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August 25, 2020

Subject: Draft Final Remedial Investigation/Feasibility Study Report, Grain Handling Facility at Freeman, Freeman, Washington

Dear Ms. Treccani:

The enclosed Draft Final Remedial Investigation/Feasibility Study Report for the Grain Handling Facility at Freeman in Freeman, Washington is submitted on behalf of Union Pacific Railroad.

If after reviewing this material, if you have any questions or comments, please contact me at (503) 501-7553, or via email at mark.ochsner@jacobs.com.

Sincerely,
Jacobs Engineering Group Inc.

Mark Ochsner
Senior Project Manager

Enclosure: An electronic copy of the above-referenced documents

Copy to (Electronic Only):

Anne Walsh/UPRR
Jeremy Schmidt/Ecology
Jerry Eide/Cenex Harvest States
David Hodson/Jacobs

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Grain Handling Facility at Freeman, Freeman, Washington

Remedial Investigation/Feasibility Study Report

Draft Final

August 2020

Union Pacific Railroad

Remedial Investigation/Feasibility Study Report
Grain Handling Facility at Freeman
Freeman, Washington

August 2020

Prepared for:

Washington State Department of Ecology
Toxics Cleanup Program – Eastern Region Office
4601 North Monroe Street
Spokane, WA 99205

Attention: Sandra Treccani, P.G.

On behalf of:

Union Pacific Railroad
1400 W. 52nd Avenue
Denver, CO 80221

Cenex Harvest States, Inc.
14603 Highway 27
Freeman, WA 99015

Technical Certification

This Remedial Investigation/Feasibility Study Report has been prepared under the direction of a Registered Civil Engineer and Certified Hydrogeologist in the State of Washington.

DAVID J. HODSON
55535
8-19-20

David Hodson

August 14, 2020

David J Hodson, P.E. No. 55535
Project Manager

Date

SIMON KLINE
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August 14, 2020

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Principal Geologist

Date

Executive Summary

This Remedial Investigation/Feasibility Study (RI/FS) Report for the Grain Handling Facility at Freeman (GHFF) at 14603 Highway 27, Freeman Washington, presents information regarding the nature and extent of contamination, potential exposure pathways, preliminary cleanup goals, and an evaluation of remedial action alternatives to address impacted media and potential risk to human health and the environment. The RI/FS is required in accordance with and complies with the 2015 Enforcement Order No. DE 12863 issued to Union Pacific Railroad (UPRR) and Cenex Harvest States, Inc. (CHS) by the Washington State Department of Ecology (Ecology).

A Draft RI was submitted in September 2018. This RI/FS report includes the 2018 information, presents an updated conceptual site model (CSM) based on additional data collected in 2019, defines remedial action objectives, and provides an evaluation of feasible remedial alternatives to achieve the preliminary cleanup levels, and comply with other requirements under Model Toxics Control Act (MTCA) for selection of a final remedial action.

This RI/FS identifies a preferred remedial alternative based on the updated CSM and evaluation of remedial alternatives.

Site Description and History

The GHFF property is on the eastern side of State Highway 27 in the town of Freeman, Washington, approximately 20 miles southeast of Spokane, Washington (Site). Freeman is a rural community. About 2,400 people reside within a four-mile radius of Freeman. For the purposes of this RI/FS, and as defined under the MTCA, the Site is defined as the lateral and vertical extent of impacted environmental media above preliminary cleanup levels (Figure ES-1).

The approximate 1-acre property is owned by UPRR, currently leased to CHS, Inc. d/b/a Primeland Cooperatives under a lease agreement that commenced in 1995, and is used as a seasonally active grain handling facility. Rockford Grain Growers, a dissolved agricultural cooperative, was the original operator of the facility, which was constructed in 1955. The GHFF is believed to have been operated as a grain handling facility since 1955.

The grain facility consists of 11 steel grain silos, one steel grain elevator, and one subterranean receiving pit. UPRR owns and operates a railway line that parallels State Highway 27 and traverses the property from the southeast to the northwest.

Carbon tetrachloride has historically been used at grain handling facilities to control pests. Although there are no records indicating the use of carbon tetrachloride at the GHFF, impacts to soil beneath the GHFF suggest that carbon tetrachloride was used and released at the GHFF sometime in the past. Due to the presence of carbon tetrachloride in groundwater and local use of the groundwater for drinking water and irrigation, the GHFF was placed on the Federal National Priorities List (Site ID WAN001003081) in September 2015.

Nature and Extent of Contamination

Environmental investigations were conducted at the Site and downgradient areas from 2014 through 2019. Soil, groundwater, surface water, air, and soil vapor samples were collected and analyzed for constituents of concern (COCs). Based on the potential historical use of chemicals at the GHFF and results of the environmental investigation conducted, carbon tetrachloride, chloroform, and carbon disulfide have been identified as Site COCs.

Extensive soil sampling has been conducted at the GHFF and surrounding area, including beneath the grain handing silos. The combination of soil, soil vapor, and passive soil vapor results indicate limited residual COCs remain in soil beneath the GHFF. Soils with the highest COC concentrations are detected either below or within the capillary fringe of the groundwater table. At the GHFF, the water table is present at approximately 30 feet below ground surface (bgs) and groundwater flows to the south-southwest.

Groundwater samples and soil boring data were collected from 2014 through 2019 from more than 50 locations, including investigation borings, dedicated monitoring wells, and water supply wells, which provide an in-depth representation of groundwater conditions and subsurface geology throughout the Site. The extensive data collection work provides information on how and where COCs move through the Site and pose risks to people in order to develop and evaluate cleanup alternatives to reduce concentrations of COCs to acceptable levels and protect human health and the environment.

Groundwater data indicate that elevated concentrations of carbon tetrachloride are present in groundwater and extend from the GHFF south of State Highway 27 (Figure ES-1). Carbon tetrachloride has been detected in water supply wells south of State Highway 27, including the Primary Freeman School District Well (WS5) located 1,200 feet downgradient from the GHFF. Point-of-entry treatment systems have been installed at the Primary Freeman School District Well (WS5) and three other residential wells used for domestic use where elevated concentrations of carbon tetrachloride have been detected. Point-of-entry treatment systems are installed before water from the supply well enters the Freeman School District water supply or residences. Nearby surface water bodies (Little Cottonwood Creek) do not appear to be affected by impacted groundwater.

In general, the relatively large, low concentration, dissolved-phase plume exists well bgs within a complex, multi-layered system of clay and fractured basalt above granite bedrock. The movement of COCs is affected by how groundwater flows within the open spaces (generally to the south-southwest of the GHFF) and the pumping of current water supply wells. The diffuse nature of the plume and the type of COCs within this complex hydrogeologic system makes it difficult to reduce concentrations using conventional treatment technologies such as air sparging/soil vapor extraction, bioremediation, or chemical oxidation. In addition, the existence of water supply wells currently being employed for domestic use precludes use of chemicals or technologies during cleanup that could result in new or additional water quality issues in such wells.

The highest concentrations of carbon tetrachloride detected in groundwater at the Site were about 60 to 70 feet beneath the GHFF. Concentrations ranged from 810 micrograms per liter (µg/L) (2019 sample) to 1,000 µg/L (2016 sample). In comparison, the highest carbon tetrachloride concentration detected at Primary Freeman School District Well (WS5) in 2019 was 7.1 µg/L. From 1992 through 2019, carbon tetrachloride concentrations ranged from less than 0.5 µg/L (in 2011 sample) to 61.8 µg/L (2018 sample). Primary Freeman School District Well (WS5) is the Freeman School District drinking water well; water is extracted based on demand and treated prior to use.

Carbon tetrachloride was detected at the highest concentrations at the GHFF and decrease with distance and depth to up 3,000 feet downgradient of the GHFF and greater than 200 feet bgs. Chloroform concentrations in groundwater similarly decrease with distance from the GHFF.

Potential Exposure Pathways

Based on extensive data collection at the Site, the most significant complete exposure pathways are via direct contact with or ingestion of groundwater, or inhalation of vapors. The current treatment systems in place at the Freeman School District and residential wells with elevated concentrations (where residents have accepted treatment) reduce the potential risk from this pathway. Cleanup alternatives are evaluated in this RI/FS on their effectiveness at permanently reducing concentrations in groundwater to address this risk.

Several other potential exposure pathways were evaluated. Surface soil at the Freeman School District and residential properties is an incomplete residential exposure pathway because COCs were not detected in surface soil samples at concentrations above preliminary cleanup levels. Surface and subsurface (excluding saturated zone) soil at the GHFF is a complete exposure pathway, but COCs have not been detected in surface and subsurface (excluding saturated zone) soil above preliminary cleanup levels. Saturated soil samples indicate relatively low levels of COCs at or near the groundwater interface at the GHFF and represent potential leaching to groundwater. However, soil analytical results do not indicate a significant secondary source of carbon tetrachloride that may present a threat to groundwater. Likewise, the risk of exposure to COCs discharged from the GHFF migrating to vapor and indoor air at the Freeman School District and residential properties are not a concern because the concentrations detected are consistent with background levels in air (as determined by a site-specific evaluation in accordance with Ecology requirements). The absence of COCs in soil, the fact that COCs in groundwater are relatively deep and low in concentration, and the existence of low permeability soils above groundwater which generally inhibit the production and upward migration of COC vapor, contribute to the low risk potential associated with vapor and indoor air.

If in the future buildings are constructed or drinking water wells installed at the GHFF, groundwater used for drinking water or other purpose could create exposure pathways that may need to be mitigated.

Remedial Actions Objectives and Preliminary Cleanup Levels

Remedial action objectives (RAOs) were developed to address potential risk to humans and environment. The remedial action objectives for the Site are:

- Eliminate potential exposure of COCs through the groundwater direct contact (dermal, ingestion and inhalation) exposure pathway
- Reduce COC concentrations in groundwater below applicable cleanup levels at a standard point of compliance within a reasonable restoration timeframe, to the maximum extent practicable

The above RAOs and applicable or relevant and appropriate requirements guided the identification of numerical site-specific cleanup levels. The following preliminary Groundwater Cleanup Levels were identified (MTCA Method B):

- Carbon tetrachloride: 0.63 µg/L
- Chloroform: 1.4 µg/L
- Carbon disulfide: 800 µg/L

Evaluation of COCs in soil included comparison of COC concentrations to preliminary cleanup levels for surface soil, vadose zone, and saturated soils. COCs were not detected in surface and vadose zone soils at concentrations above preliminary cleanup levels. The following preliminary Saturated Soil Cleanup Levels were identified for saturated soils (MTCA Protection of Groundwater - Saturated):

- Carbon tetrachloride: 2.2 µg/kg
- Chloroform: 4.8 µg/kg
- Carbon disulfide: 270 µg/kg

Remedial Action Alternatives

Remedial action alternatives were developed by assembling remedial components evaluated in the FS process. Remedial action alternatives include components that directly address cleanup of groundwater and actions to address potential exposure to impacted domestic water supply resources. The following remedial alternatives were developed to address the Site remedial action objectives:

- **Alternative 1: Permeable Adsorptive Barrier, Institutional Controls, Groundwater Monitoring and Reporting, and Point-of-Entry Domestic Water Treatment**

  A permeable adsorptive barrier involves injection of zero-valent iron (ZVI) and activated carbon into the subsurface at the downgradient edge of the GHFF using a series of closely spaced injection points or wells. The carbon retards the migration of COCs migrating from the GHFF via adsorption and the presence of ZVI helps degrade the COCs. The estimated time to achieve cleanup goals with this alternative is 32 years based on reducing COC migration from the GHFF.

  The treatment systems for the water supply wells at the Freeman School District and the residences would be maintained, installation of new groundwater supply wells in the impacted aquifer would be prohibited, other existing supply wells with COCs above cleanup levels would receive treatment systems (unless the property owner declines), and safeguards would be implemented for construction workers who may be exposed to COCs. Groundwater would be monitored/sampled on a routine basis to assess progress towards achieving cleanup goals. If additional residences are determined to be using groundwater with concentrations above cleanup levels for domestic use, point-of-entry treatment systems will be installed (unless the property owner declines).

Mechanisms for providing clean drinking water to residences other than point-of-entry treatment systems are evaluated in this FS. Such mechanisms included constructing several miles of new pipeline to connect to the City of Spokane's water system, creating a local water supply wellfield near Freeman but separate from the existing contaminated aquifer, and replacing current individual property wells (including the Primary Freeman School District Well [WS5]) with new wells that withdraw water from a much deeper, non-impacted aquifer. Although each of these approaches has benefits, their drawbacks include excessive construction costs, uncertainty about whether the new wellfield or wells would provide sufficient yield and acceptable water quality, and potential long-term charges imposed on property owners.

- **Alternative 2: Groundwater Recirculation (extraction, treatment, and infiltration), Institutional Controls, Groundwater Monitoring and Reporting, and Point-of-Entry Domestic Water Treatment**

  An extraction well would be installed about 400 feet south and downgradient of the GHFF in an area of relatively higher COC concentrations. Groundwater would be removed at this location, piped to a treatment system at the GHFF, treated using activated carbon adsorption and/or air stripping, and the treated water would be reinjected into the subsurface at four infiltration points north, east, and west of the extraction well location. Like Alternative 1, this alternative includes continued treatment systems for the water supply wells at the Freeman School District and the residences.

  The advantage of this cleanup alternative is that the infiltration of treated groundwater at the plume margin areas will facilitate flushing of the aquifer to accelerate reductions in COC concentrations and at the same time mitigate the likely adverse effects of dewatering the aquifer around the extraction well from groundwater extraction alone. The estimated time to achieve cleanup goals with this alternative is 17 years based on the flow of clean and treated water through the aquifer.

  Ecology has approved an Interim Action Work Plan that describes this remediation system to be initially implemented as an interim remedial action. If selected, Alternative 2 would serve as the final remedial action alternative. However, Alternative 2 is intended to be adaptable with the ability to modify the configuration and operation of the remedy based on results, if necessary.

After screening of potentially feasible cleanup alternatives for the Site in accordance with WAC 173-340-360 (Table ES-1), the alternatives were evaluated in accordance with WAC 173-340-360(3)(f) relative to the following criteria: overall protectiveness, permanence, cost, long-term effectiveness, short-term risk management, implementability, and consideration of public concerns. A disproportionate cost analysis was performed, and the results are presented in Table ES-1. Alternatives 1 and 2 are considered protective, will comply with MTCA threshold criteria, and are expected to require 32 and 17 years of operation, respectively. The highest MTCA benefit score is associated with Alternative 2 (Groundwater Recirculation, Institutional Controls, Groundwater Monitoring and Reporting, and Point-of-Entry Domestic Water Treatment), which also has the highest cost ($12,700,000 estimated remedy cost) (Table ES-1).

Recommendations

Alternative 2 (Groundwater Recirculation, Institutional Controls, Groundwater Monitoring and Reporting, and Point-of-Entry Domestic Water Treatment) is identified as the preferred remedy. Groundwater extraction, treatment, and infiltration to remove contaminant mass, enhance clean-water pore flushes, and intercept and cutoff plume migration through preferential groundwater flow paths is a proven approach to reduce groundwater concentrations and achieve restoration at the standard point of compliance.

Treatment technologies (for example, air stripping or granular activated carbon) for COCs are readily available and effective. The infiltration of treated groundwater will mitigate dewatering of the aquifer near existing water supply wells and enhance aquifer flushing and plume cleanup. Continued operation and maintenance of the point-of-entry domestic water treatment systems will provide continued protection against exposure to COCs in groundwater while the remedy is implemented. Selection, design and implementation of the groundwater recirculation system in conjunction with institutional controls is expected to achieve the RAOs identified for the Site.

Table ES-1. Disproportionate Cost Analysis and Comparison to Model Toxics Control Act Criteria

		Alternative 1 **Permeable Adsorptive Barrier, Institutional Controls, Groundwater Monitoring and Reporting, and Point-of-Entry Domestic Water Treatment**	**Alternative 2** **Groundwater Recirculation (extraction, treatment, and infiltration), Institutional Controls, Groundwater Monitoring and Reporting, and Point-of-Entry Domestic Water Treatment**
1 Meets Remedial Action Objectives		Yes	Yes
2 Compliance with MTCA Threshold Criteria			
• Protect human health and the environment • Comply with cleanup standards • Comply with applicable state/federal laws • Provide for compliance monitoring		• Yes • Yes • Yes • Yes	• Yes • Yes • Yes • Yes
2 Restoration Timeframe		32 years	17 years
• Potential risk to human health and environment • Practicability of achieving shorter restoration time • Current use of site, surrounding area, and resources • Future use of site, surrounding area, and resources • Availability of alternative water supplies • Likely effectiveness/reliability of institutional controls • Ability to monitor migration of hazardous substances • Toxicity of hazardous substances at the site • Natural processes that reduce concentrations		• Low • Low • Commercial and Residential • Commercial and Residential • Components available and evaluated • Medium • High • Medium • No	• Low • Medium • Commercial and Residential • Commercial and Residential • Components available and evaluated • Medium • High • Medium • No
4 Relative Benefits Ranking (Score 1 to 10)			
Weighting	*Criteria*		
17%	*Overall Protectiveness*	3	9
17%	*Permanence*	6	8
17%	*Long-term Effectiveness*	6	8
17%	*Management of Short-term Risk*	7	8
17%	*Implementability*	4	5
17%	*Consideration of Public Concerns*	6	9
MTCA Overall Benefit Score (1 to 10)	Row A	5.3	7.8

Table ES-1. Disproportionate Cost Analysis and Comparison to Model Toxics Control Act Criteria

		Alternative 1 **Permeable Adsorptive Barrier, Institutional Controls, Groundwater Monitoring and Reporting, and Point-of-Entry Domestic Water Treatment**	**Alternative 2** **Groundwater Recirculation (extraction, treatment, and infiltration), Institutional Controls, Groundwater Monitoring and Reporting, and Point-of-Entry Domestic Water Treatment**
5 Disproportionate Cost Analysis			
Capital Cost		$3,660,000	$4,630,000
Annual Cost		$277,000	$469,000
Duration (Years)		32	17
Estimated Remedy Cost	Row B	$12,600,000	$12,700,000
Magnitude of Cost Compared to Lowest Cost Alternate		--	101%
Magnitude of Relative Benefit to Most Permanent Alternative Benefit Ratio/Relative Cost (divided by 1,000,000)	Row C = Row A / (Row B / 1,000,000)	0.43	0.62
6 Remedy Permanent to the Maximum Extent Practicable		No	Yes

Notes:
All costs rounded to three significant figures.

Contents

Appendixes

A Soil Boring Logs, Geophysical Survey, Monitoring Sampling Forms Well Completion Diagrams, and Well Development Logs
B Basalt Aquifer Characterization
C Domestic Well Logs
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E Analytical Summary Tables
F Analytical Laboratory Reports and Data Validation Memorandums
G ECA Geophysics – Geophysical Investigation Report, UPRR GHFF and the Freeman School District Complex
H Vapor Intrusion Assessment Report
I Terrestrial Ecological Evaluation
J Cost Estimates
K Restoration Timeframe Estimates

Tables

Figures

Acronyms and Abbreviations

°C	degree(s) Celsius
µg/kg	microgram(s) per kilogram
µg/L	microgram(s) per liter
$\mu g/m^3$	microgram(s) per cubic meter
amsl	above mean sea level
ARAR	applicable or relevant and appropriate requirement
bgs	below ground surface
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CHS	CHS, Inc.
CHS/Primeland	CHS, Inc. d/b/a Primeland Cooperatives
CLARC	Cleanup Levels and Risk Calculation
COC	constituent of concern
CRBG	Columbia River Basalt Group
CSM	conceptual site model
DCA	disproportionate cost analysis
Ecology	Washington State Department of Ecology
EPA	U.S. Environmental Protection Agency
fs	feasibility study
ft^3	cubic foot (feet)
ft/ft	foot (feet) per foot
g/cm^3	gram(s) per cubic centimeter
GAC	granular activated carbon
GHFF	Grain Handling Facility at Freeman
gpm	gallon(s) per minute
HAPSITE	Hazardous Air Pollutants on Site
ICP	institutional controls plan
IHS	indicator hazardous substance
Jacobs	Jacobs Engineering Group Inc.
mg/L	milligram(s) per liter
MNA	monitored natural attenuation
MTCA	Model Toxics Control Act
O&M	operations and maintenance
Order	Enforcement Order No. DE 12863
PAB	permeable adsorptive barrier
POC	point of compliance
RAO	remedial action objective

RI	remedial investigation
SSE	southeast
SIM	selected ion monitoring
SPOC	standard point of compliance
TM	technical memorandum
UPRR	Union Pacific Railroad
VI	vapor intrusion
VOC	volatile organic compound
WAC	Washington Administrative Code
ZVI	zero-valent iron

1. Introduction

On behalf of the Union Pacific Railroad (UPRR), Jacobs Engineering Group, Inc., prepared this Remedial Investigation (RI)/Feasibility Study (FS) Report for the Grain Handling Facility at Freeman (GHFF) at 14603 Highway 27, Freeman Washington (Site). For the purposes of this RI/FS, the Site is defined as the lateral and vertical extent of impacted environmental media. The Site location is shown on Figure 1-1. This RI/FS Report presents the activities and findings associated with RI activities conducted at the Site between May 2016 and December 2019, evaluates potential remedial action alternatives to address impacted environmental media at the Site, and recommends a preferred remedial action alternative.

1.1 Purpose and Scope

The purposes of this RI/FS Report are the following:

- Describe the physical characteristics of the Site, including the geological and hydrogeological setting
- Present a summary of previous RIs and activities conducted at the Site
- Describe the nature, extent, and distribution of constituents of concern (COCs) in environmental media and evaluate the potential risk posed by the COCs
- Present a conceptual site model (CSM) based on current understanding as of this RI/FS Report
- Identify remedial action objectives and evaluate potential remedial action alternatives to address impacted environmental media at the Site

1.2 Regulatory Framework

From May 2016 through August 2019, RI activities were conducted in accordance with the specific cleanup action requirements of the Model Toxics Control Act (MTCA) Cleanup Regulation (Chapter 173-340 WAC). Historical Site activities summarized in this RI/FS report have been conducted under the 2015 Enforcement Order No. DE 12863 (Order) issued to UPRR and CHS, Inc. (CHS) by the Washington State Department of Ecology (Ecology) (Ecology, 2015). The purpose of the Order is to require remedial action at the GHFF where there has been a release or threatened release of hazardous substances. The Order requires a RI/FS report to address impacted media at the GHFF. Specifically, carbon tetrachloride, chloroform, and carbon disulfide have been identified as Site COCs.

The Site was listed on the U.S. Environmental Protection Agency (EPA) National Priorities List with the Site EPA identification WAN001003081 on September 30, 2015.

This RI/FS Report provides information required under the MTCA, Chapter 173-340-350 WAC, Remedial Investigation and Feasibility Study; and follows guidance provided in ASTM International Designation: E 1689-95 – Standard Guide for Developing Conceptual Site Models for Contaminated Sites. The updated CSM presented in this RI/FS Report is intended to be a working document, current at the time of RI/FS Report development, and may be amended or updated in the future if additional substantive site characterization data are obtained.

1.3 Organization of this Report

This report is organized into the following sections:

- **Section 1, Introduction,** presents the purpose and general organization of the report
- **Section 2, Site Background,** describes the site background
- **Section 3, Site Setting,** describes the site setting, including climate, topography, watershed, geology, and hydrogeology.

- **Section 4, Nature and Extent of Contamination,** describes the RI activities and results, and nature and extent of COCs in relevant environmental media.
- **Section 5, Conceptual Site Model,** describes the CSM, including the potential receptors and exposure pathways.
- **Section 6, Development of Cleanup Levels,** presents preliminary cleanup levels considered to address COCs in impacted environmental media.
- **Section 7, Feasibility Study of Remediation Alternatives,** presents and the feasibility process, an evaluation of remedial components considered to address COCs in impacted environmental media, and remedial action objectives (RAOs).
- **Section 8, Assembly of Remedial Action Alternatives,** presents the development of remedial action alternatives considered to address COCs in impacted environmental media.
- **Section 9, Remedial Alternative Evaluation,** presents an evaluation of remedial action alternatives considered to address COCs in impacted environmental media.
- **Section 10, Recommended Remedial Alternative,** presents the recommended remedial alternative.
- **Section 11, References,** presents the references used in preparation of this document.

The following appendixes are provided to support this RI/FS Report:

- **Appendix A, Soil Boring Logs, Well Completion Diagrams, Well Development Logs, and Monitoring Sampling Forms,** presents all available soil boring logs, well completion diagrams, well development logs and monitoring sampling forms generated during RI activities at the Site.
- **Appendix B, Basalt Aquifer Characterization,** presents an evaluation of the characterization of the basalt aquifer based on RI conducted at the Site.
- **Appendix C, Domestic Well Logs,** presents domestic well logs for domestic wells at the Site.
- **Appendix D, 2019 Groundwater Modeling Report,** presents the aquifer test and groundwater modeling report.
- **Appendix E, Analytical Summary Tables,** presents a summary of available analytical data generated during RI and groundwater monitoring at the Site.
- **Appendix F, Analytical Laboratory Reports and Data Validation Memorandums,** presents analytical laboratory reports and data validation memorandums for sampling conducted in September 2019.
- **Appendix G, ECA Geophysics – Geophysical Investigation Report, UPRR GHFF and the Freeman School District Complex,** presents a geophysical investigation report associated with geophysical RI conducted in 2019 at the Site.
- **Appendix H, Vapor Intrusion Assessment Report,** presents a summary of vapor intrusion (VI) data and evaluation for the Site.
- **Appendix I, Terrestrial Ecological Evaluation,** presents a terrestrial ecology evaluation conducted for the Site.
- **Appendix J, Cost Estimates,** presents detailed cost estimates generated for remedial action alternatives developed for the Site, excluding domestic water supply components.
- **Appendix K, Restoration Timeframe Estimates,** presents an evaluation of restoration timeframes for the remedial alternatives.

2. Site Background

This section presents a summary of the site background.

2.1 Site Description

The GHFF is located at 14603 Highway 27 (on the eastern side of the highway) in the town of Freeman, Washington, approximately 20 miles southeast of Spokane, Washington. The property is owned by UPRR, currently leased to CHS, and used as a seasonally active grain handling facility. The facility consists of 11 steel grain silos, 1 steel grain elevator, and 1 subterranean receiving pit. UPRR owns and operates a railway line that parallels State Highway 27 and traverses the property from the southeast to the northwest (Figure 2-1).

Approximately 0.5 mile northeast of the GHFF is a former clay borrow pit and associated pond known as the Old Freeman Clay Pit (Figure 2-2). The abandoned clay pit may have been used for illegal dumping or disposal (Leinart, 2012). As of the writing of this RI/FS report, the pit property is owned by Mutual Materials Company. Northwest of the GHFF is the Freeman Store. Approximately 0.25 mile southeast of the GHFF is a former brick kiln. West and south of the GHFF is the Freeman School District, several residences, and sanitary wastewater treatment lagoons. One or more former residences were previously located southwest of the GHFF and are now part of the Freeman School District. West and south of the Freeman School District and lagoons is land generally used for agricultural production.

2.2 Site History

The Cenex Harvest States grain handling facility is leased by CHS d/b/a Primeland Cooperatives (CHS/Primeland) from UPRR under a 99-year lease agreement. CHS/Primeland purchased Rockford Grain Growers in 1993. Rockford Grain Growers, a now insolvent agricultural cooperative, was the original operator of the facility, which was constructed in 1955. The GHFF is believed to have been operated as a grain handling facility since 1955. However, a review of historical aerial photographs from 1937 and 1946 indicate unidentifiable activities at the location of the GHFF prior to 1955.

Additional information on the operations and history of GHFF is presented in *Site Investigation, Freeman Groundwater Contamination, Freeman, Washington* (EPA, 2014)

2.3 Freeman School District

The Freeman School District is directly across State Highway 27 from the GHFF. The Freeman School District covers approximately 56 acres of land and includes an elementary school, middle school, and high school. There are three water supply wells in the Freeman School District. The well (Primary Freeman School District Well [WS5]) that supplies drinking water to the school was installed in 1980 and, as of the writing of this RI/FS report, is the sole source of water for the Freeman School District. The Primary Freeman School District Well (WS5) is located near the southern perimeter of the Freeman School District. The second well is a former residential well in the northeastern area of the Freeman School District (labeled as the Out-of-Use Freeman School District Well [W26]). As of the writing of this RI/FS report, this well is not used as a water supply well for the Freeman School District. The third well is an out-of-service former residential well (labeled as Out-of-Use Marlow Well [W20]) on the eastern side of the Freeman School District. The three wells are shown on Figure 2-2.

The Primary Freeman School District Well (WS5) is constructed with a 6-inch-diameter steel conductor casing to 52 feet below ground surface (bgs) with an open borehole extending from approximately 52 to 215 feet bgs (Appendix A). Water extracted from the Primary Freeman School District Well (WS5) is pumped approximately 1,800 feet to the treatment system on the western side of the Freeman School District. The treatment system consists of an air stripper that was put into operation in late August 2013 to treat carbon tetrachloride in groundwater extracted from the Primary Freeman School District Well (WS5) (E&E, 2014). After the air stripping process and before entering the water distributions system, the water is treated with chlorine for disinfection. The Freeman School District operates the treatment system and monitors the water quality on a monthly basis.

2.4 Interim Remedial Action Activities

2.4.1 Point-of-entry Treatment Systems

Carbon tetrachloride has been detected in five residential water supply systems. As part of first interim action conducted at the Site, granular activated carbon (GAC) point-of-entry treatment systems were installed in September 2016 to treat the domestic water supply for two residential users of groundwater with impacted water supplies (where residents have accepted treatment). In March 2019, a third point-of-entry treatment system was installed for a residential user of groundwater with impacted water supplies. A fourth residential user of groundwater with impacted water supplies has declined installation of a point-of-entry treatment system, because carbon tetrachloride concentrations are below the drinking water standard, which is the federal maximum contaminant level of 5 micrograms per liter (µg/L). The fifth impacted residential water supply is not in use as of April 2020 because the residence is vacant and the owner has not requested a treatment system.

An enclosed treatment shed with a concrete floor was built to house each of the treatment systems. Each treatment system includes pre-treatment for suspended solids removal (the unit process called “Sanitizer” by the equipment supplier is used as a granular media filter) followed by two 3-cubic-foot (ft^3) GAC vessels in parallel (a lead and lag vessel). At least 12 other residential water supply wells were tested where the water did not require treatment.

The treatment systems were expanded to include two 6-ft^3 GAC vessels (a lead and lag vessel) in June 2017. The two 6-ft^3 vessels were added in parallel to the 3-ft^3 vessels and are used exclusively for irrigation water at the residences. A sample port was installed between the two vessels (midpoint) and after the two vessels (effluent).

The treatment systems have been performing as designed (that is, removing carbon tetrachloride and chloroform) based on a routine monitoring and sampling program. The routine program, which has consisted of weekly sampling conducted from September 2016 through January 2019 and biweekly sampling conducted since February 2019, is used to determine when GAC vessels require replacement. Performance samples are collected from the influent, midpoint, and effluent sample ports of each system. Samples are also collected from the midpoint and effluent sample ports from the larger 6-ft^3 irrigation vessels when irrigation is occurring (late spring to early fall). Based on sampling data and flow rates through the systems, the lead vessel of the smaller 3-ft^3 point-of-entry treatment systems is changed every 3 months. The lag vessel is then moved to the lead position and a new carbon vessel is placed in the lag position. The larger vessels are changed out twice per year.

Detailed performance sampling results are excluded from the RI/FS report, but a statistical summary of data is provided in Table 2-1. Carbon tetrachloride has been detected in only 3 of 150 samples of effluent from 1 of the treatment systems. One of these detections exceeded the MTCA Method B groundwater criterion at a concentration of 0.97 µg/L but was an initial startup sample. Repeat sampling the following day detected carbon tetrachloride at 0.24 µg/L and below the MTCA criteria. Carbon tetrachloride was detected in only 1 out of 51 samples of the Marlow irrigation system treatment effluent, and below the MTCA criteria. Carbon tetrachloride has been detected in only 2 of 144 effluent samples from another treatment system, and both detections were below the MTCA criteria. Carbon tetrachloride has not been detected in an irrigation system treatment effluent. Carbon tetrachloride has not been detected in the effluent samples from a third treatment system, which is sampled infrequently, only when the well has been used during the biweekly sampling period. Laboratory method detection limits for the sampling program are below the MTCA Method B groundwater criteria and generally established at 0.2 µg/L for carbon tetrachloride. The data show that the point-of-entry treatment systems are operating effectively.

2.4.2 Groundwater Recirculation

The Ecology-approved (Ecology, 2020) Third Revised Interim Remedial Action Work Plan (Jacobs, 2020) describes an interim remedial action consisting of groundwater recirculation (extraction, treatment, and infiltration) targeting the core of impacted groundwater. The recommended interim remedial action consists of groundwater recirculation (extraction, treatment, and infiltration) with the following components:

- Groundwater extraction at one new well in the core of the plume in the vicinity of well MW-19D and well cluster MW-27 through MW-31
- Treatment of extracted groundwater above ground using air stripping and/or liquid-phase GAC at a treatment plant at the GHFF
- Infiltration (recirculation) of treated groundwater at up to four new wells located up- and cross-gradient of the plume

The proposed interim remedial action is predicted by groundwater model simulations to provide good hydraulic capture of the core of impacted groundwater and to provide effective clean water flushing through the aquifer. The proposed extraction well location was selected because it is within a relatively high concentration area just upgradient of water supply wells, and is within a fairly uniform fractured basalt unit that will facilitate effective contaminant mass removal. The proposed infiltration wells are at the up- and cross-gradient margins just outside of the existing carbon tetrachloride plume and will enhance aquifer restoration efforts by directing clean water flushing toward the extraction well. Infiltration is also intended to mitigate potential aquifer dewatering from groundwater extraction alone. The upgradient infiltration wells at the GHFF are intended to provide flushing of the upper unconsolidated zone while the cross-gradient infiltration wells east and west of the extraction well will provide flushing of the underlying fractured basalt. Air stripping and/or liquid-phase GAC will be used to remove carbon tetrachloride from extracted groundwater before groundwater is reinfiltrated into the aquifer zones identified above.

Construction of the interim remedial action is anticipated to be completed in fall 2020.

3. Site Setting

The regional physiographic and hydrogeologic setting of the Freeman area provides a general framework for the available published literature with respect to the primary geologic units, depositional history, and related terminology used in the following sections.

3.1 Data Sources

In conjunction with developing the approach for the RI, the following documents were reviewed and form the basis of the physiographic setting, regional geology, and the hydrogeologic conditions near the GHFF.

Published literature/resources for regional geologic conditions:

- Geologic Quadrangle Map, Greenacres Quadrangle, Washington and Idaho (Weiss, 1968)
- Preliminary Geologic Map of the Spokane SE 7.5-Minute Quadrangle, Spokane County, Washington (Derkey et al., 1973)
- *Clay Deposits of Spokane County Washington* (Hosterman, 1969)
- *The Columbia River Basalt Group in the Spokane Quadrangle, Washington, Idaho, and Montana* (Griggs, 1976)

Published literature/resources for hydrogeologic conditions:

- *Hydrogeology of the West Plains Area of Spokane County*, *Washington* (Deobald and Buchanan, 1995)
- *Hydrology of the Hangman Creek Watershed (WRIA 56), Washington and Idaho* (Buchanan, 2003)
- *Hangman Creek Watershed (WRIA 56), Hydrogeologic Characterization & Monitoring Well Drilling* (Northwest Land & Water, Inc., 2011)
- *The Hydrogeologic Framework and Geochemistry of the Columbia Plateau Aquifer System, Washington, Oregon, and Idaho* (Whiteman et al., 1994)
- *Feasibility Evaluation, Production Well Evaluation – Carbon Tetrachloride Contamination, Freeman School District, Freeman Washington* (GeoEngineers, 2013)

3.2 Climate

As described by Buchanan (2003), the climate in the Freeman area is generally warm and dry during the summer and cool and moist during the winter. Because of the large range in elevation in the watershed, significant variation in precipitation occurs from less than 16 inches per year in the lower part of the basin that is sub-arid, to more than 40 inches per year in the upper part that is sub-humid. Area weighted calculations of evapotranspiration in the watershed, when compared to the areal distribution of precipitation, show that there is a moisture surplus of 173,882 acre-feet per year. This excess water is free to either run off into surface streams, or to infiltrate into the ground to recharge shallow and/or deep aquifer systems.

3.3 Topography

The GHFF is immediately north of State Highway 27 near Freeman, Washington, at an elevation of approximately 2,600 feet above mean sea level (amsl). The surface topography near the GHFF slopes to the southwest to a topographic low, then at the nearby drainage changes direction and generally slopes to the southwest toward Rock Creek (Figure 3-1). The topography of the area exhibits the undulating rolling-hills characteristics common to the Palouse Formation. Northeast of the Site is Mica Peak, which at its highest elevation is approximately 5,000 feet amsl at the summit, or roughly 2,400 feet higher in elevation than the GHFF.

3.4 Watershed

The GHFF lies approximately 3 miles northeast of Rock Creek, and the nearest tributaries are Little Cottonwood Creek and Cottonwood Creek, which flow to the southwest and discharge to Rock Creek (Figure 3-2). The Site lies within the Rock Creek subwatershed, which is within the Hangman Creek watershed. As described by Buchanan (2003), the Hangman Creek drainage basin is in eastern Washington and northern Idaho, and comprises 431,220 acres, with 64 percent (276,803 acres) in Washington and 36 percent (154,417 acres) in Idaho. Rock Creek is a tributary of Hangman Creek, which generally flows to the northwest along the western margin of Spokane and discharges to Spokane River, which in turn flows westward to the Columbia River. Ultimately, all surface water and groundwater within the study area are inferred to generally flow westward within the Columbia Basin.

3.5 Geology

The three primary geologic units in the study area are listed below, from oldest to youngest:

- Pre-Tertiary (Precambrian) – metamorphic basement rock complex
- Tertiary – volcanic rocks with sedimentary interbeds
- Quaternary – undifferentiated unconsolidated sediment, consisting of alluvium, glacial deposits, and eolian (wind blow) loess

Figure 3-3 presents a generalized stratigraphic sequence, showing the geologic units, typical thicknesses of primary units, and the groundwater yield from published sources. A description of these geologic units, from oldest to youngest, and their depositional history follow.

Basement Rock Complex. As described by Derkey et al. (1973), the pre-Tertiary basement rock complex consists of metamorphosed, deformed, and foliated sedimentary rocks that were later intruded upon by igneous rocks, predominantly granite. The basement rock complex in the Spokane Southeast (SE) quadrangle consists of gneiss, quartzite, siltite, and a variety of granitic intrusions (Derkey et al., 1973). The geologic map of the Greenacres Quadrangle (Weiss, 1968) shows the area approximately 2 miles northeast of the GHFF along the base of Mica Peak as quartzite, and further east at the peak of Mica Peak as gneiss.

Volcanic Rocks with Sedimentary Interbeds. The basement rocks are stratigraphically overlain by younger basalt flows associated with the Columbia River Basalt Group (CRBG). The GHFF lies along the northeastern margin of the Columbia Plateau, which marks the northeastern extent of the CRBG unit. The CRBG was deposited during an extended period of Miocene volcanism (23 to 5 million years ago) that extruded a series of fluid lava flows. The lava flowed from north-northwest-trending fissures, as much as 90 miles long, which were primarily in northeastern Oregon and southeastern Washington (Griggs, 1976). The resulting basalt deposits are hundreds to thousands of feet thick and extend throughout the Columbia Plateau.

The CRBG has been extensively studied and is subdivided into five formations. Two of these formations, the Grande Ronde and Wanapum, have been identified via whole rock chemical analysis to be found near the Freeman area in the Spokane SE quadrangle (Derkey et al., 1973). The Grande Ronde Basalt is the most voluminous of the CRBG formations, comprising 85 to 88 percent of the total volume of the CRBG (Whiteman et al., 1994). The Grande Ronde Basalt Formation is widespread throughout the area except where the elevation of pre-Miocene basement rocks is higher than the top of the formation; generally, this occurred at steptoes (or at elevated topography, such as Mica Peak). The top of the Grande Ronde Basalt is often marked by (1) a weathered zone frequently described in water well reports as a water-bearing, fractured or vesicular zone with minor clay; and/or (2) a sedimentary interbed (Latah Formation) that separates it from the overlying Wanapum Basalt Formation. The Wanapum Basalt stratigraphically overlies the Grande Ronde, and is the second-most voluminous of the CRBG formations, comprising about 6 percent of the total volume of the CRBG (Whiteman et al., 1994). The Wanapum Basalt pinches out at steptoes (or at the base of higher elevation basement rocks such as Mica Peak), or where it has been removed by erosion within drainage creeks or rivers. The contact between Wanapum (younger flow) and Grande Ronde (older, deeper flow) usually occurs between 2,100 and 2,200 feet amsl in the Spokane area (Deobald and Buchanan, 1995). Surface exposures of basalt, particularly along drainages are abundant in the region, and the basalt unit is observed at more than 200 feet thick in public supply wells from a review of well logs in the Ecology database.

The Latah Formation is a sedimentary interbed, which was deposited by fluvial or lacustrine processes between episodes of lava flows from the CRBG. The Latah Formation is poorly indurated lacustrine (fine-grained) and fluvial (coarser grained) deposits of finely laminated siltstone, claystone, and minor amounts of sandstone. Hosterman (1969) maps a relatively small area immediately south of the GHFF as the Latah Formation, underlying roughly 20 to 40 feet of loess (Palouse Formation). However, Derkey et al. (1973) noted that in the Spokane SE quadrangle, the thickness of the Latah Formation could not be determined, largely because the Latah Formation is easily eroded and covered with residual soil. Hosterman (1969) notes that the Latah Formation near the town of Mica (roughly 2 miles north of the GHFF) was subject to chemical weathering because the unit was not protected by overlying basalt flows; thus, in areas near and presumably south of Mica, the Latah Formation is absent or is saprolite (that is, decomposed rock; see additional discussion on saprolite below).

Undifferentiated Unconsolidated Sediment. Weiss (1968) and Hosterman (1969) map the surficial deposits in the Freeman vicinity as the Palouse Formation, which is eolian (windblown) deposit of fine-grained unstratified silt and clay with lesser amounts of fine sand and volcanic ash (referred to as loess). Hosterman (1969) maps the typical thickness of the loess in the range of approximately 10 to 40 feet thick near the GHFF; the maximum observed thickness of loess in Spokane County is 76 feet. The Palouse Formation exhibits a characteristic dune-like appearance and is thicker where glacial floods have not removed it because of erosion.

The term saprolite refers to chemically weathered rock that represents a deep weathering process that transforms the parent bedrock into fine-grained clay-like consistency (that is, in-place transformation from parent rock to soil). Hosterman (1969) provides a detailed summary of saprolite clays found within Spokane County, which are derived from the chemical alteration of both the basalt and pre-Tertiary (igneous or metamorphic) rocks. The Freeman clay pit, located 500 feet northeast of the GHFF, confirms the presence of both the pre-Tertiary origin saprolite along the northeastern half of the clay pit deposit, and basalt origin saprolite south of the clay pit. The basalt saprolite averages about 14 feet thick near Freeman based on 11 auger holes (Hosterman, 1969).

Site-specific Geology. As depicted on Figure 3-3 and in greater detail in Appendix B, the generalized stratigraphic sequence consists of a surficial layer of loess overlaying at least two discrete tholeiitic CRBG flows with both fractured and unfractured intervals with areas of palagonite alteration. This is, in turn, underlain by pre-Tertiary basement rocks (drill cuttings indicating a granitic gneiss composition similar to the “Gneiss near Chester Creek,” documented on the USGS Quadrangle Map [Weiss, 1968]).

Upgradient of the GHFF, observations by Hosterman (1969) suggest that the easternmost or northeastern margin/edge of the uppermost basalt (flow) may extend to the Old Freeman Clay Pit (Figure 2-2), and may be absent in areas further northeast of the pit with the elevation rise from Mica Peak. In addition, the uppermost unconsolidated sequence is complicated in that both the top of the basalt and upper sequence of the basement rock complex have undergone substantial chemical weathering/alteration into saprolite, effectively changing the uppermost portion of parent rock into fine-grained soil-like consistency, which is layered with or adjacent to other fine-grained geologic units, such as the loess or low-energy deposits of the Latah Formation. Although there are multiple geologic units within the uppermost unconsolidated sedimentary sequence upgradient of the GHFF, the hydraulic properties of the various units may behave like the fine-grained loess deposits that make up the surficial unit for the remaining area of the site, with respect to groundwater flow (that is, permeability) characteristics. This circumstance is taken into consideration when developing the CSM and related hydrogeologic conditions.

Additional geologic investigation was completed during 2018 and 2019 and focused on an area of the Site from the GHFF to the Primary Freeman School District Well (WS5), approximately 1/3 mile to the south. Four deep borings were drilled along a transect between these two locations to better characterize groundwater flow through the CRBG flows and into the basement rock complex. Through drilling, coring, borehole and surface geophysics and hydrophysics, site-specific geology from these investigations was characterized and refined.

The loess comprising the Palouse Formation overlies the entire Site but in general begins thinning out towards the northeast, with thicknesses near 10 feet at the GHFF and up to 85 feet on higher elevation hillsides. Underlying the loess, and under differing degrees of alteration and fracturing, the CRBG onlaps onto the basement rocks and thickens away from the GHFF and the elevated topography to the northeast. The CRBG at the Site has intervals of fractured and relatively unfractured rock that may be related to their locations within the individual flow. Colonnades and fanning columns are areas of lower fracture density than the top and bottom of flows and vesicular zones, as seen on Figure 3-4 (Riedel et al., 2013). In addition, the local CRBG was chemically altered to a rock known as palagonite near the contact with the basement rock. Palagonite is an assemblage of a yellowish mineral rind surrounding pillow basalts (often with olivine) as a result of a basalt flow area quenched rapidly from contact with standing water and is common on the edge of basalt flows. Intervals that had undergone heavy palagonite alteration were very soft during drilling, with abundant clay and silt sized particles and little to no fracturing remaining, effectively acting as a fine-grained impermeable layer. Intervals that only had slight mineral alteration kept their associated fractures intact.

In addition, the new boring near the Primary Freeman School District Well (WS5) showed evidence of multiple basalt flows at the Site when an approximately 13-foot-thick clay paleosol containing well-preserved pieces of wood was penetrated at 270 feet bgs, indicating that a significant amount of time had passed between flows. Below the paleosol, the second, older flow was massive and unfractured until encountering the basement rock. The basement rock was partially penetrated in three of the deep borings, ranging from 225 feet bgs near existing well MW-19D (approximately 400 feet south of the GHFF) to 372 feet bgs near the Primary Freeman School District Well (WS5). Although no borehole imagery was taken, rock cuttings from the air-hammer drilling indicated a basement rock primarily composed of quartz, muscovite mica, and feldspars that would be analogous to the granitic gneiss found north of the GHFF. These new deep basalt, paleosol, and basement rock findings are discussed in greater detail in Appendix B. The investigation conducted at the four new borings (identified as RC-01 through RC-04) is further discussed in Section 4.5.2.

3.6 Hydrogeology

As described by Buchanan (2003) and GeoEngineers (2013), the Freeman area generally is underlain by a minimum of two aquifer systems. These aquifers typically occur within the CRBG, and to a lesser degree, within the basement rocks. The CRBG units are generally suitable for extracting groundwater of sufficient quantity for either public or domestic water supply and water distribution systems. The wells completed in basement rock units are typically of relatively low yield compared to the CRBG system, yet sufficient for domestic water supply in certain areas (Figure 3-3). Appendix C shows maps from an Ecology database records search for domestic wells near Freeman, including the locations of 86 domestic wells advanced into the CRBG and 69 domestic wells advanced into the basement rock. Eight of the CRBG domestic wells were advanced through the CRBG into the underlying basement rock and thus completed within both units. The Appendix C maps illustrate that wells completed within the basement rock are located in the upland areas northeast of the GHFF, while wells in areas west and south are completed within the onlapping CRBG.

The term aquifer is used to define a saturated geologic formation (or formations) sufficiently permeable to transmit economic quantities of water to wells (public users) and springs (Fetter, 1994) for beneficial uses. Based on Ecology's definition (173-531 WAC), the term groundwater means any water below the land surface in a zone of saturation. To develop the GHFF CSM for characterization of the nature and extent of contamination from the (former) source area, the two general aquifers described above were considered as part of the general/regional flow regime. Also included were potential shallower zones of saturation (that is, groundwater) identified within unconsolidated sediments lying above or hydraulically connected to the underlying CRBG and basement rock aquifers. The potential shallower zones of saturation in the upper unconsolidated sedimentary unit above the CRBG may serve as a mechanism for contaminant movement, transport, or storage, and are a key component of the groundwater CSM.

3.6.1 Columbia River Basalt Group Aquifer System

The CRBG consists of a series of individual basalt flows. Groundwater is most readily transmitted through the broken vesicular and scoriaceous interflow zones that characterize the top of each flow (or effectively between individual flows). The interflow zones are separated by the less porous and less transmissive entablature and colonnade, which comprise 90 to 95 percent of the total flow volume (Whiteman et al., 1994). The flows are locally interlayered with sedimentary deposits of the Latah Formation. This system of multiple flows and interlayered sedimentary deposits creates multiple stacked confined to semiconfined aquifers that can yield significant volumes of groundwater to wells. Howard Consultants, Inc. (1995) estimate aquifer yield from wells completed in Wanapum at up to 1,500 gallons per minute (gpm) for wells in the Palouse region near Whitman County (which is due south of Spokane County).

The CRBG is overlain, in places, by relatively coarse-grained Quaternary deposits. In other locations, the CRBG directly crops out on the surface. Recharge to the CRBG occurs through direct precipitation, vertical infiltration from the overlying unconsolidated sediments, and lateral recharge from upgradient areas to the north and east. A minor component of recharge could migrate upward as leakage from underlying basement rocks, depending on head conditions. Discharge from the CRBG occurs through leakage to adjacent aquifers, along gaining reaches of streams, and to water supply wells.

3.6.2 Basement Rock Aquifer System

Groundwater is also observed within the basement rocks that underlie the CRBG, in weathered and fractured zones. Porosity and permeability are generally low or relatively low in comparison to the CRBG. The yield of water wells penetrating the basement rock aquifer generally is low, typically on the order of several gpm or less. Recharge to the basement rock aquifer occurs primarily within upgradient areas to the east, with groundwater flowing laterally to discharge areas within the plateau interior. Recharge could also occur through leakage from the overlying CRBG.

3.6.3 Surface Water and Groundwater Interaction

Buchanan (2003) and the hydrogeologic study performed by Northwest Land and Water, Inc (2011) describe the general characteristics of surface water and groundwater interaction within the Hangman Creek watershed. These studies noted that Hangman Creek and its tributaries are fed by direct precipitation runoff and baseflow groundwater. The source of baseflow to creeks includes discharge from adjacent alluvial/colluvial deposits and from basalt and/or Latah Formation aquifers. Discharge from basalt/Latah aquifers may occur directly, where these aquifers intersect creek beds, or indirectly via the alluvial/colluvial deposits.

3.6.4 Site-specific Hydrogeology

Key findings from the data review/evaluation and development of a groundwater flow model are presented in this section to provide an interpretation of the hydrostratigraphic units (and related well groupings) to develop groundwater flow maps, which are the basis for describing the nature and extent of contamination. The data review consists of the following specific evaluations:

- **Nature and occurrence of groundwater,** which includes a review of the boring logs to identify the generalized stratigraphic units and well diagrams to understand the screen intervals and related groundwater elevations. This information is synthesized into hydrogeologic cross sections illustrating the generalized stratigraphy and hydrogeologic conditions.
- **Groundwater elevations** to evaluate relative head differences and inferences on hydraulic connection between different geologic units, and Site hydrographs showing temporal changes to assess hydraulic interconnection between well groupings and geologic units.
- **Aquifer testing** to evaluate hydraulic properties (permeability and storativity) and hydraulic interconnection.
- **Geochemical data** (general chemistry) to evaluate wells screened in different hydrostratigraphic units.

A hydrostratigraphic unit is defined by Chapter 173-351-100 of WAC (Definitions) as follows:

> *"Hydrostratigraphic unit" means any water-bearing geologic unit or units hydraulically connected or grouped together on the basis of similar hydraulic conductivity which can be reasonably monitored; several geologic formations or part of a geologic formation may be grouped into a single hydrostratigraphic unit; perched sand lenses may be considered a hydrostratigraphic unit or part of a hydrostratigraphic unit, for example.*
>
> *Note: 'Hydraulically connected' denotes water-bearing units which can transmit water to other transmissive units.*

The primary importance of developing and defining the hydrostratigraphic units is to (1) establish consistent nomenclature to describe the CSM, and (2) group wells relative of their screen zones according to specified hydrostratigraphic units to develop representative groundwater flow maps. Collectively, characterizing and defining the hydrostratigraphic units into the CSM assists in evaluating the nature and extent of contamination, modelling efforts, contaminant fate and transport, and the FS.

3.6.4.1 Stratigraphic Sequence and Hydrogeologic Cross Sections

Tables 3-1 and 3-2 provide an inventory of the borings/wells completed as part of the RI. Appendix A includes boring logs and well construction diagrams. Figure 3-5 shows the location of these soil borings/wells in plan view, and the orientation/location of three hydrogeologic cross sections (A-A', B-B', and C-C') developed in the vicinity of the GHFF. Figure 3-6 (Cross Section A-A') is oriented north to south, extending from the areas just north of the GHFF southward to the southern extent of the RI areas. Figure 3-7 (Cross Section B-B') is oriented north to south but focuses on the conditions beneath an area immediately south of the GHFF at an enhanced horizontal scale. Figure 3-8 (Cross Section C-C') is oriented generally northwest to southeast, showing subsurface characteristics beneath and extending about 1,000 feet southeast of the GHFF.

As shown on Figures 3-6 and 3-7, and in Appendix B, the stratigraphic sequence near and beneath the GHFF consists of approximately 50 feet of unconsolidated sediment (undifferentiated), 20 to 60 feet of tholeiitic CRBG basalt (interpreted as the Wanapum Formation), underlain by lower granitic gneiss basement rock. Following the investigative fieldwork in 2018 and 2019, the subsurface displayed significantly greater heterogeneity in areas downgradient of the GHFF than previously documented, with the basalt showing the presence of several hydrostratigraphic units within the same lithology (see Section 3.6.4.6).

The stratigraphic sequence shown on Figure 3-8 illustrates the heterogenous nature of the subsurface units in upland areas near the GHFF, and the presence of significant zones of saprolite (basalt origin) at soil boring SB-34 and from monitoring well MW-14D. Although undifferentiated on the generalized hydrogeologic cross sections, the published data from Hosterman (1969) and results from the RI confirm that there are significant zones of saprolite from both basalt and pre-Tertiary (bedrock) origin.

3.6.4.2 Nature and Occurrence of Groundwater

Based on field observations during drilling, a review of the RI boring logs, and evaluation of representative groundwater level measurements obtained during successive groundwater sampling events, saturated conditions (that is, monitorable groundwater) were identified and confirmed in the following generalized geologic units:

- **Upper unconsolidated sediments.** This unit is undifferentiated and consists primarily of loess (silty clay), with lesser amounts and limited thickness of either Latah Formation (sedimentary interbed) and/or saprolite (from either the underlying basalt or lower basement rocks). Saturated zones (that is, groundwater) were typically observed at the base of this unit, generally at the transition from upper unconsolidated sediment to the underlying CRBG.

- **Intermediate basalt unit.** This unit is inferred as the upper CRBG (that is, Wanapum Basalt). In areas beneath the GHFF, saturated zones (that is, groundwater) were typically observed within fractured, rubbly, vesicular, and/ or weathered zones. Further south in the vicinity of boring RC-03, the basalt is increasingly chemically altered with depth until transformation to a palagonite occurs at the boundary with underlying basement rock. Continuing south, near the MW-6S/6U/6D well cluster and RC-04, the basalt is even more heterogeneous with large intervals of fresh, unfractured rock, intervals of slight to moderate alteration and palagonitization, fractured basalt, and clay paleosols separating discrete basalt flows.
- **Lower basement rocks.** This unit is interpreted primarily as a granitic gneiss that may be fresh, decomposed, or weathered, such as in the vicinity of the former clay pit. The boring logs often characterize these materials as sandstone or sand, which is common depending on the nature of weathering or degree of decomposition.

Cross sections in Appendix B illustrate groundwater elevations from measurements in August 2019, which are considered generally representative of average groundwater elevations to conceptualize head differences observed between wells and among the three generalized geologic units. Table 3-3 summarizes the well clusters, screen depths, geologic units, groundwater elevations, and the head differences (also illustrated on Figures 3-6 and 3-7). Well clusters in similar locations but screened in respective upper and lower geologic units are instructive for evaluating the hydraulic connection between different units and/or vertical interconnection between units.

As shown on Figures 3-6 and 3-7, groundwater elevations near the GHFF for wells screened in the upper unconsolidated sediment and intermediate basalt are in the range of approximately 2,555 to 2,570 feet amsl. Monitoring wells screened in the lower basement rock (inferred weathered granitic gneiss) exhibit groundwater elevations in the range of 2,550 to 2,575 feet amsl, which is comparable to the elevations in the above units. The assessment of head differences for the above well pairs supports the conclusion that near the GHFF and extending south to at least the MW-9S/9D well pair, the upper unconsolidated sedimentary unit is in hydraulic connection and equilibrium with the intermediate basalt wedge in this area. The basalt beneath the GHFF is relatively thin (roughly 20 to 60 feet thick) and significantly fractured and/or weathered with at least one more competent/denser (less fractured or weathered) core in the middle depth of the basalt formation as the unit thickens to the south/southwest. Potentiometric surface or hydraulic head in wells completed in the fractured/altered basalt below the competent/unfractured basalt core in the downgradient area inclusive of RC-03 and RC-4 are dramatically depressed (60 to 90 ft lower) than in wells completed in the upper basalt/loess overburden and in the granitic basement rock formation.

Extending further south, the head assessment was bolstered by the incorporation of hydrophysical logging (see Appendix B) under ambient conditions (no active pumping on the logged well but potential influence from the pumping schedule of the Primary Freeman School District Well [WS5]). The logging was conducted at three locations, RC-02, RC-03, and RC-04, showing both vertical and horizontal flow of groundwater through the fractured intervals of basalt. At an approximate location between the MW-9S/9D well pair and MW-19D, there is a transition to hydraulically separate upper and lower saturated zones given the substantial head differences (summarized in Table 3-3 and shown on Figure 3-7). As the basalt sequence (wedge) thickens to the south-southwest, the interior of the CRBG formation becomes more competent (less fractured, less weathered, lack of vesicles), confirmed by borehole geophysical and hydrophysical logging, thus creating a dense flow interior with relatively low horizontal or vertical permeability in this interval (Figure 3-7; Figure 6 in Appendix B). This separation continues farther south and southwest, where the wedge of unfractured basalt thickens and even reaches the basalt/sediments boundary at RC-04.

The upper saturated zone consists of the saturated upper unconsolidated sediments and the upper (fractured) portion of the basalt above the unfractured interval. The lower saturated zones dip down underneath the unfractured basalt wedge (and therefore enter confining aquifer conditions) between the domestic Marlow Well and the MW-26, MW-35, and MW-36 well cluster (RC-03). At this cluster the groundwater elevation (hydraulic head) differences observed between MW-36 (screened in the shallow fractured basalt) and MW-26 and MW-35 (screened in the underlying fractured basalt and palagonite below the unfractured interval) are more than 90 feet. Further south at the MW-31 through MW-34 (RC-04) and MW-6 well clusters, groundwater elevation stratification between all three generalized geological units is present where MW-6S is screened in the upper sediments, MW-31 is screened in the basement rock, and the remaining wells are located within the basalt. All three units exhibit different hydraulic head.

Ambient hydrophysical logging at locations RC-02 through RC-04 identified inflow and outflow through various fractures within each borehole and indicated intervals of upflow and downflow as formation water flowed through the network (Appendix B, Figure 7). The northernmost borehole, RC-02 closest to the GHFF indicated downward flow throughout the borehole (123 to 225 feet bgs) that exited at the bottom fractures at approximately 2,430 feet amsl. Continuing south away from the GHFF flow at borehole RC-03 (measured from 115 to 195 feet bgs) indicated downward flow from the upper fractures and upward flow from the bottom fractures and palagonite, consolidating and exiting at fractures at approximately 2,450 feet amsl. At the deepest borehole, RC-04, proximal to the Primary Freeman School District Well (WS5), ambient hydrophysical logging indicated upward flow from the fractures at the clay paleosol and fractured basalt above and flows out of the borehole between 2,450 and 2,350 feet amsl. To summarize, the ambient hydrophysical logging indicated downward hydraulic flow in the basalt in the northern portion of the site, general upward flow in the deeper portions of the basalt near the Primary Freeman School District Well (WS5), and a consolidated flow in between (Appendix B, Figure 7).

As shown on Figures 3-6 and 3-7, several public supply wells are open hole within the CRBG unit and span upwards of 140 to 150 feet of the basalt sequence (such as the Primary Freeman School District Well [WS5] and Lashaw wells). Groundwater elevations obtained from these types of open hole public water supply wells are not illustrated on the hydrogeologic cross sections because they could intersect more than one saturated zone, which may complicate the hydrogeologic interpretation and analysis.

3.6.4.3 Hydrographs

Figure 3-9 (all wells, hydrograph 1) presents a groundwater elevation hydrograph for RI wells with available measurements to show general characteristics or common well groupings. Three general groupings of wells express a common elevation range. The upper group consists of wells close to the GHFF that range from 2,550 to 2,580 feet amsl, the intermediate group consists of 2 wells (wells MW-20D and MW-16D) south of the site, and the lower group consists of wells south of the Site (MW-04D, MW-06D, MW-15D, MW-18D, and MW-21D) (some lines on the hydrograph are difficult to view because they are covered by other lines; see additional discussion below).

Figure 3-10 (upper grouping, hydrograph 2) shows a hydrograph with a subset of wells from the upper group that range in elevation from approximately 2,550 to 2,580 feet amsl. The wells close to the GHFF, such as MW-08S, MW-09S, MW-10S, MW-11S, and MW-13S, exhibit a similar temporal pattern and generally a similar or common elevation in the range of approximately 2,565 to 2,572 feet amsl. Well MW-6S exhibits a similar temporal pattern, but the elevation is approximately 10 feet lower, which could indicate that it is approximately 0.25 mile (about 1,300 feet) south of the above set of wells, reflecting that the hydraulic gradient may be sloping in that direction away from the GHFF. The similarities in the elevations and temporal patterns for this well group suggest that this set of wells is hydraulically connected and responding to a common recharge source or groundwater flow mechanism.

Wells MW-1S and MW-12S are north of the Site and exhibit relatively higher elevations than the upper well group. Their relative temporal pattern from late summer through fall does not correlate with the other wells. For example, from August to December 2016, the elevations from wells MW-1S and MW-12S were decreasing, whereas the elevations in the upper well group during the same period were increasing. This phenomenon may suggest that wells MW-1S and MW-12S are influenced by a different recharge mechanism (such as recharge from the lower granite unit) or may have limited hydraulic connection with the adjacent wells south near the site. Well MW-12S is completed in the lower unit (weathered granite), whereas the rest of the upper well group is screened in either the upper unconsolidated sediment or the basalt unit. Based on these characteristics, wells MW-1S and MW-12S should be given special consideration (or grouped separately) with respect to development of hydrostratigraphic units and for interpretations on the groundwater flow maps.

Figure 3-11 (lower well grouping, hydrograph 3) shows monitoring wells south of the GHFF (MW-4D, MW-6D, MW-18D, and MW-21D) that are screened in the basalt unit, with groundwater elevations in the range of 2,455 to 2,465 feet amsl. This elevation range is roughly 90 feet lower than the elevation range of the upper well group. These wells are south of the Primary Freeman School District Well (WS5) in the lower portion of the basalt unit, which is generally thickening to the south-southwest. The basalt unit thickens to the southwest, and typical basalt flows exhibit dense flow interiors, often serving as confining layers; therefore, this lower well group is inferred to be hydraulically separate from the upper unconsolidated sediment and/or separate from the overlying upper basalt unit in the area south of the MW-6S/6D well pair.

As annotated on Figure 3-11 (hydrograph 3), well MW-16D expresses an intermediate elevation, but considering its distance from the Site (roughly 1 mile south-southwest) and that the screen depth is in the top portion of basalt, it may be hydraulically connected with an upper unconsolidated and/or upper basalt zone. Well MW-17D also expresses an intermediate elevation with limited fluctuation, which could indicate that it was completed in weathered granite.

3.6.4.4 Aquifer Testing

Section 4.5.4 summarizes the aquifer testing conducted on the GHFF and Freeman School District. Three areas identified for aquifer testing included the MW-9S/MW-9D and MW-6S/MW-6D well pairs targeting the upper fractured basalt zone, and MW-35 targeting the deeper fractured basalt beneath the unfractured basalt wedge. Key findings from these aquifer tests are as follows:

- The upper fractured basalt at the MW-6S/MW-6D well pair did not produce sustainable flow at low pumping rates (less than 1 gpm). Recovery from the pumping well (EW-6U) took over 24 hours.
- The upper fractured basalt at the MW-9S/MW-9D well pair produced sustainable flow of more than 30 gpm. Drawdown was observed in all monitored observation wells.
- The lower fractured basalt at MW-35 produced sustainable flow of approximately 4.5 gpm, which was lower than initially anticipated. The MW-35 aquifer testing data indicated no significant connection between the upper and lower fractured basalt separated by the unfractured basalt wedge.

The groundwater modeling report (in Appendix D) provides additional information about the aquifer testing performed at the site.

3.6.4.5 Geochemical Data

Major ions were collected as part of the RI to assist with groundwater evaluations to support development of the CSM.

Appendix E presents the major ion data collected during the RI including (dissolved phase) sodium, potassium, calcium, magnesium, chloride, and sulfate. In general, the wells have relatively low concentrations for the suite of major ion data. For example, both chloride and sulfate concentrations are typically below 10 milligrams per liter (mg/L) (to put this in context, the risk-based maximum contaminant level for chloride and sulfate is 250 mg/L [173-200 WAC]). Total dissolved solids for domestic and monitoring wells at the Site are low, and generally in the range of 200 to 250 mg/L. Relatively low concentrations (that is, low ion abundance) may suggest the groundwater has undergone a relatively short flow path or a short duration of residence time in the saturated zone (or aquifer). Wells exhibiting low ion abundance would be consistent with a recharge area where the flow path or residence time is limited, in contrast to a discharge zone area where the ion abundance might be higher because of a longer flow path or longer residence time within the host rock (or sediment) formation.

The analysis of geochemistry of the regional setting indicates that the groundwater observed beneath the GHFF likely represents a recharge area with limited residence time within the various geologic units. In addition, two monitoring wells (MW-12S and MW-1S) are anomalous in that they also exhibit different characteristics for the Site hydrograph. This difference may suggest that these wells are influenced by a different recharge source or could be hydraulically isolated from the other shallow well grouping.

These observations have been considered when grouping wells by hydrostratigraphic unit for development of flow maps in subsequent sections.

3.6.4.6 Hydrostratigraphic Units

Based on the preceding data reviews and analysis from the CSM and groundwater flow model, the interpreted hydrostratigraphic units and representative wells are summarized as follows:

- **The upper unconsolidated sediment and upper fractured basalt hydrostratigraphic unit.** As shown on Figures 3-6 and 3-7, this hydrostratigraphic unit encompasses the area beneath the GHFF and extends south from the Site with the sediments continuing south into the Palouse region but the upper fractured basalt portion thins out near the MW-6S/6U/6D well cluster. The data review demonstrates that the upper unconsolidated sediment is in hydraulic connection with the underlying heavily fractured and weathered basalt where present in this area. Wells screened in this hydrostratigraphic unit include the following:
  - **Unconsolidated sediment:** wells MW-6S, MW-8S, MW-9S, MW-10S (cross-screened into upper fractured basalt), MW-11S, MW-13S, MW-24S, and MW-25S
  - **Upper fractured basalt:** wells MW-7S, MW-10S (cross-screened into unconsolidated sediment), MW-9D, MW-9U, MW-30, and MW-36

  The upper fractured basalt portion of this hydrostratigraphic unit may extend further south beyond well MW-6S to include wells such as MW-20D and perhaps MW-16D into the upper well group. However, there are insufficient data to conclude that these more distant wells are connected to the upper wells in the vicinity of the GHFF.
- **Saprolitic basalt and granite hydrostratigraphic unit.** This unit is located above and upgradient of the GHFF and represents shallow groundwater in the saprolitic granite near the former clay pit and saprolitic basalt in the area of MW-1S. The groundwater elevation is anomalously high, which suggests that this well could be perched and may have limited hydraulic connection to adjacent wells farther south. The following wells were screened in this hydrostratigraphic unit:
  - Saprolitic Basalt and Granite: wells MW-1S, MW-2D, MW-5D
- **Unfractured basalt hydrostratigraphic unit.** This unit comprises relatively unfractured sections within the basalt flows and acts as a hydraulic barrier that can separate the upper unconsolidated sediment and upper fractured basalt from deeper portions of fractured and altered basalts below. In addition to this ‘upper’ unfractured interval as described in Section 3.4.6.2, the lowermost basalt flow under the clay paleosol was found to be unfractured to the contact with the underlying basement rock (televiewer data and no flow zone in the hydrophysical logging). The following wells were screened in this hydrostratigraphic unit:
  - **Unfractured basalt:** well MW-6U, portions of the screen interval of the Primary Freeman School District Well (WS5) (inferred), and identified within borings RC-03 and RC-04 (no new wells completed in unfractured basalt because of lack of water)
- **Lower fractured basalt hydrostratigraphic unit.** This unit represents the majority of the flow pathways of groundwater at the Site. As shown on Figures 3-6 and 3-7, this hydrostratigraphic unit is located under the unfractured portion of the basalt with a northern extent south of the MW-27 through MW-30 well cluster and extending to the south beyond the study area. It is currently theorized that this unit is the primary source of groundwater for the Primary Freeman School District Well (WS5). Hydraulic head for onsite wells screened in this interval are under confined conditions and rise into the unfractured basalt at approximately 2,475 feet amsl. The following wells were screened in this hydrostratigraphic unit:
  - **Lower fractured basalt:** wells MW-15D, MW-18D, MW-21D, MW-33, MW-34, and MW-35
- **Palagonite hydrostratigraphic unit.** This unit represents the heavily altered basalt and palagonite texture that increases in intensity (and decreases in permeability) towards the contact with the basement rock. This unit extends north to MW-28, has the greatest thickness and alteration at MW-26, and lessens in magnitude southward towards MW-6D. Fractures are less prevalent or

annealed by the soft clay-like properties of the palagonite mineralization. The following wells were screened in this hydrostratigraphic unit:

  - **Palagonite:** wells MW-4D, MW-26, MW-6D

- **Clay paleosol hydrostratigraphic unit.** This unit was only identified from the deep boring at RC-04 at approximately 2,300 feet amsl. The unit is a combination of low-permeability clay with highly fractured basalt above and below the clay layer. The extent, thickness, and continuity of this layer are unknown but assumed to be at least sub-horizontal in orientation (as if a weathered surface of the lowermost basalt flow in the study area was left exposed on the surface for an undetermined amount of time before the next basalt flow covered it). The following well was screened in this hydrostratigraphic unit:
  - **Clay Paleosol:** well MW-32
- **Basement rock hydrostratigraphic unit.** This hydrostratigraphic unit is the granitic gneiss below the basalt at the vast majority of the Site and under the unconsolidated sediments at the hills north of the GHFF. Based on the regional setting, and from observations during the field investigations, this unit is inferred to have relatively low permeability. Given the depositional environment and the degree of weathering, there may be heterogeneous lenses or discontinuous saturated zones that complicate the interpretation of groundwater elevations from within this unit.
  - **Basement rock:** wells MW-1D, MW-3D, MW-12S, MW-14D, MW-31, MW-27

The following wells were excluded from the above hydrostratigraphic well groups for the following reasons:

- MW-19D, MW-28, and MW-29 are not distinguished as being upper or lower fractured basalt because fractured basalt in this area is not divided by the unfractured basalt, which occurs further to the south; however, MW-30 is retained in the upper fractured basalt because it is screened in the uppermost portion of the fractured basalt in the same vicinity.
- MW-17D is excluded because of uncertainty in contacts between the Saprolitic basalt and granite and deep fractured basalt hydrostratigraphic units in this vicinity.
- Wells MW-16D and MW-20D were completed in a basalt unit, south of the MW-6S/6D well pair, and roughly 1 mile from the GHFF. There are extensive distances between wells in this area, so the lateral and vertical hydraulic connection between these wells and the wells near the Site is uncertain; as such, they are not part of a unique hydrostratigraphic unit.

3.6.4.7 Horizontal Groundwater Flow Direction and Hydraulic Gradient

This section presents the horizontal groundwater flow direction and hydraulic gradient for the hydrostratigraphic units (and the well groups) described in Section 3.6.4.6. Details on vertical gradients and flow conditions are provided in the conceptual site model discussion presented in Section 5.3 (and associated figures) and in Appendix B, Basalt Aquifer Characterization.

Figure 3-12 presents the groundwater elevations, inferred contours, and the inferred groundwater flow direction for the wells grouped into the upper unconsolidated sediment and shallow fractured basalt hydrostratigraphic unit (near the GHFF). The generalized groundwater flow direction for this hydrostratigraphic unit is to the south-southwest. The hydraulic gradient near the Site is relatively flat, estimated at 0.0014 foot per foot (ft/ft) from wells MW-9S and MW-11S. It steepens to the south with an estimated gradient of 0.014 ft/ft between wells MW-11S and MW-06S.

A general southern or southwestern flow direction in the uppermost hydrostratigraphic unit would be consistent with the regional geologic framework and the watershed boundaries such that flow is away from the topographic high of Mica Peak, and generally flows to the southwest into Rock Creek.

The southern extent of groundwater flow interpretation for this upper unit extends from the GHFF southward down to approximately the MW-6S/6D well pair. It is likely that an upper water bearing zone extends further south than the MW-6S/6D well pair, however, there are insufficient well data to confirm this hypothesis.

The groundwater flow interpretation shown on Figure 3-12 excludes groundwater elevation data from well MW-1S because it is inferred to be perched and/or hydraulically connected to a different recharge source, which is based on the analysis of Site hydrographs. Well MW-1S has been classified in the saprolitic basalt and may be hydraulically connected with the lower weathered basement rock unit, given that it correlates well with MW-12S, which is completed in granitic gneiss. The basement rock wells in this area (that is, monitoring wells MW-1D, MW-3D, and MW-12S) exhibit a slightly higher groundwater elevation, which suggests they are hydraulically linked to recharge sources further upslope to the northeast associated with Mica Peak.

Figure 3-13 shows groundwater elevations for wells near and south/southwest of the MW-6S/MW-6D well pair and screened in the basalt unit. These wells provide groundwater elevation data in the transitional zone where the basalt thickens and a dense unfractured wedge sits within the interior. Where present, the dense flow interior would create relatively low horizontal and vertical permeability and effectively act as a confining unit (barrier) to restrict or confine groundwater movement. Based on the groundwater elevations and screen interval depths, wells MW-16D, MW-20D, and MW-36 (shown as green symbols and with green water elevation data) represent groundwater elevations from saturated zones above the dense flow interior and within the upper fractured basalt. Wells MW-4D, MW-6D, MW-15D, MW-18D, MW-21D, MW-26, MW-33, MW-34, and MW-35 (shown in light blue symbols and posted values) are screened within the lower fractured basalt below the dense unfractured flow interior. In this area, it is interpreted that the unfractured basalt hydraulically separates the upper and lower fractured zones, which are reflected in the groundwater elevation (head) differences of roughly 60 feet between the upper and lower well groups.

Although there is limited well coverage and enough uncertainty that precludes any attempts at contouring elevations in this southerly area, the wells in the lower fractured basalt unit (MW-4D, MW-6D, MW-15D, MW-18D, MW-33, and MW-35) exhibit elevations that suggest a flow direction generally turning to the west-southwest, which would fit the regional watershed setting of surface water and drainage basin features generally flowing westward. However, considering the relatively large area and extensive thicknesses/depths of units, there are uncertainties in the lateral and vertical hydraulic interconnection, and additional subsurface data would be needed to better understand the groundwater flow characteristics in this more southerly area.

Figure 3-14 shows the groundwater elevations, inferred contours, and inferred groundwater flow direction for the lower basement rock hydrostratigraphic unit in the vicinity of the GHFF. The general flow direction for this hydrostratigraphic unit is to the south-southwest, and the hydraulic gradient is approximately 0.02 ft/ft. The contours shown are based on limited data from wells MW-1D, MW-3D, MW-5D, MW-14D, and MW-17D. Figure 3-14 excludes contours of the anomalous elevations from wells MW-2D and MW-12S.

3.6.4.8 Surface Water and Groundwater Interaction

The interconnectivity of groundwater and surface water was evaluated as part of the Little Cottonwood Creek investigation (Section 4.5.5). Groundwater and surface water interaction was evaluated using the collocated monitoring wells and stream gauges MW-22S/SG-01 and MW-23S/SG-02. Artesian conditions were encountered in monitoring wells MW-22S and MW-23S with head differences several feet higher than the stream, suggesting the shallow water bearing unit is confined and there is limited or no interconnectivity with Little Cottonwood Creek.

4. Nature and Extent of Contamination

From May 2016 through August 2019, RI activities were conducted at the Site and surrounding area to supplement previous RI data and evaluate the presence and extent of COCs in soil, groundwater, surface water, air, and soil vapor. Field investigation activities were conducted in accordance with the *Remedial Investigation/Feasibility Study Work Plan, Grain Handling Facility at Freeman*, *Freeman, Washington* (CH2M, 2016a), and subsequent addenda, as follows:

- *Focused Residential Parcel Surface Soil Sampling and Analysis Plan, Grain Handling Facility at Freeman, Freeman, Washington (CH2M, 2016b)*
- *Background Air Sampling Work Plan Addendum – Freeman, Washington (CH2M, 2016c)*
- *Soil Vapor Sampling Addendum for the Grain Handling Facility at Freeman, Freeman, Washington (CH2M, 2016d)*
- *Work Plan Addendum for Source Area Investigation, Grain Handling Facility at Freeman, Freeman, Washington (CH2M, 2017a)*
- *Revised Work Plan Addendum for Aquifer Testing, Grain Handling Facility at Freeman, Freeman, Washington (CH2M, 2017b)*
- *Work Plan Addendum for Vapor Intrusion Investigation, Grain Handling Facility at Freeman, Freeman, Washington (CH2M, 2017c)*
- *Little Cottonwood Creek Hydrologic Investigation Addendum for the Grain Handling Facility at Freeman, Freeman, Washington (CH2M, 2017d)*
- *Work Plan Addendum for Exploratory Excavation of a Subsurface Anomaly, Grain Handling Facility at Freeman, Freeman, Washington (CH2M, 2017e)*
- *Work Plan Addendum, Rock Coring Investigation, Grain Handling Facility at Freeman, Freeman, Washington (Jacobs, 2018b)*
- *Work Plan Addendum, Revised Additional Source Area Investigation, Grain Handling Facility at Freeman, Freeman, Washington (Jacobs, 2019)*

An iterative approach was conducted during RI activities that can be broadly categorized into the following areas:

- Source area delineation (Section 4.4)
- Groundwater characterization (Section 4.5)
- Exposure assessment (Section 4.6)

Descriptions of RI activities and results for these categories are presented in this section.

Analytical summary tables are provided in Appendix E. Analytical laboratory reports are provided in Appendix F.

4.1 Previous Actions and Investigations

A summary of previous actions and investigations is presented in Table 4-1.

4.2 Constituents of Concern

COCs[1] are hazardous substances known to have been potentially released to the environment (including hazardous substances from subsequent degradation of their parent products that were released to the environment) and detected in samples of environmental media (for example, air, soil, groundwater) at the Site. Soil and groundwater at the GHFF and groundwater downgradient of the GHFF contain elevated concentrations of carbon tetrachloride, chloroform, and carbon disulfide, which have been designated as the COCs for the site. Carbon tetrachloride, and to a lesser extent carbon disulfide, have been used as fumigants to control insects in stored grain, while chloroform may be present as an impurity or a degradation breakdown product of carbon tetrachloride. These COCs are the focus of the RI. The general physical and chemical characteristics of these COCs are summarized in Sections 4.2.1 and 4.2.2.

4.2.1 Physical and Chemical Characteristics of Carbon Tetrachloride

Carbon tetrachloride is classified as a volatile organic compound (VOC) with the chemical formula CCl_4. It is a clear, nonflammable liquid, nearly insoluble in water (aqueous solubility of 1,160 mg/L at 25 degrees Celsius [°C] and 800 mg/L at 20°C [Verschueren, 1996]), and has a sweet odor. Carbon tetrachloride has a molecular weight of 153.8 grams per mole, vapor pressure of 91.3 millimeters of mercury, with an odor threshold of 10 parts per million. Because of its density of 1.59 grams per cubic centimeter (g/cm^3), it will sink in water (density = 1 g/cm^3) if present as a free phase.

4.2.2 Physical and Chemical Characteristics of Chloroform

Chloroform is classified as a VOC with the chemical formula $CHCl_3$. It is a clear, colorless liquid, with a pleasant odor, and aqueous solubility of 7,950 mg/L at 25°C (Mackay et al., 1980). Chloroform has a molecular weight of 119.36 grams per mole, vapor pressure of 159 millimeters of mercury, with an odor threshold of 85 parts per million. Because of its density of 1.47 g/cm^3, it will sink in water if present as a free phase.

4.2.3 Physical and Chemical Characteristics of Carbon Disulfide

Carbon disulfide is classified as a VOC with the chemical formula CS_2. It is a clear, colorless liquid, with an ether-like odor, and aqueous solubility of 2,160 mg/L at 25°C (Mackay et al., 1980). Carbon disulfide has a molecular weight of 76.13 grams per mole, vapor pressure of 359 millimeters of mercury, with an odor threshold of 0.1 part per million. Because of its density of 1.266 g/cm^3, it will sink in water if present as a free phase.

4.3 Screening Levels

This section summarizes screening levels (SLs) selected for the Site to identify COCs in impacted environmental media and to assess the extent of impacted environmental media during remedial investigation activities. Site SLs are numerical values that have been selected for those constituents detected in one or more Site media (soil, groundwater, surface water, air, and sub-slab soil vapor). The SLs were selected from the MTCA Cleanup Levels and Risk Calculation (CLARC) data tables. Background air SLs are also presented because background concentrations of carbon tetrachloride in air, discussed in Section 4.6.4.1, are higher than the Method B cleanup level for carcinogenic effects.

Table 4-2 includes a summary of Site SLs.

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[1] COCs differ from indicator hazardous substances (IHSs) because WAC 173-340-200 defines IHSs as a 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. The Site is not contaminated with a large number of hazardous substances, so identification of IHSs is not necessary.

4.4 Source Area Delineation

Previous (pre-2016) investigation activities indicated the presence of COCs in soil at and surrounding the GHFF. The results of those previous investigation activities could indicate the presence of a secondary source, and possibly nonaqueous phase liquid that could be an ongoing contribution of dissolved-phase COCs in downgradient groundwater. Therefore, between May 2016 and August 2019, additional investigation was conducted to evaluate the potential presence and extent of COCs in soil and nonaqueous phase liquid at and surrounding the GHFF. The investigation consisted of the following activities:

- Soil boring and soil sampling
- Geophysical survey
- Passive soil vapor survey
- Soil vapor sampling

Groundwater sampling was also conducted to support source area delineation. Information on groundwater sampling is presented in Section 4.5.

Soil analytical results for COCs are provided in Tables 4-3 through 4-5. Passive soil vapor analytical results for carbon tetrachloride are provided in Table 4-6. Soil vapor analytical results for COCs are provided in Table 4-7. Sub-slab soil vapor analytical results for COCs are provided in Table 4-8.

4.4.1 Soil Borings and Soil Sampling

Drilling activities were conducted at the GHFF and surrounding area to characterize subsurface soils and identify potential carbon tetrachloride source areas. Soil borings were advanced in unconsolidated material using sonic drilling to refusal at or near competent bedrock and in areas at and surrounding the Site (Figure 4-1). Where no bedrock was encountered, soil borings were advanced upwards of 150 feet bgs. Soil boring details are provided in Table 3-1. Soil boring logs are provided in Appendix A.

Soil samples (locations SV-105 through SV-110 and SV-112 through SV-114) were also collected beneath the GHFF concrete slab in March 2018 to assess the potential presence of COCs in shallow soils beneath the facility. Samples were collected from immediately below the concrete slab and 3 feet below the concrete slab at 9 locations using a hand auger after coring through concrete (Figures 4-1 and 4-2). Six (locations SV-108 through SV-110 and SV-112 through SV-114) of the 9 locations are beneath the silos in the GHFF access tunnels. Three (locations SV-105 through SV-107) of the 9 locations are aboveground and in between or adjacent to the larger silos.

Shallow soil samples were collected during December 2018 from five borings, identified as SB-201 through SB-205 on Figure 4-3, at the northeastern corner of the GHFF. Additional soil samples were collected beneath the GHFF grain silos in February 2019 to further assess the potential presence of COCs in shallow soils beneath the facility. These soil samples were collected during drilling of 3 horizontal borings beneath the silos (Figure 4-1) at a depth of 10 feet bgs. Additional shallow and deep soil samples were collected during drilling of deeper soil borings SB-206 through SB-208 during June 2019 from areas east and southeast of the GHFF; specific locations were north (SB-206; 77 feet bgs), west (SB-207; 77 feet bgs), and south (SB-208; 92 feet bgs) of the Marlow and Randall domestic wells. Soil samples were collected every 5 feet to the base of the unconsolidated aquifer (top of basalt). No detections of carbon tetrachloride or other Site COCs were identified in these offsite soil samples (Figure 4-3).

Soil samples were collected during drilling and concrete coring activities from the retrieved continuous soil cores and hand augers, respectively. Soil samples were screened for the presence of VOCs using a photoionization detector with an 11.7 electron volt lamp for headspace analysis. From many soil borings, soil samples were collected every 5 feet and submitted to Pace Analytical Services for VOC analysis by EPA Method 8260B. Several samples were analyzed by a mobile laboratory and have elevated reporting limits.

Carbon tetrachloride results for soil samples collected during the RI are presented on Figure 4-3. A summary of the key findings from these investigation activities follows:

- Carbon tetrachloride concentrations in soil samples were significantly below the SL of 14,000 micrograms per kilogram (µg/kg). The highest carbon tetrachloride concentration detected in soil samples was 160 µg/kg (SB-04/MW-9S at 35 feet bgs).
- The majority of detected carbon tetrachloride concentrations were from samples collected within the GHFF and at depths more consistent with the depth of groundwater. The majority of soil samples with detected concentrations of carbon tetrachloride occurred below 20 feet bgs.
- Carbon tetrachloride was only detected in a few near-surface (that is, upper 5 feet) soil samples at relatively low concentrations up to 8.3 µg/kg (SV-106); this highest detection was located immediately beneath the slab between the two medium-sized silos.
- Carbon tetrachloride was infrequently detected outside of the GHFF. Carbon tetrachloride was only detected in soil samples outside the GHFF at soil borings SB-18, SB-20, SB-22, and SB-34.
- Chloroform was detected in soil samples from two soil borings (SB-20 and SB-22) in the UPRR right-of-way southeast of the GHFF. Chloroform detections ranged from 2.2 to 10 µg/kg, significantly below the SL of 32,000 µg/kg.
- Carbon disulfide was not detected in the 37 soil samples for which it was analyzed.
- Carbon tetrachloride or chloroform were infrequently detected (3 of 415 samples) in vadose zone soil samples at concentrations above the MTCA Protection of Groundwater, Vadose at 13°C screening levels of 42 and 74 µg/kg, respectively. Carbon disulfide was not detected in vadose zone soil samples at concentrations above reporting limits. Vadose zone soil sample results are presented in Table 4-4. Vadose zone soil samples are those assumed to be 30 feet bgs and above.
- Carbon tetrachloride or chloroform were infrequently detected (16 of 263 samples) in saturated soil samples at concentrations above the MTCA Protection of Groundwater, Saturated SLs of 2.2 and 4.8 µg/kg, respectively. Detected results are likely associated with dissolved-phase carbon tetrachloride and chloroform levels in groundwater. Saturated zone soil sample results are presented in Table 4-5. Saturated soil samples are assumed to be those below 30 feet bgs.
- Soil analytical results indicate relatively low levels of COCs at or near the groundwater interface and do not indicate a significant secondary source of carbon tetrachloride that may present a threat to groundwater.

4.4.2 Geophysical Surveys

A geophysical survey was conducted in August 2017 over a 1.5-acre area to evaluate the potential presence of subsurface anomalies (such as underground storage tanks or piping) that may exist at the Site with the potential to contain or have contained carbon tetrachloride source material. The geophysical survey, conducted on August 17, 2017, identified a metallic anomaly near monitoring well MW-9U (Figure 4-2). An exploratory excavation was conducted on November 2, 2017, to identify the subsurface metallic anomaly. The subsurface metallic anomaly was exposed and identified as an abandoned steel culvert. Two excavations at each end of the culvert were completed. Soil samples (from locations GSNE and GSSW) were collected from the excavation and submitted to Pace Analytical Services for VOC analysis by EPA Method 8260B. One water sample (from location GSNE) was collected from water within the culvert and submitted for VOC analysis by EPA Method 8260B.

COCs were not detected in the soil and water samples. Soil analytical results for COCs are provided in Table 4-3. Groundwater analytical results for carbon tetrachloride, chloroform, and carbon disulfide are provided in Table 4-9.

An additional surface-based geophysical survey was conducted by ECA Geophysics during May 2019 using multi-electrode electrical resistivity and induced polarization surveying along 6 transect lines extending broadly across approximately 76 acres of the Site and Freeman School District property. The additional surface geophysical survey was conducted in an attempt to further characterize the vertical and lateral extent of the primary geological units at the site, including the upper unconsolidated sediments, the intermediate basalt, and the basement granitic gneiss. The geophysical surveying was intended to supplement the additional lithology characterization and downhole geophysics and hydrophysics investigations conducted at borings RC-01 through RC-04, which are situated between the GHFF and the Primary Freeman School District Well (WS5).

The observable depth of multi-electrode electrical resistivity and induced polarization surveys is related to the length of the survey transect lines, and lengths were selected to achieve an energy penetration depth of approximately 300 feet bgs. Transect lengths ranged from approximately 1,660 to approximately 2,080 feet. Three transects (Lines 1 through 3) were aligned generally northwest to southeast through the GHFF and between the railroad tracks to the north and Highway 27 to the south. Additional transects were aligned north-south along Jackson Road (Line 4) to the west and along the eastern school property boundary (Line 5), and along the former railroad alignment at the south boundary of the school property (Line 6). The actual energy penetration depth ranged from less than 230 feet along Line 5 to depths of approximately 300 to 320 feet along other transects. Drilling at RC-03 identified the bottom of the basalt at a depth of approximately 245 feet bgs (along Line 5) and drilling at RC-04 identified the bottom of the basalt to be much deeper at approximately 370 feet bgs; thus the surface-based geophysical surveying was not able to resolve the depth of the basement rock unit.

Results of the May 2019 ECA Geophysics survey are provided in Appendix G. The most significant finding within the ECA Geophysics report is the interpreted presence of a buried channel, extending generally from the GHFF and then south and southwest through the school campus to the general location of the school wastewater treatment ponds. The report indicates that such a channel is not a preferential flow pathway because it is interpreted as filled principally with clay. Although interpreted by the vendor, the presence of such an interpreted channel is far from certain given a variety of limitations within the analysis. The report acknowledges that survey data have nonunique solutions, and interpretations are based predominantly upon boring log data, yet there are very few deep boring logs upon which to base the interpretations. Further confounding interpretation is that discrepancies can arise where boring log data are not close to a survey transect line, and because of access constraints, no borings lie directly at the intersection of multiple transects in order to tie findings between transects. The report also makes literal interpretations of numerous boring log lithology descriptions, identifying various sands, silts, and clay that are actually saprolitic basalt and granite sequences and not sedimentary sequences, further confounding use of the survey for its intended purpose of identifying contacts between units overlying and underlying the primary basalt aquifer.

For these reasons, limited value is placed on this surface geophysical survey unless there is additional corroborating data. While a clay-filled buried channel is one potential interpretation of the complex data collected during the May 2019 geophysical survey, such a channel would not provide any preferential pathway for contaminant migration, which is supported by data indicating that the interpreted channel does not align with the location of high COC concentrations in groundwater, which is further to the east.

4.4.3 Passive Soil Vapor Survey

In September 2017, a passive soil vapor survey was conducted at the GHFF to evaluate the presence of carbon tetrachloride source areas, and not to evaluate potential VI at the GHFF. The results are only used as an indicator of potential source areas and are not compared to SLs. Of the 100 planned passive soil vapor survey sampling locations, 92 passive soil vapor samplers were installed from 3 to 5 feet bgs using direct push drilling, and 82 were retrieved for analysis of VOCs by modified EPA Method TO-17. The remaining 10 samples could not be collected because of collapsed boreholes. The sampling period was approximately 30 days. Under the passive sampling conditions (exposure for a 30-day period in fine-grained soils), carbon tetrachloride is estimated to migrate a distance of approximately 1 meter. The passive soil vapor samplers (Waterloo Thick Membrane Sampler) and analytical services were provided by Eurofins Air Toxics.

Passive soil vapor analytical results for carbon tetrachloride are provided in Table 4-6. Figure 4-4 presents the inverted weight distribution of carbon tetrachloride detected in the samplers. Carbon tetrachloride concentrations were relatively low, with concentrations ranging from 9.1 to 480 micrograms per cubic meter (μg/m^3). The highest concentrations were observed directly south of the two most southeastern silos. These two locations were further investigated with vadose zone soil borings to evaluate depth-specific carbon tetrachloride concentrations in soil and soil vapor to evaluate the presence of residual sources at the site. Figure 4-5 shows the correlation of carbon tetrachloride concentrations in passive soil vapor samples and where carbon tetrachloride was detected in soil samples

4.4.4 Soil Vapor Sampling

Depth-specific soil vapor sampling was conducted at the GHFF in January 2018 to evaluate the presence of carbon tetrachloride source areas, and not to evaluate potential VI at the GHFF. Soil vapor samples were collected from four locations (SB101A, SB102A, SB103A, and SB104A) (Figure 4-4) with two sets of vapor probes nested in one boring. Locations were identified where the highest levels of carbon tetrachloride were observed in a passive soil vapor sample result. A total of 16 vapor probes was installed at the targeted depths of 5, 15, and 25 feet bgs, and immediately above the water table. From the 16 vapor probes, 9 soil vapor samples were collected. In some instances, samples could not be collected because of insufficient air flow (that is, under vacuum) resulting from fine-grained soils. Samples were collected in 6-liter SUMMA cans fitted with 24-hour regulators. Soil vapor samples were submitted to Pace Analytical Services for VOC analysis by EPA Method TO-15 selected ion monitoring (SIM).

Sub-slab soil vapor sampling (locations SV-105, SV-107, and SV-111 through SV-114) was conducted at the GHFF in March and April 2018 to evaluate potential carbon tetrachloride source material beneath the facility. Sub-slab soil vapor samples were collected in the access tunnel that underlies the smaller silos and grain unloading area, and at the exterior of the facility in between the three larger silos. The purposes of the sub-slab sampling were to evaluate carbon tetrachloride concentrations in soil vapor to assess the presence of carbon tetrachloride source areas. Samples were collected using 6-liter SUMMA cans fitted with 24-hour regulators. Sub-slab soil vapor samples were submitted to Pace Analytical Services for VOC analysis by EPA Method TO-15 SIM. Soil vapor sampling forms are provided in Appendix A.

Soil vapor analytical results for carbon tetrachloride, chloroform, and carbon disulfide are provided in Table 4-7. Sub-slab soil vapor analytical results for carbon tetrachloride, chloroform, and carbon disulfide are provided in Table 4-8.

A summary of the key findings from these investigation activities are as follows:

- Carbon tetrachloride, chloroform, and carbon disulfide were detected in all nine soil vapor samples at the four sampling locations. Carbon tetrachloride and chloroform concentrations increased with depth. Carbon tetrachloride and chloroform concentrations from 5-foot-bgs samples ranged from 8.7 μg/m^3) (SB-101A) to 2,160 μg/m^3 (SB-103A), and from 3.4J μg/m^3 (SB-101A) to 2,000 μg/m^3 (SB-103A), respectively. Carbon tetrachloride concentrations ranged from 19,700 μg/m^3 (SB-104A, 27 feet bgs) to 28,000 μg/m^3 (SB-101A, 25 feet bgs) in samples collected below 15 feet bgs. The highest chloroform concentration was detected at 4,170 μg/m^3 (SB-101A, 25 feet bgs). Carbon disulfide was detected up to 199J μg/m^3 (SB-101A, 25 feet bgs).
- Carbon tetrachloride, chloroform, or carbon disulfide were detected at concentrations above reporting limits in the GHFF sub-slab soil vapor samples at all six locations. Carbon tetrachloride concentrations ranged from 1.4 μg/m^3 to 503 μg/m^3. Chloroform concentrations above reporting limits ranged from 0.19J to 56.4 μg/m^3. Carbon disulfide concentrations ranged from 2.5 to 17 μg/m^3.
- Sub-slab soil vapor and soil vapor sample analytical results at the GHFF indicate relatively low levels of carbon tetrachloride and chloroform in soil and/or off-gassing from groundwater and do not indicate a significant secondary source of carbon tetrachloride. Locations with elevated carbon tetrachloride and chloroform concentrations in sub-slab soil vapor and soil vapor samples are generally consistent with locations with carbon tetrachloride and chloroform concentrations in soil and groundwater.
- The highest carbon tetrachloride concentrations detected in soil vapor was 28,000 μg/m^3 from a deep sample collected right above the water table. The corresponding concentrations of carbon tetrachloride in groundwater ranged from 289 to 1,000 μg/L. Based on Henry's Law, 289 μg/L of carbon tetrachloride in groundwater can produce an equilibrium soil vapor concentration of 317,000 μg/m^3, which is more than one order of magnitude higher than the highest level

(28,000 µg/L) detected from soil vapor samples collected at the site. The data do not suggest significant carbon tetrachloride in soil; groundwater is likely the primary source of carbon tetrachloride detected in soil and soil vapor at the site.

4.4.5 Source Area Delineation Summary

Source area investigation activities were first conducted at the GHFF in 2014 and then more extensively between May 2016 and April 2018. Extensive soil sampling has been conducted at the site, including beneath the grain handing infrastructure. The combination of soil, soil vapor, and passive soil vapor results indicate that residual COCs remain beneath the GHFF and extending slightly downgradient. However, the results do not indicate the presence of primary and significant secondary sources of COCs. Concentrations of COCs detected in soil samples collected downgradient of the GHFF suggest COCs have migrated in groundwater (dissolved-phase) as opposed to nonaqueous phase liquid migration.

4.5 Groundwater Characterization

Previous domestic well sampling indicated the presence of COCs in groundwater downgradient of the GHFF. Therefore, between May 2016 and August 2019, additional investigation was conducted to evaluate the presence and extent of COCs in groundwater downgradient of the GHFF, consisting of the following activities:

- Soil boring, soil sampling, and grab groundwater sampling
- Borehole geophysics, hydrophysics testing, and packer testing
- Monitoring well installation
- Groundwater monitoring
- Aquifer testing
- Surface water sampling

Soil analytical results for COCs are provided in Table 4-3. Groundwater analytical results for COCs are provided in Table 4-9. Surface water analytical results for COCs are provided in Table 4-10. Analytical summary tables are provided in Appendix E. Analytical laboratory reports are provided in Appendix F.

4.5.1 Soil Borings, Soil Sampling, and Grab Groundwater Sampling

Drilling activities were conducted outside the boundaries of the GHFF to evaluate the presence and extent of COCs in groundwater. Soil borings were advanced in the shallow unconsolidated unit using sonic drilling to the basalt interface and then using air rotary drilling to evaluate groundwater in the basalt and bedrock units, as shown on Figure 4-1. In several instances, soil borings were converted to monitoring wells (Section 4.5.2). Soil boring details are provided in Table 3-1. Soil boring logs are provided in Appendix A.

Before determining the extent of COCs in soil, soil samples were collected every 5 feet in the shallow unconsolidated unit at soil borings. Soil samples were submitted to Pace Analytical Services for VOC analysis by EPA Method 8260B.

In some instances, the objective of a soil boring was to install a monitoring well in the basalt unit. At these locations, and where groundwater was observed in the shallow unconsolidated unit, an attempt was made to collect a grab groundwater sample at the unconsolidated/consolidated unit contact, including at monitoring wells MW-14D, MW-15D, MW-17D, and MW-21D. Grab groundwater samples were collected from some locations within the basalt unit before a monitoring well was constructed, including at monitoring wells MW-17D, MW-18D, and MW-20D. Grab groundwater samples were also collected from some soil borings where no monitoring wells were installed, including at soil borings SB-34, SB-35, SB-41, SB-43, SB-206, SB-207, and SB-208. Grab groundwater samples were submitted to Pace Analytical Services for VOC analysis by EPA Method 8260B.

A summary of the key findings from these investigation activities follows:

- COCs were not detected in soil samples collected from the unconsolidated unit more than approximately 250 feet from the GHFF.
- Carbon tetrachloride was infrequently detected in grab groundwater samples collected at the unconsolidated sediment/basalt unit contact, except at monitoring wells MW-14D (20.3 µg/L at 30 feet bgs), MW-15D (2.1 µg/L at 20 feet bgs), and soil borings SB-34 (9.5 µg/L at 63 feet bgs), SB-43 (1.5 µg/L at 40 feet bgs), and SB-206 (0.5J µg/L at 77 feet bgs).
- Carbon tetrachloride was detected in grab groundwater samples collected within the basalt unit at levels generally consistent with monitoring well sample results.

Soil analytical results for carbon tetrachloride and chloroform are provided in Table 4-3. Groundwater grab sample analytical results for carbon tetrachloride, chloroform, and carbon disulfide are provided in Table 4-9.

4.5.2 Borehole Geophysics, Hydrophysics Testing, Packer Testing

To better understand the distribution of carbon tetrachloride within the fractures of the basalt and underlying basement rock downgradient of the GHFF, four borings roughly along the plume axis were drilled and subject to the following characterization methods to determine hydraulic conductivity and carbon tetrachloride concentrations: rock coring, analysis of drill cuttings and fluid returns, borehole geophysics, borehole hydrophysics, and packer testing of selected intervals. These new borings were identified as RC-01 (at the GHFF), RC-02 (near existing well MW-19D), RC-03 (downgradient of the Marlow/Randall wells and north of existing well MW-4D), and RC-04 (near the Primary Freeman School District Well [WS5]), as shown on Figure 4-1. The investigations were separated into a 2018 portion that focused on the shallow basalt to determine the degree of weathering and fracturing at the loess contact, and a 2019 investigation focused on the interior of the basalt and basement rock. Both investigations are documented in Appendix B.

A summary of the key findings from these investigation activities follows:

- The shallow basalt investigation indicates that the degree of fracturing at the GHFF was high with pervasive weathering down to at least 20 feet bgs, and this persists south to boring RC-02 and RC-03. However, shallow basalt cored at RC-04 proximal to Primary Freeman School District Well (WS5) was unfractured in the upper 20 feet with 100 percent rock quality designation for the entire interval.
- Groundwater samples were taken from open fracture intervals in the shallow basalt from borings RC-02 and RC-03 and submitted for laboratory analysis of Site COCs. Carbon tetrachloride groundwater concentrations ranged from 184 to 293 µg/L, which are within an order of magnitude to existing residential well concentrations in the shallow basalt. These data indicate that carbon tetrachloride is present in fractures within the shallow basalt in a relatively uniform distribution (that is, similar concentrations laterally and vertically within the basalt) in the area extending from the GHFF and up to 1,000 feet south of the GHFF.
- Considerable variability was encountered in the basalt at all borehole locations. Intervals of intense alteration within otherwise unaltered basalt were observed in rock cuttings and geophysical televiewer logs. Large (1-foot diameter) vug-like openings consistent with a palagonite texture were observed in RC-03 contributing to ambient inflow at depth in comparison to the more traditional fractures and vesicular textures located above. This palagonite alteration was most intense near the contact with the underlying basement rock and lessened to the south and higher up in the basalt flow. At the southern end of the site, evidence of two discrete basalt flows was observed in RC-04 with wood fragments present in a clay paleosol of the older (lower) flow at 275 to 285 feet bgs. Basement rock was encountered in three deep basalt borings (RC-02, RC-03, and RC-04) and appears to be a granitic gneiss.
- Borehole geophysical logging revealed that fracture orientation had preference to one or two directions for all three deep boreholes. However, dip direction was more randomized and it is inferred

that the fracture network does not have a preferential pathway inside the discrete basalt flows. Fracture porosity was determined at all three deep basalt borings with multiple zones of porosity encountered, often in the same borehole. Fracture porosity ranged from 0 percent in the lower basalt flow under the clay paleosol at RC-04 to 0.117 percent in the broken-up basalt immediately above and below the same paleosol / borehole.

- Hydrophysical ambient flow logging at the boreholes indicated a downward hydraulic gradient in RC-02 within the logged interval, a consolidating flow at 160 to 168 feet bgs at RC-03, and an upward gradient throughout the entire flowing fracture interval at RC-04 (142.5 to 288 feet bgs). Carbon tetrachloride was not detected in any packer interval that was sampled with an upward hydraulic gradient, indicating groundwater under confining conditions is not contaminated at the site. This upward gradient may be preventing carbon tetrachloride-contaminated groundwater found in shallower intervals (above approximately the 2,400-foot-amsl elevation) from migrating deeper into the aquifer.
- Carbon tetrachloride grab samples collected during the investigation indicate that the entire open borehole interval at RC-02 has carbon tetrachloride-contaminated groundwater, similar in magnitude to the shallow basalt investigation sample. No packer testing was completed at RC-03; however, recently installed monitoring wells MW-26, MW-35, and MW-36 at this location indicate that depths with an upward hydraulic gradient had no detections of carbon tetrachloride.
- At RC-04, all packer test intervals sampled in the basement rock and immediately below the paleosol layer and above (up to 120 feet bgs) registered non-detects for carbon tetrachloride. The Primary Freeman School District Well (WS5) is screened from 52 to 215 feet bgs, is located less than 50 feet from RC-04, and has 5 µg/L of carbon tetrachloride in groundwater from the last round of quarterly sampling (June 2019). However, the recent (summer 2019) well installations at RC-04 had detections of carbon tetrachloride at screened intervals of 165 to 185 feet bgs and 254 to 274 feet bgs. From these results, the upper basalt flow is affected by carbon tetrachloride, but underneath the clay paleosol at 275 feet bgs and in the lower basalt flow, groundwater has no detections of carbon tetrachloride.

4.5.3 Monitoring Well Installation

A total of 39 monitoring wells was installed at the GHFF and surrounding area between May 2016 and August 2019. Two wells (MW-22S and MW-23S) were abandoned following installation because of artesian conditions. The monitoring well installation program was adaptively managed to characterize the nature and extent of the COCs in groundwater and monitor concentration trends. The monitoring well network targeted various hydrostratigraphic units including the upper unconsolidated sediment and upper fractured basalt near the GHFF, lower fractured basalt, palagonite zone, clay paleosol, and the basement granitic gneiss. Monitoring well construction details, including well depth, screened interval, and hydrostratigraphic unit, and survey information are provided in Table 3-2. The monitoring well network is shown on Figure 4-6. Well construction as-built drawings are provided in Appendix A.

4.5.4 Groundwater Monitoring

Groundwater monitoring has been conducted quarterly at monitoring wells and existing domestic water wells since June 2016. Monitoring wells were added to the monitoring program after installation. Domestic wells were added to the program based on property owner permission. An overview of the groundwater monitoring program is provided in Table 4-11. Groundwater samples were submitted to Pace Analytical Services for analysis of VOCs and water quality parameters (Table 4-11).

Carbon tetrachloride and/or chloroform detections have exceeded SLs (carbon tetrachloride, 0.63 µg/L; chloroform, 1.4 µg/L) in several monitoring and domestic wells. Carbon tetrachloride results in groundwater samples are shown on Figure 4-7 and in cross section along the axis of the plume on Figure 4-8. Chloroform results in groundwater samples are shown on Figure 4-9. Groundwater analytical results for carbon tetrachloride, chloroform, and carbon disulfide are provided in Table 4-9. A summary of the key findings from groundwater monitoring at monitoring wells for the primary hydrostratigraphic units (Section 3.6.4.6) are presented in the following sections.

4.5.4.1 Upper Unconsolidated Sediment and Upper Fractured Basalt Hydrostratigraphic Unit

This unit encompasses the area in the vicinity of the GHFF, extends south, and consists of two distinct formations that appear to be hydraulically connected: the shallow unconsolidated sediment unit and the underlying fractured basalt unit. The following wells were screened in this hydrostratigraphic unit:

- **Unconsolidated sediment:** wells MW-6S, MW-8S, MW-9S, MW-10S, MW-11S, and MW-13S
- **Upper Fractured Basalt:** wells MW-7S, MW-9D, MW-9U, MW-19D, MW-30, and MW-36

The wells installed in this unit contain the highest concentrations of COCs in groundwater. COC concentrations generally decrease with distance and depth from the GHFF in this unit. Starting at the GHFF, the highest concentrations of carbon tetrachloride and chloroform were observed at monitoring wells MW-9S and MW-9U. Monitoring well MW-9U was originally installed as a pumping well during aquifer testing in 2017 and is now sampled as a monitoring well. Monitoring well MW-9U is near monitoring wells MW-9S and MW-9D. Carbon tetrachloride concentrations at monitoring well MW-9U ranged from 298 µg/L (January 2018, assuming 16 µg/L value for December 2018 was an outlier) to 820 µg/L (August 2017). Within the unconsolidated sediments, carbon tetrachloride concentrations at monitoring well MW-9S were generally slightly less, with concentrations typically in the range of 300 to 350 µg/L during 2019, 500 µg/L during 2017, and as high as 1,000 µg/L in December 2016. Likewise, carbon tetrachloride was detected at lower concentrations at monitoring wells in the unconsolidated unit within and near the GHFF boundaries: MW-7S (less than 0.2 to 2.1 µg/L), MW-8S (121 to 274 µg/L), and MW-10S (non-detect to 34 µg/L).

Approximately 350 feet south of the site, carbon tetrachloride was detected in monitoring well MW-19D at concentrations between 329 µg/L (October 2017) and 509 µg/L (January 2019).

Approximately 1,300 feet south of the site, carbon tetrachloride was detected in monitoring well MW-6U at concentrations between 15.3 µg/L (August 2017) and 82.3 µg/L (September 2019).

Carbon tetrachloride was not detected in monitoring wells MW-6S and MW-13S (with the exception of a single detection below 0.6 µg/L in June 2019), which are screened within the unconsolidated sediments. Monitoring well MW-6S is just west of the Primary Freeman School District Well (WS5), approximately 1,400 feet south of the GHFF. Monitoring well MW-13S is approximately 900 feet southeast of the GHFF.

4.5.4.2 Lower Fractured Basalt Hydrostratigraphic Unit

This unit generally encompasses the area south of the GHFF in the southern portion of the Freeman School District, and further south. Monitoring wells installed in this unit include MW-15D, MW-18D, MW-21D, MW-28, MW-34, and MW-35. With the exception of new well MW-28 closer to the GHFF (314 µg/L in Jul 2019), carbon tetrachloride concentrations in this unit were significantly lower than in the Upper Unconsolidated Sediment and Upper Fractured Basalt.

From approximately 1,000 to 1,700 feet from the GHFF, carbon tetrachloride was detected in an area containing monitoring wells MW-4D, MW-6D, MW-15D, MW-34, and MW-35 at concentrations ranging from non-detect (MW-6D; June and September 2019) to 40 µg/L (MW-35; August 2019).

Further south of the GHFF (approximately 0.75 mile), carbon tetrachloride was not detected in monitoring wells MW-18D and MW-21D.

4.5.4.3 Palagonite Hydrostratigraphic Unit

This unit represents the heavily altered basalt and palagonite texture that increases in intensity (and decreases in permeability) towards the contact with the basement rock. Fractures are less prevalent or annealed because of the soft clay-like properties of the palagonite mineralization and concentrations within this unit are lower than within the overlying lower fractured basalt. Carbon tetrachloride concentrations are non-detect in the heavily altered zone at MW-26, and range from non-detect to 7.3 µg/L within wells MW-4D and MW-6D.

4.5.4.4 Basement Rock Hydrostratigraphic Unit

This deepest identified unit generally encompasses the area stretching from west of the GHFF, to the north and east. The lower basement rock generally consists of weathered granite and granitic gneiss (Section 3.5). Monitoring wells installed in this unit include MW-1D, MW-2D, MW-3D, MW-5D, MW-12S, MW-14D, MW-17D, MW-27, and MW-31. Carbon tetrachloride has infrequently been detected in samples collected from these wells. Exceptions are a single low-level detection of carbon tetrachloride of 1.2 µg/L in well MW-2D in March 2018, a single detection of 0.97 µg/L in well MW-12S in September 2018, and detections in MW-27 during July and August 2019 (15.6 and 11.7 µg/L, respectively). No other detections have been recorded for any other monitoring wells in this unit (MW-1D, MW-3D, MW-5D, MW-12S, MW-14D, and MW-17D). Well MW-27 is located at the interface of the fractured basalt and the basement rock, where overlying COC concentrations are typically several hundred µg/L.

4.5.4.5 Descriptive Statistics and Trends

Descriptive statistics (detection frequency, concentration range, median, and standard deviation) and temporal characteristics (recent trends) were developed for wells throughout the Site with validated data available through December 2019. A total of 57 existing Site wells was identified for analysis; the Marlow and Randall point-of-entry treatment system influent water samples were also included, resulting in 59 evaluated sampling locations.

Table 4-12 presents summary statistics developed from previous sampling events at these 59 Site locations within the existing network. The table also presents the results of a nonparametric Mann-Kendall statistical trend analysis. A minimum of four sampling results was required to perform the trend analysis, but the ability of the statistical test to identify a trend when one exists for such low sample counts is poor. A general rule-of-thumb for statistically significant trend analysis is eight or more samples. Twelve of the 59 locations had less than 4 available samples such that no analysis could be performed; these locations were the residential Davey Well and monitoring wells MW-22S, MW-26, MW-28, MW-29, MW-30, MW-31, MW-32, MW-33, MW-34, MW-35, and MW-36. An additional 5 of the 59 locations had less than the ideal 8 samples, which limits the power of the test. These five locations include two domestic wells (Atwood Shop and Lashaw Agricultural Well) and three monitoring wells (MW-24S, MW-25S, and MW-27). The trend analysis was performed at the 95 percent confidence level, and non-detect data were assigned a common value less than the lowest measured value in the data set.

Sufficient data were available to perform statistical trend analyses for 47 locations at the Site when using all available data. Table 4-12 summarizes the trend analyses. When evaluating all available data, 37 locations exhibited no trend or stable concentrations. Increasing concentration trends were identified at four wells (Primary Freeman School District Well [WS5], Out-of-Use Freeman School District Well [W26], MW-19D, and MW-25S), and decreasing concentration trends were identified at four wells (MW-9S, MW-10S, MW-20D, and the Randall domestic well) as well as for the influent groundwater for both the Marlow and Randall Well point-of-entry treatment systems.

There are insufficient data to perform additional analyses to identify any potential seasonal trends that may not be apparent when evaluating all available raw data. Such analyses would require screening the already sparse data into subsets for individual seasons, months, or other time periods of interest, but only a few years of data are available for most Site wells. Based on the limited available data to date, there do not appear to be seasonal trends that differ from those identified using the full data set, but a few more years of quarterly sampling data will be necessary to facilitate a statistically significant evaluation.

4.5.5 Aquifer Testing and Slug Testing

Aquifer testing was performed in September and October 2017 to evaluate aquifer properties. The objectives of the aquifer testing were as follows:

- Provide an estimate of the hydraulic properties of the fractured upper basalt unit
- Evaluate the effect of pumping in the fractured upper basalt unit and in water-bearing units above and below that key horizon.

- Evaluate the yield of the extraction well and the radius of influence during pumping
- Provide data to support further development and refinement of the groundwater flow model

Aquifer tests were conducted at wells EW-6U and EW-9U (Figure 4-6). Data collected before aquifer testing suggested that the primary contaminant mass detected in groundwater was in the fractured basalt zone. Therefore, the target zone of the aquifer testing was the fractured upper basalt zone, with observations in the shallow unconfined, upper fractured basalt, and deep basalt saturated zones.

Between September 10 and 13, 2019, slug tests were performed in 10 newly installed monitoring wells to evaluate hydrogeologic characteristics of the site. A summary of slug test evaluations and results is presented in Appendix D. The estimated hydraulic conductivity among all 10 wells ranged over 4 orders of magnitude, from 0.02 foot/day (0.00001 cm/s) to 88 feet/day (0.31 cm/s). The highest values (more than 10 feet/day [3.5E-03 cm/s]) are at the bottom of the younger basalt flow (MW-33), just below the top of the older basalt flow (MW-32), and in shallow basalt at MW-36. Wells screened in granitic material generally have the lowest values, less than 0.1 foot/day (3.5E-5 cm/s).

A description of the development, calibration, and application of the groundwater flow model used to evaluate hydrogeological characteristics is provided in Appendix D.

4.5.5.1 Well EW-6U Aquifer Test

Well EW-6U was selected for aquifer testing because of its downgradient location from the GHFF and proximity to the Primary Freeman School District Well (WS5). A temporary extraction well (EW-6U) and an observation well (MW-6U) were installed in an upper basalt fracture zone to facilitate aquifer testing. Temporary construction consisted of driving the drill casing into basalt (approximately 25 feet bgs) and sealing the upper unconsolidated water bearing zone, then drilling an open hole to the target depth (62 feet bgs). Pressure transducers were outfitted in wells MW-6S, MW-6D, MW-6U, and EW-6U to monitor the water level response during pumping.

Pumping of well EW-6U did not produce a sustainable flow at low pumping rates (less than 1 gpm). The well was pumped dry on two occasions and allowed to recover, which took more than 24 hours. The flow rate into the well was estimated at less than 0.1 gpm, indicating that the water removed during pumping was largely casing storage.

4.5.5.2 Well EW-9U Aquifer Test

Well EW-9U was selected for aquifer testing because of its location at the GHFF and at the area of highest carbon tetrachloride detections in groundwater. A temporary extraction well (EW-9U) and an observation well (MW-9U) were installed in an upper basalt fracture zone to facilitate aquifer testing. Temporary construction consisted of driving the drill casing into basalt (42 feet bgs) and sealing the upper unconsolidated water bearing zone, then drilling open hole to the target depth (72 feet bgs). Pressure transducers were outfitted in wells EW-9U (pumping well), MW-7S, MW-8S, MW-9S, MW-9D, and MW-9U to monitor the water level response during pumping. Water-level measurements were manually collected from wells MW-1D, MW-2D, MW-3D, MW-4D, and MW-10S. The observation wells were screened in various geologic units, as follows:

- **Upper unconsolidated sediments:** MW-1S, MW-8S, and MW-9S
- **Upper unconsolidated sediments/upper fractured basalt:** MW-7S and MW-10S
- **Intermediate/lower fractured basalt:** MW-9D and MW-9U
- **Basement rock (decomposed granite):** MW-1D, MW-2D, MW-3D, and MW-14D

Well completion details are shown in Table 3-2. Manual water levels were routinely collected from wells equipped with pressure transducers for comparison to transducer data at each well location.

4.5.5.3 Step-drawdown Testing

Before conducting the constant rate aquifer testing, a step-drawdown test was completed to evaluate the range of drawdown with varying pumping rates and the optimum yield of well EW-9U. EW-9U was pumped for approximately 1.5 hours each at 31 gpm, 40 gpm, 48 to 40 gpm (dropping), and 43 gpm. The step-drawdown test suggested that EW-9U could sustain a pumping rate of approximately 30 gpm during longer-term constant rate testing.

4.5.5.4 Constant Rate Aquifer Testing

An initial constant rate test was conducted, but the pump ceased operating after approximately 12 hours of operation at a rate of 31 gpm. A second constant rate test was conducted following water elevation recovery from the first test. The second test was conducted for 24 hours at a pumping rate of 35 gpm. The starting depth to water was approximately 33 feet, and the drawdown during testing was approximately 26.5 feet (final depth to water was approximately 60 feet). A detailed description of the constant rate test results and development, calibration, and application of the groundwater flow model used to evaluate hydrogeological characteristics is provided in Appendix D.

4.5.5.5 Well MW-35 Aquifer Test

An aquifer pumping test was conducted at new well MW-35 within the lower fractured basalt shortly after well completion and development in August 2019. The well was originally anticipated to provide flow of up to 20 to 30 gpm but ultimately was only able to produce approximately 4.5 gpm. A constant rate test was conducted for approximately 8.5 hours at this pumping rate with monitoring conducted in new wells screened above (MW-36) and below (MW-26) this interval within the new RC-03 well cluster. Surrounding wells MW-4D, MW-6D, MW-6S. MW-26, MW-27, MW-31, MW-32, MW-34, and MW-36 were monitored during testing with either transducers or periodic manual measurements. Pumping at MW-35 did not induce water level changes in overlying or underlying zones within the same well cluster, indicating low permeability of the overlying unfractured basalt and the underlying palagonite alteration zone. The only well to indicate a gradual water level decline during the testing was nearby well MW-4D screened in the upper portion of the palagonite alteration zone and located about 150 feet south of the pumping well. While the aquifer test at MW-35 did not indicate high aquifer productivity within the specific fracture sets screened, the hydrophysics testing conducted at RC-03 within this general elevation range identified flow rates to the borehole at significantly higher rates. A longer screen interval within this zone would be necessary to ensure intersection with other local fracture sets and maximize groundwater yield.

4.5.6 Surface Water Sampling

The interconnectivity between Little Cottonwood Creek and the shallow aquifer (above basalt) was evaluated near the Freeman School District's constructed wetlands located near the southern end of the Freeman School District property. Little Cottonwood Creek is an ephemeral stream that is dry most of the year and runs northeast to southwest along the southern boundary of the Freeman School District, then turns south into the agricultural area (Figure 2-2).

Two pairs of staff gauges (SG-01 and SG-02) and shallow unconfined monitoring wells (MW-22S and MW-23S) were installed in December 2017 (Figure 4-6). Both monitoring wells were artesian (for example, flowing wells under pressure) and were abandoned after installation and sampling at monitoring well MW-22S. No samples were collected at monitoring well MW-23S.

Monitoring well MW-22S and staff gauge locations SG-01 and SG-02 at Little Cottonwood Creek were sampled for VOCs during the December 2017 quarterly groundwater monitoring event. Carbon tetrachloride was detected in MW-22S at 2.2 µg/L. Carbon tetrachloride and chloroform were not detected in surface water samples collected from the creek. Investigation results suggest shallow impacted groundwater is confined and does not interact with Little Cottonwood Creek.

4.5.7 Groundwater Characteristics and Extent of Impacted Groundwater Summary

- Groundwater flow direction and gradients can be variable and influenced by domestic pumping and heterogenous flow paths within the basalt unit.
- The vertical and lateral extent of carbon tetrachloride and chloroform in groundwater has been adequately defined to evaluate remedial action alternatives. Some data gaps exist, particularly the western extent of carbon tetrachloride from MW-20D. However, obtaining access to this area may not be feasible because of property ownership and agricultural use. Additionally, addressing this and other potential data gaps is not anticipated to be required to evaluate remedial action alternatives because these data gaps do not appear to be associated with defining the core of impacted groundwater that would be targeted for remedial action.
- Carbon tetrachloride and chloroform concentrations above SLs were detected at the highest concentrations at the GHFF, with decreasing concentrations approximately 2,700 feet south of the GHFF.
- Carbon tetrachloride concentrations in groundwater were detected vertically to 220 feet bgs in MW-6D (palagonite zone within lower fractured basalt), at 280 feet bgs at MW-33 (bottom of lower fractured basalt below the palagonite zone), and up to 250 feet bgs in MW-27 (within the granitic gneiss basement rock). Vertical migration of COCs is likely influenced by pumping at the Primary Freeman School District Well (WS5) and open borehole wells associated with the domestic wells.
- Impacted groundwater largely resides within the basalt unit, throughout its thickness in upgradient areas between the GHFF and well cluster MW-27/28/29/30, and then bifurcated above and below an unfractured zone at locations farther downgradient.
- Impacted groundwater was identified in deep well MW-27 at the very top of the basement granitic gneiss but was not present within the basement rock farther downgradient at MW-31.
- Carbon tetrachloride was not detected within the deep paleosol at MW-32 or within the palagonite at the base of the lower fractured basalt at MW-26.
- The highest concentrations of COCs in groundwater appear to be stable. Of the 47 wells where sufficient data were available to perform statistical trend analysis, stable concentrations (no trend) were identified at 37 wells. Increasing concentrations were identified at four wells (MW-19D, MW-25S, Primary Freeman School District Well [WS5], and Out-of-Use Freeman School District Well [W26]), and decreasing concentrations were identified at five wells (Marlow Well, MW-9S, MW-10S, MW-20D, and Randall Well).
- Surface water bodies (Little Cottonwood Creek) do not appear to be affected by impacted groundwater.

4.6 Exposure Pathway Investigations

Investigation activities were conducted to evaluate the potential exposure of COCs at the Freeman School District and residences because of the potential exposure of COCs to residential and commercial worker receptors, as follows:

- Residential surface soil sampling
- Commercial surface soil sampling
- Groundwater sampling
- Air sampling
- Sub-slab soil vapor sampling

Air (background, indoor, outdoor, and crawl space) and sub-slab vapor sampling results were used to conduct a VI assessment.

Analytical summary tables are provided in Appendix E. Analytical laboratory reports are provided in Appendix F.

4.6.1 Residential Surface Soil Sampling

Surface soil samples were collected in September 2016 from three residential properties to assess carbon tetrachloride in surface soils because carbon tetrachloride was detected in groundwater from the three domestic wells on these properties and water is used for irrigation. Soil samples were spatially distributed on the properties (Figure 4-10) and screened for the presence of VOCs using a photoionization detector with an 11.7 electron volt lamp for headspace analysis. Five samples were collected from each residential property and submitted to Pace Analytical Services for VOC analysis by EPA Method 8260B.

Carbon tetrachloride and chloroform were not detected in surface soil at the three residences (Table 4-3), indicating that direct contact receptor exposure to COCs is unlikely.

4.6.2 Commercial Surface Soil Sampling

Surface soil (1-foot bgs) samples were collected in June 2018 from eight locations (PH01 through PH08) at the GHFF to assess carbon tetrachloride in surface soils from potential surface releases (Figure 4-1). Eight potholes were dug using a shovel and eight soil samples were collected and submitted to Pace Analytical Services for VOC analysis by EPA Method 8260B.

Carbon tetrachloride was detected in one surface soil sample (PH-03) at 73 µg/kg, which is below the SL (14,000 µg/kg) (Table 4-3).

4.6.3 Groundwater Sampling

Groundwater sampling was conducted to evaluate the presence and extent of COCs in groundwater, including a comparison to SLs selected based on the protection of drinking water. A summary of groundwater characterization at the Site is presented in Section 4.5.

4.6.4 Air Sampling

Indoor air assessment was conducted by collecting indoor air, outdoor air, and crawl space air samples. In addition, background air samples were collected to assess the regional contribution of COCs.

Table 4-2 provides a comparison of the MTCA standards in air for carbon tetrachloride and chloroform with background levels. Background samples were not analyzed for carbon disulfide. The MTCA Method B standard in air for carbon tetrachloride (0.417 µg/m^3) is lower than carbon tetrachloride concentrations in ambient air as shown by air sampling results described in the following sections. Air sampling results also show that the MTCA Method B standard in air for chloroform (0.11 µg/m^3) is similar to chloroform concentrations found in ambient air.

4.6.4.1 Background Air Sampling

Carbon tetrachloride is widely detected at low concentrations in ambient (both indoor and outdoor) air. Routine air sampling performed by EPA at a western Washington state site indicates that carbon tetrachloride concentrations have ranged from approximately 0.6 to 1.0 µg/m^3 from 2007 to 2013 (EPA, 2015). Emissions from use of chlorine-containing household products have been identified as a primary source of chloroform concentrations in indoor air with detected concentrations ranging from 0.98 to 5.9 µg/m^3 (Weisel et al., 2008). Chloroform also is detected at low concentrations in outdoor air, typically at levels near 0.1 µg/m^3 in western Washington state (EPA, 2015). Monitoring data for carbon tetrachloride and chloroform were collected in Spokane in 2005, as obtained from EPA's Ambient Monitoring Archive (EPA, 2020). Samples were collected over 24 hours every 6 days from 5 locations in Spokane. Carbon tetrachloride concentrations ranged from 0.59 to 0.72 µg/m^3. Chloroform concentrations ranged from 0.039 to 0.068 µg/m^3.

Under MTCA, these levels represent “area background” or concentrations of hazardous substances that are consistently present in the environment in the vicinity of a site which are the result of human activities unrelated to releases from that site. As suggested by Ecology, a study was performed to assess background concentrations of carbon tetrachloride and chloroform in ambient air. This study was performed using the background sampling procedure presented in WAC 173-340-709. The results from this background study were available for development of cleanup levels if appropriate and provided another line of evidence for assessing indoor air concentrations of carbon tetrachloride and chloroform. Background air samples were collected from four locations surrounding the GHFF in October 2016. Sampling locations were selected based on proximity to the Site and ease of access. It was assumed that 1 mile accurately represented a suitable distance from the Site so as not to be influenced by any site-specific sources, but not too far from the Site to represent the local background conditions. The samples were collected from the following four locations (Figure 4-11).

- Approximately 1 mile northeast of the Site on South Thunder Mountain Lane
- Approximately 1 mile northwest of the Site on private property near the East Palouse Highway and State Highway 27 intersection
- Approximately 1 mile southeast of the Site on private property near the South Chapman Road and State Highway 27 intersection
- Approximately 1 mile southwest of the Site on private property on East Elder Road

A Hazardous Air Pollutants on Site (HAPSITE) chemical identification system was used to screen the areas before deploying SUMMA canisters and periodically during sampling to confirm that only background levels of carbon tetrachloride or chloroform were present. A HAPSITE is a portable device that uses a gas chromatograph/mass spectrometer for on-scene real-time detection, identification, and quantification of toxic industrial chemicals. Air samples were then collected for 24-hour periods over 4 consecutive days using 6-liter SUMMA canisters and analyzed by Method TO-15 with SIM. The ambient air temperature, relative humidity, wind speed, and wind direction were also measured using a portable weather station. Background sampling results are summarized in Table 4-13.

Carbon tetrachloride concentrations in the site-specific background sampling ranged from 0.38 to 1.0 µg/m^3. This is comparable with the range observed over several years of outdoor air sampling performed in western Washington state (EPA, 2015). The site-specific background range is provided in Table 4-13 for evaluating air sampling results. An upper percentile statistic was calculated as shown in Appendix H Figure 4-12 shows the comparison of background, indoor air and outdoor air data sets for carbon tetrachloride with a background concentration range ranging from 0.6 to 1.0 µg/m^3 (EPA, 2015). Carbon tetrachloride concentrations from all samples, with a single exception, fall within the range of historically (and site-specific) background levels. That single exception is an indoor air sample collected before installation of water treatment (Section 4.6.4.1). Based on this analysis, carbon tetrachloride concentrations detected in indoor air (where water is treated by installed point-of-entry treatment system in the residences) are indistinguishable from established site-specific background concentrations.

Chloroform concentrations in the site-specific background sampling range from 0.031 to 0.11 µg/m^3. These results are consistent with outdoor air sampling results performed by EPA in western Washington state (EPA, 2015). Chloroform emissions from use of chlorine-containing products indoors provides a larger contribution to chloroform indoor air concentrations. Hypochlorite ion in cleaning products reacts with dissolved organic carbon to form volatile halocarbon compounds such as chloroform. An urban indoor air study in New Jersey detected chloroform in approximately 30 percent of samples collected with detected concentrations ranging from 0.98 to 5.9 µg/m^3. Analysis of these data showed that most data fell between 0.98 and 2.42 µg/m^3 (the interquartile range) (Weisel et al., 2008), and this range is used for assessing chloroform concentrations in indoor air. As shown on Figure 4-13, chloroform concentrations detected in indoor air are indistinguishable from concentrations associated with the use of indoor chlorine-containing products.

4.6.4.2 Indoor and Outdoor Air Sampling

Indoor and outdoor air samples were collected from the Freeman elementary school, middle school, and high school buildings, and three residences on East Prospect Lane (Randall, Marlow, and Davey residences) in August, September, and October 2016 (Figure 4-11). Indoor and outdoor air samples were collected at the residences before and following installation of the point-of-entry treatment systems (Section 2.3). After implementation of the interim remedial action, plumbing fixtures were flushed with treated water and allowed to equilibrate for at least 24 hours. This step was not necessary at the Freeman School District buildings because water is treated using an existing school water treatment system.

HAPSITE samples were collected and used as a screening tool to determine where SUMMA canisters would later be deployed.

At the schools, up to 4 outdoor air samples were collected from the perimeters of the buildings and 5 to 10 samples were then collected at regularly spaced locations. An additional five samples were collected in areas that showed the relatively highest concentrations of carbon tetrachloride or chloroform using the HAPSITE screening. Two samples were collected above sinks or showers with both hot and cold water running. These samples were used to help assess tap water as a potential source of indoor air detections. Three samples were collected from chemical storage areas.

At the residences, up to two samples of outdoor air were collected from the perimeter of each building. With the doors and windows closed, five samples were collected at regularly spaced intervals throughout the home. An additional two samples were collected in areas that showed the relatively highest concentrations of carbon tetrachloride or chloroform using the HAPSITE screening. One sample was collected above a shower or sink with both hot and cold water running. These samples were used to assess tap water as a potential source of indoor air detections. Two samples were collected from chemical storage locations.

Following the HAPSITE portion of the investigation, indoor and outdoor air samples were collected from high traffic areas over 3 consecutive days from the Freeman School District buildings and residential properties via 6-liter SUMMA canisters fitted with 24-hour flow regulators. The outdoor air sample for the schools was collected at an area central to the buildings. The residence outdoor air samples were collected directly outside the residences. Collecting the 24-hour samples over sequential days provides information on short-term daily (as opposed to seasonal) temporal variability in indoor air concentrations of carbon tetrachloride or chloroform. Air samples were submitted to Pace Analytical Services for VOC analysis by EPA Method TO-15 SIM.

Carbon tetrachloride concentrations in air at the Freeman School District School buildings ranged from 0.42 to 0.77 µg/m^3. Background level concentrations (established as 0.68 µg/m^3) were observed in the elementary school office, the middle school north modular, and the middle school office; concentrations ranged from 0.76 to 0.85 µg/m^3 in those areas. Chloroform exceeded the background level (established as 0.08 µg/m^3) in all school buildings, except the middle school south modular, with concentrations ranging from 0.1 to 1.7 µg/m^3. Carbon disulfide was not detected in any samples.

The analytical results show background level exceedances for both carbon tetrachloride and chloroform in the Davey and Randall residences, and chloroform exceedances in the Marlow residence. The carbon tetrachloride concentration decreased after the installation of the wellhead treatment system at the Randall residence. Carbon disulfide was not detected in any samples.

Carbon tetrachloride concentrations in outdoor air slightly exceeded the background level at the Marlow residence, Freeman Middle School, and Randall residence; concentrations ranged from 0.8 to 0.84 µg/m^3.

Indoor and outdoor analytical results for carbon tetrachloride, chloroform, and carbon disulfide are provided in Table 4-13.

4.6.4.3 Crawl Space Air Sampling

Crawl space samples were collected from two residential properties (Marlow and Randall) in September 2017 (Figure 4-11). The samples were collected from the lowest accessible area of the residences with

6-liter SUMMA canisters fitted with 24-hour regulators. Air samples were submitted to Pace Analytical Services for VOC analysis by EPA Method TO-15 SIM.

Carbon tetrachloride and chloroform concentrations in the indoor crawl spaces exceeded the background levels in both residences sampled. Concentrations were slightly higher than background levels and ranged from 0.8 to 0.9 µg/m^3 for carbon tetrachloride and 0.088 to 0.11 µg/m^3 for chloroform.

Crawl space analytical results for carbon tetrachloride, chloroform, and carbon disulfide are provided in Table 4-13.

4.6.5 Sub-slab Soil Vapor Sampling

Sub-slab soil vapor sampling was conducted at three Freeman School District buildings (high school, middle school, and elementary school) in December 2017 (Figure 4-11). The purpose of the sub-slab sampling was to evaluate carbon tetrachloride and chloroform concentrations in soil vapor and the potential for VI in the school buildings. One sample was collected from each of the three buildings. The high school sample was collected in the mechanical room on the lower level at the southern end of the building, the middle school sample was collected in the mechanical room on the lower level central to the building, and the elementary school sample was collected in the utility room adjacent to the gymnasium on the northern end of the building. Samples were collected using 1-liter SUMMA cans fitted with 5-minute regulators.

Carbon tetrachloride and chloroform concentrations in sub-slab soil vapor at the Freeman School District buildings did not exceed SLs of 13.9 µg/m^3 and 3.6 µg/m^3, respectively. Carbon tetrachloride concentrations ranged from 0.23 to 1.8 µg/m^3. Chloroform concentrations ranged from 0.12 to 1.8 µg/m^3.

Soil vapor analytical results for carbon tetrachloride, chloroform, and carbon disulfide are provided in Table 4-7. Sub-slab soil vapor sampling forms are provided in Appendix A.

4.6.6 Vapor Intrusion Assessment

Low concentrations of carbon tetrachloride and chloroform were detected in groundwater wells supplying tap water to the Freeman School District buildings and residences. Indoor air exposure pathways could occur from volatilization during the use of water for cooking, cleaning, or bathing, from VI via groundwater, and from background concentrations normally present in indoor and outdoor air. Chloroform is also formed in indoor air as a disinfection byproduct from the reaction between hypochlorite in cleaning products and dissolved organic carbon. The sampling and monitoring activities during the VI assessment were performed to distinguish potential VI pathways from other sources of carbon tetrachloride and chloroform. The potential for VI pathways was assessed for Freeman School District buildings and residences overlying groundwater contaminated impacted with carbon tetrachloride and chloroform. The VI assessment evaluates potential VI from groundwater as well as volatilization of COCs potentially from tap water (groundwater). The VI assessment followed guidelines developed by Ecology and was performed in accordance with workplans approved by Ecology. The details of the VI assessment are presented in Appendix H.

Shallow soil vapor sampling was attempted around the Freeman School District buildings. Soil vapor sampling was unsuccessful because of excessive vacuum encountered during probe purging, indicating tight clay soils with insufficient air movement. Carbon tetrachloride and chloroform were detected in sub-slab samples collected from the Freeman School District buildings at concentrations below SLs provided in the Ecology VI guidance. In the residences, ambient air samples were collected from the lowest levels in the buildings to assess potential volatilization from the subsurface. The lowest levels of the residences had crawl spaces or basements with either an earthen floor or a concrete floor with multiple cracks and penetrations. Based on these conditions, and with concurrence by Ecology, ambient air samples from the lowest levels of the residences were considered more appropriate to assess potential subsurface volatilization. Carbon tetrachloride concentrations in the crawl space or basement samples were similar to background levels reported in the literature and measured near the site.

Chloroform concentrations in these samples were on the low end of the range of indoor air concentrations of chloroform from indoor sources as reported in the literature.

The results from this VI assessment combined with indoor and outdoor air sampling data show that VI pathways from groundwater to the Freeman School District buildings and residences are not complete; in other words, volatilization of COCs from groundwater is not a pathway for the concentrations of COCs detected in indoor air, and indoor air concentrations are unrelated to COCs in groundwater. Ecology has concurred via personal communication with these conclusions (Ecology, 2017). The lines of evidence supporting this conclusion are:

- Indoor air concentrations of carbon tetrachloride and chloroform are consistent with site-specific background levels in air. Higher concentrations of carbon tetrachloride and chloroform in indoor air were attributable to emissions from tap water before installation of wellhead point-of-entry treatment systems based on HAPSITE survey results. Indoor air concentrations of chloroform were attributable to indoor sources such as freshly painted surfaces (confirmed by HAPSITE survey results) or observations of use of hypochlorite cleaners on sampling days.
- Soils around the buildings are fine-grained with relatively low porosity that retards vapor diffusion. This was indicated by the excessive vacuum observed during purging of soil vapor probes. The shallow groundwater is confined or semiconfined because of low permeability soils. The depth to groundwater, fine-grained soils, and low source strength in groundwater suggest that a VI pathway from groundwater is unlikely. In addition, sub-slab samples collected from the Freeman School District buildings detected carbon tetrachloride and chloroform concentrations lower than SLs.
- Complete VI pathways are not currently present at the GHFF because there are no structures at the facility beyond the tunnels. Tunnels at grain handling silos are stringently regulated by federal Occupational Safety and Health Administration standards to control hazardous atmospheres. The safety practices required for tunnels would address potential exposures from volatilization of VOCs that might be in subsurface soil.

4.6.7 Exposure Assessment Summary

- Residential surface soil sample results at locations with the highest concentrations of COCs in groundwater indicates no COCs in surface soil.
- Surface soil sample results at the GHFF are significantly below SLs.
- Groundwater (drinking water) sampling identified COCs at levels above SLs in drinking water sources. However, point-of-entry treatment systems have been installed at active domestic wells with impacted water (unless declined by the property owner). A potentially completed pathway exists where impacted groundwater is not treated prior to domestic use. Following installation of point-of-entry treatment systems to mitigate exposure, COC concentrations in indoor air in residences were indistinguishable from background levels. COCs detected in indoor air are unrelated to COCs found in groundwater.
- Comprehensive air and VI assessment, including background, indoor, and outdoor air was completed in April 2017 and presented to Ecology. The evaluation concluded that based on the comparison with background levels and the monitoring of indoor emissions sources, carbon tetrachloride and chloroform concentrations detected in indoor air in the Freeman School District buildings is unrelated to COCs detected in groundwater. Ecology concurred with this conclusion (Ecology, 2017).

5. Conceptual Site Model

This section presents a written and illustrative depiction of the CSM for the GHFF with respect to characterizing the source and physical, chemical, and biological processes that govern the transport, migration, and actual/potential impacts of COCs in air, soils, groundwater, and surface water (and/or sediments) on potential human and/or ecological receptors. Considering the hydrogeological conditions of the site, characteristics of COCs and observed groundwater impact, the CSM focuses on describing the physiographic and hydrogeologic features that influence the groundwater flow system and related nature, extent, fate and transport of COCs in groundwater. The CSM is based on the available knowledge at the time of development, is intended to be a working tool to support related site management decisions (such as mathematical modeling, RAOs, cleanup levels, cleanup action alternatives, and the FS as subsequent efforts to this RI). As new data or findings from implementation of the interim remedial action and other work at the Site becomes available, the CSM will be updated accordingly.

5.1 Primary Sources of Contamination

The use of carbon tetrachloride at the GHFF was not confirmed during interviews with facility operators or during a background review (EPA, 2014). However, because carbon tetrachloride was widely used for pest control purposes beginning in 1911 and continued until 1986 and the facility began operations in 1955, it is conceivable that carbon tetrachloride was used at this location (EPA, 2014).

5.2 Secondary Sources of Contamination

Secondary sources are those surface and subsurface environmental media affected by releases from a primary source area and could release or disperse constituents into surrounding media.

Secondary transport mechanisms act directly on secondary sources. Contaminants in the secondary source media can follow direct release pathways to receptors or become sources that might be further subject to other secondary transport mechanisms.

The results of soil and groundwater sampling conducted at and surrounding the Site indicate that carbon tetrachloride was released to surface soil within the GHFF and migrated through the subsurface to groundwater. Carbon tetrachloride was detected at relatively low concentrations in several soil samples collected at the site. However, 56 of the 66 (85 percent) soil samples where carbon tetrachloride was detected at concentrations above the reporting limits (Table 4-3) were at depths greater than 15 feet bgs. The highest carbon tetrachloride concentrations detected in groundwater samples are from shallow unconsolidated and upper fractured basalt monitoring wells (MW-9S and MW-9U, respectively) at the southeastern corner of the Site which is in close proximity to the location where highest level of carbon tetrachloride was also detected in soil vapor and soil samples at the site. These results indicate that the released carbon tetrachloride likely migrated downward into the subsurface, driven primarily by gravity through soil to the surface of the water table. Chemical mass may also have dissolved into infiltrating water and percolated into the subsurface soil, or was drawn downward during periods when the groundwater level declined. Some chemical mass absorbed to shallow soil, while some mass continued migrating downward. The migration of chemical mass through the vadose zone appears to have extended offsite primarily in alignment with the natural drainage extending from the southeastern corner of the Site toward the southeast, along the northern side of Highway 27.

Once dissolved-phase carbon tetrachloride reached groundwater, it migrated laterally and vertically following the natural groundwater flow gradient. Groundwater flow at the Site is primarily toward the south-southwest. Dispersion and diffusion processes spread the dissolved-phase carbon tetrachloride laterally and vertically. The pathway is unpredictable in the heterogenous basalt, which controls groundwater flow and carbon tetrachloride migration. Local basalt geology is complex, including an interior unfractured interval that separates flow into upper and lower fractured basalt hydrostratigraphic units, and with a palagonite alteration zone in deep portions of the lower unfractured basalt overlying the basement granitic gneiss. Domestic wells, including the Primary Freeman School District Well (WS5), are completed as open holes within this complex basalt geology and pumping from such wells potentially exacerbates downward and downgradient carbon tetrachloride migration.

Carbon tetrachloride present in groundwater and soil can volatilize and migrate upward into soil vapor. The soil vapor in turn can migrate into ambient air or into buildings; however, previous soil vapor sampling and VI evaluations have indicated that significant VI impacts above regulatory targets are not expected. The relatively low source strength (low concentrations in both groundwater and soils within capillary fringe of the water table and absence of impacted soils at shallower depth), deep groundwater table (35 to 40 feet beneath of the site), and low-permeability soils (predominantly clay soils above water table) minimizes volatilization and upward vapor migration.

5.3 Conceptual Site Model Description

Carbon tetrachloride has historically been used at grain handling facilities to control pests. Although there are no records indicating that carbon tetrachloride was used at the GHFF, impacts on soil beneath the Site suggest that carbon tetrachloride was used and released at the site. Carbon tetrachloride applied within grain silos or released at or near the surface adjacent to the silos has migrated from these source areas for short distances laterally across the ground surface and vertically through unconsolidated subsurface soil to groundwater. Carbon tetrachloride can migrate via vapor pathways to indoor air but this has not been identified as a significant exposure risk for the site. Once in groundwater, contaminant transport beneath the Site and surrounding area is affected by soil/groundwater interactions and biodegradation. As groundwater flows through contaminant-affected soil, absorbed carbon tetrachloride can dissolve into groundwater. Any dissolved carbon tetrachloride will move with groundwater but at a different velocity because of continuing solute-soil interactions. This movement creates a plume extending downgradient from the GHFF.

Groundwater flow within the complex heterogenous basalt aquifer can be accelerated by fractures and pore spaces. Basalt rock has considerable pore space at the tops and bottoms of lava flows. Numerous basalt (lava) flows commonly overlap, and basalt flows can be separated by soil zones or alluvial material that form permeable zones. Columnar joints that develop in the central parts of basalt flows create passages that allow water to move vertically through the basalt. Contaminant transport can also be accelerated through domestic wells constructed using long open boreholes, such as at the Primary Freeman School District Well (WS5). Lateral and vertical contaminant transport can also be accelerated by variable pumping at domestic wells.

Once in groundwater, carbon tetrachloride can volatize in the vadose zone and migrate into crawl spaces and indoor spaces in structures above impacted groundwater; this however has not been identified as a significant exposure risk for the site. Carbon tetrachloride can also volatize in tap water after extraction from domestic wells screened within the carbon tetrachloride plume. However, carbon tetrachloride is being removed from groundwater using point-of-entry treatment systems at the Freeman School District and surrounding residences. Point-of-entry treatment systems have been installed at three of five impacted residential domestic wells. The RI and risk evaluation process has not identified evidence of significant VI and volatilization of carbon tetrachloride from groundwater. As discussed in Section 4.5.6 there is little to no connection between the shallow aquifer and the surface water of Little Cottonwood Creek.

Additional CSM details were identified during late 2018 and 2019 investigations described in Appendix B, particularly with regard to migration of COCs from the shallow subsurface at the GHFF downward through the upper unconsolidated aquifer and into the complex underlying basalt aquifer. The basalt was found to exhibit considerable variability including both highly fractured and unfractured zones, intervals of intense weathering and alteration, and evidence for at least two discreet basalt flows separated by a clay paleosol that developed at the top of the older flow before being overlain by the more recent flow. The new complexities within the basalt aquifer are illustrated on Figure 4-8 and in simplified form on Figure 5-1. Beneath the GHFF the subsurface consists of three primary geologic units: the upper unconsolidated aquifer (loess) overlying an intermediate basalt further overlying a basement granitic gneiss. In areas close to the GHFF, between wells MW-9S/9D and the new well cluster at RC-02 near MW-19D, the intermediate basalt is highly fractured throughout. A wedge of unfractured basalt is present shortly downgradient of the RC-02 well cluster, beginning beneath the Marlow and Randall wells and thickening to the south/southwest. This zone of unfractured basalt bifurcates the basalt into an upper fractured basalt and lower fractured basalt. Significant portions of the Primary Freeman School District Well (WS5) are inferred to be screened through this unfractured basalt, as is well MW-6U which could explain this well's poor performance during previous aquifer testing. Monitoring well MW-6S is screened in both the unconsolidated overburden aquifer and the apparent distal terminus of the upper fractured basalt. Beneath the lower fractured basalt is a zone of moderately to heavily altered basalt identified as a palagonite. Alteration is more extreme with depth to the contact with the underlying basement rock and alteration within this zone generally seals existing fractures and limits permeability. The palagonite zone extends between the new RC-02 and RC-03 well clusters, across the bottom of the Primary Freeman School District Well (WS5) screen, through well MW-6D and to the RC-04 well cluster, and for an indeterminant distance downgradient. Groundwater flow within the lower fractured basalt is confined between the unfractured basalt and palagonite zones within the area between the RC-03 and RC-04 well clusters. The new deep RC-04 boring identified a clay paleosol beneath the palagonite alteration zone and separating the overlying basalt from an older basalt beneath, both of which onlap to the basement rock. The interior of the clay paleosol exhibited low permeability (clay) but the top and bottom intervals exhibited significant fracturing and permeability (common to basalt flow tops and bottoms). The underlying (older) basalt exhibited essentially no fracturing.

The general migration of COCs through this complex geology is illustrated on Figure 5-1. Downward migration of COCs dissolved in groundwater begins near wells MW-9S/9D with the highest concentrations present in the intermediate-depth MW-9U. Groundwater gradients are downward in this area and the highly fractured basalt provides little resistance to continued downward migration as groundwater flows downgradient enhanced in part by domestic well pumping. COCs become well-distributed through the middle and deeper portions of the fractured basalt in the vicinity of the RC-02 well cluster, although the highly altered palagonite greatly limits the migration of COCs into the underlying basement rock. Although the greatest mass of COCs appear to migrate strongly downward between the GHFF and RC-02, a still-significant mass of COCs migrates along the fractured basalt flow top, thus impacting the Marlow and Randall domestic wells and downgradient portions of the upper fractured basalt. Higher COC concentrations extend further downgradient with the upper fractured basalt than within the lower fractured basalt. Within the lower fractured basalt in the vicinity of the RC-03 well cluster, COC concentrations are approximately one order of magnitude lower than present in deep basalt at the RC-02 well cluster. The palagonite alteration zone continues to limit additional downward migration as evidenced by low concentrations within well MW-4D near the top of the palagonite (moderate alteration) but with non-detectable COCs within well MW-26 near the base of the palagonite. The palagonite also appears to provide some protection against downward migration at the RC-04 well cluster, with low detections in MW-6D within the palagonite, and COC concentration only slightly above the cleanup criteria in well MW-33 below the palagonite. The clay paleosol and the underlying unfractured older basalt present further restrictions to downward migration, and neither MW-32 nor MW-31 have detectable COC concentrations.

Groundwater extraction from domestic wells, especially the Primary Freeman School District well (WS5) which operates almost full time in summer months at approximately 55 gpm capacity, accelerates groundwater flow and COC migration toward the wells when it is active. The Primary Freeman School District well (WS5) when active reduces downgradient plume migration. Some escape only occurs during the winter months when the Primary Freeman School District well (WS5) pumping frequency is low.

5.4 Potential Receptors and Exposure Routes

Exposure pathways refer to the media and routes through which contaminants can reach human or ecological receptors. Environmental media can be affected by contaminants originating from primary or secondary sources. Exposure pathways are considered potentially complete or incomplete depending on whether the contaminants have the potential to affect human or ecological receptors, currently or in the future. A CSM identifying potential receptors and exposure pathways is presented on Figure 5-2.

The following exposure pathways and receptors were identified:

- Release of COCs in surface soil to residents, commercial workers, and construction workers
- Migration of COCs to subsurface soil to construction workers
- Leaching of COCs to groundwater to drinking water receptors
- Migration of COCs in groundwater to indoor air to residents and commercial workers

5.5 Human Exposure Pathways

For COCs, the following potential human receptors and pathways were considered:

- Current and future residents, Freeman School District students[2], and commercial workers (including Freeman School District employees) from potential exposure to dust or volatile emissions (inhalation) and direct contact (incidental ingestion and dermal absorption) with affected surface soil
- Current and future commercial and construction workers from potential exposure to dust or volatile emissions (inhalation) and direct contact (incidental ingestion and dermal absorption) with affected subsurface soil during onsite business activities, construction, or remediation
- Current and future construction and remediation workers, from potential exposure via dermal contact or inhalation of volatile compounds in affected groundwater during construction or remediation
- Current and future residents, Freeman School District students, and commercial workers (including Freeman School District employees) from potential exposure to vapors emitted to the indoor air from groundwater
- Current and future residents, Freeman School District students, and commercial workers (including Freeman School District employees) from potential exposure to affected groundwater during use as a current or future water supply
- Current and future residents, Freeman School District students, and commercial workers (including Freeman School District employees) from potential inhalation exposures to VOCs in vapors migrating into indoor air

Figure 5-2 shows the potential exposure pathways at the Site and an explanation for the designations are as follows:

- Current and future residents are not exposed to COCs from application of potentially impacted groundwater to surface soil (irrigation), because COCs have not been found in surface soil.
- Current and future commercial workers (at the GHFF only) could be exposed to COCs, because COCs have been found in surface soil. However, COC concentrations are below SLs.
- Current and future construction workers could be exposed to COCs, because COCs have been found in subsurface soil. However, COC concentrations are below SLs.
- Current and future residents and commercial workers at the Freeman School District are not exposed to COCs through VI, including groundwater to indoor air (Section 4.6.4). The VI assessment concluded that the VI pathway is incomplete for the residences evaluated and Freeman School District. The VI assessment would apply to future residents assuming the Site conditions do not change significantly. Current commercial workers at the GHFF are not exposed to COCs through VI, because there are no occupational structures at the GHFF beyond tunnels where worker health and safety is regulated under federal Occupational Safety and Health Administration standards. Future commercial workers could be exposed to COCs through VI from releases at the Site if occupational structures are constructed at the GHFF.
- Current and future residents could be exposed to COCs via the ingestion, inhalation, and dermal pathway from extracted groundwater because COCs have been found in groundwater. However,

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[2] Based on exposure assumptions, Freeman School District students are assumed to have lower exposure frequency and duration compared with commercial workers. Age-dependent adjustment factors are applied

treatment systems exist at affected domestic wells (where residents have accepted treatment) and will be installed at the request of domestic well owners for future affected domestic wells.

- Current Freeman School District students and commercial workers (including Freeman School District employees) are not exposed to COCs from ingestion of groundwater used for drinking water, because drinking water wells are not located at the GHFF and drinking water is treated at the Freeman School District. Future commercial workers could be exposed to COCs from ingestion of groundwater used for drinking water if drinking water wells are installed at the GHFF.
- Current and future residents, Freeman School District students, and commercial workers (including Freeman School District employees), and construction workers are not exposed to COCs from groundwater to surface water pathways because surface water sampling did not indicate the presence of COCs.

5.6 Terrestrial Ecological Evaluation

Pathways to ecological receptors are also considered to be incomplete because soil impacts are localized to deeper subsurface soil and impacted groundwater does not migrate to surface water bodies. Under WAC 173-340-7491(1)(b), no further terrestrial ecological evaluation is required because soil impacted with hazardous substances is covered by buildings, paved roads, pavement, or other physical barriers that will prevent plants or wildlife from being exposed to the soil contamination. Therefore, no preliminary cleanup levels have been identified as no significant terrestrial risk is anticipated at the Site (WAC 173-340-745(5)(b)(ii).

The terrestrial ecological evaluation is presented in Appendix I.

6. Development of Cleanup Levels

This section discusses preliminary cleanup standards that could be used to develop and evaluate cleanup action alternatives. The preliminary cleanup standards listed in this section are not approved by Ecology as final cleanup standards for the site. Final Cleanup standards will be established in the Cleanup Action Plan (CAP). Preliminary cleanup standards have been initially established during scoping of the RI and may be further refined during the RI/FS per WAC 173-340-350(9)(a).

WAC 173-340-700(3) states that “cleanup standards” shall consist of the following:

- *Cleanup levels for hazardous substances present at the site*
- *The location where these cleanup levels must be met (point of compliance [POC])*
- *Other regulatory requirements that apply to the site because of the type of action and/or location of the site (‘applicable state and federal law’)*

6.1 Method for Determining Preliminary Cleanup Levels

The MTCA Cleanup Regulations (Sections 173-340-720, WAC) establish procedures to develop cleanup levels. MTCA Method A cleanup levels are intended to provide conservative cleanup levels for sites undergoing routine site characterization or cleanup actions or for sites with relatively few hazardous substances. MTCA Method B procedures can be used at any site and employ a risk-based evaluation of potential human health and environmental exposures to Site COCs. MTCA Method C procedures are used for industrial land use exposures.

For this FS, preliminary cleanup levels for potable groundwater and saturated soils were developed using MTCA Method B guidelines. Preliminary groundwater cleanup levels include human health protection from VI, so separate preliminary soil vapor cleanup levels have not been developed. The Method B procedure requires that a cleanup level for one media must also be protective of the beneficial uses of other potentially affected media.

Preliminary cleanup levels based on Method B for groundwater are derived through selection of the most stringent concentration as available in the following sources:

- Concentrations established under applicable state and federal laws (that is, ARARs review)
- Concentrations for human health protection per equations presented in WAC 173-340-720 (potable groundwater)

As presented in Section 4.4.1, COC concentrations in soil samples collected during the RI did not exceed MTCA Method B cleanup levels. As described in Section 4.4.1, COCs were only infrequently detected in saturated soil samples at concentrations above the protection of groundwater SLs for saturated zone soils and results are likely associated with dissolved-phase carbon tetrachloride and chloroform levels in groundwater. However, preliminary saturated soil cleanup levels were developed for consideration during development of remedial action alternatives. Remedial action evaluation of impacted saturated soils will be conducted as part of remedial action evaluation of groundwater.

The selection of final cleanup levels will be made by Ecology in a Cleanup Action Plan.

6.2 Preliminary Groundwater Cleanup Levels

Findings of the RI indicate that COCs are present in groundwater beneath and near the Site. Groundwater is a drinking water source. Preliminary groundwater cleanup levels are determined by considering the following complete exposure pathways:

- Human health protection from direct groundwater contact, ingestion, and inhalation
- Human health protection from tap water to indoor air inhalation
- Human health protection from VI[3]

Table 6-1 presents a summary of preliminary cleanup levels.

6.3 Preliminary Soil Cleanup Levels

Findings of the RI indicate that COCs are only present in saturated soil at concentrations above preliminary cleanup levels beneath and near the GHFF. Proposed saturated soil cleanup levels are determined by considering the protection of groundwater.

Table 6-1 presents a summary of preliminary saturated soil cleanup levels.

6.4 Proposed Remediation Levels

MTCA recognizes that a cleanup action may involve a combination of cleanup action components and that remediation levels may be used to identify concentrations (or other methods of identification) of hazardous substances at which different cleanup action components will be used (WAC 173-340-355). Remediation levels are concentration thresholds above which particular cleanup action components may be applied, and are usually specific to a particular remediation technology. Remediation levels have not been identified in this RI/FS report.

6.5 Proposed Points of Compliance

For the purpose of evaluating the remedial action alternatives in this RI/FS, the point of compliance for groundwater will be the standard point of compliance (SPOC), which is defined as follows: "…throughout the site from the upper most level of the saturated zone extending vertically to the lowest most depth which could potentially be affected by the site" (WAC 173-340-720[8]).The achievement of groundwater cleanup levels will be measured at the SPOC using a network of existing and potentially new groundwater monitoring wells located where impacted groundwater is present.

6.6 Applicable or Relevant and Appropriate Requirements

MTCA requires that cleanup levels comply with legally applicable state and federal laws and regulations, as well as other applicable or relevant and appropriate requirements (ARARs), WAC 173-340-700(6), and WAC 173-340-710. This section discusses the ARARs that potentially apply to the cleanup alternatives.

"Legally applicable" requirements under MTCA are *"those cleanup standards, standards of control, and other environmental protection requirements, criteria, or limitations adopted under state or federal law that specifically address a hazardous substance, cleanup action, location or other circumstances at the site"* (WAC 173-340-710(3).

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[3] Groundwater cleanup levels are protective of VI because the depth to groundwater (approximately 30 feet bgs) and fine-grained soils contribute to vapor attenuation at the site.

To be an ARAR, the requirement must meet either of these following requirements per WAC 173-340-710:

- **Legally applicable requirements i**nclude those cleanup standards, standards of control, and other environmental protection requirements, criteria, or limitations adopted under state or federal law that specifically address a hazardous substance, cleanup action, location or other circumstances at the site.
- **Relevant and appropriate requirements.** Relevant and appropriate requirements include those cleanup standards, standards of control, and other environmental requirements, criteria, or limitations established under state or federal law that, while not legally applicable to the hazardous substance, cleanup action, location, or other circumstance at a site, address problems or situations sufficiently similar to those encountered at the Site that their use is well suited to the particular site.

The three categories of ARARs are as follows:

- Chemical-specific ARARs are numerical values that represent a health-based or risk-based standard or the results of methodologies that, when applied to site-specific conditions, are used to establish the acceptable amount or concentration of a chemical that may be found in, or discharged to, the ambient environment.
- Location-specific ARARs are restrictions on the conduct of activities solely because the Site occurs in certain environmentally sensitive areas. Examples include wetlands, floodplains, endangered species habitat, or historically significant resources.
- Action-specific ARARs are technology-based or activity-based requirements or limitations on actions taken with respect to hazardous wastes.

Potential ARARs are provided in Tables 6-2 through 6-4. Sites that are cleaned up under an order or decree may be exempt from obtaining a permit under certain state laws and all local regulations but they must still meet the substantive requirements of these other laws. WAC 173-340-710(9).

A summary of “To Be Considered” advisories and guidance is provided in Table 6-5.

7. Feasibility Study of Remediation Alternatives

7.1 Remedial Action Objectives

The RI provides sufficient information about the nature and extent of contamination and exposure pathways at the Site to evaluate remedial action alternatives. The first step in the process of evaluating alternatives is to describe the RAOs for the Site, which are the goals that proposed remedial actions are expected to accomplish, such as protecting human health and the environment by eliminating COCs above action goals or eliminating exposures to human and ecological receptors. RAOs can differ with each specific site, depending on site conditions, exposure scenarios, and receptors. This RI/FS sets forth RAOs used to guide the development of proposed alternatives for the site. The development of RAOs is a critical prerequisite to the development of remedial alternatives.

The RAOs for groundwater include:

- Eliminate potential human exposure to COCs through the groundwater direct contact (dermal, ingestion, and inhalation) exposure pathway
- Reduce COC concentrations in groundwater below applicable cleanup levels at the SPOC within a reasonable restoration timeframe

7.2 Remedial Target Areas

Remedial target areas represent the three-dimensional extent of impacted media to be addressed by each remedial alternative. Target areas are developed based on the cleanup levels presented in Section 6.2. The cleanup levels were compared to the analytical data for the relevant COCs to identify the estimated extent of impacted media in which the site-specific cleanup goals are exceeded.

The remedial target area is defined by groundwater in exceedance of the preliminary cleanup level in the SPOC, which is estimated from at least the GHFF to the Lashaw Well (north to south) and between monitoring wells MW-20D and Out-of-Use Marlow Well (No. 2) (west to east).

7.3 Identification and Evaluation of Remedial Components

This section describes the identification and screening of remedial components to satisfy the RAOs and cleanup levels defined for the Site addressed in this RI/FS.

After potentially applicable remedial components are identified, remedial technology components are screened for effectiveness and implementability. Effectiveness and implementability refer to the ability of the remedial technology to meet an RAO. This initial screening eliminates those technologies that are clearly not applicable or not workable for the COCs or Site characteristics found at, and in the vicinity of, the Site.

Table 7-1 provides the rationale for either retaining or screening out particular technologies based on effectiveness and implementability. In many cases, a technology is not applicable to the Site based on the lack of significant impacts to specific Site media. For instance, soil vapor extraction is not warranted when Site investigations have shown that COC concentrations in soil and soil vapor do not exceed screening criteria and there is not a risk of VI, and soil capping or soil removal is not warranted when Site investigations have shown that COC concentrations in surface and subsurface (upper 15 feet) soil do not exceed screening criteria.

7.3.1 No Action

No Action represents a situation where no further administrative or physical actions would be taken at the site. No Action is intended primarily for comparison to other alternatives.

7.3.2 Institutional Controls

Institutional controls are often included in remedies because, if properly implemented, monitored, and enforced, they can protect human health and the environment by reducing or eliminating receptor exposure to hazardous substances during potential remedial action at a site. In addition, the short-term cost of institutional controls is much less than that of other conventional remedies (for example, monitoring, containment, or treatment). However, institutional controls have notable limitations. Institutional controls do not reduce the toxicity or the volume of contamination; rather, they reduce receptor exposure to residual contamination.

Institutional controls are administrative or legal instruments (for example, deed restrictions/notices, easements, covenants, and zoning) that impose restrictions on the use of contaminated property or resources. Institutional controls for groundwater include restrictive covenants that limit the potential future use of affected groundwater. For example, an institutional control may disallow extraction of groundwater from specific locations or aquifers for domestic purposes (including drinking water, direct household use, and agricultural irrigation) to eliminate receptor contact (exposure) with impacted groundwater. Groundwater institutional controls may be applied through local ordinances such as easements, well-drilling prohibitions, building permit restrictions, land use zoning restrictions, and the use of state registries of contaminated sites. Ongoing site inspections and groundwater monitoring may also be necessary to track groundwater contaminants and confirm that institutional controls remain effective. The intent of institutional controls is to limit or eliminate exposure pathways to receptors. Under MTCA, the legal instruments for applying institutional controls are termed environmental covenants, equivalent to restrictive covenants for a specific property or portion of a property.

The specifics of the institutional controls required as a component of the selected cleanup action for the Site will be documented within an institutional controls plan (ICP) developed in consultation with Ecology as part of the remedial design process. The ICP will define property use limitations and any worker protection standards applicable to specific areas of the site, and will identify responsibilities for institutional controls implementation, provisions for inspection and maintenance of any engineering controls, and protocols for notification regarding the presence of institutional controls (that is, notification triggered by utility on-call requests).

Administration and implementation of institutional controls would not reduce or remove the groundwater contaminant source or alter existing toxicity of COCs dissolved in groundwater at the Site. Institutional controls are an effective means to reduce human exposure to contaminants through acceptable land-use and resource-use practices. Institutional controls could be instituted that would preclude the use of impacted groundwater for domestic use (including drinking water, household, and irrigation use) and require certain health and safety measures of construction workers who may encounter contaminated soil or groundwater in the subsurface.

Administration of institutional controls would be implementable at the Site without significant delays, with specific controls identified within an ICP developed in consultation with Ecology.

Institutional controls are retained for COCs in Site groundwater as a potential component of active remedial alternatives. By preventing exposure to groundwater contaminants through institutional controls, the protection of human health may be achieved at a nominal cost.

7.3.3 Groundwater Monitoring and Reporting

Groundwater monitoring consists of the collection and analysis of groundwater samples, and it will be implemented if site-specific cleanup standard goals are selected such that residual levels of contamination that may negatively affect groundwater quality are left in place. A groundwater monitoring program provides the means for tracking any changes to the nature and extent of contaminants left in place, as well as the long-term performance of the selected Site remedial action. In general, monitoring or sampling and analysis are not implemented as standalone response actions; rather, they are combined with other remedial components to meet RAOs.

Groundwater monitoring is retained in combination with other remedial components to evaluate the performance of the remedial alternative.

7.3.4 Monitored Natural Attenuation

Monitored natural attenuation (MNA) employs naturally occurring biological, chemical, and physical processes to reduce environmental contaminants in soils and groundwater. This passive, non-invasive remediation method is extensively used to effectively diminish both inorganic and organic contaminants. MNA is not the same as a “no action” alternative; MNA requires extensive, long-term Site monitoring to ensure that established remediation goals are being achieved. Natural processes involved in MNA may include the following:

- **Biodegradation or bioremediation** – the breakdown of contaminants by microorganisms.
- **Dilution/dispersion** – the lowering of contaminant concentrations as the contaminants migrate away from the source. This requires downgradient monitoring to assess contaminant concentrations trends relative to remedial goals.
- **Absorption or adsorption** – the reduction of contaminant concentrations because of incorporation into or adhesion onto soil particles or aquifer materials such as organic carbon. This requires long-term monitoring to assess whether the conditions necessary to maintain low solubility of contaminants can persist.
- **Volatilization** – the reduction of volatile contaminant concentrations through vaporization or evaporation into the atmosphere. Investigations at the Site have shown that existing COC volatilization from groundwater does not lead to soil vapor concentrations indicative of VI risks.
- **Abiotic degradation** – the breakdown of contaminants through a series of naturally occurring chemical reactions.
- **Precipitation** – the reduction of contaminant concentrations because of the formation of low-solubility mineral phases. This process is generally applicable to inorganic contaminants, such as metals, and is not generally applicable to the Site COCs in groundwater. It requires long-term monitoring to assess whether the conditions necessary to maintain low solubility of contaminants can persist.

Long-term monitoring provides documentation that the above natural attenuation processes are occurring, and that adequate progress toward remedial goals is being maintained.

MNA can be an effective treatment for low-concentration dissolved-phase COCs in groundwater, and can provide gradual treatment to cleanup criteria over long-time periods. MNA can be most effective when source area soils do not present an ongoing threat for leaching of COCs to groundwater (true at the site) and where secondary sources of COCs in groundwater, such as separate phase “free product,” are not present or are removed by treatment (site investigations have not identified concentrations suggesting the presence of free product). MNA is expected to effectively reduce COC concentrations to below remedial objectives over many decades.

MNA is readily implementable at the site. Only minor modifications to the existing monitoring well network and analytical requirements would likely be necessary.

MNA is not retained for consideration because there is not strong evidence of natural processes in MNA occurring at the Site.

7.3.5 Containment

Containment isolates contamination to reduce direct contact with human or ecological receptors and/or reduce migration of contaminants in soil to surface water, groundwater, or ambient air. Containment typically includes caps, barriers, and hydraulic controls (that is, groundwater pumping). In general, containment may not fully comply with ARARs and RAOs and, depending upon the remedial design and media of interest, may not reduce the toxicity or the volume of contamination.

One retained remedial technology is the placement of a permeable adsorptive barrier (PAB) in which liquid activated carbon and ZVI can be injected within the aquifer to provide an adsorptive coating on the aquifer matrix to which Site COCs become bound. Such injections can be used to isolate higher-concentration areas of groundwater contamination or oriented to act as a transect perpendicular to the groundwater flow direction to limit migration of dissolved-phase contaminants beyond the transect. The small carbon particle size facilitates placement of a PAB that cannot be achieved within the Site environment using traditional slurry walls, grout curtains, or sheet pile walls.

Groundwater extraction is another retained remedial technology, wherein strategic groundwater extraction provides hydraulic capture to reduce further downgradient migration of dissolved-phase COCs in Site groundwater. Groundwater extraction as a containment remedy would require combination with treatment remedial technologies to address COCs within extracted groundwater, and discharge options including aquifer reinjection/infiltration or release to surface water must be evaluated. The use of aquifer infiltration in combination with groundwater extraction is the assumed discharge option for this RI/FS Report. Aquifer infiltration can provide enhanced hydraulic control, with groundwater recirculated between the infiltration and extraction locations, and it mitigates potential aquifer dewatering that could occur with other discharge options. Other options, such as discharge to surface water, are not considered at this time because of the stated public perception that this is a waste of the valuable groundwater resource.

7.3.6 Removal

Removal of contamination reduces direct human or ecological receptor contact with contaminants and reduces migration of contaminants in soil to surface water, groundwater, or ambient air. Removal typically includes soil removal, free product recovery, and groundwater extraction. In general, removal reduces the toxicity or the volume of contamination.

Groundwater extraction and groundwater recirculation are the retained remedial technologies under removal. As with groundwater extraction for hydraulic capture under containment, groundwater removal requires combination with treatment and selection of a treated effluent discharge option; groundwater infiltration (recirculation) is the selected discharge option for purposes of this RI/FS Report. The groundwater extraction technologies are further discussed in Section 7.2.6.

7.3.7 Treatment

Under treatment, potential physical, chemical, and biological treatment were evaluated (Table 7-1). Chemical and biological treatment, including both in situ and ex situ applications, were not retained, with the exception of permeable reactive barriers, which were not retained for stand-alone use but for consideration in combination with PAB containment. When used in combination with a PAB as an in situ treatment, a micro-scale reactive co-injectant could be added with the activated carbon source to provide treatment of adsorbed COCs. Such an approach would require bench-scale and field-scale treatability studies to evaluate treatment effectiveness and implementability. Retained physical treatment remedial technologies include the in situ application of liquid-phase carbon in the form of a PAB and the ex situ treatment of extracted groundwater using options of liquid-phase GAC and air stripping with vapor-phase GAC.

7.3.8 In Situ Treatment

The placement of a PAB, which also is considered a containment technology, is a retained remedial technology that is suitable under containment to sequester contaminants, and can also provide effective treatment with some modifications. Activated carbon sequestration and treatment is a relatively new technology that involves the injection of carbonaceous materials (for example, activated carbon) into the aquifer to adsorb dissolved-phase COCs and retard their further migration. Additional injectants, including reducing agents such as zero-valent iron or micronutrients and electron acceptors such as calcium sulfate, can be added to the injected carbonaceous media to stimulate in situ abiotic or biologic degradation of sorbed COCs. The additional injectants serve to regenerate the carbonaceous media and also provide remediation of the sequestered COCs. This process is ideally used on low solubility compounds that strongly adsorb to materials such as activated carbon. Bench-scale and field-scale treatability studies would be required to evaluate the sorption characteristics of Site COCs to injectable activated carbon, to evaluate the implementability of Site injections, and to evaluate the treatment effectiveness of one or more co-injectants.

In-situ treatment using activated carbon to sequester contaminants, and amendments to enhance treatment of these sorbed contaminants, is a relatively new technology that has proven effective for some sites. The effectiveness of the technology must be demonstrated using bench-scale and field-scale treatability studies to evaluate the impact of site-specific COCs and geology on sorption characteristics and injectability, and to document successful COC sequestration and/or treatment.

The small (micrometer-scale) carbon particle size used for this developing technology facilitates injection under a wider variety of hydrogeologic conditions than achievable for larger particle size or highly viscous injectants. However, field-scale treatability studies would be necessary to determine the feasibility of injecting within the challenging hydrogeologic conditions at the site, namely the fractured basalt aquifer system.

The technology is retained based on the greater potential for successful injection due to the small particle size for liquid activated carbon available with this developing technology. Bench-scale and field-scale treatability studies will be required to evaluate the ultimate feasibility of including this treatment technology as part of a final remedial alternative for the Site.

7.3.9 Groundwater Extraction and Ex Situ Treatment

Groundwater extraction was retained as a representative component for both containment and treatment purposes because it addresses RAOs by minimizing further migration of COCs in groundwater (containment) and provides the means for removing contaminated groundwater for subsequent ex situ treatment. Groundwater removal can include conventional groundwater extraction using wells, drains, or trenches. Groundwater extraction wells, in the form of domestic water supply wells, already exist at the site, and additional extraction wells have been installed as part of pilot testing at the site. Groundwater removal would require aboveground treatment of the extracted groundwater using various treatment processes as well as discharge of the treated groundwater effluent. Treated effluent discharge options typically include permitted discharge to a local surface water body (that is, stream, river, or lake), discharge to a local publicly owned treatment works facility, re-use for purposes such as irrigation, or reinjection/infiltration back into the original or an alternate aquifer. Viable discharge options are evaluated based on site-specific conditions. For the GHFF, the most feasible options are permitted discharge to a local surface water creek/stream or reinjection/infiltration to the local aquifer.

Advantages of groundwater extraction are as follows:

- Provides rapid and efficient removal of dissolved contaminants from fractured basalt. aquifer zones
- Serves to contain the groundwater contaminants, minimize further migration, and remove mass.
- Because groundwater flows through preferential pathways toward extraction wells, the technology bears lowest risk from potential data gaps and uncertainties in aquifer characterization
- In fractured basalt which has limited water-bearing adsorption capacities, groundwater recirculation (extraction and injection/infiltration) can quickly flush out impacted groundwater from the fractured basalt zones and restore a significant portion of the impacted aquifer volume in a reasonable timeframe.
- Recirculation also preserves water sources and protect domestic water supply wells.

Limitations of groundwater extraction are as follows:

- A long remediation timeframe may be required to achieve cleanup goals sitewide.
- Requires long-term operations and maintenance (O&M), electrical energy consumption, and consumption of raw materials.

- Residual contaminant mass within vadose zone soil pores cannot be removed by groundwater pumping.
- Frequent occurrence of tailing and rebound of contaminants concentrations, because of slow dissolution from aquifer matrix storage, may result in longer operation of remedy with little mass removal during the late treatment timeframe.
- System designs may fail to reduce impacted groundwater migration as predicted, given the complex hydrogeology of the Site and the presence of a fractured basalt aquifer. Long operational timeframes may lead to failure of the pumping equipment.
- Biofouling of the extraction wells (and injection/infiltration wells if injection/infiltration is required for discharge or recirculation approaches) and associated treatment stream is a common problem that can severely affect system performance.

7.3.9.1 Activated Liquid-phase Carbon

Activated carbon is commonly used to remove COCs from groundwater as part of ex situ treatment systems. When used in direct contact with extracted groundwater, the activated carbon is referred to as “liquid-phase.” For this ex situ treatment, extracted groundwater is pumped through a vessel containing activated carbon that provides physical filtration of particulates and adsorption of numerous organic contaminants, including the Site COCs. The loading capacity of the activated carbon can be determined based on the influent concentrations and sorption characteristics of specific COCs being treated, such that a carbon vessel exchange schedule can be developed.

Ex situ treatment of extracted groundwater using activated carbon to adsorb contaminants is a well-established and proven treatment remedial technology for organic contaminants such as carbon tetrachloride and its degradation products. Carbon vessels are exchanged as the loading capacity of the activated carbon is approached, and the adsorbed contaminants are destroyed (such as by incineration) or disposed offsite.

Adsorption of organic contaminants using activated carbon is common and easily implemented, both technically and administratively.

Liquid-phase activated carbon adsorption technology is retained based on its common use for ex situ treatment of organic contaminants in groundwater.

7.3.9.2 Air Stripping

Air stripping is another commonly applied treatment remedial technology for VOCs including carbon tetrachloride and its degradation products. The treatment process takes advantage of the volatile nature of contaminants by passing a large volume of air across or through extracted groundwater, where the water has typically been sprayed into fine droplets or spread into thin layers to increase the surface area in contact with air. Volatile contaminants are transferred from the dissolved phase to the vapor phase, and the vapors are either released directly to the atmosphere under a discharge permit, or are treated by a separate process such as vapor-phase activated carbon.

Ex situ treatment of extracted groundwater using air stripping to transfer contaminants from the dissolved phase to the vapor phase is a well-established and proven treatment remedial technology for organic contaminants such as carbon tetrachloride and its degradation products. In some circumstances, contaminants stripped to the vapor phase may be released directly to the atmosphere under an air discharge permit. Depending on the concentrations of contaminants being treated, and specific atmospheric discharge permit requirements, the vapor stream may require treatment before release to the atmosphere, which is most commonly done using vapor-phase activated carbon (discussed separately below).

Air stripping of volatile organic contaminants is common and easily implemented, both technically and administratively.

Air stripping technology is retained based on its common use for treatment of volatile organic contaminants in groundwater.

7.3.9.3 Vapor-phase Activated Carbon

This remedial technology involves passing a vapor stream containing organic contaminants such as carbon tetrachloride through activated carbon, to which the organic contaminant is adsorbed. This treatment remedial technology is commonly applied following air stripping, or can be used when volatile contaminants are extracted directly from soils using soil vapor extraction. The loading capacity of the activated carbon can be determined based on the influent concentrations and sorption characteristics of specific COCs being treated, such that a carbon vessel exchange schedule can be developed.

Removal of volatile organic contaminants from a vapor stream using adsorption to activated carbon is a well-established and proven treatment remedial technology for organic contaminants such as carbon tetrachloride and its degradation products. Carbon vessels are exchanged as the loading capacity of the activated carbon is approached, and the adsorbed contaminants are destroyed (such as by incineration) or disposed of offsite.

Adsorption of organic contaminants using activated carbon is common and easily implemented, both technically and administratively.

Vapor-phase activated carbon adsorption technology is retained based on its common use for treatment of volatile organic contaminants within the vapor phase, such as following use of air stripping.

7.4 Technology Treatability Studies

Some remediation technologies described will require treatability studies to fully evaluate the feasibility of their use at the Site and to provide data to support a remedial design if these technologies are selected as a component of a final remedial action. A pilot-scale test of the PAB technology is necessary to evaluate injectability of the treatment media into the heterogenous aquifers and treatment effectiveness. Additional borehole testing (geophysics and hydrophysics, as described in Section 4.5.2) and aquifer testing would be needed to support final design determinations for extraction and injection/infiltration wells installed as part of any selected remedy using hydraulic containment or groundwater extraction and treatment technologies. As described in Section 4.5.4, various aquifer testing has already been completed and demonstrated significant aquifer heterogeneity at the Site that complicates implementation of groundwater extraction and treatment technologies.

7.5 Conclusions

Section 7.3 presents an evaluation of remedial components that may be applicable for implementation at the Site. A summary of the retained remedial components for remedial action at the Site is as follows:

- **Institutional Controls** – Actions using non-engineering methods whereby potential receptor exposure to impacted groundwater is restricted or regulated. Institutional controls, including ordinances, zoning restrictions, land use restrictions, aquifer restrictions, environmental covenants, deed notices, and advisories are potentially applicable for the Site.
- **Monitoring** – Collection and analysis of groundwater samples to evaluate COC concentrations. The data can be used to evaluate the extent of COC migration, distribution, remediation, or degradation. Groundwater monitoring is retained as a component to developed remedial action alternatives for the Site.
- **Engineering Controls/Containment** – Physical methods or actions taken to reduce migration of COCs in groundwater and reduce direct exposure by receptors to COCs. Engineering controls/ containment remedial technologies retained for development into remedial action alternatives include permeable adsorptive barriers and groundwater extraction.

- **Removal** – Physical methods or actions taken to reduce potential receptor exposure to COCs in groundwater. Removal remedial technologies retained for development into remedial action alternatives include groundwater extraction and groundwater recirculation.
- **Treatment** – Methods or actions taken to physically or chemically reduce contaminant mass (light nonaqueous phase liquid) and concentrations of COCs in groundwater. Treatment remedial technologies retained for development into remedial action alternatives include active liquid-phase carbon, air stripping, and vapor-phase activated carbon.
- **In Situ Treatment** – Methods or actions taken to physically or chemically reduce contaminant mass (light nonaqueous phase liquid) and concentrations of COCs in groundwater using belowground actions. The in situ treatment remedial technology retained for development into remedial action alternatives includes PABs.

8. Assembly of Remedial Action Alternatives

In this section, the representative remedial components identified in Section 8 are assembled into remediation alternatives to address impacted media at, and in the vicinity of, the site. An integral component of these Site remedial alternatives is the long-term provision of clean domestic water, which is currently provided via point-of-entry (wellhead) treatment systems operated by the Freeman School District and as part of the existing interim remedial measures protecting human health for local property owners (Section 2.4). This section includes a discussion of potential domestic water supply components (Section 8.2), and the selection of a domestic water supply component that provides long-term protection at a reasonable cost. Complete remedial alternatives, including the provision of a clean domestic water supply, are assembled using combinations of retained components from Section 7.

8.1 Remediation Alternatives

The assembly of representative remedial components into remedial alternatives is shown in Table 8-1. The assembled alternatives consist of the following:

- Alternative 1: PAB, Institutional Controls, Groundwater Monitoring and Reporting, and Domestic Water Supply
- Alternative 2: Groundwater Recirculation (extraction, treatment, and infiltration), Institutional Controls, Groundwater Monitoring and Reporting, and Domestic Water Supply

Each remediation alternative consists of several combined remedial components (Table 7-1) to achieve RAOs and meet ARARs. Each remediation alternative is described in greater detail in Sections 8.1.1 and 8.1.2, while domestic water supply components are discussed in Section 8.2.

Feasibility-level (-30 percent/+50 percent) cost estimates for remediation alternatives, excluding domestic water supply components, are presented in Table 8-2 and in Appendix J.

8.1.1 Alternative 1 – Permeable Adsorptive Barrier, Institutional Controls, Groundwater Monitoring and Reporting, and Domestic Water Supply

Alternative 2 includes a PAB along the downgradient property boundary of the GHFF, groundwater monitoring and reporting, domestic water supply, and institutional controls). The PAB is intended to isolate higher concentrations of Site COCs at the source area via adsorption to activated carbon and abiotic degradation using ZVI injected into the aquifer.

8.1.1.1 Groundwater Monitoring and Reporting

The groundwater monitoring and reporting component of Alternative 1 would require long-term groundwater monitoring to evaluate stability of dissolved-phase carbon tetrachloride and degradation product concentrations within the aquifer to support evaluation of the performance of the remedial alternative.

A groundwater monitoring plan will be prepared to describe the monitoring activities required to assess the effectiveness of the remedial alternative. Monitoring would include the Site COCs. Groundwater monitoring would be required until the RAOs are achieved. Monitoring is anticipated to be conducted more frequently during early years to establish the baseline and trend, and less frequently over time once the baseline and trend are established.

8.1.1.2 Domestic Water Supply

A domestic water supply component will be provided to owners of property overlying portions of the groundwater aquifer affected by carbon tetrachloride and its degradation products at concentrations exceeding the cleanup criteria. The domestic water supply component will achieve the RAO for protection of human health by eliminating receptor exposure to COCs through the groundwater direct contact (ingestion and inhalation) exposure pathway. Several potential components for providing clean domestic water to domestic users at the Site are evaluated separately, and one is selected in Section 8.2.

8.1.1.3 Institutional Controls

Institutional controls reduce unacceptable receptor exposure to COCs until the proposed RAOs are achieved. Institutional controls will include limitations on excavation and construction activities for the GHFF, guidelines for drilling at the Site, and limitations on groundwater extraction for domestic consumption at properties where COC concentrations in groundwater exceed cleanup levels. Specific institutional controls to be implemented as part of Alternative 1 include the following:

- Construction worker protections described within a site-specific health and safety plan, regulating training and personal protective equipment requirements for workers that may contact Site media with COC concentrations exceeding cleanup or screening criteria.
- Restriction on construction of occupational structures without an engineered vapor barrier or VI mitigation system at the GHFF, to reduce potential commercial worker exposure via VI.
- Informational notices, including deed notices and advisories, to notify property owners where COC concentrations in groundwater beneath their properties exceed cleanup levels.
- Restrictions on extraction-based beneficial uses of groundwater from the shallow and CRBG aquifers where dissolved-phase COC concentrations exceed the cleanup criteria (area to be specifically defined in the ICP). The restrictions could include the following, depending on the domestic water supply component selected (discussed in Section 8.2):
  - Prohibition on the drilling of new groundwater wells for any domestic purpose (including drinking water, household, irrigation, fire protection, and livestock use) that are screened or partially screened within the defined portions of the shallow and CRBG aquifers without use of an appropriately designed point-of-entry domestic water treatment system. This includes a prohibition on drilling a domestic water supply well into these aquifers on the GHFF.
  - Requirement that any existing groundwater supply well screened, or partially screened, within the defined portions of the shallow and CRBG aquifers be properly sealed and permanently abandoned in accordance with State of Washington well standards unless equipped with an appropriately designed point-of-entry domestic water treatment system, or unless the property owner explicitly declines the use of such treatment system. This would include any existing groundwater extraction well used for drinking water, household, irrigation, fire protection, and livestock purposes.

The institutional controls will be fully described in an ICP developed during the remedial design phase in consultation with Ecology. The required institutional controls for the Site will remain in place until removal is approved by Ecology. The required institutional controls are expected to be a combination of controls and/or notices to prevent receptor exposure to contaminated groundwater. They will be applied to properties where COC concentrations in groundwater exceed cleanup levels. Potential options and implementation steps for required institutional controls for the Site groundwater include the following:

1. Environmental covenants: Environmental covenants could be placed on each affected property prohibiting the installation of new domestic water supply wells. The covenants would be prepared by UPRR, recorded by the property owner with the County, and remain with the land regardless of ownership. If the property owner does not accept the covenant, government controls and/or informational tools (deed notices and/or advisories) would be considered.

2. Deed notice and advisories: A deed notice that notifies owners and potential buyers of the presence of underlying groundwater contamination could be prepared by UPRR, recorded by the property owner with the County, and remain with the land regardless of changes in ownership.

3. Database searches: UPRR could conduct annual searches of Ecology's water resources database to determine whether new drinking water wells have been installed. Additionally, UPRR could conduct

annual reviews of commercially available real estate databases (e.g., Zillow and Redfin) and the Spokane County Tax Assessor database to identify real estate transactions for affected properties. UPRR will notify affected new property owners of groundwater conditions. UPRR will notify Ecology on an annual basis if any new domestic water supply wells or new property owners have been identified.

4. Zoning overlay: A zoning overlay could be issued by Spokane County to prohibit the installation of new drinking water wells in connection with new construction.

8.1.1.4 Source Area Containment with Permeable Adsorptive Barrier

A PAB would involve the injection of activated carbon and ZVI into the aquifer to retard further migration of Site COCs via adsorption. The PAB would be installed as a transect along the downgradient GHFF boundary, using a series of closely spaced injection borings or wells. The spacing of injections would be determined as part of field pilot-scale testing and would be based on the achievable site-specific injection radius. Field pilot-scale testing would also be used to optimize dosing requirements and to evaluate the benefit of potential co-injectants, such as micro-scale zero-valent iron.

Site COCs that are adsorbed to the PAB are anticipated to undergo degradation via natural abiotic and biodegradation processes, plus additional degradation provided by any co-injectants. The PAB would provide an added measure of containment for groundwater COCs at the source area but does not substantially reduce the overall time to achieve cleanup criteria and meet the Site RAOs (further discussed in Section 9).

Bench-scale and/or field-scale treatability and pilot testing will be required before implementation of a PAB to determine the following:

- Confirm commercially available liquified activated carbon products (such as Regenesis Plumestop or Remediation Products, Inc. BOS 100) sufficiently adsorb carbon tetrachloride and its degradation products
- Evaluate the effectiveness of one or more co-injectants
- Identify general (bench-scale testing) and final design (field/pilot-scale) dosing requirements
- Evaluate the injectability of liquified activated carbon within the site-specific hydrogeologic conditions, and determine the achievable injection radius
- Characterize potential changes in aquifer geochemistry resulting from injection of activated carbon and any co-injectants and evaluate possible negative impacts
- Assess the effectiveness of the PAB to contain/treat Site COCs

Figure 8-1 provides a conceptual layout for the placement of the PAB.

8.1.2 Alternative 2 – Groundwater Recirculation (extraction, treatment, and infiltration), Institutional Controls, Groundwater Monitoring and Reporting, and Domestic Water Supply

Alternative 2 includes groundwater extraction, treatment, and infiltration for containment and in situ treatment of impacted groundwater, groundwater monitoring, domestic water supply, and institutional controls. A groundwater extraction system, combined with infiltration of treated groundwater, would provide hydraulic containment of groundwater and remove contaminant mass from the aquifer, with active ex situ treatment of COCs.

8.1.2.1 Groundwater Monitoring and Reporting

Groundwater monitoring is necessary to evaluate the operation and effectiveness of the groundwater recirculation process. In addition to the groundwater monitoring and reporting program required for

Alternative 1, Alternative 2 will include groundwater recirculation process monitoring of groundwater extraction rates, treatment system operational efficiency, and compliance with treated groundwater/effluent discharge requirements associated with groundwater infiltration. In addition, the progress of the remediation will be tracked through monitoring of decreasing COC concentrations and hydraulic capture zone (groundwater elevation) monitoring. A groundwater monitoring plan will be prepared during the remedial design phase to describe the monitoring activities required to assess the effectiveness of the groundwater recirculation system.

8.1.2.2 Domestic Water Supply

Alternative 2 would use the same domestic water supply component (evaluated in Section 8.2) selected for Alternative 1.

8.1.2.3 Institutional Controls

Each institutional control described for Alternative 1 will also be implemented for Alternative 2.

8.1.2.4 Removal and Treatment with Recirculation

Alternative 2 would use groundwater extraction, treatment, and recirculation within the area of higher dissolved-phase COC concentrations located south of Highway 27 and surrounding well MW-19D and nearby domestic water supply wells in an attempt to intercept and remediate impacted Site groundwater. The Primary Freeman School District Well (WS5) and its point-of-entry water treatment system would continue to operate.

This component includes the following:

- Groundwater extraction from a proposed extraction well located near existing well MW-19D, which will require installation on privately owned property. The groundwater extraction rate is anticipated to be in the range of 30 to 60 gpm, and will be evaluated during remedial design, testing, and optimization evaluation.
- Conveyance of extracted groundwater via underground piping to a small groundwater recirculation system located at the GHFF, anticipated to require installation on or across privately owned property. It is anticipated that the space requirement for a small groundwater recirculation system will be approximately 25- by 25-feet.
- Ex situ treatment of COCs in the extracted groundwater at a small aboveground groundwater treatment system to be located at the GHFF; liquid-phase activated carbon adsorption and/or air stripping will be the remedial technologies used to treat the Site COCs (Table 7-1).
- Infiltration of the treated groundwater to establish recirculation within the aquifer; four infiltration wells are anticipated in peripheral areas north, east, and west of the extraction well near the limits of dissolved-phase COC concentrations exceeding cleanup criteria, and within 1,000 feet of the groundwater recirculation system (conceptualized locations are shown on Figure 8-2).
- Groundwater recirculation via infiltration of extracted and treated groundwater will facilitate clean-water flushing to accelerate aquifer restoration while also mitigating potential aquifer dewatering from groundwater extraction alone.
- Periodic groundwater monitoring to evaluate hydraulic capture of dissolved-phase Site COCs.
- Routine O&M of the aboveground groundwater recirculation system to maintain treatment effectiveness.

Additional field investigation and groundwater modeling at the time of any proposed well installation would include the following:

- Additional aquifer characterization during well drilling at proposed extraction and infiltration locations, including borehole geophysical logging, hydrophysical logging, and packer testing to evaluate aquifer properties and determine final well construction

- Additional aquifer testing on completed wells to confirm acceptable extraction and infiltration capacities
- Additional groundwater modeling to support the design and decide on the optimal extraction rate and infiltration rate to each infiltration well

It will be necessary to implement an adaptive optimization process during system startup and operation to evaluate whether the groundwater recirculation system is providing an added measure of containment for groundwater COCs exceeding the cleanup criteria. This component is anticipated to accelerate aquifer restoration for major portions of impacted aquifers, but does not necessarily reduce the overall time to achieve sitewide cleanup criteria and meet the Site RAOs (further discussed in Section 9). Groundwater recirculation systems commonly provide diminishing returns over time, with dissolved-phase concentrations within the capture zone decreasing steadily during early operational years but requiring many decades to approach and achieve cleanup criteria. In the case of carbon tetrachloride, with particularly low MTCA cleanup criteria, there is uncertainty whether complete aquifer restoration to the cleanup criteria could occur faster using a groundwater recirculation system versus natural attenuation processes. That said, the use of treated groundwater recirculation is anticipated to provide improvements versus extraction alone.

A conceptual layout of the groundwater recirculation system components and an illustration of a conceptual capture zone is presented on Figure 8-2. A cross section showing the conceptual locations and screen intervals of the extraction and infiltration wells is presented on Figure 8-3.

8.2 Domestic Water Supply Components

Several options exist for maintaining a clean domestic water supply for property owners overlying portions of the aquifer with COC concentrations exceeding cleanup criteria, including the following:

- Domestic Water Supply Component 1 – City Connection
- Domestic Water Supply Component 2 – Offsite Wellfield
- Domestic Water Supply Component 3 – Point-of-entry Treatment
- Domestic Water Supply Component 4 – Deep Extraction Wells

Feasibility level (-30 percent/+50 percent) cost estimates for domestic water supply components is presented in Table 8-3.

8.2.1 Domestic Water Supply Component 1 – City Connection

Under water supply Component 1, residential and school domestic water users in areas where groundwater contaminant concentrations exceed the cleanup criteria are connected to one of several nearby City water supply systems by extending the City pipeline network to these properties within Freeman, Washington. The City of Spokane’s water supply system is the largest such system, while other smaller systems are located closer to Freeman. A detailed evaluation of the local water supply system networks would be conducted to identify the most suitable City water distribution system to connect with.

This component would require construction of several miles of new water supply pipeline to connect Freeman with a nearby City network, with additional distribution piping installed for each affected property owner and the Freeman School District. It is assumed that ownership of the new piping network would be retained by the City (and by property owners between the new water meter and point-of-entry) to which connection is made, and that the City (and property owners) would then be responsible for long-term O&M costs associated with the new distribution system. Such O&M costs would be paid for through new rate payers within Freeman.

Favorable aspects of this component include the following:

- Engineered City water supply connections are a durable long-term solution, lasting many decades.
- Costs to implement include only capital expenditures, with long-term O&M paid for by the City water utility via new rate payers.

- Water quality is generally high and is more easily managed as part of a single large distribution system.

Challenges and disadvantages of this component include the following:

- Installation of several miles of pipeline, including numerous road crossings and potential buried utility conflicts, is a significant construction effort subject to numerous permitting and access easement requirements.
- Installation costs are high.
- Water users would be required to pay for water, leading to lower anticipated community support.

8.2.2 Domestic Water Supply Component 2 – Offsite Wellfield

Under water supply Component 2, a local domestic water supply wellfield would be installed within or near Freeman, outside the aquifer area where COC concentrations exceed the cleanup criteria. Similar to Component 1, this component would require a local water distribution network to convey domestic water to individual property owners. Additional aquifer testing and groundwater modeling would be required to evaluate potential locations for the wellfield, identify the number of wells required, and determine sustainable extraction rates. This component would require the identification and purchase of property for the wellfield, and would likely require installation of storage tanks to moderate high water-demand cycles and support fire suppression. Component 2 would also require the establishment of a local water board to oversee O&M of the wellfield and distribution system, and to collect and manage any water usage fees. Once installed, the ownership of the wellfield and distribution system would be transferred to the new water board.

Favorable aspects of this component include the following:

- Properly designed extraction wells and water distribution systems are a durable long-term solution, lasting many decades.
- Costs to implement include only capital expenditures, with long-term O&M paid for by the newly established water board, likely via new local rate payers.
- Water quality is more easily managed as part of a single distribution system.

Challenges and disadvantages of this component include the following:

- The component requires identification and purchase of property.
- Installation of distribution pipeline network, including numerous road crossings and potential buried utility conflicts, can be subject to numerous permitting and access easement requirements.
- Costs increase with distance from Freeman.
- The wellfield and water distribution system requires establishment of a local water board to take ownership of the system, and for system O&M.
- Operation of the wellfield could alter the existing distribution of contaminants within the local aquifer, or negatively affect existing extraction wells.
- Water users would be required to pay for water, leading to lower anticipated community support.

8.2.3 Domestic Water Supply Component 3 – Point-of-entry Treatment

Under water supply Component 3, the existing interim measure point-of-entry (that is, wellhead) treatment systems would remain in operation at private properties and the Freeman School District until cleanup criteria are achieved at individual wells. Additional point-of-entry treatment systems would be installed if new properties are affected by groundwater with concentrations exceeding the cleanup criteria, or if property owners who previously declined an interim measure system elect to have a system installed. Limited capital expenditure is required for this component, but UPRR would continue to pay the long-term

O&M costs for these systems (that is, carbon exchanges and routine maintenance), including continuance of the domestic water sampling program.

Favorable aspects of this component include the following:

- Limited capital investment is required because systems are already in place and operating successfully.
- Wellhead treatment systems are a well-established and reliable technology and are readily applied to potential future receptors.
- There is no requirement for a water distribution network to individual properties.
- Property owners and the Freeman School District do not pay a traditional water bill.

Challenges and disadvantages of this component include the following:

- Point-of-entry treatment presents risk for exposure if treatment systems fail; however, appropriate system design, including excess capacity, greatly diminishes such risk.
- Long-term O&M costs are high; smaller individual treatment systems may have shorter service life than larger engineered treatment systems.
- The component requires frequent (that is, biweekly to monthly) sampling of multiple systems and routine maintenance, which may disrupt property owners.

8.2.4 Domestic Water Supply Component 4 – Deep Extraction Wells

Under water supply Component 4, individual property (and the Freeman School District) wells would be replaced with deeper wells screened within the non-impacted basement granite aquifer. The new wells would be constructed to be fully sealed through the impacted shallow and CRBG aquifers. This component requires pilot-scale and aquifer testing to determine the yield and general water quality (that is, geochemistry) of the deep granitic aquifer, to facilitate design of wells suitable for domestic water supply. Low-yield conditions may require the installation of storage tanks to moderate short-term demands, and multiple wells may be required to achieve the yield required for the Freeman School District. Once the well are installed, ownership of each well would be transferred to property owners.

Favorable aspects of this component include the following:

- Properly designed deep extraction wells are a durable long-term solution, lasting many decades.
- There is no requirement for a water distribution network to individual properties.
- Costs to implement include primarily capital expenditures, and there are no, or limited, ongoing sampling and O&M requirements.
- Property owners and the Freeman School District will continue not to pay a traditional water bill.

Challenges and disadvantages of this component include the following:

- The component requires pilot-scale and aquifer testing to confirm sufficient yield and water quality of the deep basement aquifer.
- Different groundwater geochemistry within the deep granitic aquifer could lead to minor perception issues for individual domestic users (that is, change in taste) or to more significant issues of corrosion or scale release within household piping, and would require evaluation during pilot-testing.
- There is a risk of “dry hole” during drilling, given limited characterization of the deep granite aquifer and unknown fracture distribution; unsuccessful drilling attempts will increase capital costs.
- Property owners could have greater energy costs to extract groundwater if the hydrostatic pressure within the basement granite aquifer is significantly lower than within the CRBG aquifer.

8.2.5 Domestic Water Supply Component Selection

Each domestic water supply component would provide clean potable water for domestic use (Freeman School District and residences) and would meet the RAO for protection of human health by eliminating receptor exposure to COCs through the groundwater direct contact (ingestion and inhalation) exposure pathway. In selecting a preferred domestic water supply component, the following arguments were considered:

- All components provide a similar level of protection in the near term. The point-of-entry treatment systems have been successfully and reliably operating at individual wells for several years as part of the interim remedy.
- The remaining three components would provide water from unimpacted sources and would provide similar degrees of long-term protectiveness and permanence. However, the connection to a City water supply is anticipated to cost several times more than either of the other two remaining components in achieving this level of protectiveness (Table 8-3). The much higher costs result from the requirement for several miles of conveyance piping to reach any of the nearest City distribution networks. A formal disproportionate cost analysis (DCA) has not been performed but is not necessary because it is difficult to justify doubling or tripling costs to achieve the same level of protectiveness provided by other available components. The connection to a City water supply is eliminated from further consideration.
- The remaining components (Offsite Wellfield and Deep Extraction Wells) offer similar degrees of long-term protectiveness and permanence, and the costs are difficult to distinguish without additional investigation and field testing to identify a suitable wellfield location, well yields, and other design parameters. For instance, the costs for an offsite wellfield can increase as the required distance to end users increases, but deep rock drilling and the risk of dry holes can similarly increase costs for the deep extraction wells. Both components require additional field investigation and pilot-scale testing before implementation. The Offsite Wellfield Component offers some benefit in that delivered water quality can be more easily managed in a single common system versus separate individual user wells, while the Deep Extraction Well Component does not require domestic water users to pay a water utility bill. The critical deciding factor, however, is implementability. The Offsite Wellfield Component requires the identification, availability, and purchase of suitably located property and would require establishment of a local water board to take ownership of the wellfield, manage its operation, and collect usage fees. These requirements, particularly relating to a new local water board, present significant administrative challenges that do not exist for the Deep Extraction Well Component . The Deep Extraction Well Component would not change the mechanism by which domestic users receive water and would not require trenching or other construction to install a distribution system.
- The point-of-entry treatment systems and the Deep Extraction Well Component both offer similar levels of protectiveness and neither changes the mechanism by which domestic users receive water, nor requires the property owner to pay a traditional water utility bill. The Deep Extraction Well Component requires significantly greater capital costs while the point-of-entry treatment systems require long-term O&M costs; these factors may balance out depending on the design life for each component . The Deep Extraction Well Component may, however, increase energy costs for individual property owners for pumping from deeper wells, and the drilling and installation of new deep wells would have greater short-term impacts on property owners than would the addition of the point-of-entry treatment systems.

Based on the above evaluation, the continued use of point-of-entry domestic water treatment systems is selected as the preferred component for provision of water for domestic use, until cleanup criteria are achieved for the impacted portions of the shallow and CRBG aquifers. Water supply extraction wells protected by such properly engineered, operated, and maintained treatment systems would not be subject to the institutional controls restricting water supply well completion within the shallow and CRBG aquifers.

9. Remedial Alternative Evaluation

The following section discusses the remedial action alternatives selected for evaluation to address groundwater contamination. As presented in Section 8.2, clean domestic water will be provided using the existing (and future installed, as necessary) point-of-entry domestic water treatment systems as part of each remedial alternative under consideration. As such, the following two complete remedial alternatives are evaluated against the MTCA criteria in this section:

- Alternative 1: PAB, Institutional Controls, Groundwater Monitoring and Reporting, and Point-of-Entry Domestic Water Treatment
- Alternative 2: Groundwater Recirculation (extraction, treatment, and infiltration), Institutional Controls, Groundwater Monitoring and Reporting, and Point-of-Entry Domestic Water Treatment

9.1 Feasibility Study Evaluation Criteria

This section presents an evaluation of the minimum requirements and procedures for selecting cleanup actions under MTCA (WAC 173-340-360).

9.1.1 Model Toxics Control Act Threshold Criteria

Cleanup actions selected under MTCA must meet four threshold requirements identified in WAC 173-340-360(2)(a) to be accepted by Ecology, as follows:

- Protect Human Health and the Environment
- Comply with Cleanup Standards
- Comply with Applicable State and Federal Laws
- Provide for Compliance Monitoring

9.1.2 Model Toxics Control Act Selection Criteria

When selecting from remedial alternatives that meet the threshold requirements, the following three criteria, identified in WAC 173-340-360(2)(b), must be evaluated:

- Use permanent solutions to the maximum extent practicable. A DCA is conducted to assess the extent to which the remedial alternatives address this criterion. The general procedure for conducting a DCA is described in Section 9.4.
- Provide a reasonable restoration timeframe. MTCA places a preference on remedial alternatives that can achieve the required cleanup goals at the POCs in a shorter period of time. Factors to be considered in evaluating whether an alternative provides for a reasonable restoration timeframe are identified in WAC 173-340-360(4)(b).
- Consider public concerns. Consideration of public concerns is an inherent part of the Site cleanup process under MTCA. The draft FS report is issued for public review and comment, and Ecology determines whether changes to the report are needed in response to public comments.

9.1.3 Model Toxics Control Act Disproportionate Cost Analysis

WAC 340-173-360(3)(e) describes the procedure for conducting a DCA. A DCA is an analysis where the difference in costs between more a more permanent remedy and less permanent remedies are compared to the differences between the remedies. The DCA involves ranking cleanup action alternatives against one another using the evaluation criteria described below. Seven criteria are considered in the evaluation, as specified in WAC 173-340-360(3)(f), which are discussed in Sections 9.1.3.1 through 9.1.3.7.
Table 9-1 presents a summary of an evaluation of the seven criteria.

9.1.3.1 Overall Protectiveness

This evaluation criterion assesses how each alternative provides and maintains adequate protection of human health and the environment. Alternatives are assessed to determine whether they can adequately protect human health and the environment from unacceptable risks posed by contaminants present at the Site in both the short- and long terms. This criterion is also used to evaluate how risks would be eliminated, reduced, or controlled through treatment, institutional controls, or other remedial activities.

9.1.3.2 Permanence

This evaluation criterion assesses the degree to which the alternative permanently reduces the toxicity, mobility, or volume of hazardous substances, including the adequacy of destroying hazardous substances, the reduction or elimination of hazardous substance releases and sources of releases, the degree of irreversibility of treatment, and the characteristics and quantity of the treatment residuals.

9.1.3.3 Cost

This evaluation criterion considers engineering, construction, administrative, and O&M (including institutional controls and administration of such controls) costs incurred over the life of the project. Costs for remedial alternatives are provided in Appendix J.

9.1.3.4 Long-term Effectiveness

This evaluation criterion assesses the long-term effectiveness and permanence of the remedy in protecting human health and the environment after completing the remedial action. This criterion has two components: (1) magnitude of the residual risk, and (2) extent and effectiveness of controls necessary to manage the residual risk.

9.1.3.5 Short-term Risk Management

This evaluation criterion considers the effect of implementing or constructing each alternative on the protection of human health and the environment. The short-term effectiveness evaluation only addresses protection before achieving the RAOs.

9.1.3.6 Implementability

This evaluation criterion assesses the technical and administrative feasibility (that is, the ease or difficulty) of implementing each alternative. This criterion also considers the availability of necessary facilities, services, and materials; access for construction, operations, and monitoring; integration with existing property use; and current or future remedial actions.

9.1.3.7 Consideration of Public Concerns

This criterion addresses the issues and concerns the public and state, local, or federal agencies may have regarding each of the alternatives, and will be addressed after comments have been received from the public.

9.2 Model Toxics Control Act Threshold Criteria Evaluation

This section presents the evaluation of the remedial alternatives for compliance with the MTCA threshold criteria.

9.2.1 Protection of Human Health and the Environment

Alternatives 1 and 2 provide protection of human health and the environment through a combination of (1) containment for groundwater COCs at the source area; (2) provision of an alternate source of water for domestic use; and (3) institutional controls. In each alternative, the institutional controls and execution of point-of-entry domestic water treatment to reduce potential for human exposure to impacted groundwater while natural attenuation processes reduce COC concentrations in groundwater over time. Alternatives 1 and 2 provide source area (Alternative 1) or sitewide (Alternative 2) groundwater containment and treatment.

9.2.2 Compliance with Cleanup Standards

Alternatives 1 and 2 would comply with groundwater cleanup standards via natural attenuation processes, including abiotic and/or biologically mediated degradation, throughout the site. Alternative 2 would include treatment of groundwater extracted for supplemental hydraulic containment, with treated effluent concentrations below the cleanup standards.

9.2.3 Compliance with Applicable State and Federal Laws

Alternatives 1 and 2 would each comply with MTCA regulations and applicable state and federal laws, identified as ARARs in Section 6.1.

9.2.4 Provisions for Compliance Monitoring

Each identified alternative would provide for compliance monitoring. Worker protection monitoring during remedial construction would be performed in accordance with health and safety protocols outlined in a site-specific health and safety plan. Periodic groundwater monitoring (that is, water levels), sampling, and laboratory analyses would provide both performance and confirmation monitoring for each alternative.

9.2.5 Model Toxics Control Act Threshold Criteria Compliance Conclusion

Based on the above evaluation, Alternatives 1 and 2 are each expected to comply with the MTCA threshold criteria. Each alternative is thus advanced to the next evaluation stage.

9.3 Reasonable Restoration Timeframe Evaluation

A cleanup action is considered to have achieved restoration once cleanup standards have been met. Both alternatives are expected to comply with cleanup standards (Section 9.2.2). The restoration timeframe for Alternatives 1 and 2 is the time to meet groundwater cleanup levels at the SPOC.

A batch pore-flush method was used to estimate the remedial timeframes for both alternatives. This approach estimates the length of time required for clean and treated water to move through the aquifer (naturally and during groundwater recirculation) and dilute and reduce the maximum detected COC concentrations to preliminary cleanup levels at the SPOC. Inputs for this approach include aquifer characteristics, plume dimensions, current maximum contaminant concentrations, preliminary cleanup levels, and groundwater extraction rates. Calculations and assumptions are presented in Appendix K. As shown in Appendix K, remedial timeframes were estimated for each aquifer zone (shallow loess, fractured basalt, and palagonite) for each alternative. The estimated remedial timeframes identified below are based on the longest duration of the three zones. It is noteworthy that the basalt aquifer, which is the zone from which the domestic wells extract water and accounts for more than 90 percent of estimate plume volume, are expected to be cleaned up the fastest due to the aquifer's hydraulic properties. The estimated remedial timeframes plume-wide are:

- Alternative 1: PAB, Institutional Controls, Groundwater Monitoring and Reporting, and Point-of-Entry Domestic Water Treatment – 32 years
- Alternative 2: Groundwater Recirculation (extraction, treatment, and infiltration), Institutional Controls, Groundwater Monitoring and Reporting, and Point-of-Entry Domestic Water Treatment – 17 years

WAC173-340-360(4)(b) provides a list of factors to be considered to determine whether a cleanup action provides for a reasonable restoration timeframe. Table 9-2 presents an evaluation of the remedial alternatives with respect to these factors. Based on this evaluation, both remedial alternatives are expected to provide for a reasonable restoration timeframe.

9.4 Disproportionate Cost Analysis

A DCA is performed to evaluate whether a remedial action achieves the MTCA selection criteria of using permanent solutions to the maximum extent practicable. The DCA provides a quantitative analysis of the environmental benefits of each remedial alternative, and then compares alternative benefits versus costs. Costs are determined to be disproportionate to benefits if the incremental cost of a more permanent alternative over that of a lower-cost alternative exceeds the incremental benefits achieved by the alternative over that of the lower-cost alternative. Under MTCA, alternatives with disproportionate costs are considered “impracticable.”

The following sections discuss the DCA and it is summarized in Table 9-2. The environmental benefits of each alternative are quantified by first rating them with respect to each of the six criteria discussed in Section 9.1.3. For each criterion, each remedial alternative was assigned a ranking score ranging from 1 to 10 with 10 indicating that the criterion was satisfied to a very high degree and 1 indicating the criterion was satisfied to a very low degree. Each evaluation criteria was assigned an equal weighting factor, as follows:

- Overall protectiveness: 17 percent
- Permanence: 17 percent
- Long-term effectiveness: 17 percent
- Short-term effectiveness (management of short-term risk): 17 percent
- Implementability: 17 percent
- Consideration of public concerns: 17 percent

For both remedial alternatives, an MTCA benefit score is calculated by multiplying the six criteria ranking scores by their corresponding weighting factors and taking the sum of these weighted values. The benefits ranking of each alternative is then divided by the alternative’s estimated cost to calculate a benefit/cost ratio, which is a relative measure of the cost effectiveness of the alternative. The costs for each remedial alternative, excluding the point-of-entry domestic water treatment component, are summarized in Appendix J.

9.4.1 Remedial Alternatives Selected for Evaluation

Given the selection of point-of-entry domestic water treatment as the preferred domestic water supply component, the following complete remedial alternatives will be evaluated:

- Alternative 1 – PAB, Institutional Controls, Groundwater Monitoring and Reporting, and Point-of-Entry Domestic Water Treatment
- Alternative 2 – Groundwater Recirculation (extraction, treatment, and infiltration), Institutional Controls, Groundwater Monitoring and Reporting, and Point-of-Entry Domestic Water Treatment

9.4.2 Overall Protectiveness

The remedial alternatives would all be protective of human health and the environment, but they vary in the remedial components used to achieve that protectiveness. Both alternatives provide clean domestic water via existing (and potentially future installed) point-of-entry domestic water treatment systems, which immediately meets the RAO for protection of human health exposures to Site groundwater. Both alternatives use natural attenuation processes, demonstrated as effective via a long-term groundwater monitoring program, to reduce COC concentrations and achieve the cleanup standards over time. The time required to achieve the groundwater cleanup standards for the sitewide POC is anticipated to be more than 15, regardless of which remedial alternative is selected. While Alternatives 1 and 2 are anticipated to provide some to significant improvement, respectively, in COC concentration reductions within the near term (that is, 5 to 10 years), for certain portions of the shallow and CRBG aquifers, there are numerous examples of source-isolation and groundwater recirculation system operations, including aggressive groundwater recirculation operations, that have not achieved cleanup criteria after 15 to 30 years of operation because of diminishing returns as concentrations approach low cleanup levels. The low MTCA cleanup level of 0.63 μg/L for carbon tetrachloride has significant influence on the time required to achieve the groundwater cleanup standards, particularly on a sitewide basis. The federal standard for carbon tetrachloride in drinking water is 5 μg/L.

While remediation timeframes are long for this site, all alternatives are anticipated to achieve the cleanup levels over time and the point-of-entry domestic water treatment systems protect human health during this period. Alternative 1 is given a lower score of 3 for overall protectiveness because this alternative is anticipated to leave higher COC concentrations in place for significantly longer times than the more aggressive Alternative 2. Alternative 2 is given a score of 9 based on significant improvements to near-term COC concentration reductions over much broader areas of the impacted aquifers, and greater confidence in reduction of overall contaminant migration.

9.4.3 Permanence

Natural attenuation includes multiple processes that reduce the toxicity, mobility, or volume of dissolved-phase contaminants in the Site aquifer, including (1) abiotic degradation and/or biodegradation that permanently degrades organic contaminants into simpler component compounds, often with reduced toxicity; and (2) adsorption of contaminants onto the aquifer matrix or other materials such as organic carbon. Abiotic and biologically mediated degradation processes are irreversible, while adsorption characteristics can be dependent upon aquifer geochemistry that may be subject to changes over long time periods. While point-of-entry domestic water treatment systems do not directly reduce toxicity, mobility, or volume of dissolved-phase COCs in impacted Site aquifers, they do provide a proven clean water source for domestic use while COC concentrations in Site groundwater are reduced to below cleanup levels. Alternative 1 provides for reduction of contaminant mobility with the use of a source-area PAB, which provides greater adsorption capacity to the aquifer along the infiltration transect and reduces contaminant mobility beyond the source area. Alternative 1 is given a score of 6 based on this moderate improvement in permanence. Alternative 2 provides greater certainty for permanently halting further migration of dissolved-phase COCs in sitewide groundwater using groundwater extraction (and infiltration following treatment) for long-term hydraulic control. Extracted groundwater would be treated to remove COCs via adsorption to liquid-phase activated carbon, and adsorbed COCs would ultimately be permanently destroyed (that is, incineration) or isolated within an engineered landfill (limiting mobility) following exchange of carbon reactor vessels. Alternative 2 controls COC mobility at approximately the current distal limit of dissolved-phase COCs as well as at the area of high concentrations near existing well MW-19D and surrounding domestic water wells. Thus, Alternative 2 provides better reduction of general contaminant mobility versus Alternative 1, and is given a score of 8 for permanence.

9.4.4 Long-term Effectiveness

The use of point-of-entry domestic water treatment systems is a proven approach to eliminating human health exposures and meeting RAOs, and the systems are relatively simple to operate while dissolved COC concentrations in Site groundwater are reduced to below cleanup levels. Natural attenuation processes that currently degrade, and limit the overall extent of, COCs in groundwater are somewhat slow processes, but they can be expected to continue operating in perpetuity; a long-term monitoring program will be in place to document progress toward the RAOs. Institutional controls in the form of deed restrictions that “run with the land” are durable administrative measures that further limit the potential for human health exposures during the time required to fully achieve RAOs. All alternatives incorporate the above approaches. Alternative 1 provides moderate long-term effectiveness using a PAB to isolate contaminants within the source zone, but the technology requires further pilot-scale testing. Alternative 1 is given a score of 6 for long-term effectiveness. Alternative 2 provides a significant increase in long-term hydraulic capture via groundwater extraction, treatment, and infiltration. Alternative 2 is given a score of 8 based on these improvements in long-term effectiveness.

9.4.5 Short-term Risk Management

Alternative 2 was rated high (8) for short-term risk management because there are minimal short-term risks (that is, worker safety concerns, and dust and erosion control) associated with the potential drilling of limited extraction and infiltration wells, while requiring additional shallow trenching for conveyance piping that presents incremental additional risks to workers. Alternative 1 was given a slightly lower rating of 7 because of the greater amount of drilling required to inject the PAB, particularly with work required along local Highway 27, and additional health and safety concerns associated with the subsurface infiltration.

9.4.6 Implementability

Each alternative generally uses readily available services, equipment, and construction techniques While all share an implementation challenge of establishing effective institutional controls with multiple property owners. Alternative 2 has construction and administrative challenges because it requires placement of infrastructure including extraction and infiltration wells, a small treatment plant, and conveyance piping, within private property. Given these modest challenges, Alternative 2 is given a score of 5. Implementation of Alternative 1 is more challenging because of the highly heterogeneous nature of the fractured basaltic aquifer into which the PAB must be injected; additional pilot-scale testing will be required before implementation. The injection of a PAB will require support from a specialty vendor. For these reasons, Alternative 1 is given a score of 4.

9.4.7 Consideration of Public Concerns

The provision of clean water for domestic use, via point-of-entry domestic water treatment systems, is anticipated to garner a baseline of favorable public support for each alternative. Alternative 2 is given a score of 6, based on an anticipated public perception that the PAB may achieve the RAOs throughout the site. Alternative 2 is rated highest, with a score of 9, based on anticipated public perception that the groundwater extraction, treatment, and infiltration systems are providing more aggressive treatment of impacted groundwater at the site.

9.4.8 Benefits Rankings, Estimated Costs, and Benefit/Cost Ratios

The MTCA benefits rankings, estimated costs, and benefit/cost ratios for the remedial alternatives are presented in Table 9-2. The MTCA benefits rankings are calculated for each alternative by multiplying the assigned rating value for each of the six evaluation criteria by their corresponding weighting factors and summing the weighted values. The benefits rankings range from a low of 5.0 for Alternative 1 to a high of 8.1 for Alternative 2.

Estimated capital and O&M costs for the long-term compliance monitoring program are based on assumptions that only a modest number of additional monitoring wells will be required, and analytical requirements will be relatively limited, without the need for specialty analyses. These assumptions are also subject to change during final remedial design.

The benefit/cost ratio is a relative measure of cost effectiveness and is calculated by dividing each alternative’s benefits ranking by its estimated cost (Appendix J). Alternative 1 has the lowest benefit/cost ratio (0.43)). Alternative 2 has the highest benefit/cost ratio (0.62) (Table 9-2).

9.4.9 Disproportionate Cost Analysis Conclusions

Based on the results of the DCA presented above and in Table 9-2, Alternative 1 has a lower benefit/cost ratio compared to Alternative 2. Given this finding, only Alternative 2 is considered permanent to the maximum extent practicable. Alternatives 1 and 2 were found to have similar costs when applying the estimated time to cleanup; the additional costs of the groundwater extraction, treatment, and infiltration systems are not disproportionate to the improvements in remedy protectiveness, performance, and effectiveness provided by this alternative.

10. Recommended Remedial Alternative

Remedial components, combined with existing and effective point-of-entry domestic water treatment systems providing an unimpacted domestic water supply, have been identified that are anticipated to effectively address the RAOs for the site. The DCA (Table 9-2) found that remedial alternatives described in Section 8 had benefit/cost ratios between 0.43 and 0.62, but only Alternative 2 is considered under MTCA to be permanent to the maximum extent practicable. The highest scoring alternative was Alternative 2, consisting of a groundwater recirculation system for active hydraulic capture and remediation of impacted groundwater aquifers, institutional controls, and point-of-entry domestic water treatment systems providing protection of human health during the time required for aquifer restoration at the proposed SPOC. Alternative 2 had the higher cost of the two alternatives evaluated but was found to provide offsetting improvements in remedy protectiveness, performance, and effectiveness, and is thus identified as the preferred remedial alternative. The groundwater recirculation portion of Alternative 2 is consistent with the recommended interim remedial action (Section 2.4.2).

The preferred remedy (Alternative 2) would likely reduce mass in the shortest time of the alternatives for a reasonable cost (based on the DCA). The general effectiveness of Alternative 2 was evaluated using the groundwater model developed for the site, as updated following additional hydrogeological data collection during late 2018 and through 2019. The development of the groundwater model, including an analysis of the preferred Alternative 2, is discussed in Appendix D. The groundwater model indicates that the proposed groundwater recirculation system will provide hydraulic capture for the area with the highest COC concentrations in groundwater (Figure 10-1).

The conceptual layout of Alternative 2 was presented on Figure 8-2 and the single new extraction well and four new infiltration wells were loaded into the groundwater model. The existing domestic wells and the Primary Freeman School District Well (WS5) were assumed to continue operating at their current capacity and configuration in addition to the new remedial alternative infrastructure. For modeling purposes, the new groundwater extraction well was assumed to operate at 50 gpm, and this extraction was split within model layers such that 10 gpm was extracted from the shallow fractured basalt aquifer and 40 gpm was extracted from the deep fractured basalt aquifer. However, implementation of Alternative 2 would include borehole geophysics and packer testing to construct the well and evaluate the initial extraction rate. Operational and performance data collected during the interim remedial action and an initial optimization phase will be used to determine the optimum extraction rate.

The two upgradient infiltration wells at the GHFF were assumed to be screened throughout the saturated portion of the upper unconsolidated aquifer and underlying basalt aquifer, with each well reinjecting at 5 gpm. The western and eastern infiltration wells were assumed to be screened throughout the upper and lower fractured basalt aquifer and to reinject at rates of 25 and 15 gpm, respectively. Infiltration at these cross-gradient wells at locations at the periphery of the impacted groundwater aquifer encourages clean water flushing of the aquifer between the infiltration wells and the extraction well, while preventing dewatering of existing domestic wells surrounding the new extraction well. Groundwater recirculation in this manner is anticipated to significantly accelerate local aquifer restoration.

Figure 10-1 summarizes results of groundwater modeling for Alternative 2, illustrating groundwater capture zones within model layers representative of the upper and lower fractured basalt (layers 2 and 5, respectively) after 15 years of simulation. The figure illustrates the groundwater elevation contours (light blue) from which groundwater flow directions can be inferred. Groundwater flows locally from the new infiltration wells toward the new extraction well, and more regionally to the south-southwest toward the Primary Freeman School District Well (WS5). Figure 10-1 also shows the inferred lateral limits of select carbon tetrachloride concentrations (10, 100, and 400 µg/L) within the representative shallow and deep fractured basalt aquifer model layer using first quarter 2020 data. Figure 10-1 illustrates the hydraulic capture zones, drawn based on standard flow-net practices, for both the new mid-plume extraction well and the Primary Freeman School District well (WS5). These capture zones encompass areas where groundwater ultimately migrates into one of the two extraction wells and can be compared against the inferred lateral limits of carbon tetrachloride at various concentrations.

Figure 10-1 illustrates capture zones developed from the potentiometric surface (light blue water elevation contours) within representative model layers and does not illustrate the complexities of groundwater migration from one model layer into another layer along specific aquifer flow paths. Groundwater migration through some aquifer materials (or model layers) is slow while it can be rapid within the highly fractured basalt. In general, groundwater migration between the GHFF (that is, wells MW-9S and MW-9D) and the new extraction well requires about half a year within the more-permeable portions of the aquifer. Thus, there is significant flushing potential within the mid-plume area over the course of a 10, 15, or 20 year remedial time period.

Figure 10-1 illustrates effective capture of the high-concentration groundwater impacts south of Highway 27 and near MW-19D and surrounding domestic wells. This area is shown to be flushed by clean water reinjected at new outlying wells and migrating to the new groundwater extraction well. Primary Freeman School District Well (WS5) provides less robust capture in the shallower zone, but still provides good capture near the downgradient limit of groundwater exceeding the federal MCL. Hydraulic capture and clean water aquifer flushing are more pronounced within the higher-permeability deep fractured basalt aquifer, with hydraulic capture extending well beyond the lateral limits of groundwater impacts for both the new and school extraction wells. More discussion of the modeling results is provided in Appendix D.

Alternative 2 provides good hydraulic capture of high-concentration impacted groundwater and exhibits effective clean water flushing through, and restoration of, key aquifer zones, while point-of-entry domestic water treatment systems provide ongoing protection of human health. If Alternative 2 is selected as the remedy for the site, then it is recommended that the extraction and infiltration locations and flow rates be further optimized using performance data obtained during operation of the proposed interim remedial action and the groundwater model as part of the remedial design phase of work. The remedial design, including number and placement of wells and flow rates, may be modified during this optimization phase.

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