundwater at Superfund Sites. Publication No. Directive 9283.1-36. Office of Solid Waste and Emergency Response, US Environmental Protection Agency. August.

Fan, Dimin, Ying Lan, Paul G. Tratnyek, Richard L Johnson, Jan Filip, Denis M. O'Carroll, Ariel Nunez Garcia, and Abiniash Agrawal. 2017. "Sulfidation of Iron-Based Materials: A Review of Processes and Implications for Water Treatment and Remediation." *Enviornmental Science and Technology* 51:13070-13085.

G-Logics. 2009a. Groundwater Sampling, January 2009, Commercial Property, 401 Lund Road, Auburn, Washington. January 26.

G-Logics. 2009b. Release Report, DS Waters of America, Inc. Commercial Property, 401 Lund Road, Auburn, Washington. July 29.

Geomatrix. 2003. Final Report: Remedial Investigation Work Plan, Boeing Auburn Plant, Auburn, Washington. Geomatrix Consultants. October.

GSI Environmental. 2016. Development of an Expanded, High-Reliability Cost and Performance Database for In-Situ Remediation Technologies. US Department of Defense. March 31.

Hydraulics & Pneumatics. "Engineering Essentials: Hydraulic Fluids." Hydraulics & Pneumatics,. https://www.hydraulicspneumatics.com/200/TechZone/HydraulicFluids/Article/False/6449/TechZone-HydraulicFluids.

ITRC. 2011. Integrated DNAPL Site Strategy -Technology/Regulatory Guidance. Interstate Technology & Regulatory Council, DNAPL Site Characterization Team. November.

ITRC. 2018. LNAPL-3: LNAPL Site Management: LCSM Evolution, Decision Process, and Remedial Technologies. Interstate Technology & Regulatory Council. March.

Kennedy/Jenks. 1992. Letter: Transmittal of Laboratory Analysis Reports, Building 17-03 Subsurface Investigation BECE No. 0071; WOR No. AUB-A-92466-245. From Susan Roth, Project Geologist, Kennedy/Jenks Consultants, to Jeff Kellett, Boeing Commercial Airplane Group, The Boeing Company. November 13.

Kennedy/Jenks. 1993. Technical Report, Environmental Monitoring Report 17-03 Building Demolition, Boeing Auburn. Kennedy/Jenks Consultants. January.

Kennedy/Jenks. 1995. Technical Report, Hydrogeologic Investigation Building 17-05, Boeing Auburn. Kennedy/Jenks Consultants. February.

Kennedy/Jenks. 1996. Technical Report: Subsurface Investigation, Building 17-07 Plating Shop Degreaser Area, Boeing Auburn. Kennedy/Jenks Consultants. May.

Kennedy/Jenks. 1997a. Building 17-03/17-05 Chrome Waste Piping Investigation, Boeing Auburn - Final. Kennedy/Jenks Consultants. May.

Kennedy/Jenks. 1997b. Technical Report, Building 17-05 Area Hydrogeologic Characterization, Boeing Auburn. Kennedy/Jenks Consultants. May.

Kueper, B.H., H.F. Stroo, C.M. Vogel, and C.H. Ward. 2014. *Chlorinated Solvent Source Zone Remediation*. New York, NY: Springer.

LAI. 2004a. Agency Review Draft Report, Interim Remedial Action Boeing Auburn Area 1 (Building 17-05) 700 15th Street SW, Auburn, Washington. Landau Associates, inc. December 20.

LAI. 2004b. Draft: Area 1 Remedial Investigation Report, Boeing Auburn Facility, Auburn, Washington. Landau Associates, Inc. January 30.

LAI. 2004c. Interim Remedial Action Work Plan, Boeing Auburn Area 1 700 15th Street SW, Auburn, Washington. Landau Associates, Inc. May 7.

LAI. 2004d. Memorandum: Soil Excavation Near Area of Concern A-01. From Eric Weber, Landau Associates, Inc., to James Bet and Ken MacNair, The Boeing Company. May 3.

LAI. 2005a. Draft (2nd Report): Interim Remedial Action, Boeing Auburn Area I (Building 17-05) 700 15th Street SW, Auburn, Washington. Landau Associates, Inc. June 7.

LAI. 2005b. Draft: Supplement to Final Interim Remedial Action Work Plan. Landau Associates, Inc. October 11.

LAI. 2008. Interim Remedial Action Boeing Auburn Area 1, Auburn, Washington. Landau Associates, Inc. April 22.

LAI. 2012. Draft: Spring 2011 Remedial Investigation Data Summary Report, Boeing Auburn Facility, Auburn, Washington. Landau Associates, Inc. March 1.

LAI. 2013. Memorandum: Screening Levels for Yard and Ditch Surface Water, Boeing Auburn Plant, Auburn, Washington. From Chip Halbert and Jennifer Wynkoop, Landau Associates, Inc., to James Bet, The Boeing Company. December 13.

LAI. 2014. Final: Supplemental Remedial Investigation Data Summary Report Fall 2012 to Fall 2013, Boeing Auburn Facility, Auburn, Washington. Landau Associates, Inc. December 19.

LAI. 2016. Groundwater Modeling Report, Boeing Auburn Facility, Auburn, Washington. May 2.

LAI. 2017a. Technical Memorandum: 2015 Surface Water Investigation. Landau Associates, Inc. March 24.

LAI. 2017b. Letter: 2017 Feasibility Study Additional Field Activities Data Submittal, Former Building 17-03 and AOC A-01, Boeing Auburn Facility, Auburn, Washington. From Sarah Fees and Jennifer Wynkoop, to Robin Harrover, Washington State Department of Ecology; Neal Hines, Washington State Department of Ecology. December 15.

LAI. 2017c. Letter: 2017 Feasibility Study Field Activities Data Submittal and Recommendations, Boeing Auburn Facility, Auburn, Washington. From Sarah Fees and Jennifer Wynkoop, Landau Associates, Inc., to Robin Harrover and Neal Hines, Washington State Department of Ecology. August 9.

LAI. 2017d. Letter: AGW278 Resampling Data Submittal, Boeing Auburn Facility, Auburn, Washington. From Sarah Fees LG and Jennifer Wynkoop, to Robin Harrover and Neal Hines, Washington State Department of Ecology. December 18.

LAI. 2017e. Algona Pilot Test Report, Boeing Auburn Facility, Auburn, Washington. Landau Associates, Inc. September 22.

LAI. 2017f. Letter: Cyanide Investigation Data Submittal, Building 17-07 Area of Concern A-09, Boeing Auburn Facility, Auburn, Washington. From Sarah Fees LG and Jennifer Wynkoop, to Robin Harrover and Neal Hines, Washington State Department of Ecology. November 10.

LAI. 2017g. Agency Review Draft: Feasibility Study Work Plan, Boeing Auburn Facility, Auburn, Washington. Landau Associates, Inc. May 22.

LAI. 2017h. Remedial Investigation Report, Boeing Auburn Facility, Auburn, Washington. Landau Associates, Inc. September 15.

LAI. 2017i. Letter: Revised 2017 Feasibility Study Field Activities Data Submittal - Building 17-06, Boeing Auburn Facility, Auburn, Washington. From Sarah Fees and Jennifer Wynkoop, to Robin Harrover and Neal Hines, Washington State Department of Ecology. December 8.

LAI. 2018a. Letter: 2017 Feasibility Study Data Submittal, Additional Surface Water Sampling and Soil Port Water Sampling, Boeing Auburn Facility, Auburn, Washington. From Sarah Fees and Jennifer Wynkoop, to Robin Harrover, Washington State Department of Ecology. April 17.

LAI. 2018b. Technical Memorandum: Algona Pilot Test - Second Year of Monitoring, Boeing Auburn Facility, Auburn, Washington. Landau Associates, Inc. October 1.

LAI. 2018c. Feasibility Study Work Plan, Boeing Auburn Facility, Auburn, Washington. Landau Associates, Inc. October 23.

LAI. 2018d. Letter: Surface Water Sampling and Pore Water Installation Data Submittal. From Sarah Fees and Jennifer Wynkoop, to Robin Harrover, Washington State Department of Ecology. November 13.

LAI. 2019a. Letter: 2017/2018 Feasibility Study Data Submittal - Additional Work at Building 17-06, Boeing Auburn Faciilty, Auburn, Washington. From Jennifer Wynkoop, Principal, to Robin Harrover, Washington State Department of Ecology. February 8.

LAI. 2019b. Letter: 2018 Cyanide Investigation Data Submittal, Building 17-07 Area of Concern A-09, Boeing Auburn Facility, Auburn, Washington. From Sarah Fees LG and Jennifer Wynkoop, to Robin Harrover, Washington State Department of Ecology. May 15.

LAI. 2019c. Technical Memorandum: Phase 9 Interim Groundwater Monitoring Program, Boeing Auburn Facility, Auburn, Washington. Landau Associates, Inc. May 7.

LAI. 2019d. Final: Site-Wide Natural Attenuation Assessment Report, Boeing Auburn Facility, Auburn, Washington. Landau Associates, Inc. July 16.

Mackay, D.M. and J.A. Cherry. 1989. "Groundwater contamination: pump-and-treat remediation." *Environmental Science & Technology* 23 (No. 6):630-636.

NRC. 2005. Contaminants in the Subsurface: Source Zone Assessment and Remediation. D.C. Committee on Source Removal of Contaminants in the Subsurface. Washington, National Research Council.

NRC. 2013. Alternatives for Managing the Nation's Complex Contaminated Groundwater Sites. Washington, D.C. National Research Council.

OI Analytical. 2009. An Overview and Comparison of Methods for Cyanide Analysis. March.

PGG. 1999. 1999 Hydrogeologic Characterization Report, City of Auburn, Volume 1. Pacific Groundwater Group.

PTI. 1989. Draft Report Section 1-7: Background Concentrations of Selected Chemicals in Water, Soil, Sediments, and Air of Washington State. PTI Environmental Services. April.

Sale, T., and C. Newell. 2011. Decision Guide: A Guide for Selecting Remedies for Subsurface Releases of Chlorinated Solvents. Publication No. ESTCP Project ER-200530. Department of Defense Environmental Security Technology Certification Program (ESTCP). March.

Sale, T.C., C. Newell, H. Stroo, R. Hinchee, and P. Johnson. 2008. Frequently Asked Questions Regarding Management of Chlorinated Solvents in Soil and Groundwater. Environmental Security Technology Certification Program. August.

SECOR. 1996. Preliminary Subsurface Investigation 17-06 Building, Briquetting Machines, BCAG, Auburn, Washington. September 9.

Seyedabbasi, M., C.J. Newell, D.T. Adamson, and T.C. Sale. 2012. "Relative Contribution of DNAPL Dissolution and Matrix Diffusion to the Long-Term Persistence of Chlorinated Solvent Source Zones." *J Contam Hydrol* 134-135.

Sleep, B.E., A.J. Brown, and B.S. Lollar. 2005. "Long-Term Tetrachloroethene Degradation Sustained by Endogenous Cell Decay." *Journal of Environmental Engineering and Science* 4 (1):11-17. doi: 10.1139/s04-038.

Stroo, H. and C. Ward. 2010. *In Situ Remediation of Chlorinated Solvent Plumes*, *SERDP ESTCP Environmental Remediation Technology*. New York, NY: Springer-Verlag New York.

WDOH. 2013. Letter: Letter Health Consultation, Boeing Commercial Airplane Fabrication Division, Auburn Plant, Exposures to Surface Water in Chicago Avenue Ditch and Government Canal, Algona, King County, Washington. From PhD Rhonda S. Kaetzel, DABT, Washington State Department of Health, to City of Algona. March 28.

WDOH. 2014. Letter Health Consultation, Boeing Commercial Airplane Fabrication Division, Auburn Plant Exposures to Surface Water Seasonal Sampling 2013, Algona, King County, Washington. Washington State Department of Health. August 15.

Whatcom County Superior Court. 2007. Consent Decree No. 07 2 02257 7 RE Whatcom Waterway Site; State of Washington Department of Ecology v. Port of Bellingham, Washington State Department of Natural Resources, Meridian-Pacific Hwy L.L.C., and the City of Bellingham. Executed September 20, 2017; Entered September 24, 2007.