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

November 29, 2018
DAT-2018-043

Mr. Raman Iyer
Section Manager
Washington State Department of Ecology, Northwest Regional Office
3190 160th Avenue SE
Bellevue, WA 98008-5452

Subject: Submittal of Supplemental Feasibility Study, Powder Mill Gulch, Boeing Everett Site; Agreed Order DE96HS-N274

Dear Mr. Iyer:

As requested by Ecology's August 6, 2018 letter regarding *The Boeing Everett Site, Final Decision to Submit Supplemental Feasibility Study, Agreed Order DE96HS-274*, The Boeing Company (Boeing) hereby submits the Supplemental Feasibility Study (SFS) for the Boeing Everett tricholorethene (TCE) plume at Powder Mill Gulch (PMG).

Boeing appreciates the opportunity to present an innovative technology which emerged after the submittal of the feasibility study report (AECOM/LAI 2015) and meets both Boeing and Ecology's desire for an increased mass removal rate and a quicker restoration timeframe. In the SFS, Boeing has presented, evaluated and compared a fifth remedial alternative (Alternative 5) for PMG with the four alternatives presented in the feasibility study report (AECOM/LAI 2015), and evaluated the use of several points of compliance (POC) in conjunction with implementation of Alternative 5 as requested in Ecology's letter. Additionally, Boeing has evaluated a standard POC option (POC Option 1) as well as an additional conditional POC (CPOC) option (POC Option 2a) as necessary and/or allowable under MTCA to be used with Alternative 5.

Alternative 5 is comprised of dynamic groundwater recirculation (DGR) in the downgradient plume and enhanced in situ bioremediation (EISB) in the source area. The SFS evaluation shows Alternative 5 as the preferred remedy because it will increase TCE mass recovery, provide enhanced hydraulic capture and control of the TCE plume, treat residual contamination in the source area, and reduce the overall restoration time frame compared to the other alternatives.

The results of the SFS POC evaluation shows that Option 1 (standard POC) is the appropriate and preferred POC option. The SFS POC evaluation results in Option 2a (transition zone CPOC) as the preferred option if Ecology's sets the cleanup level in groundwater equal to the surface water quality standard (SWQS), thereby necessitating use of a CPOC because it will not be practicable to meet the SWQS in groundwater in a reasonable restoration timeframe.

Thank you for the opportunity to provide this SFS and the collaboration between Boeing and Ecology leading up to its preparation. We look forward to discussing the SFS with you and your team and hope that this may lead us to a mutually agreeable remedy and cleanup levels for the PMG TCE plume, while reserving the legal rights Boeing has asserted.

Please contact me if you have any questions.

Sincerely,

Katie Moxley
Manager, Environmental Remediation
The Boeing Company
(425) 237-1905 (office)
(206) 579-2110 (mobile)

CC (electronic copy):

Darin Rice, Tom Buroker, Dean Yasuda, Thea Levkovitz, Department of Ecology
Ivy Anderson, Assistant Attorney General, Attorney for Department of Ecology
Deborah Taege, Stanley Alpert, The Boeing Company
Mike Dunning, Perkins Coie
Mike Palacios, Heather Griffin, Mark Sadler, Wendy McClure, City of Everett
Scott Lathrop, Exotic Tool Welding Inc.
Roger Hoot, Dianne Riter, BBNC
Edgar Wellbaum, Well Energy Corp
Greg Bertch, Bertch Capital Partners
Kristin Paul, Benjamin Hochron, PGIM Real Estate
Robert List, MMA Environmental
Dr. Tong Li, Groundwater Solutions

References

AECOM/LAI (AECOM and Landau Associates, Inc.). 2015. *Feasibility Study for Upland Areas and Powder Mill Gulch*, BCA Everett Plant. November 16.

Agency Review Draft
Supplemental Feasibility Study Report
BCA Everett Plant – Powder Mill Gulch
Everett, Washington

November 29, 2018

Prepared for

The Boeing Company

LANDAU ASSOCIATES

130 2nd Avenue South
Edmonds, WA 98020
(425) 778-0907

Agency Review Draft
Supplemental Feasibility Study Report
BCA Everett – Powder Mill Gulch
Everett, Washington

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

Document prepared by: ______________________________Piper M. Roelen, PE
Principal Engineer

Document reviewed by: ______________________________Jerry R. Ninteman, PE
Quality Reviewer

Date:	November 29, 2018
Project No.:	0025175.118.012
File path:	P:\025\175\FileRm\R\Feasibility Study\2018 FS Supplement\Boeing_Evt_PMG_112918_SuppFS_AgencyReviewDraft_FinalDraft.docx
Project Coordinator:	LJL

LANDAU ASSOCIATES

This page intentionally left blank.

EXECUTIVE SUMMARY

This supplemental feasibility study (SFS) for the Powder Mill Gulch (PMG) area of the Boeing Commercial Airplane (BCA) Everett Plant site (Site) located in Everett, Washington has been prepared as requested by the Washington State Department of Ecology (Ecology) in Ecology's August 6, 2018 letter (Ecology 2018) pursuant to Agreed Order No. DE 96HS-N274 (Agreed Order). The Boeing Company (Boeing) agreed to prepare the SFS as discussed in its August 21, 2018 letter (Boeing 2018b). The feasibility study (FS) report for the PMG area (AECOM and Landau Associates, Inc. [LAI] 2015) developed by Boeing and submitted to Ecology in 2015 included an evaluation of four remedial alternatives for cleanup of the groundwater trichloroethene (TCE) plume in PMG to drinking water cleanup levels at the standard point of compliance (POC; i.e., throughout groundwater in PMG). The FS evaluation was performed in accordance with the Washington State Model Toxics Control Act (MTCA).

As discussed in the above-referenced letters, this SFS:

- presents and evaluates a new (fifth) remedial alternative (Alternative 5) for PMG that will satisfy regulatory requirements; and
- evaluates Alternative 5 using several options for a standard POC or a conditional point of compliance (CPOC).

As requested by Ecology, Boeing's evaluation of the remedial alternatives and the standard POC and CPOC options are performed using the MTCA disproportionate cost analysis (DCA) process in Washington Administrative Code (WAC) 173-340-360(3)(e).

Remedial Alternatives Evaluation

The following four remedial action alternatives were evaluated in the FS to address contaminated media at the Site:

- **Alternative 1: Continued Operation of Existing Groundwater Extraction and Treatment (GET) System, and Institutional Controls**
- **Alternative 2: Enhanced *In Situ* Bioremediation (EISB) in the Source Area, Continued Operation of Existing GET System, and Institutional Controls**
- **Alternative 3: Focused *In Situ* Chemical Oxidation (ISCO), Continued Operation of Existing GET System, and Institutional Controls**
- **Alternative 4: Focused EISB, Continued Operation of Existing GET System, and Institutional Controls**

This SFS develops a fifth remedial action alternative for PMG for comparison and evaluation with the four remedial alternatives provided in the FS. This new remedial alternative is:

- **Alternative 5: Dynamic Groundwater Recirculation (DGR) in the Downgradient Plume and EISB in the Source Area** (**and Institutional Controls**, if necessary). Alternative 5 includes modifying and upgrading the existing GET system by adding groundwater injection wells and additional extraction wells. This groundwater recirculation system will be dynamically operated to optimize mass recovery through adaptive management as a DGR system. DGR is a relatively new and promising remedial technology that Boeing became aware of after submittal of the FS report that is applicable to the PMG solid waste management unit (SWMU) and should remove groundwater contamination in the TCE plume at a faster rate than the other alternatives presented in the FS thus reducing the restoration time frame. Alternative 5 also includes implementation of additional EISB in the source area to treat residual contamination following previous source area interim action cleanup efforts.

As demonstrated in this SFS, Alternative 5 meets MTCA threshold and other requirements,[1] is permanent to the maximum extent practicable, and is the preferred remedial alternative for cleanup of the PMG SWMU. Alternative 5 will increase contaminant mass recovery rates above those already achieved by the GET system by modifying groundwater flow paths to provide flushing of pore spaces not currently accessed under natural or GET system-influenced flow conditions, accelerate the clean-up time frame through overall increased aquifer flushing rates, and provide additional hydraulic control of contamination in the downgradient portion of the groundwater plume through operation of new groundwater injection and extraction wells. Similar to Alternative 2, EISB will also be used for additional remediation of the source area. In the event that a CPOC is selected by Ecology after review of this SFS, institutional controls will be implemented in accordance with MTCA.

Point of Compliance Options Evaluation

In addition to evaluating the additional remedial alternative (Alternative 5), at the direction of Ecology, this SFS also evaluates the use of several different standard POCs and CPOCs for Alternative 5.

In Ecology's August 6, 2018 letter, Ecology requested the evaluation of four groundwater POC options using the surface water quality standard (SWQS; 0.3 micrograms per liter [µg/L] TCE) as the groundwater cleanup level (CUL), including one standard POC and three CPOC options. For the evaluation of the CPOCs, Ecology states that it is assumed that groundwater at the Site must be protective of drinking water throughout the groundwater (i.e., at the standard POC) upgradient of the established CPOC locations using a cleanup level of 4 µg/L TCE based on drinking water standards.

This is a modified approach to evaluating a standard POC option. It uses the drinking water standard of 4 µg/L for a portion of the groundwater, but also includes a second cleanup level for groundwater that is equal to the SWQS (0.3 µg/L TCE) to be used at the three CPOC options Ecology requested be evaluated (at monitoring wells upgradient of the creek, at the Boeing property line, and immediately

[1] As defined in WAC 173-340-360(2)(a&b) – protect human health and the environment, comply with cleanup standards, comply with applicable state and federal laws, provide for compliance monitoring, provide for a reasonable restoration time frame, and consider public concerns.

downgradient of the source area). Finally, Ecology also requested evaluation of a standard POC using the SWQS in groundwater throughout the site.

In addition to the four groundwater POC options identified by Ecology, Boeing evaluates a fourth CPOC option, and the standard POC option for groundwater using drinking water standards. The fourth CPOC option evaluated by Boeing uses the SWQS for groundwater in the transitional zone at the creek which is applicable under MTCA and Ecology guidance (Ecology 2017a) for groundwater abutting surface water. The Ecology guidance document defines the transitional zone (including sediment pore water and the hyporheic zone) as groundwater and shows applicable locations of transitional zone CPOCs in figures.[2] All the POC options evaluated provide that a standard POC for surface water (i.e., throughout the creek) must meet a cleanup level equal to the SWQS (0.3 µg/L TCE).

Because Ecology requires for this SFS both the standard POC for groundwater using drinking water standards and the standard POC for surface water using the SWQS be met for all the CPOC options evaluated, each CPOC option identified below (Option 2a, 2b, 3, and 4) consists of the standard POC for groundwater and surface water using the drinking water standard (4 µg/L TCE) and SWQS (0.3 µg/L TCE), respectively (i.e., Option 1), modified with an additional CPOC where the SWQS must be met in groundwater. The six POC options evaluated are as follows:[3]

- **Option 1: Groundwater and Surface Water Standard POCs**—drinking water standard (4 µg/L TCE) must be met in monitoring wells throughout the groundwater TCE plume and the SWQS (0.3 µg/L TCE) must be met within the creek water at sampling points immediately above the creek bed.
- **Option 2a: Groundwater and Surface Water Standard POCs Modified to Include Groundwater CPOC in the Transitional Zone at the Creek**—modifying the standard MTCA requirements in Option 1, the SWQS (0.3 µg/L TCE) must also be met in pore water/hyporheic zone sampling points beneath the creek bed or immediately adjacent to the creek.
- **Option 2b: Groundwater and Surface Water Standard POCs Modified to Include Groundwater CPOC in the Monitoring Wells Upgradient of the Creek**[4]—modifying the standard MTCA requirements in Option 1, the SWQS (0.3 µg/L TCE) must also be met at existing monitoring wells upgradient of the creek (see Figure 4-2b).
- **Option 3: Groundwater and Surface Water Standard POCs Modified to Include Groundwater CPOC at Boeing Property Line and Upgradient of the Creek on Boeing Property**—modifying the standard MTCA requirements in Option 1, the SWQS (0.3 µg/L TCE) must also be met at existing monitoring wells along the Boeing property line and upgradient of the creek on Boeing property (and at all groundwater monitoring points downgradient of these wells; see Figure 4-3).
- **Option 4: Groundwater and Surface Water Standard POCs Modified to Include Groundwater CPOC Immediately Downgradient of the Source Area**—modifying the standard MTCA requirements in Option 1, the SWQS (0.3 µg/L TCE) must also be met at monitoring wells

[2] See Ecology 2017a - terminology, physical setting definitions, and policy highlight (pages 1-3), and Figure 5a (page 16).
[3] POC Options 2b through 5 correspond to POC Options A through D from Ecology's decision letter (Ecology 2018).
[4] Ecology's letter referred to these wells as being located in the "buffer zone," which is not a MTCA-defined term.

located immediately downgradient of the TCE source area/detention basin (and at all groundwater monitoring points downgradient of these wells; see Figure 4-4).

- **Option 5: Groundwater Standard POC Using SWQS**—the SWQS (0.3 µg/L TCE) must be met in monitoring wells throughout the groundwater TCE plume and in creek water sampling points immediately above the creek bed (see Figure 4-5).

The use of both a standard and conditional POC is inconsistent with application of CPOCs in groundwater under MTCA.[5] Notwithstanding that issue, per Ecology's direction, Boeing developed POC Options 2b through 4 that assume the TCE drinking water cleanup level will be met in groundwater at the standard POC (i.e., including all points upgradient of these CPOCs).

As requested by Ecology, the evaluation of the POC options for Alternative 5 includes using the MTCA DCA process to determine which POC option is "permanent to the maximum extent practicable under WAC 173-340-360(3)." This requested methodology is an unconventional application of the MTCA DCA process for evaluating POCs because it is intended to be used to evaluate the application of different remedial technologies rather than POC options. Because the POC options are all being applied to the same remedial alternative in the same manner, in order to perform this unique POC DCA analysis, Boeing focused on those elements of the DCA criteria that provide a basis for meaningful comparisons between the POC options.

As demonstrated in this SFS, POC Option 1 is permanent to the maximum extent practicable and is the preferred POC option for use in combination with Alternative 5. Using the standard POC location, as provided for in POC option 1, Alternative 5 is protective of all known and potential human and ecological exposure pathways; provides for the highest overall benefits and is not disproportionately costly; is technically achievable in a reasonable restoration time frame; in combination with the applicable, relevant, and appropriate cleanup levels for both groundwater and surface water, is consistent with MTCA, the Clean Water Act, and state SWQS (WAC 173-201A) regulations; and would not require use of a CPOC. As demonstrated in the DCA, the other POC options are disproportionately costly to implement and achieve, do not provide additional overall benefit, and are inconsistent with MTCA.

As described in this SFS, the selection of POC Option 1 is also based on a large body of technical data, relevant case studies, and professional literature, all of which demonstrate that it is technically impracticable to achieve cleanup of chlorinated solvents in groundwater to concentrations much lower than the state drinking water standard (i.e., 4 µg/L TCE) in a reasonable restoration time frame. As this body of evidence shows, technical impracticability is primarily due to back diffusion and/or desorption-limited processes in an aquifer that may persist for many decades and lead to asymptotic declines in chlorinated solvent concentrations over very long time frames. Because each of the other

[5] WAC 173-340-720(8)(a) states that "Ground water cleanup levels shall be attained in all ground waters from the point of compliance to the outer boundary of the hazardous substance plume" (i.e., for CPOCs at all points in the plume downgradient of the approved CPOC location, not upgradient thereof).

POC options for the PMG SWMU requires meeting the SWQS (0.3 µg/L TCE) in groundwater within the TCE plume, this body of data indicates that it will be technically impracticable to achieve compliance at any of the other POCs in a reasonable restoration time frame, with the exception of POC Option 2a (groundwater CPOC in the transition zone beneath the creek) where significant contaminant attenuation may occur due to transition/hyporheic zone biologic and geochemical effects.

Based on the results of the evaluation requested by Ecology, Alternative 5—DGR in the Downgradient Plume and EISB in the Source Area—is the preferred, protective, and effective remedy, and that Option 1—Groundwater and Surface Water Standard POCs—is the preferred, protective, and achievable POC for the PMG area.

TABLE OF CONTENTS

FIGURES

TABLES

APPENDICES

LIST OF ABBREVIATIONS AND ACRONYMS

µg/L	micrograms per liter
AFB	Air Force Base
Agreed Order	Agreed Order No. DE 96HS-N274
AOCs	areas of concern
ARAR	applicable, relevant, and appropriate requirement
BCA	Boeing Commercial Airplane
Boeing	The Boeing Company
CPOC	conditional point of compliance
COC	constituent of concern
CSM	conceptual site model
CUL	cleanup level
CVOC	chlorinated volatile organic compound
DCA	disproportionate cost analysis
DGR	dynamic groundwater recirculation
Ecology	Washington State Department of Ecology
EISB	enhanced *in situ* bioremediation
EPA	US Environmental Protection Agency
ESTCP	Environmental Security Technology Certification Program
FS	feasibility study
gal	gallon
GET	groundwater extraction and treatment
GR	groundwater recirculation
ISCO	*in situ* chemical oxidation
LAI	Landau Associates, Inc.
MCL	maximum contaminant level
MTCA	Washington State Model Toxics Control Act
NPDES	National Pollutant Discharge Elimination System
O&M	operations and maintenance
OM&M	operations, maintenance, and monitoring
PMG	Powder Mill Gulch
POC	point of compliance
RI	remedial investigation
SFS	supplemental feasibility study
Site	Boeing Everett - Powder Mill Gulch
SWMUs	solid waste management units
SWQS	surface water quality standards
TCE	trichloroethene
TOC	total organic carbon
UIC	Underground Injection Control
WAC	Washington Administrative Code

1.0 INTRODUCTION

This document is submitted on behalf of The Boeing Company (Boeing) and presents the results of a supplemental feasibility study (SFS) for the Powder Mill Gulch (PMG) area of the Boeing Commercial Airplane (BCA) Everett Plant site located in Everett, Washington (Site; Figure 1-1). The SFS was requested by the Washington State Department of Ecology (Ecology) in its August 2018 letter (Ecology 2018) pursuant to Agreed Order No. DE 96HS-N274 (Agreed Order). A feasibility study (FS) report (AECOM and Landau Associates, Inc. [LAI] 2015) was prepared for all the Upland Area and PMG solid waste management units (SWMUs) and areas of concern (AOCs) and submitted for Ecology's review in November 2015. Ecology provided a response to the FS in August 2016 (Ecology 2016). This SFS assumes that the reader is generally familiar with the contents of the 2015 FS report and Ecology's response.

Boeing prepared this SFS to:

- present and evaluate a new remedial alternative that was proposed by Boeing (Boeing 2017b, 2018a) for PMG that will satisfy applicable regulatory requirements and is preferable to other alternatives previously considered because it achieves Site cleanup more rapidly through increased hydraulic control and enhanced mass removal and aquifer flushing; and
- evaluate several standard point of compliance (POC) and conditional point of compliance (CPOC) options.

Boeing has presented its position to Ecology that applying surface water quality standards (SWQS) to groundwater is not authorized by law (Boeing 2017a). However, Ecology has requested that Boeing evaluate the feasibility of meeting the SWQS in groundwater at PMG. Boeing provides the requested evaluation in this report without waiving its rights on that issue.

The 2015 FS report included an evaluation of four remedial alternatives for cleanup of the groundwater trichloroethene (TCE) plume in PMG. As identified in Ecology's letter (Ecology 2018), this SFS develops a fifth remedial action alternative for PMG, compares and evaluates the new remedial alternative with the four remedial alternatives presented in the FS, and evaluates the use of different standard POCs and CPOCs for the fifth remedial alternative. Finally, this SFS identifies a preferred remedial alternative that will address the contamination at the PMG area of the Site as required by Washington Administrative Code (WAC) 173-340-360, under the Washington State Model Toxics Control Act (MTCA).

1.1 Site Description and Background

A description of the Site/PMG is provided in the FS report.

1.2 Site History/Background

A discussion of the history and background of the Site/PMG is provided in the FS report.

1.3 Previous Site Investigations

A discussion of the remedial investigation (RI) and other previous investigations at PMG is provided in the FS report.

1.4 Previous Interim Actions/Remedial Actions

A discussion of previous and ongoing interim actions and other remedial actions performed at PMG is provided in the FS report.

1.5 Nature and Extent of Contamination/Conceptual Site Model

A description of the nature and extent of contamination at PMG and a conceptual site model (CSM) are provided in the FS report.

2.0 DEVELOPMENT OF ADDITIONAL REMEDIAL ACTION ALTERNATIVE

The following sections briefly summarize the four remedial action alternatives included in the FS report (and, as applicable, as subsequently modified by Ecology) and provide a detailed summary of a new, fifth remedial action alternative developed by Boeing (Alternative 5). In order to fully evaluate Alternative 5, it must be evaluated and compared against the four alternatives presented in the 2015 FS in compliance with the MTCA FS process; Section 3 of this SFS provides that evaluation. Section 4 then provides an evaluation of the applicability of POCs for use in conjunction with the implementation of Alternative 5. Sections 3 and 4 also present disproportionate cost analyses.

2.1 Summary of 2015 FS Remedial Alternatives

Four remedial action alternatives were evaluated in the FS to address contaminated media at the Site. The four alternatives are:

- Alternative 1: Continued Operation of Existing Groundwater Extraction and Treatment (GET) System, and Institutional Controls
- Alternative 2: Enhanced *In Situ* Bioremediation (EISB) in the Source Area, Continued Operation of Existing GET System, and Institutional Controls
- Alternative 3: Focused *In Situ* Chemical Oxidation (ISCO), Continued Operation of Existing GET System, and Institutional Controls
- Alternative 4: Focused EISB, Continued Operation of Existing GET System, and Institutional Controls

A brief summary of each of these remedial alternatives is included in the sections below. The alternatives as presented in the 2015 FS were modified and further defined by Ecology's FS response and subsequent submittals from Boeing. The descriptions of the alternatives in the section below incorporate these modifications.

2.1.1 Alternative 1: Continued Operation of Existing GET System and Institutional Controls

Alternative 1 consists of continued operation of the existing GET system supplemented by institutional controls. Alternative 1 includes:

- Continued GET System Operations: Operating the 12 existing groundwater extraction wells for groundwater hydraulic control and capture, and the existing groundwater treatment system for treatment of the extracted groundwater and compliant discharge of the treated groundwater to Powder Mill Creek through a National Pollutant Discharge Elimination System (NPDES) permitted outfall. The objectives of the GET system are to:
    - Minimize discharge of impacted groundwater to surface water and migration of impacted groundwater off of Boeing property;

  - Increase flushing of the aquifer in the downgradient plume for long-term groundwater restoration and cleanup to the applicable cleanup standards; and treat extracted groundwater to permanently remove contamination from the aquifer for offsite destruction/disposal.
- Institutional Controls: Establishing institutional controls on Boeing and offsite areas of the PMG SWMU until cleanup standards are met to:
  - Prevent use of groundwater and surface water as a drinking water source;
  - Prevent human consumption of surface water or freshwater organisms;
  - Limit human contact with surface water for recreational purposes; and
  - Limit intrusive activities that would bring workers into contact with contaminated groundwater, limit exposure risks, and ensure protection of workers when intrusive activities are necessary.

2.1.2 Alternative 2: EISB Source Area Remediation, Continued Operation of Existing GET System, and Institutional Controls

Like Alternative 1, Alternative 2 includes continued operation of the GET system and institutional controls, but also includes performing EISB for cleanup of residual source area contamination (beneath the detention basin). Alternative 2 includes:

- EISB Source Area Remediation: Perform focused EISB in the source area using electron donor to stimulate microbial degradation of residual concentrations of TCE and/or breakdown products and minimize future contributions to downgradient groundwater contamination. Electron donor would be introduced to the subsurface through a network of injection wells or donor borings installed in the detention basin;
- GET System Operations: Operating existing GET system for groundwater hydraulic control, capture, and treatment of contaminated groundwater to minimize discharge of impacted groundwater to surface water and migration of impacted groundwater off of Boeing property, and to increase flushing of the aquifer for restoration and cleanup of groundwater; and
- Institutional Controls: Establish institutional controls on Boeing and offsite areas of the PMG SWMU until cleanup standards are met to prevent use of groundwater and surface water as a drinking water source, prevent human consumption of surface water or freshwater organisms, limit human contact with surface water for recreational purposes, and prevent or limit worker contact with contaminated groundwater.

2.1.3 Alternative 3: Focused ISCO Remediation, Continued Operation of Existing GET System, and Institutional Controls

Like Alternative 1, Alternative 3 includes continued operation of the GET system and institutional controls, but also includes performing focused ISCO remediation for cleanup of areas with comparatively elevated TCE concentrations, such as the source area and discrete "TCE focus areas" north and south of Seaway Boulevard. Alternative 3 includes:

- ISCO TCE Focus Area Remediation: Perform remediation using ISCO where TCE focus areas remain to accelerate groundwater remediation. This would include periodic injections of a strong chemical oxidant (sodium persulfate and an activating agent) into the saturated zone through a network of injection wells to treat contaminated groundwater through direct oxidation of contaminant mass. Injections of sodium persulfate would be repeated at the TCE focus areas (four to six injection events anticipated) until rebound no longer results in groundwater concentrations above treatment goals;

- GET System Operations: Operating existing GET system for groundwater hydraulic control, capture, and treatment of contaminated groundwater to minimize discharge of impacted groundwater to surface water and migration of impacted groundwater off of Boeing property, and to increase flushing of the aquifer for restoration and cleanup of groundwater; and
- Institutional Controls: Establishing institutional controls on Boeing and offsite areas of the PMG SWMU until cleanup standards are met to prevent use of groundwater and surface water as a drinking water source, prevent human consumption of surface water or freshwater organisms, limit human contact with surface water for recreational purposes, and prevent or limit worker contact with contaminated groundwater.

2.1.4 Alternative 4: EISB Source Area and Downgradient Plume Remediation, Continued Operation of Existing GET System, and Institutional Controls

Like Alternative 1, Alternative 4 includes continued operation of the GET system and institutional controls. Also similar to Alternative 2, Alternative 4 includes EISB for remediation of the source area; however, as specified by Ecology, this alternative also includes EISB in the downgradient plume wherever necessary to achieve cleanup of groundwater. Alternative 4 includes:

- EISB Groundwater Remediation: Perform focused EISB in the source area and downgradient plume using electron donor to stimulate microbial degradation of TCE and/or chlorinated breakdown products for *in situ* destruction of contaminant mass. Electron donor would be introduced to the subsurface through a network of injection wells or donor borings installed in the detention basin and downgradient areas of the contaminant plume as necessary to achieve cleanup standards;
- GET System Operations: Operate existing GET system for groundwater hydraulic control, capture, and treatment of contaminated groundwater to minimize discharge of impacted groundwater to surface water and migration of impacted groundwater off of Boeing property, and to increase flushing of the aquifer for restoration and cleanup of groundwater;
- As seen during the performance of EISB in the source area as part of the ongoing source area interim action, toxic byproducts, such as vinyl chloride, arsenic, iron, and manganese, are temporarily generated by and/or as a result from the EISB reductive dechlorination process. Because injected electron donor and these byproducts will be present in the downgradient portion of the plume and may be captured by the GET system (which, as required by Ecology, may not be shut down during or after donor injection events), this alternative would also require an expansion of the groundwater treatment system to include construction and operation of pre-treatment trains for total organic carbon (TOC) and metals so that they will not foul the GET system air stripper (chlorinated solvent treatment train) or be passed through the treatment system and discharged into Powder Mill Creek (at the treatment system, NPDES-permitted outfall); and

- Institutional Controls: Establish institutional controls on Boeing and offsite areas of the PMG SWMU until cleanup standards are met to prevent use of groundwater and surface water as a drinking water source, prevent human consumption of surface water or freshwater organisms, limit human contact with surface water for recreational purposes, and prevent or limit worker contact with contaminated groundwater.

2.2 Additional Remedial Action Alternative—Alternative 5: Dynamic Groundwater Recirculation and Source Area EISB

This section presents an additional remedial action alternative (Alternative 5) not included with the four alternatives presented in the FS report. Alternative 5 is presented as discussed in Ecology's letter (Ecology 2018). Alternative 5 addresses Ecology's concerns related to achieving cleanup standards at the PMG SWMU in a more rapid time frame, and also limits the risks of detrimental discharges of bioremediation byproducts to Powder Mill Creek and fouling the GET system.

Alternative 5 adds groundwater injection wells and additional extraction wells to convert the GET system into a groundwater recirculation (GR) system. Through adaptive management and dynamic operation of the GR system, the remedial approach/technology would be used that has come to be known as "dynamic groundwater recirculation" (DGR) (Suthersan et al. 2015). This DGR system will increase contaminant mass recovery rates by modifying groundwater flow paths to provide flushing of pore spaces not readily or as quickly accessed under natural or GET system-influenced flow conditions, accelerate the clean-up time frame through overall increased aquifer flushing rates, and provide additional hydraulic control of contamination in the downgradient portion of the groundwater plume through operation of new groundwater injection and extraction wells. Similar to Alternative 2, EISB will also be used for additional remediation of the source area.[6] Institutional controls will be used in accordance with MTCA, if necessary, in the event that a CPOC is selected by Ecology after review of this SFS.

The sequence for design and implementation for Alternative 5 would be as follows:

1) Use initial modeling and existing GET system infrastructure to design and perform a DGR pilot study;
2) Use the pilot study results to inform and update the groundwater flow model and perform full-scale design and installation of the DGR system;
3) Optimize operations of the DGR system for maximum aquifer flushing and mass recovery through dynamic operation and manipulation of hydraulic gradients and groundwater flow paths throughout the downgradient plume. Through the optimization process, the need for additional injection or extraction wells will be evaluated, and such wells will be added if necessary; and

[6] Note that DGR is not proposed in the source area because EISB has already been performed in this area with positive results, and the presence of TOC and bioremediation byproducts in the source area would present a substantial risk of fouling DGR extraction wells, injection wells, and the groundwater treatment system.

4) Continue to optimize DGR system operations as the plume contracts and is cleaned up. If ongoing evaluation determines the need for additional injection wells on the future exterior of the plume boundary, such wells will be added as necessary.

The following sections provide the basis of selection for DGR, a plan for pilot study, a description of the conceptual design and implementation of DGR, and a summary description of the components and approach for implementation of Alternative 5.

2.2.1 Basis of Selection of Dynamic Groundwater Recirculation

Operation of a standard GET system, like the one currently in operation at PMG, is an effective and proven approach for providing hydraulic containment and capture of a dissolved-phase groundwater contaminant plume, and also provides some enhanced flushing of the contaminant plume through increased gradients and shortened flow paths. These effects have been observed and documented in each interim action monitoring report prepared since initiation of GET system operations at PMG in 2012, as evidenced by observed capture zones created by extraction wells and steady reductions in TCE concentrations in groundwater and surface water over the duration of operations.

GET systems are typically run in a static mode of operation (e.g., groundwater extraction at a set flow rate or level of groundwater drawdown) without substantial variation of extraction locations and rates. In this configuration, the gradients and flow paths do not vary over time and increased flushing often occurs only in the most conductive flow paths oriented in the direction of flow. A DGR system significantly enhances flushing and mass recovery compared to standard GET systems by shifting groundwater flow paths to access the less conductive and transverse flow paths that act as contaminant storage zones (Suthersan et al. 2017). This is accomplished through frequent selective changes to the operation and/or pumping rates of injection and extraction wells across the contaminant plume.

Several benefits can be realized with the addition of injection wells to, and dynamic operation and adaptive management of, the GET system to create a DGR system. These include:

- <u>Enhanced Containment</u>: Groundwater mounding at injection points located just outside of a plume can enhance plume containment through “pushing” groundwater (i.e., increasing hydraulic gradients) to supplement or complement the “pulling” effect of extraction wells.
- <u>Increased Contaminant Mass Recovery</u>: Varying the location and magnitude of groundwater injection and extraction will increase flushing throughout the capture zones along flow paths that may be stagnant or otherwise not accessed by the extraction wells alone. This allows for increased flushing, desorption, and recovery of additional contaminant mass at extraction wells from these flow paths.
- <u>Reduced Restoration Time Frame</u>: Enhanced mass recovery and flushing of the aquifer through more rapid and complete pore water exchanges will result in overall faster plume restoration.

The DGR approach has been shown to significantly improve contaminant removal rates compared to conventional GET approaches and reduces the restoration time frame by increasing mass recovery through advective flushing of multiple flow paths and increasing diffusive gradients (Suthersan et al. 2015). DGR is a relatively new concept for application to pump-and-treat style remedies, but has been documented to successfully achieve clean ups and reduce restoration time frames for chlorinated solvent plumes at Reese Air Force Base (AFB) in Lubbock, Texas and at a railroad property site in Allston, Massachusetts, and for an aviation fuel plume at a helicopter refueling facility spill site (Suthersan et al. 2017). The Reese AFB site is similar to PMG; it was a large, mature TCE plume where a pump-and-treat system was in operation, but conversion to and dynamic operation of a GR system, combined with source area bioremediation, dramatically expedited the cleanup from an estimated restoration time frame of more than 30 years to approximately 8 years (ITRC 2015).

Based on these principles and documented successful implementation of DGR at similar sites, DGR is a promising technology for expedited cleanup of the downgradient plume at the PMG SWMU.

2.2.2 Alternative 5—DGR Pilot Study

Prior to full-scale design and implementation, a pilot study would be conducted to demonstrate proof of concept and provide additional information and data that would be utilized for the full-scale design. We anticipate that the pilot study would be conducted in the area of higher TCE concentrations around groundwater monitoring points P8, P10, EGW090, and possibly EGW133 (see Figure 2-1). The actual number and location of injection wells and extraction wells used and installed as part of the pilot study would be determined through detailed engineering design and hydraulic evaluation/modeling as reviewed and approved by Ecology. However, for the purposes of this SFS, the pilot study is assumed to include installation of three injection wells along the eastern edge of the plume south of Seaway Boulevard (on Boeing property) and will utilize all five of the existing extraction wells currently on Boeing property.

The pilot test is anticipated to take at least 1 year to complete (not including planning, design, Ecology work plan review and approval, and construction, which could take 1–2 years to complete) to gather sufficient data to inform design and installation of the full-scale system. Additional testing duration may be necessary to provide sufficient time to adequately observe and fully evaluate the effects of static groundwater injection/recirculation, evaluate the effects and benefits of dynamic operation of the pilot system under multiple configurations, and identify differences in contaminant trends between the pilot study compared to GET system operations only. It is assumed that during the pilot test, groundwater elevation and water quality data will be collected on a monthly basis for the first 3 months, then switched to a quarterly basis as deemed appropriate and adequate to observe and evaluate the effects of various injection and extraction scenarios during the course of the study. Data and parameters collected during the pilot test would be used for evaluation of effectiveness and for design of the full-scale system. Collected data and parameters would include:

- groundwater elevations at injection wells, extraction wells, and monitoring wells/piezometers in the target area;
- groundwater TCE concentrations in monitoring wells and from extraction wells in the target area;
- extraction and injection flow rates;
- hydraulic conductivity and flow capacity data, to the extent practicable, based on injection rates; and
- observation and analysis of reinjection well fouling and effectiveness of well rehabilitation measures (if needed).

Recommended criteria indicating success of the pilot study and results necessary to conclude that full-scale implementation will be appropriate and cost-effective should include:

- ability to approximate the modeled injection rates and degree of mounding at injection wells;
- demonstration that the pilot DGR system can observably increase hydraulic gradients and change/shift flow directions compared to current conditions;
- observations that the hydraulic influence of the DGR system will address all areas of the downgradient plume (i.e., groundwater mounding from injection wells is established around the perimeter of the pilot study area, and complementary capture zones are established by extraction wells);
- observation of significant increases (e.g., 10 to 50 percent depending on location) in mass flux of recovered TCE at extraction wells;
- demonstration of more rapid decreasing trends (than current trends) in groundwater TCE concentrations in target area monitoring wells over the course of the pilot study;
- continued hydraulic capture and control of the plume such that the DGR system achieves the interim action objectives of the Downgradient Plume Interim Action (as appropriately modified for the final remedial action); and
- firm projections based on the results of the pilot study that the final remedy, under full scale implementation, would result in reducing the restoration time frame by at least 50 percent as compared to projected GET system operations and justify the effort and expense of installing and operating the DGR system.

The combination of these recommended parameters should be used to evaluate whether a full-scale DGR system will be feasible, practicable, and effective over the remainder of the downgradient plume.[7] One of the primary metrics of successful design and operation of a dynamically operated GR system is the ability to manage flow path lengths and pore volume flushing times while still maintaining hydraulic control of the plume. Based on our initial evaluation and restoration time frame modeling (see Section 2.3.6), the reduction in downgradient plume restoration time frame as a result of operation of the GR system could be as much as 50 percent (north of Seaway Boulevard) to

[7] Construction and implementation of the full-scale GR system will also be contingent upon receiving permission from off-property land owners to trench, drill, and construct the system on their properties.

70 percent (south of Seaway Boulevard).[8] If the pilot study indicates reductions in restoration time frames significantly less than these projections, the cost of full-scale implementation may be determined to be disproportionately costly in comparison to other remedial alternatives that do not include such significant construction and implementation requirements, such as FS Alternative 2 (source area EISB and downgradient operation of the GET system).

2.2.3 Alternative 5—Dynamic Groundwater Recirculation Conceptual Plan

A conceptual layout of the approximate location of groundwater injection wells and new (and existing) extraction wells for a full-scale GR system is provided on Figure 2-1. This layout (subject to change based on the results of the pilot study) is based on the following considerations and limitations:

- current known TCE plume configuration;
- site topography, natural features (wetlands, surface water, vegetation), and infrastructure;
- location, spacing, and area of influence of the existing GET system extraction wells; and
- initial (pre-pilot study) groundwater modeling results (see Appendix A).

As indicated in Figure 2-1, the conceptual layout includes:

- approximately nine new injection wells installed outside the eastern edge of the plume south of Seaway Boulevard and outside the western edge of the plume north of Seaway Boulevard,[9] and
- 12 existing extraction wells and two new extraction wells installed within the core of the plume.

The exact number and location of injection wells and new extraction wells would be determined through detailed engineering design and hydraulic evaluation/modeling including information and data derived from the results of the pilot study. The use and operation of injection wells would have to be permit-authorized by Ecology's Underground Injection Control (UIC) program. For cost estimating purposes and to address Ecology's comments,[10] it is assumed that in addition to the nine new injection wells and two new extraction wells, up to five additional injection or extraction wells may be included as part of the final DGR system design and/or as part of future optimization. As

[8] Assumes EISB is also implemented in the source area in addition to DGR system installation and operation in the downgradient plume.

[9] Note that all proposed locations of new injection wells and extraction wells north of Seaway Boulevard are on property not owned or under Boeing's direct control; therefore, installation of these wells and associated DGR infrastructure is subject to approval of the owners of these respective properties.

[10] Ecology's letter (Ecology 2018) indicated that "Ecology would revise this proposed additional alternative by adding groundwater extraction and injection wells to the interior of the groundwater plume on Boeing and City of Everett property to maximize the effectiveness of the system." Boeing's analysis is that it would not be prudent to install injection wells within the interior of the plume due to the associated risk of inadvertently spreading the boundaries of the plume and creating flow paths that would be counterproductive to the injection wells further upgradient. The cost estimates contained herein do, however, account for the potential for additional injection and extraction wells in the future as the plume contracts or if otherwise necessary. Boeing looks forward to further discussions with Ecology to develop the DGR pilot study.

necessary after operation and optimization of the new DGR system, other new injection and extraction wells not included in the initial system design may be added to supplement the system and to optimize the cleanup as the plume is decreased in size and/or to increase the effectiveness of the system through additional groundwater flow manipulation and increased flushing.

Injection wells would be supplied with treated groundwater from the existing GET system treatment train. Injection wells would be monitored through the existing GET system monitoring system that would be expanded and upgraded to include water level meters (pressure transducers) and flow meters at each injection well. The existing treated groundwater discharge line, which extends to the outfall on Powder Mill Creek beyond the north end of the plume, would be spliced/branched and valved appropriately to provide controllable and adjustable flow to each individual injection well. In addition to the existing discharge pump, booster pumps and intermediary storage tanks would be added, as necessary, to provide flow to each injection well located at higher elevations than the GET system discharge line. The new extraction wells would be tied into the existing collection and transfer piping network and instrumented and monitored in the same fashion as existing extraction wells.

For cost estimating purposes, we have assumed that up to four additional monitoring wells/piezometers may also need to be installed (during the pilot study and/or full scale implementation) to evaluate the hydrologic impacts on the groundwater table and groundwater quality resulting from operation of the injection wells. The exact number and locations would be determined through detailed engineering design and hydraulic evaluation/modeling.

2.2.4 Alternative 5—Source Area EISB

In addition to performing DGR in the downgradient portion of the plume, Alternative 5 also includes performance of EISB in the source area:

- EISB Source Area Remediation: Like Alternative 2, Alternative 5 includes performing focused EISB in the source area using electron donor to stimulate microbial degradation of residual concentrations of TCE and/or breakdown products and minimize future contributions to downgradient groundwater contamination. Electron donor would be introduced to the subsurface through a network of injection wells or donor borings installed in the detention basin.

Design of the source area EISB remedy (i.e., location and magnitude of donor injections) will be dependent on source area data at the time the design is performed. For cost estimating purposes, the injection locations and volumes are the same as for FS Alternative 2. It is assumed that up to three injection events will be performed over approximately a 3-year time frame. However, the total number of injection events will depend on monitoring data from the source area and downgradient of the source area subsequent to each prior event, with consideration for the effectiveness of the treatment and potential fouling issues of the DGR system or if other EISB-related impacts are observed in the downgradient plume (e.g., if TOC or dissolved metals resulting from EISB are observed in proximity to DGR extraction or injection wells, donor injection events may need to be delayed or discontinued).

2.2.5 Alternative 5—Institutional Controls

Alternative 5 may also include institutional controls, if necessary.

- Institutional Controls: If use of a CPOC is selected by Ecology (see Section 4), Alternative 5 will include establishing institutional controls, as required by MTCA (WAC 173-340-440[4][e]) on Boeing and offsite areas of the PMG SWMU until cleanup standards are met to prevent use of groundwater and surface water as a drinking water source, prevent human consumption of surface water or freshwater organisms, limit human contact with surface water for recreational purposes, and prevent or limit worker contact with contaminated groundwater.

Existing signage along the creek on the City of Everett property will be maintained throughout the cleanup regardless of whether other institutional controls are implemented.

2.3 Evaluation of Alternative 5 for Compliance with MTCA Requirements

This section evaluates Alternative 5 with the requirements in WAC 173-340-360(2)(a)&(b). The regulation provides the threshold and other requirements defined by MTCA for selecting cleanup actions.

2.3.1 Protection of Human Health and the Environment—WAC 173-340-360(2)(a)(i)

Alternative 5 will be protective of human health and the environment because it will effectively reduce levels of TCE in the plume at a faster rate than any of the other alternatives as a result of the combination of EISB in the source area for mass reduction, DGR in the downgradient plume to flush the aquifer and to minimize discharge of contaminated groundwater to surface water, and the implementation of institutional controls, if necessary, during cleanup to minimize potential human contact with or use of groundwater or surface water at the site. The combination of these measures will be protective of human and ecological receptors. Specifically, Alternative 5 will achieve cleanup standards, including:

- cleanup of groundwater to concentrations that are protective of drinking water standards, surface water beneficial uses, and the soil vapor to indoor air pathway; and
- cleanup of surface water to concentrations that are protective of surface water beneficial uses, including use as drinking water, consumption of organisms, recreational contact, and use/exposure by ecological receptors.[11]

[11] Boeing notes that these cleanup standards are conservative. Under current site conditions, there is negligible opportunity for exposure to contaminated groundwater or surface water at concentrations that represent a chronic or acute human or ecological exposure risk. There is currently no known usage of groundwater for drinking water or any other domestic purposes and the City of Everett supplies municipal water to all residents and businesses within the city limits. Surface water

2.3.2 Compliance with Cleanup Standards—WAC 173-340-360(2)(a)(ii)

Implementation of Alternative 5 will comply with the cleanup standards. Alternative 5 will achieve the groundwater and surface water cleanup standards as required by WAC 173-340-720 & -730 through active EISB treatment in the source area, and flushing, extraction, and treatment of groundwater in the downgradient plume through DGR. Alternative 5 should meet cleanup standards more rapidly than any other alternative. As further demonstrated in Section 3 below, compliance with these cleanup standards may be met at applicable POCs.

2.3.3 Compliance with Applicable or Relevant and Appropriate Requirements—WAC 173-340-360(2)(a)(iii)

Alternative 5 will comply with applicable state and federal laws, as required by WAC 173-340-710, in the same manner as the other four alternatives as summarized in Section 4 of the FS report. This will include, as necessary, revising the facility NPDES permit related to modification of the GET system to a DGR system, obtaining a UIC permit(s) for injection of treated groundwater related to the GR system and injection of donor for source area EISB, obtaining coverage under the construction stormwater general permit for system construction activities as necessary, and/or obtaining or complying with the substantive requirements of any other permit required by the City of Everett and Snohomish County.

2.3.4 Provide for Compliance Monitoring—WAC 173-340-360(2)(a)(iv)

Alternative 5 will comply with compliance monitoring requirements, as required by WAC 173-340-410, which include:

- Health and safety protection monitoring as provided under the procedures of the site-specific health and safety plan;
- Ongoing groundwater and surface water performance monitoring to evaluate progress in achieving cleanup objectives; and
- Confirmational monitoring in the form of sampling and monitoring of groundwater treatment system air and water effluent to comply with treatment goals and regulatory discharge limits, and final confirmation sampling after completion of the remedial action to comply with the cleanup standards in all applicable media.

2.3.5 Use Permanent Solutions—WAC 173-340-360(2)(b)(i)

In addition to threshold requirements, MTCA also requires that cleanup actions meet other requirements, including, when selecting a cleanup action, preference is given to permanent solutions to the maximum extent practicable (WAC 173-340-360[3]). Permanent solutions are cleanup actions

concentrations of TCE and other chlorinated volatile organic compounds (CVOCs) are below all ecological or human health hazard concentrations, except for human consumption of surface water as drinking water and consumption of organisms; however, there is no known current or likely future use of surface water from Powder Mill Creek as drinking water, and there is currently no known presence of fish in the section of Powder Mill Creek that is impacted with TCE. Soil vapor monitoring has demonstrated that the groundwater to indoor air pathway is not a pathway of concern in areas of the Site currently occupied by buildings.

that meet the cleanup standards without further action being required at the site (WAC 173-340-200). For some sites, determining whether a cleanup action uses permanent solutions to the maximum extent practicable, a disproportionate cost analysis (DCA) is required (WAC 173-340-360[3][e]). A summary of the DCA process and results for evaluation of Alternative 5 against the other four alternatives presented in the FS report is included in Section 3. That analysis shows that because Alternative 5 will increase contaminant mass recovery rates, accelerate the clean-up time frame through overall increased aquifer flushing rates, provide additional hydraulic control for the downgradient TCE plume, and enhance TCE mass destruction in the source area, Alternative 5 is the cleanup action alternative that is permanent to the maximum extent practicable.

2.3.6 Provide for a Reasonable Restoration Time Frame—WAC 173-340-360(2)(b)(ii)

"Restoration time frame" is defined by MTCA (WAC 173-340-200) as "the period of time needed to achieve the required cleanup levels at the points of compliance established for the site." This section summarizes how the restoration time frame(s) was estimated for Alternative 5 and evaluates it with respect to the nine factors established in WAC 173-340-360(4)(b) to assess whether the alternative provides for a reasonable restoration time frame.

The estimated restoration time frames for achieving the cleanup standards at various points of compliance using Alternative 5 (see Section 4) were determined using groundwater modeling (GMS/MODFLOW; see Appendix A) in combination with one or both of two restoration time frame estimating models, the Batch Flushing model (US Environmental Protection Agency [EPA] 1988) and the BIOCHLOR Natural Attenuation Decision Support System model (BIOCHLOR, Version 2.2, 2002 release).[12] These models are both industry standard and EPA-accepted tools for this type of application (EPA 1988, 2018). The results of particle tracking related to the MODFLOW model were used to identify flow paths, distances, and travel times that could be used as input parameters for the Batch Flushing and BIOCHLOR modeling to estimate restoration time frames associated with the source area and downgradient plume areas of PMG.

For the purposes of this SFS, for Alternative 5, the total restoration time is assumed to be the longer of the restoration time frames for the source area (resulting from EISB) and the downgradient plume (resulting from DGR). Based on the same assumptions used for restoration time frame analysis of the other alternatives (i.e., standard POC for groundwater meeting the drinking water standard), the estimated restoration time frame for DGR is approximately 15 years for the downgradient plume and approximately 23 years for the source area (see Table 2-1). Because meeting the cleanup standards site-wide is dependent on cleanup of the source area, a total restoration time frame for Alternative 5 is projected to be approximately 23 years.

[12] Data assumptions and input parameters for BIOCHLOR and Batch Flushing were the same as prior restoration time frame modeling for the Uplands/PMG FS as detailed in the *Restoration Time Frame Evaluation—Modeling Inputs/Sensitivity Analysis* Technical Memorandum (LAI 2017), except as described in Appendix A.

The restoration time frame for Alternative 5 is reasonable, based on the following MTCA restoration time frame evaluation factors in WAC 173-340-360(4)(b)(i)-(ix):

- **Potential risks to human health and the environment:** There is low risk to human health and the environment from implementation of Alternative 5. Because complete exposure pathways that present a potential, though limited, risk to human and ecological receptors are known to exist at the PMG SWMU (as described in Section 3.2.11 of the FS), Alternative 5 contains measures to address the exposure pathways and/or provide administrative or engineering controls to minimize exposure risk. Bioremediation of source area groundwater, along with flushing, capture, and treatment of contaminated groundwater in the downgradient plume will clean up the aquifer and minimize migration to Powder Mill Creek. Importantly, although the restoration time frame for the source area is longer than the downgradient plume to reach the drinking water standard, operation of the DGR system will result in conditions protective of the creek before the cleanup standards are met for the site as a whole (i.e., flushing of the downgradient aquifer and operation of the extraction wells for hydraulic control to minimize TCE discharge to the creek). Thus, the low potential risks to human health and the environment at the creek will be eliminated faster than for the entire plume, where the risks are even lower. In other words, the highest risk portion of the plume will be the fastest to reach cleanup standards. Also, Boeing does not and will not use groundwater on its property as a drinking water source. Therefore, this alternative is protective of human health and the environment.
- **Practicability of achieving shorter restoration time frame:** Based on analytical models (Batch Flushing model and BIOCHLOR), the restoration time frame for Alternative 5 is more rapid than for any of the other four alternatives presented in the FS (see Table 2-1). Accounting for the physical and administrative limitations of performing Alternative 5 at the PMG SWMU, it is not considered practicable to achieve a shorter restoration time frame. This is further demonstrated through the DCA evaluation, the results of which are described in Section 3.3.
- **Current and future use of the site, surrounding areas, and associated resources that are, or may be affected by releases from the Site:** The current use of the Boeing portion of the PMG SWMU is open space on an industrial property; the current use of the PMG SWMU off Boeing property (north of Seaway Boulevard) is for commercial/industrial office and warehousing, and open space.

  Most of the undeveloped/open space portion of the Site is located in areas with steep slopes, wetlands, or surface water (or associated buffer zones) and is unlikely or unable to be developed due to regulatory restrictions and setbacks for development in and around slopes and surface water bodies.[13] Boeing is unlikely to develop the portion of the PMG SWMU on its property. The City of Everett-owned "Lot 9" property is deed-restricted for use as open space for municipal and recreational purposes. The commercial/industrial park areas of the PMG SWMU have only recently been developed with new business spaces and are unlikely to change significantly over the duration of the cleanup.

  Utility workers (e.g., for underground power, sewer, and water) could encounter contaminated groundwater before cleanup levels are achieved, but proper use and implementation of administrative or institutional controls, if needed, can adequately manage

[13] See Chapter 19.37 of the City Everett Municipal Code—the purpose of which is to designate, classify, and protect the critical areas of the Everett community by establishing standards for development and use of properties which contain or adjoin critical areas and thus protect the public health, safety, and welfare.

this potential risk. Human contact and ecological contact/ingestion of contaminated water in Powder Mill Creek represents a risk for current and future exposure. The City of Everett property is open to the public, but signage is posted regarding the cleanup to discourage contact with the creek. Powder Mill Creek contains no known fish or shellfish populations in the TCE-impacted portion (Beamer et al. 2013),[14] thus human consumption of organisms does not occur. Surface water concentrations are below ecological or human health hazard concentrations except for those protective of human consumption of surface water as drinking water. However, there is no known current usage of the creek water for drinking water and future use as such is unlikely (see next bullet).

- **Availability of alternate water supplies:** The City of Everett supplies municipal water to all residents and businesses within the city limits, which include the PMG SWMU and surrounding areas. Therefore, use of surface water or groundwater as a water supply is not needed and would not be allowed without permission from the City of Everett and/or granting of water rights from Ecology.
- **Likely effectiveness and reliability of institutional controls:** If necessary, as required by MTCA if a CPOC is used, institutional controls used in conjunction with Alternative 5 are expected to be effective at preventing groundwater use and direct contact with contaminated groundwater during the cleanup action. The Boeing property is a fenced and access-controlled industrial property. The non-Boeing commercial properties have no complete exposure pathways, and installation of water supply wells would not be allowed by the City of Everett (the City of Everett provides municipal water supply). Institutional controls related to surface water include posted signage regarding the cleanup to discourage access to and contact with surface water, and the creek contains no known fish or shellfish populations in the segment impacted by TCE. Surface water cleanup standards are expected to be achieved for the creek relatively quickly under Alternative 5, limiting the duration of institutional controls.
- **Ability to control and monitor migration of hazardous substances from the Site:** Monitoring data indicates that TCE concentrations in the groundwater plume are steadily declining. The PMG downgradient plume IA is currently minimizing migration of hazardous substances off Boeing property and into Powder Mill Creek. DGR is anticipated to accelerate groundwater restoration and further minimize contaminant migration. There is a substantial monitoring network in place and Alternative 5 includes performance and compliance monitoring to verify that these conditions continue to improve. Therefore, the groundwater plume is and will be well-controlled and well-monitored.
- **Toxicity of hazardous substances at the Site:** The main constituents of concern (COCs) at the PMG SWMU are chlorinated solvents. The toxicity of these constituents is moderate to human and ecological receptors. Based on the relatively low and declining concentrations of COCs present, and the limited exposure scenarios for complete exposure pathways that would be likely to occur for human or ecological receptors, the toxic effects of hazardous substances at the Site provide minimal risk for adverse impacts.
- **Natural processes that reduce concentrations of hazardous substances and have been documented to occur at the Site or under similar site conditions:** The chlorinated volatile organic compounds (CVOCs) found in groundwater at the Site have moderate to high susceptibility for biodegradation. Monitoring data for CVOCs in surface water (creek and

[14] Salmonid species have been identified in the lower 200 meters of Powder Mill Creek; however, none have been observed or documented upstream of Mukilteo Boulevard, a large culvert beneath which is an apparent fish passage barrier.

wetlands) and the groundwater transitional/hyporheic zone indicate that the CVOCs attenuate rapidly over relatively short distances approaching the discharge point into the creek. This attenuation is most likely due to natural processes (e.g., aerobic and anaerobic biotic and abiotic processes) that are documented in this groundwater zone and particularly effective in degrading chlorinated ethenes (Weatherill et al. 2017, EA 2005). The attenuation is a prominent factor in further reducing risk to potential receptors. PMG SWMU groundwater data indicate that rates of natural degradation in groundwater are relatively low, but the data from the interim actions performed to date indicate that naturally occurring processes that reduce contaminant concentrations can be enhanced significantly where relatively high contaminant mass remains. Source area EISB will further stimulate biological processes in this area, and DGR in the downgradient plume will further enhance natural physical processes.

Because of the low risk to human health or the environment under current and future land uses, and Alternative 5's strong performance under the other factors identified above, Alternative 5 will achieve cleanup of the PMG SWMU within a reasonable restoration time frame.

2.3.7 Consideration of Public Concern—WAC 173-340-360(2)(b)(iii)

Although Alternative 5 has not been presented to the public at this time, Boeing considered known or potential public concerns in developing Alternative 5. Boeing is not aware of any specific concerns that have been expressed by the public to date during previous meetings with neighborhood groups in the PMG area (e.g., Boulevard Bluffs Neighborhood Coalition) over performance of EISB in the source area or groundwater extraction in the downgradient plume (as related to the other alternatives that include these elements). As discussed above, Alternative 5 is designed to achieve cleanup standards that are protective of the creek more rapidly than the other alternatives presented in the FS. This SFS will be the subject of public review and comment and Boeing looks forward to participating in that process.

3.0 DETAILED EVALUATION OF REMEDIAL ACTION ALTERNATIVES

This SFS report compares and evaluates each of the five remedial alternatives using the procedures for an FS specified in WAC 173-340-350 & -360. The evaluation process used for comparing remedial alternatives is described in detail in the FS report in Section 8.0 and associated figures. The evaluation of each alternative with MTCA requirements are detailed in the FS report at Section 8.0 for the four remedial alternatives evaluated in the FS, and in Section 2 of this SFS for Alternative 5.

For the DCA evaluation in this SFS, the same process of benefit scoring, weighting the evaluation criteria, and comparing the costs and benefits that was used in the FS is used here for evaluating all five remedial alternatives. For this evaluation, the benefit scoring used for the four FS alternatives (as modified by Ecology), are unchanged from those in the revised DCA included in Attachment 1D of Boeing's September 2017 formal dispute letter (Boeing 2017a). Cost estimates for the FS alternatives have been updated, as applicable, to reflect Ecology's modifications to the alternatives and, consistent with the assumptions of the FS, assume that the restoration time frames are based on achieving drinking water standards in groundwater.[15] The cost estimates are included in Appendix B along with the cost estimate for the new Alternative 5.

3.1 Requirements for a Permanent Solution to the Maximum Extent Practicable

The MTCA regulation requires that cleanup actions be permanent to the maximum extent practicable (WAC 173-340-360[2][b][i]). WAC 173-340-200 defines a permanent solution as one "in which [relevant cleanup standards] can be met without further action being required at the site being cleaned up or any other site involved with the cleanup action, other than the approved disposal site of any residue from the treatment of hazardous substances." However, the regulation requires that cleanup actions be permanent "to the maximum extent practicable." The regulation defines "practicable" as "capable of being designed, constructed, and implemented in a reliable and effective manner including consideration of cost. When considering cost under this analysis, an alternative shall not be considered practicable if the incremental costs of the alternative are disproportionate to the incremental degree of benefits provided by the alternative over other lower cost alternatives."

The regulation also provides a methodology for determining whether a cleanup action is permanent to the maximum extent practicable in WAC 173-340-360(3). That methodology includes the use of a DCA (WAC 173-340-360[3][e]).

[15] Consistent with the FS evaluation, for direct comparison between the five FS alternatives, the analysis is based on each alternative meeting the groundwater and surface water cleanup levels (4 micrograms per liter [µg/L] TCE in groundwater and 0.3 µg/L TCE in surface water) in their respective media at the standard POCs.

WAC 173-340-360(3)(e)(ii) provides a process under which remedial alternatives are reviewed, and WAC 173-340-360(3)(f) provides specified disproportionate cost evaluation criteria that are used to determine whether a cleanup action is permanent to the maximum extent practicable.

Under the DCA, costs are considered disproportionate to benefits if the incremental costs of the more permanent alternative exceed the incremental degree of benefits achieved by the other lower cost alternative (WAC 173-340-360[e][i]). MTCA further clarifies that "Where two or more alternatives are equal in benefits, the department shall select the less costly alternative provided that the requirements of subsection (2) of this section are met" (WAC 173-340-360[3][e][ii][C]).

3.2 Alternative 5 Benefit Analysis

Table 3-1 provides descriptions of the assumptions and considerations used for benefit scoring and ranking under each DCA evaluation criteria for Alternative 5. Based on the ranking considerations for Alternative 5 and comparison against the other four alternatives, the score/value assigned for each criterion (and associated weighting factor—consistent with the weighting factors used in the original FS/DCA)[16] are provided below:

- Protectiveness (30 percent): 9
- Permanence (20 percent): 9
- Effectiveness over the long term (20 percent): 9
- Management of short-term risks (10 percent): 8
- Technical and administrative implementability (10 percent): 8
- Consideration of public concerns (10 percent): 10
- Cost (not weighted): $14,100,000

The rationale for the scores provided to each of these criteria is discussed in Section 3.3 below.

Based on the raw scores and the weighting factor assigned to each criterion, the **overall weighted benefit score for Alternative 5 is 8.9**.

3.3 Results of Disproportionate Cost Analysis

The results of the DCA for the five alternatives identified in Sections 2.1 and 2.2 are provided as attachments to this report. Table 3-2 provides a summary of the complete DCA evaluation with

[16] Note that the use of weighting factors are not specifically included under MTCA; however, it has become a widely used and accepted practice by the regulated community and Ecology to assign weighting to the DCA criteria. For example, refer to the DCA for Whatcom Waterway/Bellingham Bay cleanup sites and associated Ecology guidance (Whatcom County Superior Court 2007, Ecology 2008). The weighting factors identified above are typical for FS DCA evaluations performed under MTCA; protectiveness, permanence, and long-term effectiveness criteria are typically weighted more heavily "since they are core to protecting human health and the environment" (Ecology 2017b). Additionally, Ecology guidance accepts and authorizes the use of alternative ranking and DCA criteria weighting. *See* Sediment Cleanup User's Manual II, at Section 12.4.5 and Appendix H (approving of ranking alternatives and using relative weights to DCA benefit criteria). Boeing used the weights provided in Appendix H, Section H.1.4 in this SFS DCA and in the 2015 FS Report.

comparisons of the benefit scores to the associated cost estimates related to each alternative, including the relative benefit-to-cost ratio used for comparing each alternative and identifying which alternative is considered permanent to the maximum extent practicable. Figure 3-1 provides a visual representation of the results provided in the tables. Appendix B includes the detailed cost estimates for Alternatives 1 through Alternative 5.

The following provides a brief summary of the rankings for each alternative for each DCA criteria:

- Protectiveness: Alternative 5 received the highest benefit ranking for the protectiveness criteria because it reduces risks more rapidly than any other alternative and achieves cleanup standards across the Site significantly faster than any of the other alternatives. As previously indicated by Ecology, "There is value in hastening groundwater cleanup…if it is technically practicable to achieve [shorter] groundwater and surface water (creek) restoration time frames…this is what we should do" (Ecology 2017c).
- Permanence: Alternative 5 received the highest benefit ranking for the permanence criteria because, in addition to irreversibly reducing contaminant toxicity, mass, and volume through source area *in situ* treatment and downgradient capture, DGR will further inhibit potential plume migration through treated water reinjection along the plume boundaries, which none of the other alternatives would do.
- Effectiveness over the long term: Alternative 5 received the highest benefit ranking for the long-term effectiveness criteria because it has the highest degree of certainty, compared to the other alternatives, that it will be successful in achieving site cleanup and be reliable while contaminant concentrations are above cleanup levels (over a shorter duration than the other alternatives).
- Management of short-term risks: Alternative 1 received the highest benefit ranking for the management of short-term risks criteria because it includes no additional drilling (unless required by Ecology for additional monitoring purposes) or construction activities that could pose risk to site workers.
- Technical and administrative implementability: Alternative 1 received the highest benefit ranking for technical and administrative implementability criteria because it includes no additional construction or implementation and minimal long term operations and maintenance (O&M); additional administrative requirements include only the implementation of institutional controls and ongoing compliance with the NPDES discharge permit (also required for all the other alternatives).
- Consideration of public concerns: All the alternatives are ranked equally for the consideration of public concerns criteria. Each alternative will consider public concerns in the same manner by responding to comments received during the required public comment period for the RI/FS (and possibly the cleanup action plan) as part of the cleanup process under MTCA.

- Cost: Alternative 1 is the least expensive alternative and Alternative 4 is the most expensive as summarized below (a breakdown of these costs is presented in Tables B-1a through B-1e) and summarized below.
  - Alternative 1: $12.3 million
  - Alternative 2: $14.0 million

- Alternative 5: $14.1 million
- Alternative 3: $21.6 million
- Alternative 4: $22.3 million

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

- Alternative 5: 8.9
- Alternative 3: 7.7
- Alternative 2: 7.5
- Alternative 4: 7.3
- Alternative 1: 6.9

Based on the weighted benefit scores identified above, Alternative 5 has the highest overall benefit score and is considered the most permanent alternative being evaluated. However, Alternative 5 is estimated to be more expensive than two other alternatives. Under the DCA, costs are considered disproportionate to benefits if the incremental costs of the more permanent alternative exceed the incremental degree of benefits achieved by the other lower cost alternative (WAC 173-340-360[e][i]).

To aid in determining whether the cost of Alternative 5 is disproportionate to its benefits and to provide a quantitative approach for direct comparison of each alternative (WAC 173-340-360[3][e][ii][C]), the benefit-to-cost ratio was determined for each alternative by dividing the calculated overall weighted benefit score by the cost of the alternative.[17] This benefit-to-cost ratio provides a metric to evaluate whether the cost of each alternative is commensurate with its benefits. The alternative with the next higher relative benefit-to-cost ratio than the most permanent alternative being evaluated is considered "permanent to the maximum extent practicable" so long as its benefits are also not disproportionate to its costs compared to other alternatives with still higher benefit-to-cost ratios.

The overall weighted benefit score, estimated cost, and calculated relative benefit-to-cost ratio identified by the DCA for each Alternative are as follows:

Remedial Alternative	Overall Weighted Benefit Score	Estimated Remedy Cost ($millions)	Relative Benefit-to-Cost Ratio
Alternative 1	6.9	$12.3	6.9
Alternative 2	7.5	$14.0	6.6
Alternative 3	7.7	$21.6	4.4
Alternative 4	7.3	$22.23	4.0
Alternative 5	8.9	$14.1	7.8

[17] This value is also then multiplied by the cost of the lowest cost alternative to normalize and scale the data to fit on the chart.

A graph of the DCA results for the PMG SWMU/AOC showing the relative benefit and cost for each alternative is presented in Figure 3-1. Relative benefit scores for each alternative are shown by benefit (green) bars. Alternatives costs are shown by cost (red) bars. The figure also displays the relative benefit-to-cost ratios with an overlying (blue) line graph; the alternative with highest benefit-to-cost ratio has the highest benefit-to-cost score on this line.

Alternative 5 has both the highest benefit score and the third lowest cost of all the alternatives resulting in the highest benefit-to-cost ratio over both higher and lower cost alternatives (as illustrated on Figure 3-1). This indicates that more expensive alternatives are disproportionately costly to their incremental increase (or decrease in this case) in benefits, and less costly alternatives have lower benefits that cannot be justified by the decrease in cost. Therefore, based on the MTCA DCA evaluation, Alternative 5, which includes *in situ* groundwater treatment in the source area with EISB and DGR to treat groundwater in the downgradient plume, is permanent to the maximum extent practicable and is the preferred alternative.

4.0 EVALUATION OF GROUNDWATER POINT OF COMPLIANCE

Under the MTCA regulation (WAC 173-340), the cleanup standards for a site remedial action consist of concentrations to which hazardous substances present at the site must be cleaned up (cleanup levels [CULs]); the location where those CULs must be met (i.e., POCs), and other applicable, relevant, and appropriate requirements (ARARs) that apply to the site, including applicable requirements for how CULs and POCs must be applied (WAC 173-340-700[3]).

Ecology's August 6, 2018 letter (Ecology 2018), states that SWQS must be met at a POC in groundwater at PMG, and requested an evaluation of four POCs (one standard POC and three CPOCs) to determine whether a CPOC may be used for the PMG SWMU. As discussed in the Executive Summary and prior submittals to Ecology (Boeing 2017a), Boeing has made clear that Ecology's application of surface water standards to groundwater is not authorized by law. Nevertheless, as requested by Ecology, Boeing has evaluated groundwater POC options in this SFS using the SWQS (0.3 micrograms per liter [µg/L] TCE) as the groundwater CUL at the standard POC and three individual CPOC locations. In addition to the POC options identified by Ecology, Boeing evaluates a standard POC option for groundwater using drinking water standards (4 µg/L TCE) and a fourth CPOC option using the SWQS as the groundwater CUL in the transitional zone at the creek. All the POC options evaluated provide that a standard POC for surface water (i.e., throughout the creek) must meet a cleanup level equal to the SWQS (0.3 µg/L TCE).

The MTCA regulation provides for the use of CPOCs for groundwater (WAC 173-340-720[8][c]&[d]). Ecology may approve use of a CPOC for the PMG SWMU, if this evaluation:

1) demonstrates that, by implementing Alternative 5, it is not practicable to meet the surface water CUL in groundwater throughout the Site in a reasonable restoration time frame such that the Site qualifies for use of a groundwater CPOC (WAC 173-340-720[8][c]); and
2) identifies how the use of an on-property or off-property CPOC complies with WAC 173-340-720(8)(c)&(d).

Additionally, per its August 6, 2018 letter (Ecology 2018), Ecology has stated that this evaluation must also demonstrate that a CPOC is permanent to the maximum extent practicable by using the MTCA DCA process (WAC 173-340-360[3]) to evaluate Alternative 5 at a series of groundwater standard and conditional POC options for PMG.

The following sections use the MTCA feasibility study process (WAC 173-340-350[8][a]&[b]), including the regulatory and Ecology criteria above, to provide a technical practicability assessment, disproportionate cost analysis, and regulatory assessment to evaluate the appropriateness and applicability of using the drinking water CUL at the standard POC for groundwater, and the SWQS as the groundwater CUL at the standard POC and four CPOCs for groundwater.

4.1 Practicability of Meeting the Surface Water Cleanup Level in Groundwater Throughout the Site in a Reasonable Restoration Time Frame

WAC 173-340-720(8), regarding POCs, first requires an evaluation of WAC 173-340-350 through -390 to assess the practicability of meeting a reasonable restoration time frame. This section provides that evaluation and demonstrates that while the drinking water standard can be met at the standard POC in a reasonable restoration time frame, the surface water CUL in groundwater cannot be met in a reasonable restoration time frame throughout the Site.

WAC 173-340-350(8)(b)(i&ii) and 173-340-350(8)(c)(i)(F) state that (paraphrased) the FS shall include alternatives with the standard POC for each environmental media containing hazardous substances, unless those alternatives have been eliminated because the cost of those alternatives are clearly disproportionate (see Section 4.3 below) and the components of that alternative are not technically possible at the site. WAC 173-340-720(8)(c) also states that “Where it can be demonstrated…that it is not practicable to meet the cleanup level throughout the site within a reasonable restoration time frame, the department may approve a conditional point of compliance…”.

4.1.1 Technical Impracticability of Meeting Surface Water Standards in Groundwater

WAC 173-340-350(8)(b)(ii) indicates that determining the feasibility of remedial alternatives or components should include evaluation of whether they will be “technically possible at the site”. Based on the current state of the science for remediation of CVOC sites (discussed below), achieving extremely low cleanup levels, such as the SWQS for TCE of 0.3 µg/L, in groundwater is not technically practicable in a reasonable time frame at nearly all cleanup sites. Thus, it is likely not currently possible to meet that extremely low surface water CUL for TCE throughout groundwater at the Site in a reasonable restoration time frame with available active remediation technologies.

In order for the SWQS to be achieved in groundwater throughout the PMG SWMU, TCE concentrations would have to be reduced over an order of magnitude below the state drinking water standard (4 µg/L for TCE) or federal maximum contaminant level (MCL; 5 µg/L for TCE), and the overall TCE concentrations in the source area would have to be reduced by approximately 5 orders of magnitude (99.999 percent reduction) from initial concentrations identified in the source area during the RI (i.e., more than 30,000 µg/L TCE). Even from current high concentrations of approximately 300 µg/L, a 3-order of magnitude (99.9 percent) reduction would be necessary to achieve the SWQS throughout the PMG SWMU. Available literature data, as discussed below, indicates that achieving such significant reductions to such low levels of CVOCs throughout the plume is essentially unachievable within a reasonable restoration time frame by active remedial technologies.

In a recent US Department of Defense Environmental Security Technology Certification Program (ESTCP) publication (ESTCP 2016), a large data mining and evaluation exercise was completed to develop a comprehensive remediation performance and cost database. In this study, data from 235 Department of Defense CVOC cleanup sites were evaluated that used *in situ* remediation technologies, including 117 EISB sites, 70 ISCO sites, 23 thermal treatment sites, 21 chemical reduction sites, and 4 surfactant flushing sites.[18] The study evaluated CVOC concentrations at each site before and after cleanup, and the corresponding order of magnitude concentration reductions achieved at the site for the various remedial technologies. The results of the study identified that the mean concentration reduction for all 235 sites was 1.1 orders of magnitude (91 percent), and "Only 7% of 235 sites achieved MCLs (e.g., 5 µg/L for PCE and TCE) at every monitoring well…" (ESTCP 2016). These performance results were reportedly statistically consistent regardless of the time frame of active remediation or the duration of monitoring following the active treatment period.[19] More specifically and more pertinent to the PMG SWMU, only one site achieved both a final parent CVOC concentration that was at or below 1 µg/L (actual final concentration was not identified) and a concentration reduction of 5 orders of magnitude (99.999 percent).[20]

The ESTCP study builds on previous studies (e.g., ITRC 2011, NRC 2005, 2013) that reached similar conclusions regarding the impracticability of achieving typical CULs (e.g., MCLs) in a reasonable restoration time frame in aquifers impacted by a CVOC source zone. It is widely understood and accepted based on numerous studies and publications (e.g., Mackay and Cherry 1989, Ball et al. 1998, Chapman and Parker 2005, Sale et al. 2008) that the primary factor that limits an *in situ* remedial action's ability to achieve very low CULs is matrix diffusion (back diffusion and desorption) related to low-permeability soils such as silts and clays, which can be a very slow process and result in the cleanup of groundwater taking many decades.

The findings in these studies are directly applicable to the Site. Specifically, the matrix diffusion effects for TCE sorbed to silts in the aquifer may result in the ongoing presence of TCE in groundwater above the SWQS that may persist for many years to decades. Based on these findings, it is not technically practicable or feasible for Alternative 5 (or any other remedial alternative) to achieve the SWQS at the groundwater standard point of compliance within a reasonable restoration time frame under the factors provided in WAC 173-340-360(4).[21] Therefore, the MTCA criteria in WAC 173-340-720(8)(c) for use of a CPOC at the PMG SWMU have been satisfied if SWQS are used as CULs for groundwater.

---

[18] Department of Defense cleanup sites provide a particularly relevant sample for consideration here because of the number of Department of Defense sites that historically used solvents, particularly TCE, and that have large, mature TCE groundwater plumes. (*See generally* ESTCP 2016.)

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

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

[21] However, based on previous evaluation of contaminant concentration attenuation in groundwater approaching the surface water body (Boeing 2017b), current Site data and data trends demonstrate that the SWQS can be achieved in groundwater in the transitional zone/hyporheic zone beneath the creek.

4.1.2 Reasonableness of Estimated Restoration Time Frames to Meet Cleanup Standards at Evaluated Points of Compliance

Depending on the POC selected and the CUL required for that POC (see Section 4.3.1 below), the estimated restoration time frame for Alternative 5 ranges from 15 to 23 years, respectively, for downgradient plume and source area cleanup to the drinking water standards, and likely more than 44 years for cleanup of the entire groundwater plume to the SWQS.[22]

The relatively short restoration time frames (15 to 23 years) for cleanup of groundwater in the source area and downgradient plume (at the standard POC) to drinking water standards are considered reasonable based on the factors identified under WAC 173-340-360(4)(b) as shown in Section 2.3.6. Also as shown in Section 4.3.3, the standard POC in groundwater using the drinking water standards is permanent to the maximum extent practicable. Therefore, under MTCA, a CPOC would not be allowable,[23] and the standard POC using drinking water cleanup levels for groundwater should be selected for use at the Site.

However, if Ecology selects the SWQS as the CUL for groundwater, the much longer restoration time frame (44 years or more) for cleanup to the SWQS in groundwater throughout the Site is not reasonable, particularly when assessed in the context of the technical impracticability of doing so, as discussed in Section 4.1.1 above. Thus, the MTCA criteria in WAC 173-340-720(8)(c) for use of a CPOC at the Site would be satisfied (and necessary) if SWQS are used as CULs for groundwater. However, it will also be technically impracticable to meet the SWQS in a reasonable restoration time frame at Ecology's requested CPOC locations within the groundwater TCE plume. The exception to this issue may be the use of a CPOC located in the transitional/hyporheic zone (included in the CPOCs evaluated in Section 4.3), where the unique nature of contaminant attenuation in this zone (Weatherill et al. 2017, EA 2005) should allow for a reasonable restoration time frame.

4.2 Factors for Use of an Off-Property Conditional Point of Compliance

Under WAC 173-340-720(8), where a CPOC is to be set off-property, additional evaluation is required. This section turns to that demonstration.

Per WAC 173-340-720(8)(d)(i), certain conditions must be met in order to use a CPOC where the groundwater cleanup level is based on protection of surface water beneficial uses for a property abutting surface water (although such a CPOC would only be "off property" at locations on the City of

[22] Note that, as described in Appendix A, experimental isotherm data from literature indicate that at low TCE concentrations in an aquifer, the assumption for retardation factors generally used in the Batch Flushing model are not reasonably predicted by linear isotherms due to desorption or back diffusion limited behaviors and are better predicted by non-linear isotherms such as those described by the Freundlich desorption isotherm. So for TCE concentration decreases between 4 µg/L and 0.3 µg/L, the Batch Flushing Model using the Freundlich equation predicts substantially longer site-wide restoration time frames.

[23] WAC 173-340-350(8)(c)(i)(F) states "The feasibility study shall include alternatives with the standard point of compliance for each environmental media containing hazardous substances, unless those alternatives have been eliminated under (b) of this subsection, and may include, as appropriate, alternatives with conditional points of compliance."

Everett Lot 9 property, this situation also appears to be applicable to Boeing property abutting Powder Mill Creek). Each condition (paraphrased) is provided below, followed by specific comments relative to the site and Alternative 5 (in *italics*):

a) It must be demonstrated that contaminated groundwater is entering and will continue to enter the surface water even after implementation of the cleanup action.

   Groundwater and surface water sampling data collected during current and ongoing implementation of the Phase 1 and Phase 2 interim actions has demonstrated that CVOC-contaminated groundwater discharge to the creek has been substantially reduced by operation of the GET system as documented in quarterly interim action monitoring reports submitted since GET system startup in 2012. However, ongoing creek sampling data shows that discharge to the creek continues (also documented in the same quarterly reports). That discharge is likely to continue despite operation of the current extraction wells and future operation of new extraction wells included in Alternative 5 until the TCE-impacted plume is depleted because it is impracticable to achieve complete containment of groundwater flow from this portion of the aquifer to the creek.

b) It must be demonstrated that it is not practicable to meet the CUL at a point within the groundwater before entering the surface water within a reasonable restoration time frame.

   As demonstrated in Section 4.1 above and the references cited in that section, meeting the SWQS in groundwater is technically impracticable to achieve (other than in the transitional/hyporheic zone beneath the creek [Weatherill et al. 2017, EA 2005]) within a reasonable restoration time frame regardless of the remedial alternative selected. Table 4-1 and Figure 4-8 show the modeled restoration time frames and demonstrate the significant increase in restoration time frame length to achieve the SWQS within the plume without proportionate cleanup benefit. Based on the analysis in Section 4.1, the very long, unreasonable time frames estimated for achieving the SWQS in groundwater may be significantly underestimated due to matrix diffusion effects.

c) Use of a mixing zone to demonstrate compliance with surface water CULs is not allowed.

   Use of a surface water mixing zone (as defined in WAC 173-201A) to demonstrate compliance with surface water CULs (SWQS) in surface water is not proposed under Alternative 5.

d) All known available and reasonable methods of treatment must be provided to groundwater discharges prior to release to surface water.

   Multiple possible cleanup alternatives have been analyzed for this Site in the 2015 FS report and this SFS. As shown in Sections 2 and 3, conversion of the GET system to a DGR system enhances hydraulic control and capture of contaminated groundwater and provides all known available and reasonable methods for treatment and flow of groundwater before discharge to surface water.

   Operation of the GET system has provided (and continues to provide) treatment of groundwater in the downgradient plume and has proven to be effective as documented in quarterly interim action monitoring reports submitted since GET system startup in 2012. Substantial source area treatment has already been completed resulting in significantly less mass available to discharge to surface water as documented in monthly and quarterly source area interim action progress reports from 2006 to 2018.

In addition to the significant cleanup results achieved by operation of the GET system, Alternative 5 enhances and expands the GET system and includes injection wells and additional extraction wells for enhanced downgradient plume capture and treatment and additional source area EISB treatment to further enhance and optimize protection of the surface water and reduction of restoration time frames. As discussed in Section 2.2.1, DGR systems are proven, effective systems to address large, mature solvent plumes. Thus, operation of the GET system and the implementation of Alternative 5 provide all known available and reasonable methods of treatment for this Site.

e) Groundwater discharges must not violate sediment quality values.

Previous sediment evaluations (AECOM 2016) have demonstrated sediment in Powder Mill Creek does not violate any applicable TCE and other CVOC sediment quality values and indicated that sediments in Powder Mill Creek are primarily granular in nature,[24] providing minimal potential for sorption of TCE/CVOCs to the sediment matrix. The decreases of TCE and other CVOC concentrations and discharges to Powder Mill Creek over time corresponding to the decreases from historically high concentrations in the aquifer represents a reduced risk of impacts to sediment quality because as these discharges provide progressively lower concentration gradient-driven potential for sorption to fine-grained materials and/or organic materials in sediment and accumulation and increased potential for desorption.

f) Groundwater and surface water monitoring shall be conducted to assess long-term performance including for potential bioaccumulation.

Performance and compliance monitoring is included in Alternative 5 to assess long-term performance and will be planned and documented in an Ecology-approved cleanup action plan as required by MTCA. TCE is known to have low or negligible tendencies to bioaccumulate in the food chain or aquatic organisms based on low measured bioconcentration factors and estimated bioaccumulation factors (EPA 2017).

g) Notice of the proposal to use a CPOC shall be provided to the natural resource trustees, the Department of Natural Resources, and the US Army Corps of Engineers.

Such notice will be provided as required if a CPOC is selected for the PMG SWMU.

In addition to the conditions above, per WAC 173-340-720(8)(d)(ii), for properties near, but not abutting surface water "the affected property owners between the source of contamination and the surface water body must agree in writing to the use of the conditional point of compliance." This is applicable to the PMG SWMU because contamination in groundwater originating from the Boeing property also flows across other properties not owned by Boeing prior to discharge to portions of the surface water. Boeing anticipates that, if necessary, the owners of the Lot 9 property (City of Everett), the Powder Mill Business Center property (PowderMill Phase 1 LLC), and the Seaway Center property (Seaway West LLC) will be willing to provide written agreement to the use of a CPOC if selected and approved by Ecology, and Boeing will work with these owners and Ecology to secure their agreement.

[24] The investigation results indicated that "The sediments generally consist of silt, silty sand, and sand. The sand size ranges from fine to coarse-grained sand" and "The thickness of soft sediment ranged from approximately 3 inches to 1 foot, and the average grain size was 80 percent sand" (AECOM 2016).

In summary, the conditions for use of a CPOC at a property abutting surface water, as found in WAC 173-340-720(8)(d)(i), have been or can be satisfied such that such a CPOC can be approved by Ecology.

4.3 WAC 173-340-360 Evaluation and Disproportionate Cost Analysis for Optional Points of Compliance

Sections 4.1 and 4.2 demonstrate that, consistent with MTCA, Ecology can approve an off-property groundwater CPOC in the absence of approval of the standard groundwater POC. This section evaluates the potential locations for the CPOCs that Ecology identified and requested Boeing to evaluate. Section 3.0 demonstrated that under WAC 173-340-360, Alternative 5 will be effective in more rapidly achieving cleanup standards. Additionally, Ecology requested that Boeing "include a Disproportionate Cost Analysis…looking at the new remedial alternative [Alternative 5] to meet all four potential groundwater points of compliance options [the options provided in Ecology's letter] to determine which of those are permanent to the maximum extent practicable under WAC 173-340-360(3)" (Ecology 2018, Attachment A). This section provides that analysis.

The DCA process specified in WAC 173-340-360(3) is intended to be used to evaluate whether remedial alternatives are (or are not) permanent to the maximum extent practicable and involves comparing the benefits of each alternative, based on a series of specified evaluation criteria (see WAC 173-340-360[3][f]), to the cost of each alternative, and selecting the alternative whose incremental costs are not disproportionate to the incremental benefits. Per Ecology's direction, this section describes the results of a DCA evaluation for the four POC options identified by Ecology as well as the standard POC option and a transitional zone CPOC option as required or allowable under MTCA.

4.3.1 Points of Compliance Being Evaluated

The POC options and associated cleanup levels for each media that are being evaluated for Alternative 5 in this SFS are listed below. Each POC option must include meeting a cleanup level equal to the SWQS (0.3 µg/L TCE) at the standard POC for surface water (i.e., throughout the creek).[25] Ecology also stated in its letter (Ecology 2018) that "Ecology anticipates that groundwater throughout the site will meet a groundwater cleanup level protective of drinking water (4 µg/L TCE)." This statement was further clarified by Ecology in a September 21, 2018 meeting as a requirement applied to groundwater for each CPOC option regardless of where the SWQS is required to be met at any of the CPOC locations. Therefore, in addition to the four POC options Ecology requested for evaluation (Options 2b through 5 below), Boeing evaluates the standard POC option for groundwater and surface water using these groundwater and surface water cleanup levels as the appropriate and applicable baseline option for PMG (Option 1 below). Option 1 is protective of human and ecological receptors and is consistent with the POC used for evaluation of the five remedial alternatives as discussed in Section 3.

[25] Boeing commits to address groundwater seeps as discussed in its November 16, 2017 letter (Boeing 2017b).

Ecology has instructed that: "where [groundwater] cleanup levels are based on protecting nearby surface water, compliance with those standards [e.g., the surface water quality criteria] *will generally be based on surface water monitoring performed as close as possible to the groundwater/surface water interface* [emphasis added]…" (Ecology 1991). MTCA (WAC 173-340-720[8][d][i&ii]) is a reflection of the regulatory implementation of this statement. At the Site, the closest points that are possible to the groundwater/surface water interface are in the creek immediately above the creek bed, as identified in POC Option 1, or in pore water immediately beneath the creek bed. Therefore, Boeing also evaluates a CPOC option using the SWQS for groundwater in the transitional zone (in pore water) at the creek (Option 2a below) that is applicable under MTCA and Ecology guidance (Ecology 2017a) for contaminated groundwater abutting surface water. The Ecology guidance document specifically clarifies and defines the transitional zone as groundwater, states that the transitional zone includes the hyporheic zone and sediment pore water, and illustrates CPOC locations in the transitional zone.[26]

Importantly, Ecology's requirement to meet the requirements for Option 1 under all circumstances consequently means that each CPOC option evaluated below (Options 2a through 4) consists of the standard POC for groundwater and surface water using the drinking water standard (4 µg/L TCE) and SWQS (0.3 µg/L TCE), respectively (i.e., Option 1), plus an additional CPOC where the SWQS must also be met in groundwater). The six POC options evaluated are:[27]

- **Option 1: Groundwater and Surface Water Standard POCs**—the drinking water standard (4 µg/L TCE) must be met in monitoring wells throughout the groundwater TCE plume and the SWQS (0.3 µg/L TCE) must also be met within the creek water at sampling points immediately above the creek bed (see Figure 4-1).
- **Option 2a: Groundwater and Surface Water Standard POCs Modified to Include Groundwater CPOC in the Transitional Zone at the Creek**—modifying the standard MTCA requirements in Option 1, the SWQS (0.3 µg/L TCE) must also be met in pore water/hyporheic zone sampling points beneath the creek bed or immediately adjacent to the creek (see Figure 4-2a).[28]
- **Option 2b: Groundwater and Surface Water Standard POCs Modified to Include Groundwater CPOC in the Monitoring Wells Upgradient of the Creek[29]**—modifying the standard MTCA requirements in Option 1, the SWQS (0.3 µg/L TCE) must also be met at existing monitoring wells upgradient of the creek (see Figure 4-2b).[30]

---

[26] See Ecology 2017a—terminology, physical setting definitions, and policy highlight (pages 1–3), and Figure 5a (page 16).

[27] POC Options 2b through 5 correspond to POC Options A through D from Ecology's decision letter (Ecology 2018).

[28] Except on Boeing property where groundwater compliance samples will be located "within the surface water as close as technically possible to the point or points where ground water flows into the surface water" as allowable under WAC 173-340-720(8)(d)(i) for properties abutting surface water; also see Ecology Implementation Memorandum No. 16 (Ecology 2017a) Figure 4a and associated explanatory statements (page 13).

[29] Ecology's letter referred to these wells as being located in the "buffer zone," which is not a MTCA-defined term.

[30] For purposes of this SFS, these wells are assumed to include (from south to north) PMG-P20, PMG-P12A, PMG-P12B, PMG-P14A, PMG-P14B, PMG-P16, PMG-P18, PMG-P3, PMG-P5, PMG-P7, EGW202, EGW195, EGW197, EGW199, and EGW205. Per Ecology's request, Boeing has also included costs for installation and monitoring of up to seven additional monitoring wells upgradient of the creek to be used for POC Option 2b.

- **Option 3: Groundwater and Surface Water Standard POCs Modified to Include Groundwater CPOC at Boeing Property Line and Upgradient of the Creek on Boeing Property**—modifying the standard MTCA requirements in Option 1, the SWQS (0.3 µg/L TCE) must also be met at existing monitoring wells along the Boeing property line and upgradient of the creek on Boeing property (and at all groundwater monitoring points downgradient of these wells; see Figure 4-3).[31]
- **Option 4: Groundwater and Surface Water Standard POCs Modified to Include Groundwater CPOC Immediately Downgradient of the Source Area**—modifying the standard MTCA requirements in Option 1, the SWQS (0.3 µg/L TCE) must also be met at monitoring wells located immediately downgradient of the TCE source area/detention basin (and at all monitoring points downgradient of these wells; see Figure 4-4).
- **Option 5: Groundwater Standard POC Using SWQS**—the SWQS (0.3 µg/L TCE) must be met in monitoring wells throughout the groundwater TCE plume and in the creek water at sampling points immediately above the creek bed (see Figure 4-5).

Figures 4-6a and 4-6b provide conceptual cross sections illustrating the relative locations of the four CPOC options (POC options 2a–4) in relation to Powder Mill Creek, the Boeing property line, and the source area.

The use of both a standard POC and CPOC is inconsistent with application of CPOCs in groundwater under MTCA.[32] Notwithstanding that issue, per Ecology's direction, Boeing evaluated POC Options 2b through 4 assuming the TCE drinking water cleanup level will be met at the standard POC (i.e., at all points *upgradient* of the CPOC) in addition to meeting the SWQS in groundwater at and downgradient of the CPOC.

As requested by Ecology, the evaluation of the POC options for Alternative 5 includes using the MTCA DCA process to determine which POC option is "permanent to the maximum extent practicable under WAC 173-340-360(3)." This requested methodology is unconventional for evaluating POCs because the DCA process is typically used to evaluate the application of different remedial technologies for a cleanup that may have various technical, administrative, and regulatory advantages and disadvantages that are assessed by each of the DCA criteria. Here, the POC options are all being applied to the same remedial alternative applied in the same manner at the Site. Therefore, as a result of the MTCA-specific definitions for several of the DCA evaluation criteria, there may be no or negligible distinguishing characteristics within the evaluation criteria to differentiate between the POC options. Or, because of the limited areas within the DCA criteria where distinctions may be drawn between the POC options, benefit scoring may result in counter-intuitive rankings. Because of these issues, it was necessary to focus on applicable DCA criteria that can be compared between the POC

[31] Under WAC 173-340-720(8)(d)(i) Ecology may also approve the location for a CPOC that is "located within the surface water as close as technically possible to the point or points where ground water flows into the surface water" for properties abutting surface water.

[32] WAC 173-340-720(8)(a) states that "Ground water cleanup levels shall be attained in all ground waters from the point of compliance to the outer boundary of the hazardous substance plume" (i.e., for CPOCs at all points in the plume downgradient of the approved CPOC location, not upgradient thereof).

options, primarily related to the time frame necessary to achieve the cleanup levels for surface water and groundwater at each POC and the technical challenges in being able to monitor and achieve the cleanup levels at these POCs. Therefore, these elements within the WAC 173-340-360(3)(f) criteria are the focus of the POC options DCA evaluation.

4.3.2 Point of Compliance Evaluation Criteria

Because the same remedial technology is being evaluated in the same manner for all the POC options under Alternative 5 as Ecology requested, and because Ecology is requiring that groundwater meet drinking water criteria (4 µg/L TCE) throughout the plume and that surface water meet the SWQS (0.3 µg/L TCE) in the creek for *all* POC options, the sole variable for this DCA analysis is the location of the point(s) in groundwater at which the SWQS must be met. Therefore, while all elements of the DCA criteria were assessed, the most relevant elements of the DCA evaluation criteria to this sole variable (the location of the SWQS POC/CPOC) are used to compare the POC options for Alternative 5. The complete MTCA descriptions of each DCA evaluation criteria provided in WAC 173-340-360(3)(f) are listed below. However, only those elements where meaningful comparisons can be made between POC options actually impact the DCA evaluation of the POC options.

The following provides a brief summary explanation of how each element of each DCA criteria does or does not provide meaningful comparison as applied each of the POC options:

- <u>Protectiveness</u>—Overall protectiveness of human health and the environment, including the degree to which existing risks are reduced, time required to reduce risk at the facility and attain cleanup standards, on-site and off-site risks resulting from implementing the alternative, and improvement of the overall environmental quality.
  - Elements that are equal between POC options:
    - <u>Overall protectiveness of human health and the environment</u>—Each POC alternative is considered to be equally protective of human health and the environment. Once compliance is achieved at the standard POC, as included in POC Option 1 (i.e., drinking water cleanup levels met in groundwater and SWQS met in surface water), which is required for all the POC options, surface water and groundwater will be protective of all applicable exposure pathways and human and environmental receptors. Specifically, when the SWQS are met at the surface water standard POC (at the point or points in the creek closest to where groundwater discharges to the creek), this condition will be protective of all surface water beneficial uses, including human consumption as drinking water and organisms as well as exposure for terrestrial and aquatic organisms. And when the drinking water CUL is met in groundwater at the standard POC (monitoring wells throughout the Site), this condition will be protective of use of the aquifer as a drinking water source and, as explained in the next paragraph, protective of surface water beneficial uses.

      It was previously demonstrated that when drinking water cleanup levels were achieved in groundwater at the standard POC, SWQS would be met in the creek (Boeing 2017b, c). The data trends from this previous evaluation show that, if the drinking water cleanup level for TCE (4 µg/L) is met throughout groundwater, surface water TCE concentrations will not only meet but are predicted to be below the SWQS (0.3 µg/L). Specifically, an evaluation of TCE concentrations in groundwater and surface water along groundwater flow path transects between the core of the plume and the creek demonstrated that once TCE concentrations have been reduced to 4 µg/L in groundwater throughout the Site that the TCE concentrations in the creek would be well below the SWQS of 0.3 µg/L, see Figure 4-7(and Figures 4-7a–c).

- Degree to which existing risks are reduced and time required to reduce risk at the facility—The potential degree to which existing risks can be reduced are negligible and equal between each POC option. Currently, risks at the Site are negligible as there are no uses of impacted surface or groundwater at the Site for drinking water, no known harvesting of aquatic organisms for consumption (because there are no known or documented presence of fish or shellfish in the impacted portion of the creek; Beamer et al. 2013), and TCE concentrations in surface water are below published EPA freshwater benchmark and screening level values for aquatic and terrestrial ecological receptors.[33] Furthermore, once compliance is achieved at the standard POC as included in POC Option 1 (which is required for all the POC options); there will be no risk to human health and the environment as described in the bullet above. Therefore, the risk cannot be meaningfully reduced through demonstration of compliance at any of the other POC options. Accordingly, the time required to reduce risk is also the same for each POC option.
- On-site and off-site risks resulting from implementing the alternative—As the application of the remedial technology is the same for each POC option, there is no difference in the on-site and off-site risks resulting from its implementation (which are negligible).
- Improvement of the overall environmental quality—The reduction of TCE concentrations from the drinking water standards to the SWQS in groundwater does not result in any substantive improvement of the overall environmental quality at the Site because the flora and fauna in the area of the groundwater plume will not be adversely impacted when the drinking water standard is met in groundwater (and the SWQS is met in surface water) under all the POC options.

– Elements where meaningful comparison can be made between POC options:

- Time required to attain cleanup standards—Because each CPOC option requires additional reduction of TCE concentrations from the drinking water standard to the SWQS at groundwater monitoring locations progressively farther away from the creek and closer to the source area, the restoration time frame required for attaining the cleanup standards is also progressively longer for each POC located farther away from the creek.[34]

[33] EPA Region 3 Freshwater Screening Benchmarks (July 2006); EPA Region 4 Freshwater Surface Water Screening Values (August 1999); and EPA Region 5 Ecological Screening Levels (August 2003).

[34] Note, that the cleanup time frame to achieve the cleanup of groundwater to the drinking water standards and of surface water to the SWQS is anticipated to be equal for all the POC options; however, the restoration time frame, which is the time frame that the remedy will take as required to meet different levels at different POCs, is longer for each option that requires

- Permanence—The degree to which the alternative permanently reduces the toxicity, mobility, or volume of hazardous substances, including the adequacy of the alternative in destroying the hazardous substances, the reduction or elimination of hazardous substance releases and sources of releases, the degree of irreversibility of waste treatment process, and the characteristics and quantity of treatment residuals generated.
  - Elements that are equal between POC options:
    - The degree to which the alternative permanently reduces the toxicity of hazardous substances—While Alternative 5 will reduce concentrations of TCE in groundwater thereby permanently reducing risk, the toxicity of TCE and other CVOCs in the downgradient groundwater plume are not reduced under Alternative 5 as they are not converted through the remedial alternative to less toxic by-products, but rather they are transferred onto activated carbon and landfilled. Therefore, this criterion is not applicable or different for any of the POC option locations.
    - Degree to which the alternative permanently reduces the mobility of hazardous substances—Alternative 5 will reduce the mobility of TCE and CVOCs in the groundwater plume equally through hydraulic control and capture regardless of any POC option location.
    - Adequacy of the alternative in destroying the hazardous substances—Alternative 5 will destroy TCE in equal measure in the downgradient plume through adsorption to granular activated carbon and disposition as hazardous waste through landfilling or thermal desorption and in the source area through EISB; therefore, this criterion is not applicable or different for any of the POC option locations.
    - Reduction or elimination of hazardous substance releases and sources of releases—There are no known remaining releases or sources of releases of hazardous substances at the Site; therefore, this criterion is not applicable or different for any of the POC option locations.
    - The degree of irreversibility of waste treatment process—The Alternative 5 DGR treatment system is an *ex situ* system; therefore, it is completely irreversible as it pertains to the TCE groundwater plume, regardless of the POC option selected. The treatment of contaminant mass in the source area and the associated irreversibility of the process through EISB will be equal regardless of the POC; therefore, this criterion is not applicable or different for any of the POC option locations.
  - Elements where meaningful comparison can be made between POC options:
    - Degree to which the alternative permanently reduces the volume of hazardous substances—Alternative 5 will reduce the volume (dimensions) of the groundwater plume equally through hydraulic flushing of the aquifer.

---

more of the groundwater to meet the SWQS. While this may seem counter-intuitive for POC options with lower cleanup levels to receive a lower protectiveness benefit scores due to the longer time required to reach the cleanup standards, this result is simply because the only element in the protectiveness criteria that allows for meaningful comparison between the POC options is time frame. Based on the risks and benefits to human health and the environment related to each POC option discussed above, each of the POC options are otherwise equally protective.

When the drinking water CUL (4 µg/L) is met, the actual volume of TCE in the plume will be extremely low. Therefore, in comparison to the reduction in actual volume of TCE in the aquifer through reducing concentrations from current levels to 4 µg/L, the volume of TCE will be only marginally reduced through further concentration reductions to the SWQS (0.3 µg/L) at the various POC option locations progressively farther from the creek.[35]

- The characteristics and quantity of treatment residuals generated—Similar to the bullet above, based on the very small additional volume of TCE that will be removed under each POC option in relation to the distance from the creek where the SWQS are met, the quantity of treatment residuals generated (i.e., spent granular activated carbon) that will require management and disposition will be also be marginally increased.[36]

- Effectiveness over the long term—Long-term effectiveness includes the degree of certainty that the alternative will be successful, the reliability of the alternative during the period of time hazardous substances are expected to remain on-site at concentrations that exceed cleanup levels, the magnitude of residual risk with the alternative in place, and the effectiveness of controls required to manage treatment residues or remaining wastes. The following types of cleanup action components may be used as a guide, in descending order, when assessing the relative degree of long-term effectiveness: Reuse or recycling; destruction or detoxification; immobilization or solidification; on-site or off-site disposal in an engineered, lined and monitored facility; on-site isolation or containment with attendant engineering controls; and institutional controls and monitoring.
  - Elements that are equal between POC options:
    - Degree of certainty that the alternative will be successful—Alternative 5 is likely to be successful in cleaning up the groundwater plume under all the POC options. The certainty of success in achieving the SWQS in groundwater is progressively less certain the farther the POC is away from the creek due to the technical impracticability issues discussed in Section 4.1 above. While this does provide a point of meaningful comparison between the POC options, the

[35] Assuming average groundwater plume dimensions of 2,800 feet long by 350 feet wide by 30 feet deep (which would be extremely conservative at the time the drinking water standard is met plume-wide—plume dimensions are anticipated to be significantly smaller by this time), with an average effective porosity of 0.33, and a current average TCE concentration of 40 µg/L (rough estimate of average concentrations throughout the plume), there might be roughly 2 gallons of TCE left in the dissolved phase. Once the drinking water cleanup level (4 µg/L TCE) is met, that volume could be on the order of a few cups. For comparison for each CPOC, the percent of the current minimal TCE volume remaining in the dissolved phase when cleanup levels are met at each POC would be approximately:

- CPOCs 1 and 2a: 10 percent remaining at an average concentration of 4 µg/L
- CPOC 2b: just under 10 percent remaining at an average concentration of 0.3 µg/L downgradient of the CPOC and 4 µg/L upgradient of the POC
- CPOC 3: 5 percent remaining at an average concentration of 0.3 µg/L downgradient of the CPOC and 4 µg/L upgradient of the CPOC
- CPOC 4: 2 percent remaining at an average concentration of 0.3 µg/L downgradient of the CPOC and 4 µg/L upgradient of the POC
- POC 5: 1 percent remaining at an average concentration of 0.3 µg/L throughout the plume.

[36] The sorption capacity of vapor-phase granular activated carbon is approximately 10 to 20 percent TCE per mass of carbon (US Army Corps of Engineers, Engineering and Design, Adsorption Design Guide, Design Guide No. 1110-1-2, March 1, 2001); in other words, for every 1–2 pounds of TCE removed from groundwater, approximately 10 pounds of granular activated carbon treatment residual must be managed.

benefit analysis for this consideration is accounted for under the technical implementability criteria below.

  - Magnitude of residual risk with the alternative in place—As described above, there is minimal risk for the Site currently; regardless of the POC option selected, this risk becomes even lower with Alternative 5 in place because of increased hydraulic control and capture of the groundwater plume.
  - Effectiveness of controls required to manage treatment residues or remaining wastes—Treatment residues from the Alternative 5 treatment system will all managed *ex situ* and the management thereof will be provided through qualified hazardous waste management experts and considered highly effective. This criterion is not applicable or different for any of the POC option locations.
  - Relative degree of long-term effectiveness (of remedial technology/approach as listed under this criteria)—The remedial technology/approach is the same regardless of POC option.
- Elements where meaningful comparison can be made between POC options:
  - Reliability of the alternative during the period of time hazardous substances are expected to remain on-site at concentrations that exceed cleanup levels—Alternative 5 relies on mechanical pumping systems, electronic monitoring and control systems, and electrical systems, many of which are exposed to the elements or operate in aqueous environments. The longer the DGR and treatment system is required to run, general system wearing, aging, and weathering, potential fouling of injection and extraction wells and pumps, electronic and computer monitoring and control system failures, power outages, and other electrical equipment failures will become more likely. Therefore, the longer the system is required to operate to achieve remedial action goals and objectives and to reach the lower SWQS progressively farther from the creek, the more likely that the system operations will become less efficient, effective, and reliable, and more prone to failure.

- Management of short-term risks—The risk to human health and the environment associated with the alternative during construction and implementation, and the effectiveness of measures that will be taken to manage such risks.
  - Elements that are equal between POC options:
    - Effectiveness of measures that will be taken to manage risks—Effectiveness measures for managing Alternative 5 construction and implementation risk is the same regardless of the POC option selected.
  - Elements where meaningful comparison can be made between POC options:
    - The risk to human health and the environment associated with the alternative during construction—Construction of the Alternative 5 DGR system and injection wells for EISB is the roughly the same regardless of the POC option selected; however, there would be a slight increase in risk related to the drilling and installation of additional monitoring wells for some of the POC options if required by Ecology.

        - The risk to human health and the environment associated with the alternative during implementation—While the implementation of Alternative 5 is the same regardless of the POC option selected, the length of time that the system is operated, and the surface water and groundwater plume are monitored, is longer for each POC option where the SWQS must be met progressively farther from the creek. Although the risk to the workers performing operations, maintenance, and monitoring (OM&M) on the treatment system is small and manageable, progressively longer time frames for this work with each POC option represents progressively increased risk.

- Technical and administrative implementability—Ability to be implemented including consideration of whether the alternative is technically possible, availability of necessary off-site facilities, services and materials, administrative and regulatory requirements, scheduling, size, complexity, monitoring requirements, access for construction operations and monitoring, and integration with existing facility operations and other current or potential remedial actions.

    - Elements that are equal between POC options:

        - Availability of necessary off-site facilities, services and materials—Same for Alternative 5 regardless of the POC option selected.

        - Administrative and regulatory requirements—Same for Alternative 5 regardless of the POC option selected.

        - Scheduling, size, complexity—Same for Alternative 5 regardless of the POC option selected.

    - Elements where meaningful comparisons can be made between POC options:

        - Consideration of whether the alternative is technically possible—As discussed in Section 4.1, meeting the SWQS in groundwater is considered progressively less technically practicable to achieve in a reasonable restoration time frame the closer to the source area the POC location is (i.e., where more of the plume and/or including the source area is required to meet the SWQS).

        - Monitoring/access for construction operations and monitoring—Because a large portion of the Alternative 5 system operations and monitoring will occur off of Boeing property, which requires property access agreements with three separate offsite property owners, commensurate with the length of additional time it takes to achieve the SWQS (including associated OM&M) progressively farther from the creek, the administrative implementability challenges for such activities are also increased.

        - Integration with existing facility operations—Because a portion of the Alternative 5 cleanup includes monitoring within the Boeing detention basin, where Boeing site services performs O&M of the detention basin liner and stormwater system treatment components, the presence of monitoring facilities (i.e., stickup monitoring wells) presents challenges related to integration with facility operations. Commensurate with the length of additional time it takes to achieve the SWQS in groundwater beneath detention basin, these challenges are increased.

        - Integration with current or potential remedial actions—Because a portion of the Alternative 5 cleanup includes monitoring within the Boeing detention basin, where Boeing site services performs sediment removal activities related to current and likely future Site sediment remediation activities, the presence of monitoring facilities (i.e., stickup monitoring wells) presents challenges related to integration with these remedial actions. Commensurate with the length of additional time it takes to achieve the SWQS groundwater beneath the detention basin, these challenges are increased.

- Consideration of public concerns—Whether the community has concerns regarding the alternative and, if so, the extent to which the alternative addresses those concerns. This process includes concerns from individuals, community groups, local governments, tribes, federal and state agencies, or any other organization that may have an interest in or knowledge of the Site.
    - All the POC options are ranked equally for the consideration of public concerns criteria. Each alternative will consider public concerns in the same manner by responding to comments received during the required public comment period for the RI/FS (and possibly the cleanup action plan) as part of the cleanup process under MTCA.
- Cost—The cost to implement the alternative, including the cost of construction, the net present value of any long-term costs, and agency oversight costs that are cost recoverable. Long-term costs include operation and maintenance costs, monitoring costs, equipment replacement costs, and the cost of maintaining institutional controls. Cost estimates for treatment technologies shall describe pretreatment, analytical, labor, and waste management costs. The design life of the cleanup action shall be estimated and the cost of replacement or repair of major elements shall be included in the cost estimate.
    - Elements that are equal between POC options:
        - Cost of construction—Same for Alternative 5 DGR system construction and EISB implementation, independent of the POC option selected; however, there would be increased costs related to the drilling and installation of additional monitoring wells, including accessing drilling area and restoration for locations within wetlands/buffer zones, for some of the POC options if required by Ecology.
    - Elements where meaningful comparisons can be made between POC options:
        - Long-term costs, including operation and maintenance costs, monitoring costs, equipment replacement costs, and the cost of maintaining institutional controls, and agency oversight costs—Commensurate with the length of additional time it takes to achieve the SWQS in groundwater at POC option locations progressively farther from the creek, the associated costs for OM&M, maintaining institutional controls, and agency oversight costs also increase.

4.3.3 Point of Compliance Evaluation Results

To conduct the POC/CPOC DCA, Boeing followed the same methodology as for the cleanup alternatives DCA analysis in Section 3. That is, the same weighting for the WAC 173-340-360(3)(f) criteria were used, and a benefit score was assigned to each POC/CPOC alternative based on the assessment of each alternative's benefit for each factor. Table 4-2 provides a detailed discussion of our evaluation, which is briefly summarized here:

- Protectiveness: Options 1, 2a, and 2b received the highest benefit ranking for the protectiveness criteria because they most rapidly achieve cleanup standards compared to the other options. The restoration time frames are progressively longer for each POC option to achieve SWQS in groundwater at POC locations farther from the creek.[37]
- Permanence: Option 5 received a marginally higher benefit ranking for the permanence criteria because while each POC option irreversibly reduces contaminant toxicity and mobility to the same extent through source area *in situ* treatment and downgradient capture and *ex situ* treatment, Option 5 only marginally increases the volume of actual TCE removal over the other options based on the extremely low volumes of TCE that will remain once the drinking water cleanup level is reached. However, this also results in a higher quantity of treatment residuals that must be managed.
- Effectiveness over the long term: Option 1 received the highest benefit ranking for the long-term effectiveness criteria because it has the highest degree of certainty, compared to the other alternatives, that it will be the most reliable and successful in achieving cleanup levels across the Site. Because Alternative 5 relies on mechanical pumping systems, electronic monitoring and control systems, and electrical systems that are exposed to the elements or aqueous environment, the shorter the duration that the system is required to run to achieve cleanup levels, the less likely that the system operations will be prone to operational efficiency, effectiveness, reliability, and failure issues. The longer the system is required to run to reach the lower SWQS progressively farther from the creek, each of the other five options become progressively less reliable and less certain of the remedies' ability to achieve remedial action goals and objectives and meet the cleanup standards (see Section 4.1) in groundwater.
- Management of short-term risks: Option 1 and Option 2a each received the same and marginally higher benefit ranking than the other options for the short-term risk criteria due to slightly higher risk to workers during activities such as drilling additional monitoring wells associated with other POC options and the additional risk to workers associated with the duration of O&M activities. These risks are considered minimal and can be effectively and appropriately managed; nevertheless, the additional risks cannot be eliminated entirely.
- Technical and administrative implementability: Option 1 received the highest benefit ranking for technical and administrative implementability criteria because, as discussed in Section 4.1, it is considered technically impracticable to achieve cleanup of groundwater to the SWQS in a reasonable restoration time frame for most of other POC options, and the likelihood of achieving such success is decreased the farther from the creek and closer to, or including the source area. More specifically in relationship to the other POC options:
    - The degree of technical impracticability to achieve SWQS in groundwater in a reasonable restoration time frame the closer to the POC location is to the source area

[37] As stated in Section 4.3.2, based on the risks and benefits to human health and the environment related to each POC option discussed above, each of the POC options are equally protective, but the benefits have been scored consistent with the MTCA-defined methodology discussed in this section. Note, however, that even if the protectiveness scores assigned in Table 4-2 and 4-3 were equal, this would not change to overall outcome or conclusions of the DCA evaluation for the POC options.

(i.e., where more of the plume and/or including the source area is required to meet the SWQS).

  - The degree of administrative challenges associated with maintaining property access agreements with at three separate offsite property owners increases commensurate with the length of additional time it takes to achieve the SWQS (including associated OM&M) progressively farther from the creek. Additionally, Option 1 would not require use of institutional controls (and associated 5-year reviews) that would have to be maintained with the other options.
  - The degree of challenges related to integration of the remedial action with existing facility operations (i.e., Boeing Site Services performance of O&M of the detention basin) increases commensurate with the length of additional time it takes to achieve the SWQS in groundwater beneath detention basin. Similarly, the degree of challenges related to integration with sediment and surface water remedial actions (e.g., stormwater solids/sediment removal activities) also increases with time.

- Consideration of public concerns: All the options are ranked equally for the consideration of public concerns criteria because each option is equally protective once cleanup levels protective of applicable human and ecological receptors is achieved (which is the case for POC Option 1 and consequently all other POC options). This criterion can be adjusted later if necessary after the public is allowed opportunity to review and comment on this SFS during the required public comment period for the RI/FS (and possibly cleanup action plan) as part of the cleanup process under MTCA.

- Cost: Option 1 is the least expensive alternative and Option 5 is the most expensive as summarized below (a breakdown of these costs is presented in Appendix C, Tables C-1a through C-1f) and summarized below.
  - Option 1: $14.1 million
  - Option 2a: $14.6 million
  - Option 2b: $15.6 million
  - Option 3: $16.8 million
  - Option 4: $19.4 million
  - Option 5: $22.2 million

Based on these benefit rankings for each criteria and the assigned weighting factors, the overall weighted benefit score for each alternative is as follows (from highest to lowest):[38]

- Option 1: 8.7
- Option 2a: 8.3
- Option 2b: 8.1
- Option 3: 7.8
- Option 4: 7.2
- Option 5: 6.8

[38] Note that if weighting factors were not used, the DCA analysis would result in the same conclusions as presented herein.

The results for Alternative 5 as applied to each of the six POCs identified in Section 4.3.1 are provided in greater detail in attachments to this report. As noted above, Table 4-2 provides descriptions of the considerations for benefit scoring and ranking under each evaluation criteria for each POC, along with the raw score for each criterion. Table 4-3 provides a summary of the complete DCA evaluation with comparisons of the benefit scores to the associated cost estimates related to each POC, including the relative benefit-to-cost ratio (calculated by normalizing the benefit-to-cost ratio to the benefit-to-cost ratio of the option with the highest benefit score) used for comparing each POC and identifying which POC is considered permanent to the maximum extent practicable. Figure 4-8 provides a visual representation of the results provided in the tables.

Appendix C-1(a–f) includes the detailed cost estimate for Alternative 5 based on POC Options 1 through 5. The costs used for the evaluation of each POC are based on the specific modeled restoration time frames for each POC option (see Table 4-1), applied to the OM&M periods for DGR and EISB.[39] For Options 4 and 5, the cost estimates also assume that the downgradient cleanup of the Boeing property will depend on completion of source area cleanup. In order to minimize migration of TCE that may still be originating from the source area at concentrations over the SWQS, portions of the DGR system (e.g., GET system extraction wells) may need to continue to be operated until, and potentially several years after, the source area cleanup is completed (even after DGR has functionally cleaned up the downgradient portion of the plume). Costs for additional GET system operation are included in costs for POC Options 4 and 5. Figure 4-9 provides a comparison of the estimated restoration time frames to achieve progressively lower TCE concentrations/cleanup levels and the associated costs of the cleanup; this figure demonstrates how much longer and disproportionately costly it is to achieve cleanup levels lower than the TCE drinking water standard of 4 µg/L.

The overall weighted benefit score, estimated cost, and relative benefit-to-cost ratio identified by the DCA for each POC are as follows:

Point of Compliance Option	Overall Weighted Benefit Score	Estimated Remedy Cost ($millions)	Relative Benefit-to-Cost Ratio
Option 1	8.7	$14.1	8.7
Option 2a	8.3	$14.6	8.0
Option 2b	8.1	$15.6	7.3
Option 3	7.8	$16.8	6.5
Option 4	7.2	$19.4	5.2
Option 5	6.8	$22.2	4.3

[39] Note that because Ecology is requiring that the drinking water cleanup level be met at all points upgradient of each of the CPOC options, the length of the associated restoration time frames for some of the CPOC options shown in Table 4-1 is dictated by achieving the drinking water cleanup level (4 µg/L TCE) upgradient of the CPOC rather than achieving the surface water cleanup level (0.3 µg/L TCE) at the CPOC itself.

Based on these results, POC Option 1 (groundwater and surface water standard POCs using the drinking water standard for groundwater throughout the TCE plume and the SWQS in the creek) has the highest benefit score and lowest cost (and highest benefit-to-cost ratio); therefore, it is the option that is permanent to the maximum extent practicable and the preferred option. Additionally, the standard POC location, as provided for in POC Option 1, in combination with the applicable, relevant, and appropriate cleanup levels for both groundwater and surface water, is consistent with MTCA, the Clean Water Act, and state surface water quality (WAC 173-201A) regulations.

5.0 CONCLUSIONS OF SUPPLEMENTAL FEASIBILITY STUDY

5.1 Preferred Cleanup Action

As directed by Ecology in its August 6, 2018 letter, this SFS includes analysis of Alternative 5 and an evaluation and comparison of Alternative 5 to the four remedial alternatives included in the FS, using the MTCA DCA process. Because Alternative 5 meets the MTCA threshold and other requirements,[40] and based on the results of the DCA evaluation in this SFS, Alternative 5 is the preferred remedial action alternative for the PMG SWMU/AOC. Alternative 5 consists of modifying and upgrading the existing GET system to convert and operate the system as a DGR system for cleanup of the downgradient portion of the groundwater plume and implementing EISB for additional remediation of the source area. In the event that a CPOC is selected by Ecology after review of this SFS, institutional controls will be implemented in accordance with MTCA.

Alternative 5 is the preferred remedial action over Alternatives 1, 2, 3, and 4 based on the following:

- Alternative 5 will increase TCE/contaminant mass recovery, provide enhanced hydraulic capture and control of the TCE plume, and reduce the restoration time frame compared to the other alternatives;
- Alternative 5 meets all MTCA threshold requirements, uses permanent solutions to the maximum extent practicable , and provides for a reasonable restoration time frame (depending on the POC authorized for the remedy);
- Implementation of DGR in the downgradient portion of the TCE plume is expected to achieve relatively rapid and effective TCE concentration reductions while simultaneously minimizing discharge of TCE to the creek and achieving the SWQS in the creek;
- Implementation of EISB in the source area is anticipated to effectively treat residual TCE contamination remaining in the source area beneath the detention basin; and
- Alternative 5 is the most permanent remedy evaluated in the SFS, and based on the results of the DCA, is permanent to the maximum extent practicable.

5.2 Appropriate and Preferred Point of Compliance for Alternative 5

In addition, per Ecology's direction, this SFS also evaluated the potential use of standard and conditional POC options to be used with Alternative 5. These POCs were evaluated using a similar but modified DCA process as that used to determine the preferred remedial alternative. That evaluation showed that POC Option 1 is permanent to the maximum extent practicable, provides the greatest benefits, and is not disproportionately costly. Option 1 consists of the following:

- **Point of Compliance Option 1: Groundwater and Surface Water Standard POCs** – the drinking water standard (4 µg/L TCE) must be met in monitoring wells throughout the groundwater TCE

[40] As defined in WAC 173-340-360(2)(a&b) – protect human health and the environment, comply with cleanup standards, comply with applicable state and federal laws, provide for compliance monitoring, provide for a reasonable restoration time frame, and consider public concerns.

plume and the SWQS (0.3 µg/L TCE) must be met within the creek water at sampling points immediately above the creek bed.

The MTCA evaluation results in POC Option 1 as the preferred POC option to be used in implementing Alternative 5 for at the PMG SWMU/AOC based on the following:

- As discussed in Section 4.3.2, POC Option 1 is protective of current and future potential human and ecological receptors because current Site data indicate that when the drinking water CUL (4 µg/L) is met in groundwater, the SWQS (0.3 µg/L) will also be met in the creek;
- As discussed in Section 4.1.1, it is technically impractical to meet SWQS in groundwater (except in the transitional zone) in a reasonable restoration time frame;
- As discussed in Section 4.3.3, assuming for DCA purposes that it were technically practicable to meet SWQS in groundwater, it would be disproportionately costly to do so and attempting to do so would not provide additional overall benefit above POC Option 1; and
- POC Option 1 is within Ecology's authority because it does not use the SWQS as the cleanup level for groundwater.

6.0 USE OF THIS REPORT

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

7.0 REFERENCES

AECOM and LAI. 2015. Draft Report: Feasibility Study for Upland Areas and Powder Mill Gulch, Boeing Commercial Airplanes Everett Plant, Everett, Washington. AECOM and Landau Associates, Inc. November 16.

AECOM. 2016. Feasibility Study, Sediments and Surface Water, BCA Everett Plant, Everett, Washington. August 18.

Ball, W.P, C. Liu, R.D. Wilson, and D.M. Mackay. 1998. Studies of Contaminant Diffusion in an Aquitard and Groundwater Remediation by Reactive Metals at Dover Air Force Base, Delaware. Airforce Research Laboratories, AFRL-ML-TY-TR-1998-4518. January 23.

Beamer, E.M., W.T. Zackey, D. Marks, D. Teel, D. Kuligowski, and R. Henderson. 2013. Juvenile Chinook Salmon Rearing in Small Non-Natal Streams Draining into the Whidbey Basin. December 3.

Boeing. 2017a. Formal Dispute Resolution – Ecology's Final Decision under Informal Dispute Resolution Regarding the Upland Feasibility Study Report, dated July 20, 2017, and Written Statement of Boeing's Position on Disputed Items for the Boeing Everett Facility. The Boeing Company. September 8.

Boeing. 2017b. Boeing Everett Uplands/Powder Mill Gulch Feasibility Study, Boeing's Alternative Proposals for Formally Disputed Items submitted September 8, 2017. The Boeing Company. November 16.

Boeing. 2017c. Letter from Mr. Stanley Alpert, Boeing Environment, Health and Safety Law Group to Ms. Ivy Anderson, Office of the Attorney General. The Boeing Company. December 15.

Boeing. 2018a. Boeing Everett Uplands/Powder Mill Gulch Feasibility Study, Boeing's Alternative Proposals for Formally Disputed Items submitted September 8, 2017, Supplement to Boeing's November 16, 2017 Alternative Proposals. The Boeing Company. January 22.

Boeing. 2018b. Letter Re: Response Letter – Ecology's Final Decision to Submit a Supplemental Feasibility Study (The Boeing Everett Site; Agreed Order DE96HS-N274), dated August 6, 2018. The Boeing Company. August 21.

Chapman, S.W., and B.L Parker. 2005. Plume persistence due to aquitard back diffusion following dense nonaqueous phase liquid source removal or isolation. Water Resources Research, Vol. 41, No. 12. December 6.

EA. 2005. Groundwater–surface water interactions in the hyporheic zone. Environment Agency, Science Report SC030155/SR1. July.

Ecology. 1991. Responsiveness Summary for the Amendments to the Model Toxics Control Act Cleanup Regulation, Chapter 173-340 WAC. Publication No. 91-09-918. Washington State Department of Ecology. January.

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

Ecology. 2016. Letter Re: Ecology Contingent Approval and Modifications to the Draft Boeing Everett Uplands and Powder Mill Gulch Feasibility Study (FS) Report, dated November 13, 2015. Washington State Department of Ecology. August 18.

Ecology. 2017a. Implementation Memorandum No. 16: Developing Conditional Points of Compliance at MTCA Sites Where Groundwater Discharges to Surface Water. Washington State Department of Ecology Publication No. 16-09-053. December 29.

Ecology. 2017b. Sediment Cleanup User's Manual II (SCUM II), Guidance for Implementing the Cleanup Provisions of the sediment Management Standards, Chapter 173-204 WAC. Washington State Department of Ecology Publication No. 12-09-057. December.

Ecology. 2017c. Letter Re: Ecology Final Decision Under Informal Dispute Resolution Regarding the Upland Feasibility Study (FS) report and Ecology Selected Remedies for the Boeing Everett Site. July 20.

Ecology. 2018. Letter Re: The Boeing Everett Site, Final Decision to Submit a Supplemental Feasibility Study, Agreed Order DE96HS-N274. Washington State Department of Ecology. August 6.

EPA. 1988. Guidance on Remedial Actions for Contaminated Ground Water at Superfund Sites. EPA/540/G-88/003. Office of Research and Development Publication. US Environmental Protection Agency. December.

EPA. 2017. Scope of the Risk Evaluation for Trichloroethylene. EPA-740-R1-7004. Office of Chemical Safety and Pollution Prevention. US Environmental Protection Agency. June.

EPA. 2018. "BIOCHLOR, Natural Attenuation Decision Support System." US Environmental Protection Agency. https://www.epa.gov/water-research/biochlor-natural-attenuation-decision-support-system . Accessed November 1.

ESTCP. 2016. Development of an Expanded, High-Reliability Cost and Performance Database for In-Situ Remediation Technologies; ESTCP Project ER-201120. US Department of Defense Environmental Security Technology Certification. March.

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

ITRC. 2015. "Integrated DNAPL Site Characterization and Tools Selection (ISC-1), Appendix B." Interstate Technology & Regulatory Council, DNAPL Site Characterization Team. https://www.itrcweb.org/DNAPL-ISC_tools-selection/.

LAI. 2017. Technical Memorandum: Restoration Time Frame Evaluation—Modeling Inputs/Sensitivity Analysis, Powder Mill Gulch, Boeing Everett Facility, Everett, Washington. Landau Associates, Inc. September 20.

Mackay, D.M. and J.A. Cherry. 1989. Groundwater contamination: pump-and-treat remediation. Environmental Science & Technology, 1989, Vol. 23, No. 6, pp 630–636. June.

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

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

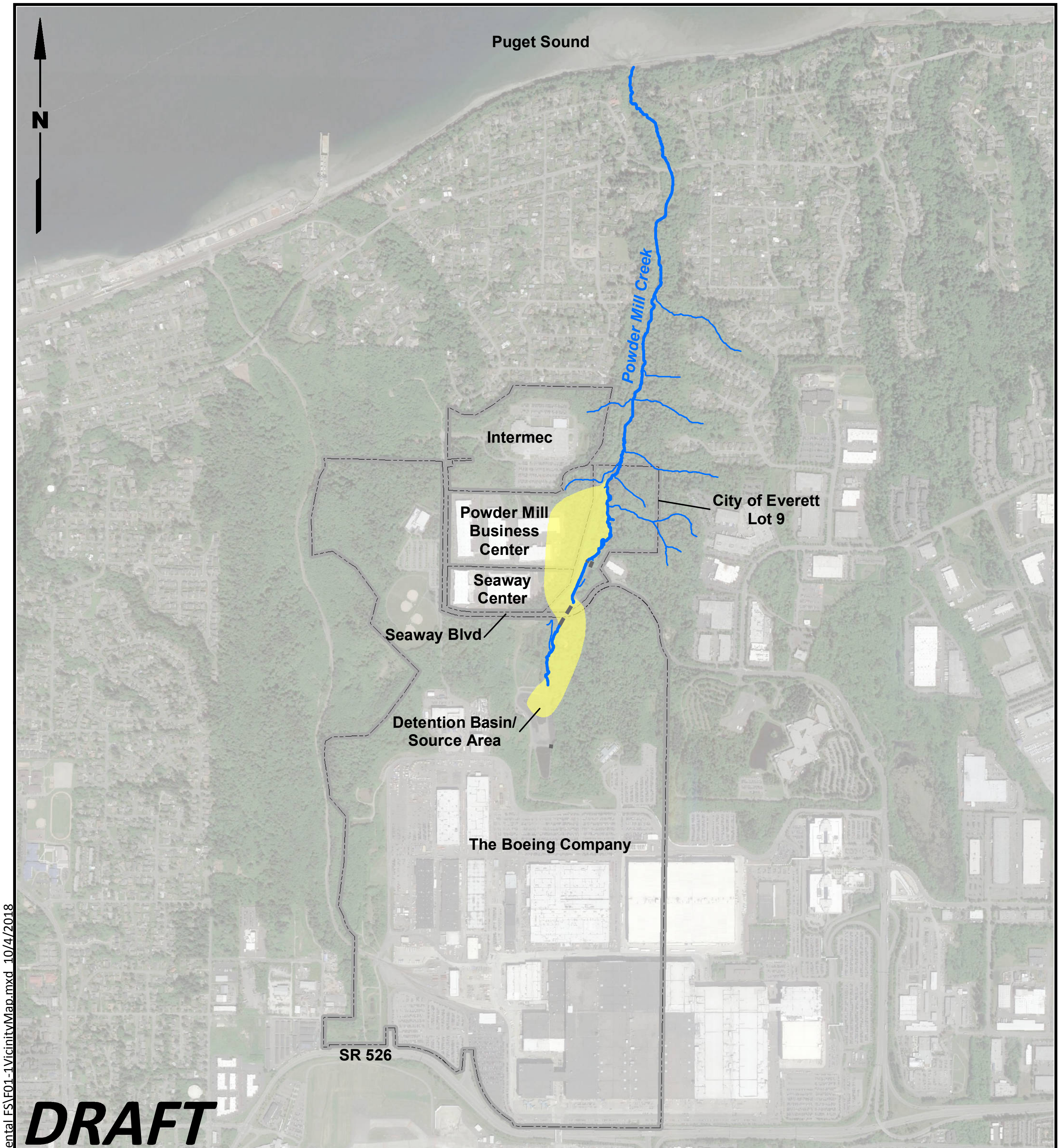
Sale, T., C. Newell, H. Stroo, R. Hinchee, and P. Johnson. 2008. Frequently Asked Questions Regarding Management of Chlorinated Solvents in Soil and Groundwater. ESTCP. August.

Suthersan, S.S., J. Horst, M. Schonbrich, N. Welty, and J. McDonough. 2017. *Remediation Engineering: Design Concepts; Chapter 5 - Dynamic Groundwater Recirculation*. Second ed. Boca Raton, FL: CRC Press.

Suthersan, S.S., E. Killenbeck, S. Potter, C. Divine, and M. Lefrancois. 2015. "Resurgence of Pump and Treat Solutions: Directed Groundwater Recirculation." *National Ground Water Association, Groundwater Monitoring & Remediation* 35 (2).

Weatherill, J.J., A. Siavash , U. Schneidewind, S. Krause, S. Ullah, N. Cassid, M. Rivett. 2017. Natural attenuation of chlorinated ethenes in hyporheic zones: A review of key biogeochemical processes and in-situ transformation potential. Water Research, Vol. 128, pp. 362-382. October 30.

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



G:\Projects\025\175\118\012\Supplemental FS\F01-1VicinityMap.mxd 10/4/2018

Legend

Property Boudary

Inferred Area with TCE Concentration in Groundwater > 4 µg/L

Note

1. Black and white reproduction of this color original may reduce its effectiveness and lead to incorrect interpretation.

0 1,700 3,400

Scale in Feet

Data Sources: Google Earth Pro, 2018.

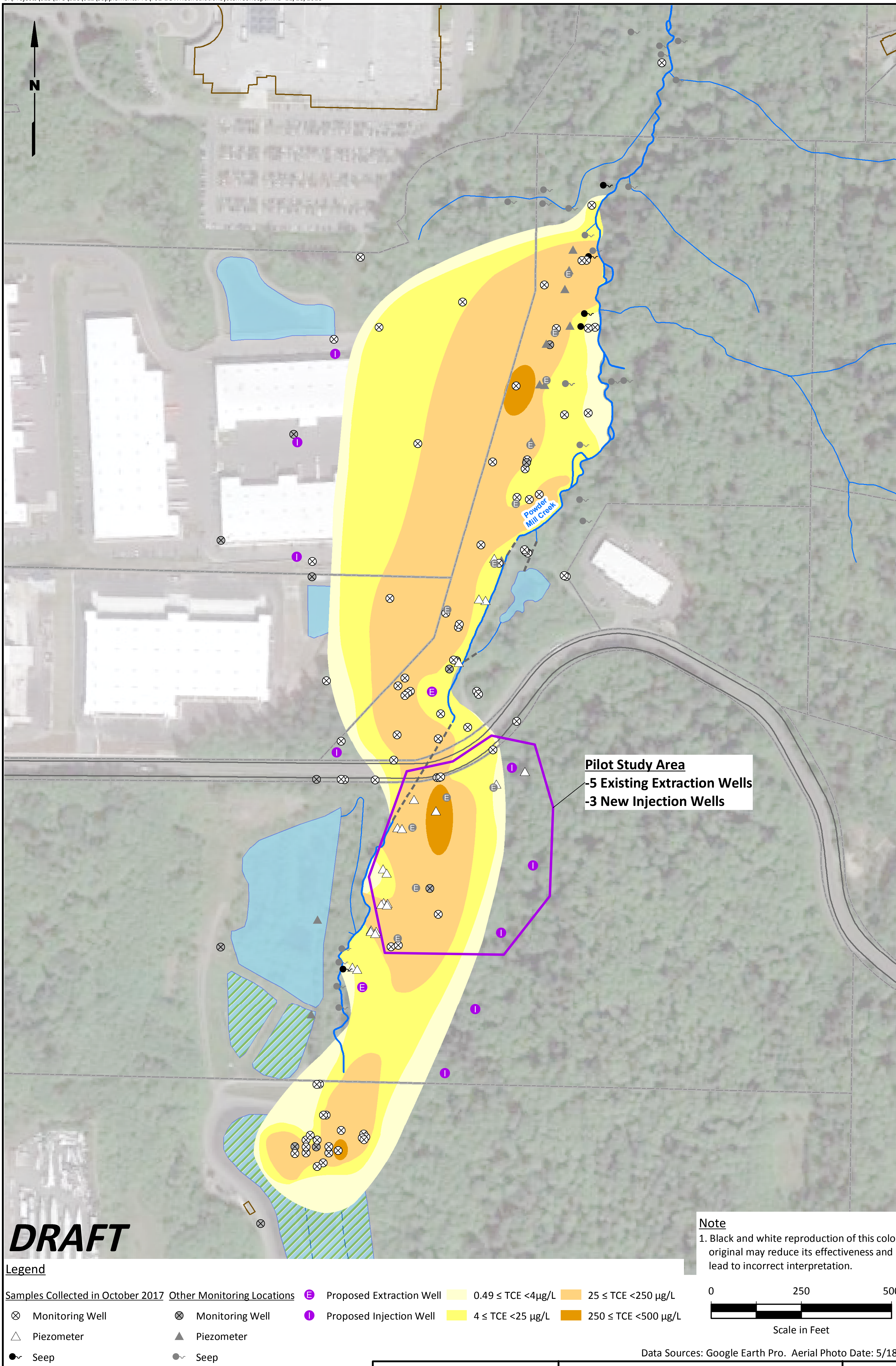
LANDAU ASSOCIATES

Supplemental Feasibility Study
Boeing Commercial Airplanes
Everett, Washington

Vicinity Map

Figure
1-1

G:\Projects\025\175\118\012\Supplemental FS\F02-1GWRecirculationSystemConcept.mxd 11/28/2018

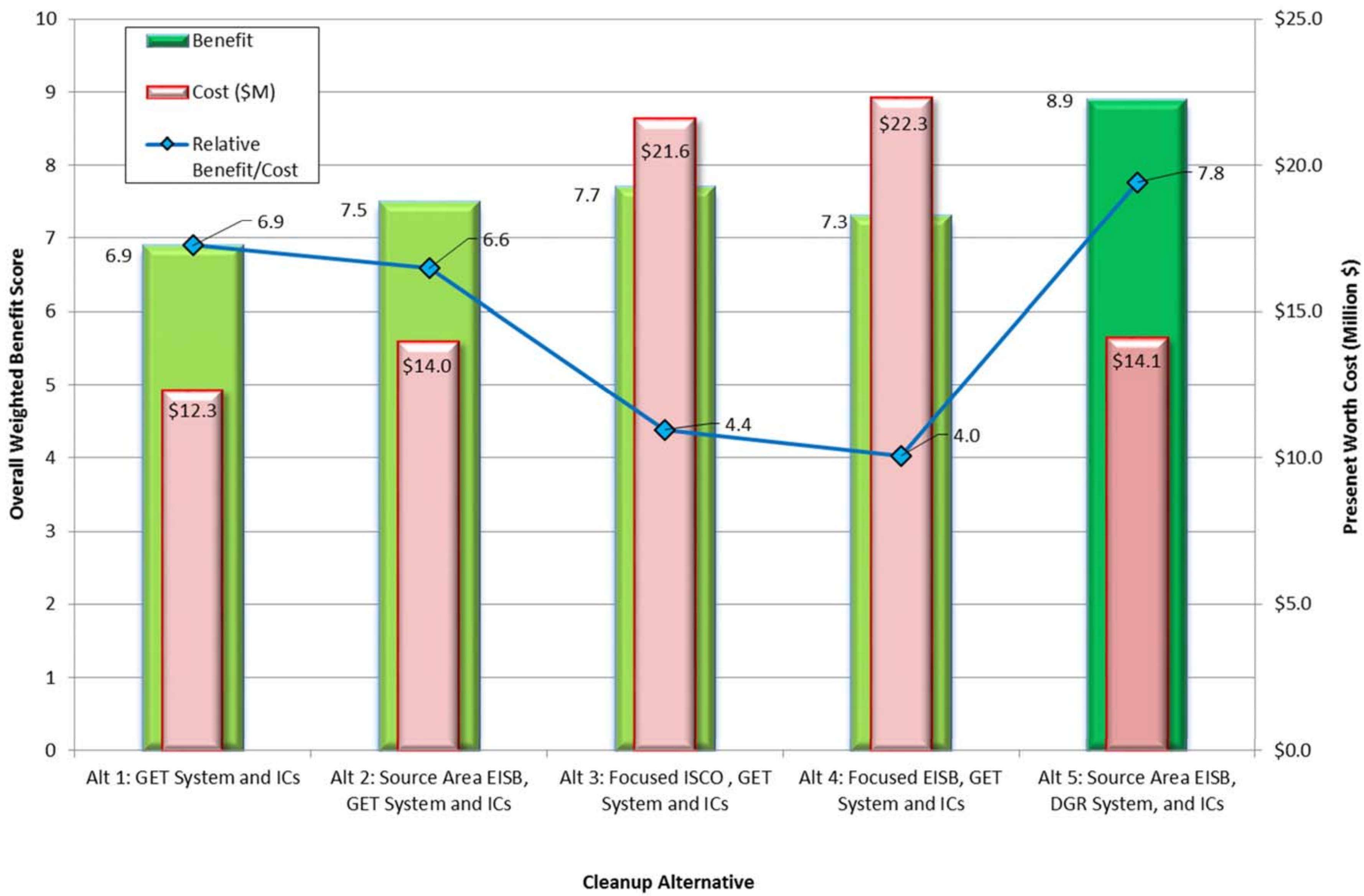


LANDAU ASSOCIATES

Supplemental Feasibility Study
Boeing Commercial Airplanes
Everett, Washington

Groundwater Recirculation System - Conceptual Layout

Figure
2-1

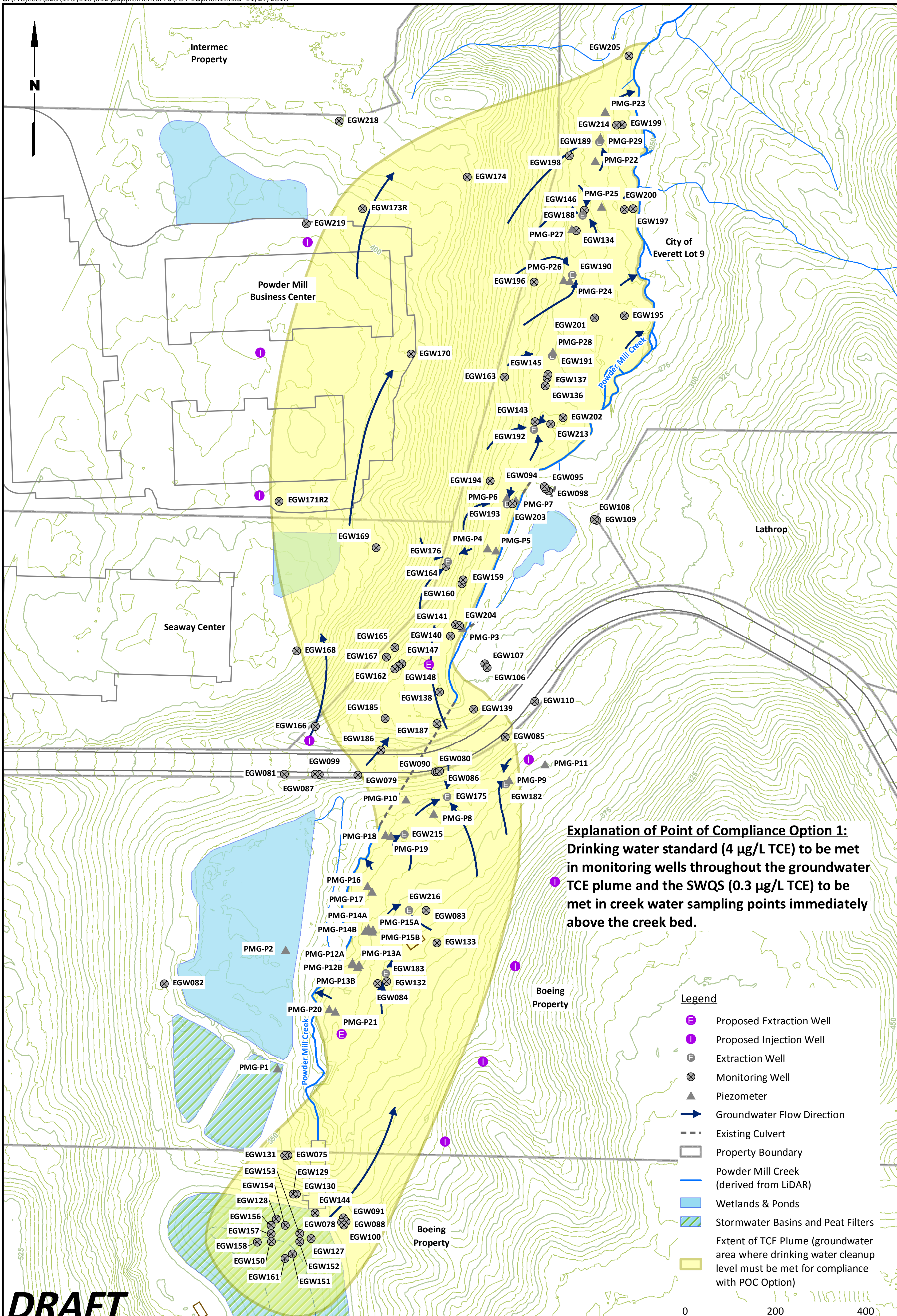


LANDAU ASSOCIATES

DRAFT

Supplemental Feasibility Study Boeing Commercial Airplanes Everett, Washington	**Summary of Remedial Alternatives Relative Benefits Ranking – All Alternatives**	Figure 3-1

G:\Projects\025\175\118\012\Supplemental FS\F04-1Option1.mxd 11/27/2018

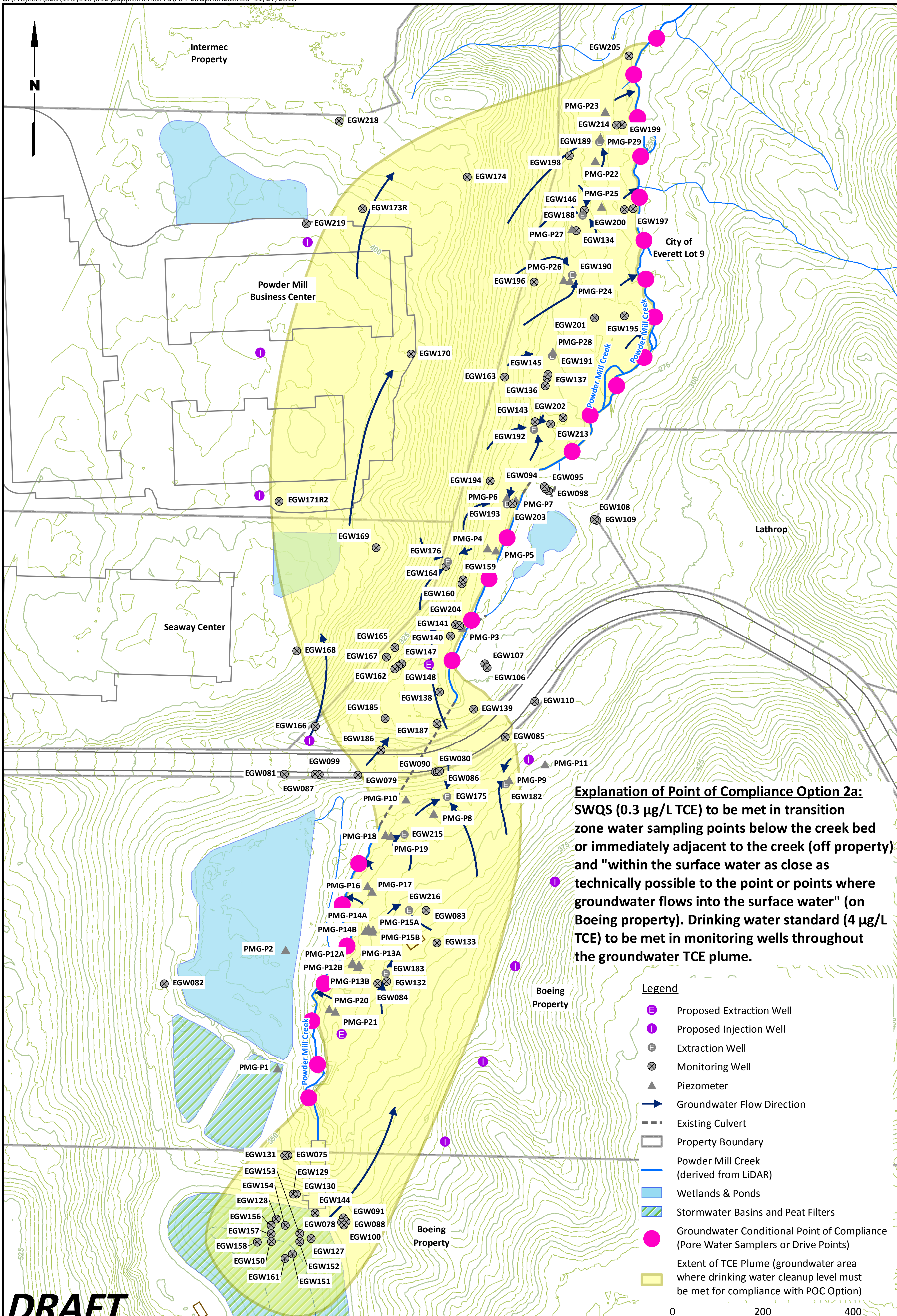


Explanation of Point of Compliance Option 1:
Drinking water standard (4 µg/L TCE) to be met in monitoring wells throughout the groundwater TCE plume and the SWQS (0.3 µg/L TCE) to be met in creek water sampling points immediately above the creek bed.

Note
1. Black and white reproduction of this color original may reduce its effectiveness and lead to incorrect interpretation.

LANDAU ASSOCIATES

Supplemental Feasibility Study Boeing Commercial Airplanes Everett, Washington	**Option 1: Groundwater and Surface Water Standard POCs**	Figure 4-1



Explanation of Point of Compliance Option 2a:
SWQS (0.3 µg/L TCE) to be met in transition zone water sampling points below the creek bed or immediately adjacent to the creek (off property) and "within the surface water as close as technically possible to the point or points where groundwater flows into the surface water" (on Boeing property). Drinking water standard (4 µg/L TCE) to be met in monitoring wells throughout the groundwater TCE plume.

Legend

- Proposed Extraction Well
- Proposed Injection Well
- Extraction Well
- Monitoring Well
- Piezometer
- Groundwater Flow Direction
- Existing Culvert
- Property Boundary
- Powder Mill Creek (derived from LiDAR)
- Wetlands & Ponds
- Stormwater Basins and Peat Filters
- Groundwater Conditional Point of Compliance (Pore Water Samplers or Drive Points)
- Extent of TCE Plume (groundwater area where drinking water cleanup level must be met for compliance with POC Option)

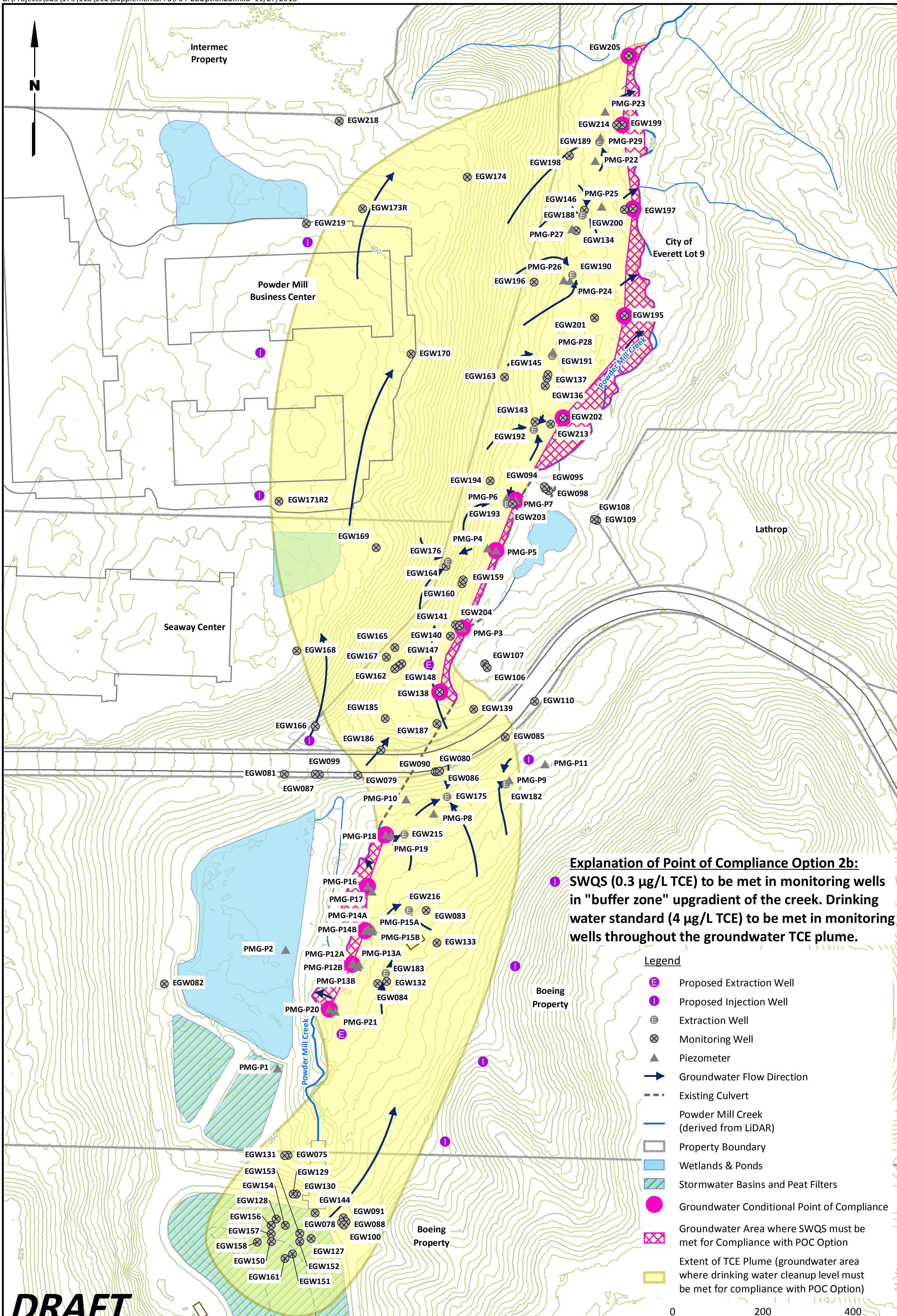
0 200 400
Scale in Feet

Note
1. Black and white reproduction of this color original may reduce its effectiveness and lead to incorrect interpretation.

LANDAU ASSOCIATES

Supplemental Feasibility Study Boeing Commercial Airplanes Everett, Washington	Option 2a: Groundwater CPOC in Transition Zone Beneath the Creek	Figure 4-2a

G:\Projects\025\175\118\012\Supplemental FS\F04-2bOption2b.mxd 11/27/2018

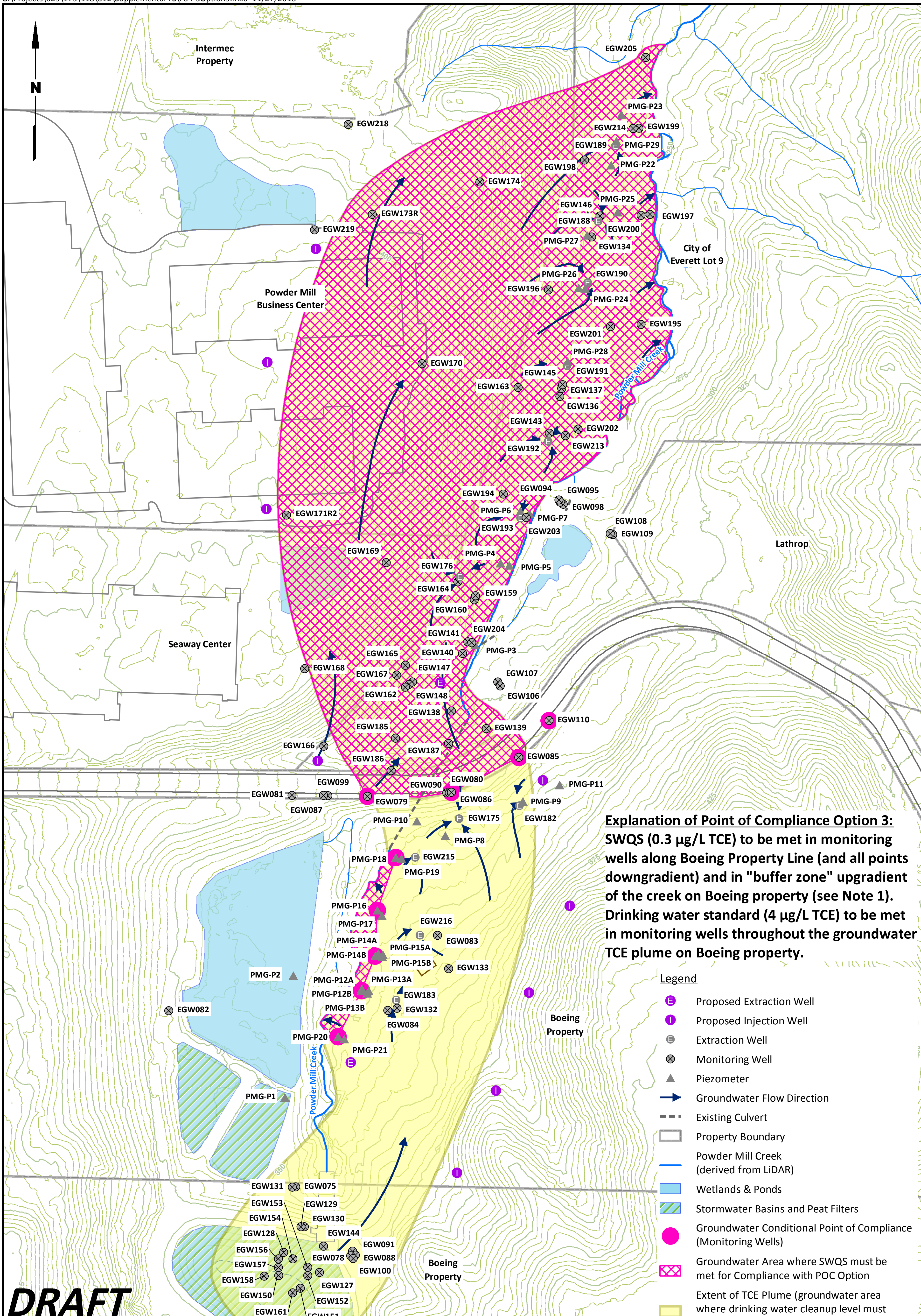


Note
1. Black and white reproduction of this color original may reduce its effectiveness and lead to incorrect interpretation.

LANDAU ASSOCIATES

Supplemental Feasibility Study Boeing Commercial Airplanes Everett, Washington	Option 2b: Groundwater CPOC in Monitoring Wells Upgradient of Creek	Figure 4-2b

G:\Projects\025\175\118\012\Supplemental FS\F04-3Option3.mxd 11/27/2018



Explanation of Point of Compliance Option 3:
SWQS (0.3 µg/L TCE) to be met in monitoring wells along Boeing Property Line (and all points downgradient) and in "buffer zone" upgradient of the creek on Boeing property (see Note 1). Drinking water standard (4 µg/L TCE) to be met in monitoring wells throughout the groundwater TCE plume on Boeing property.

Legend

- Proposed Extraction Well
- Proposed Injection Well
- Extraction Well
- Monitoring Well
- Piezometer
- Groundwater Flow Direction
- Existing Culvert
- Property Boundary
- Powder Mill Creek (derived from LiDAR)
- Wetlands & Ponds
- Stormwater Basins and Peat Filters
- Groundwater Conditional Point of Compliance (Monitoring Wells)
- Groundwater Area where SWQS must be met for Compliance with POC Option
- Extent of TCE Plume (groundwater area where drinking water cleanup level must be met for compliance with POC Option)

0 200 400

Scale in Feet

Notes

1. Under WAC 173-340-720(8)(d)(i) Ecology may also approve the location for groundwater compliance samples to be located "within the surface water as close as technically possible to the point or points where ground water flows into the surface water" for properties abutting surface water.
2. Black and white reproduction of this color original may reduce its effectiveness and lead to incorrect interpretation.

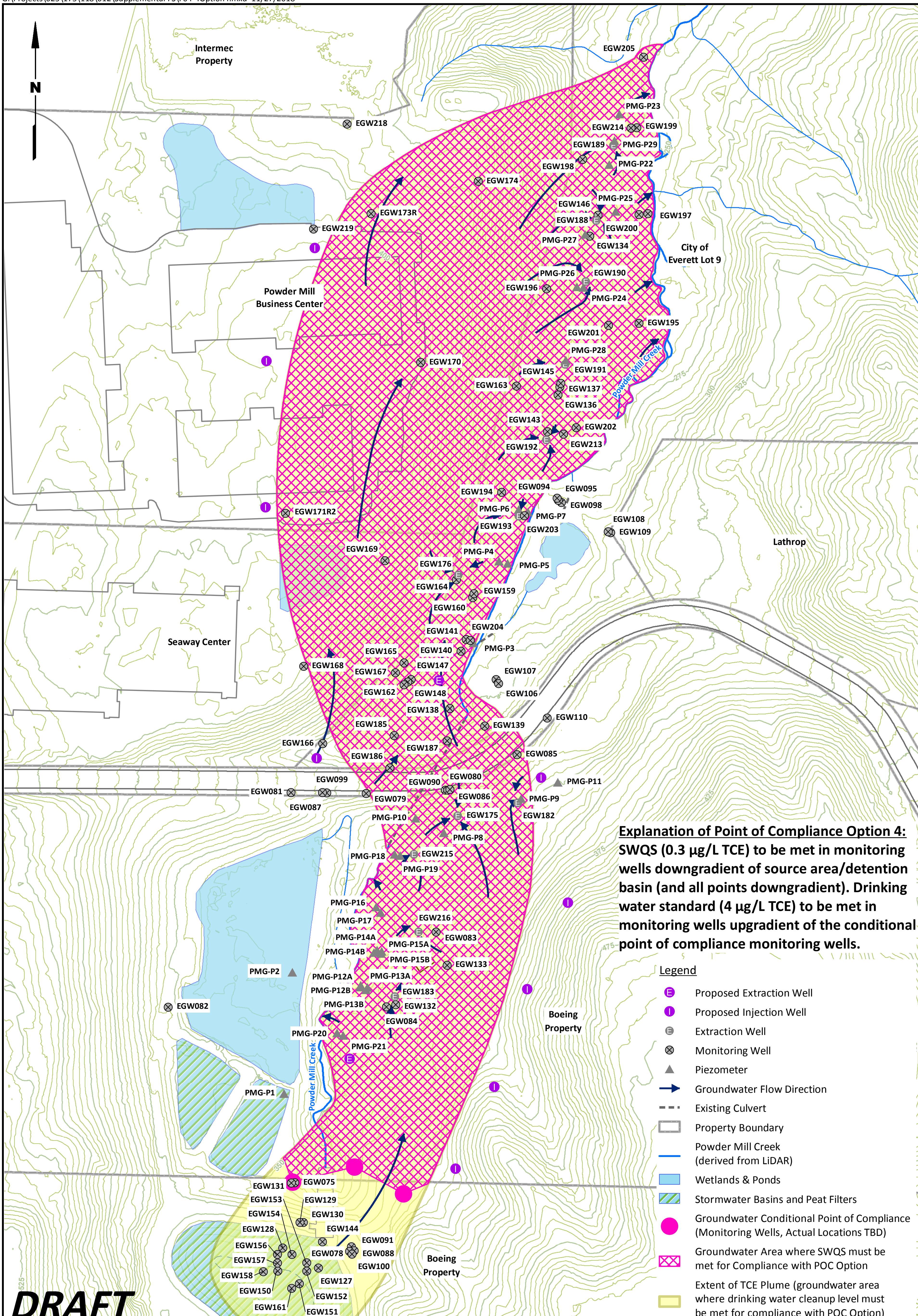
LANDAU ASSOCIATES

Supplemental Feasibility Study
Boeing Commercial Airplanes
Everett, Washington

Option 3: Groundwater CPOC at Boeing Property Line and Upgradient of Creek on Boeing Property

Figure 4-3

G:\Projects\025\175\118\012\Supplemental FS\F04-4Option4.mxd 11/27/2018



Notes

1. Under WAC 173-340-720(8)(d)(i) Ecology may also approve the location for groundwater compliance samples to be located "within the surface water as close as technically possible to the point or points where ground water flows into the surface water" for properties abutting surface water.
2. Black and white reproduction of this color original may reduce its effectiveness and lead to incorrect interpretation.

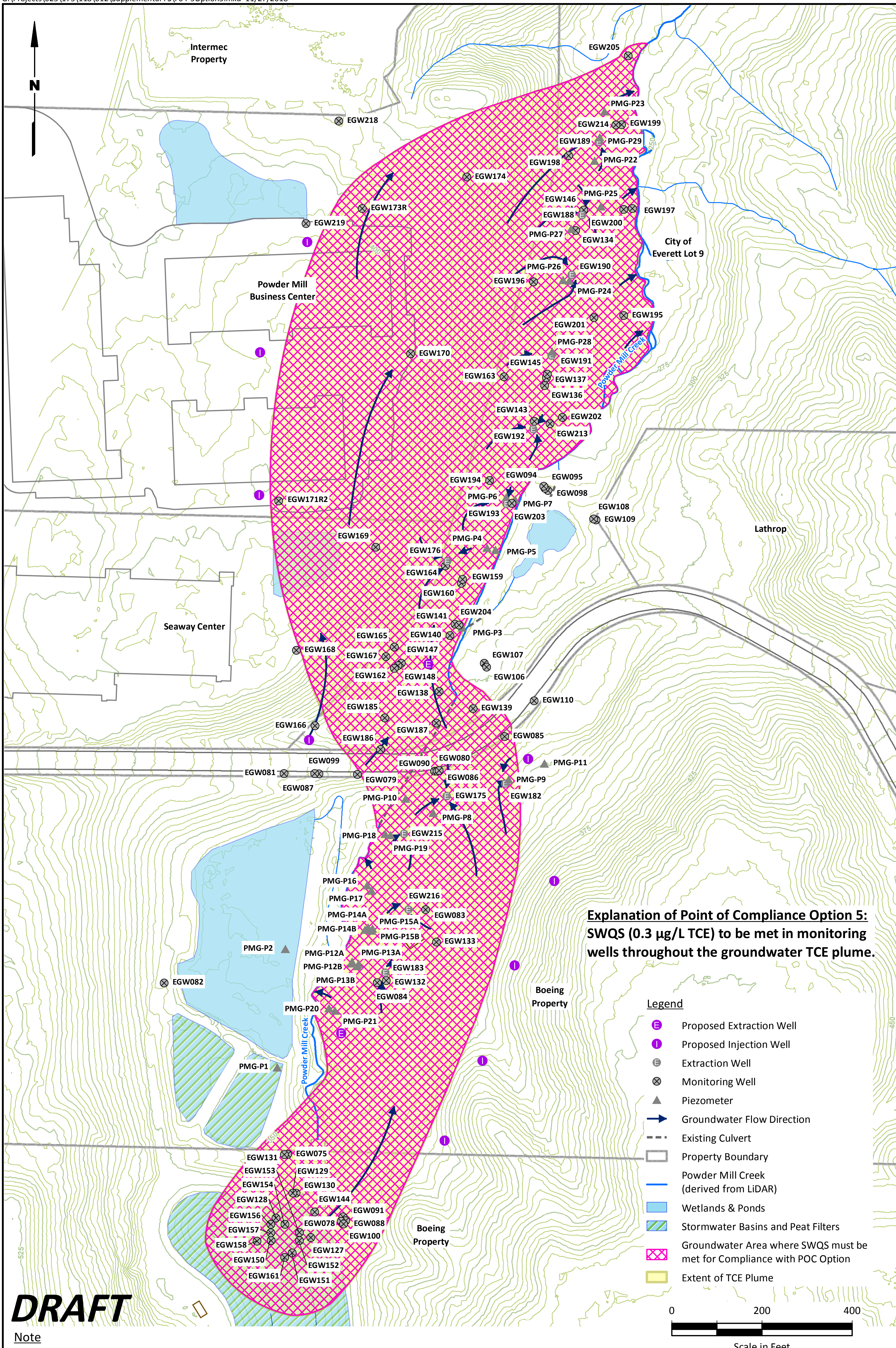
LANDAU ASSOCIATES

Supplemental Feasibility Study
Boeing Commercial Airplanes
Everett, Washington

Option 4: Groundwater CPOC Immediately Downgradient of Source Area

Figure 4-4

G:\Projects\025\175\118\012\Supplemental FS\F04-5Option5.mxd 11/27/2018

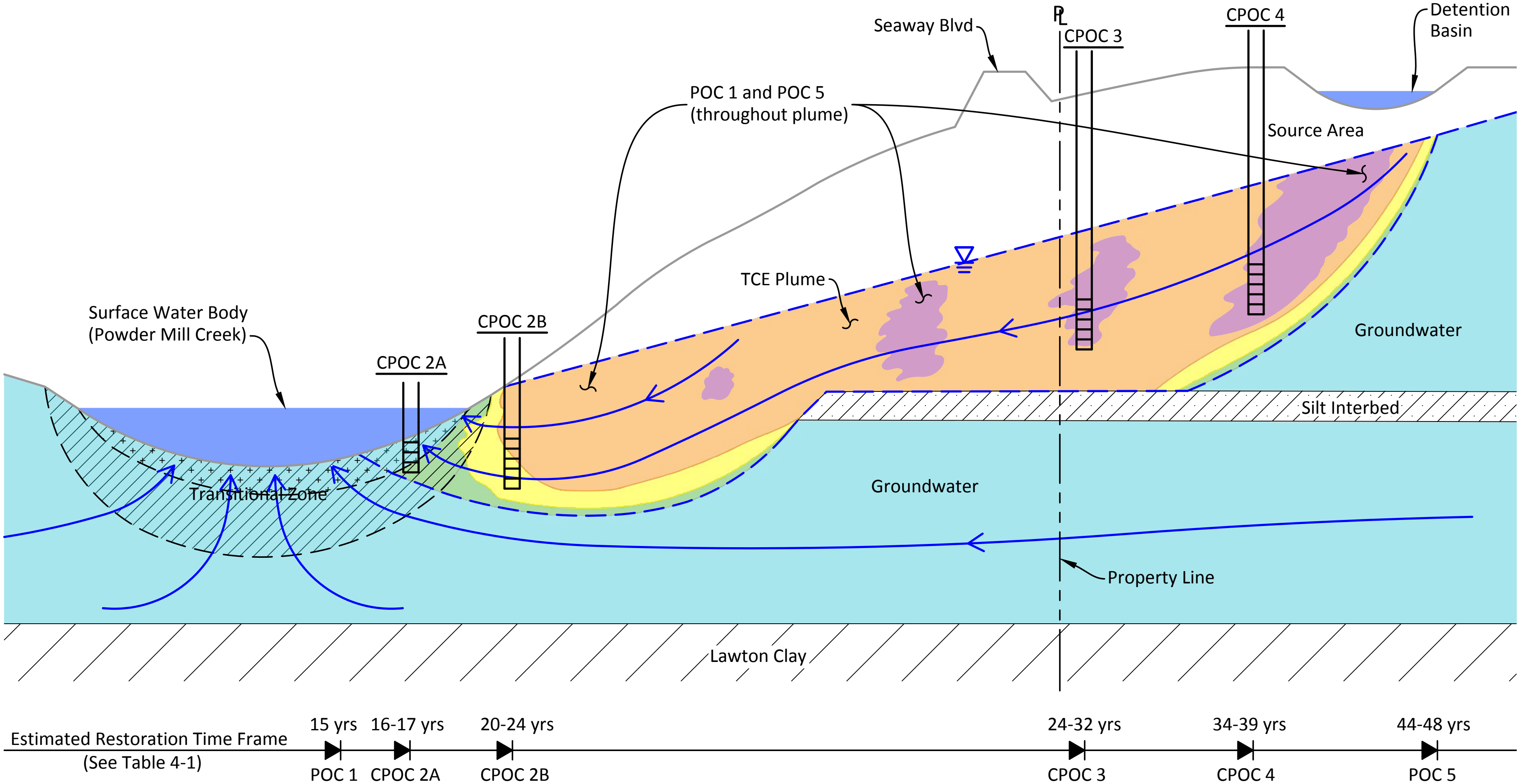


Note

1. Black and white reproduction of this color original may reduce its effectiveness and lead to incorrect interpretation.

LANDAU ASSOCIATES

Supplemental Feasibility Study Boeing Commercial Airplanes Everett, Washington	**Option 5: Groundwater Standard POC Using SWQS**	Figure 4-5



Legend

TCE Concentrations:
- <0.3 µg/L
- 0.3-4 µg/L
- 4-25 µg/L
- 25-200 µg/L
- >200 µg/L

- Sediments
- Transitional Zone
- Silt Interbed
- Lawton Clay
- Groundwater Flow

Notes

1. Adapted from Ecology 2017 (Figure 5a).
2. This graphic is only a general representation to convey relative location and restoration time frame of each standard and conditional point of compliance (POC) option. Not drawn to scale.
3. All POC options also require meeting SWQS in Powder Mill Creek.
4. Black and white reproduction of this color original may reduce its effectiveness and lead to incorrect interpretation.

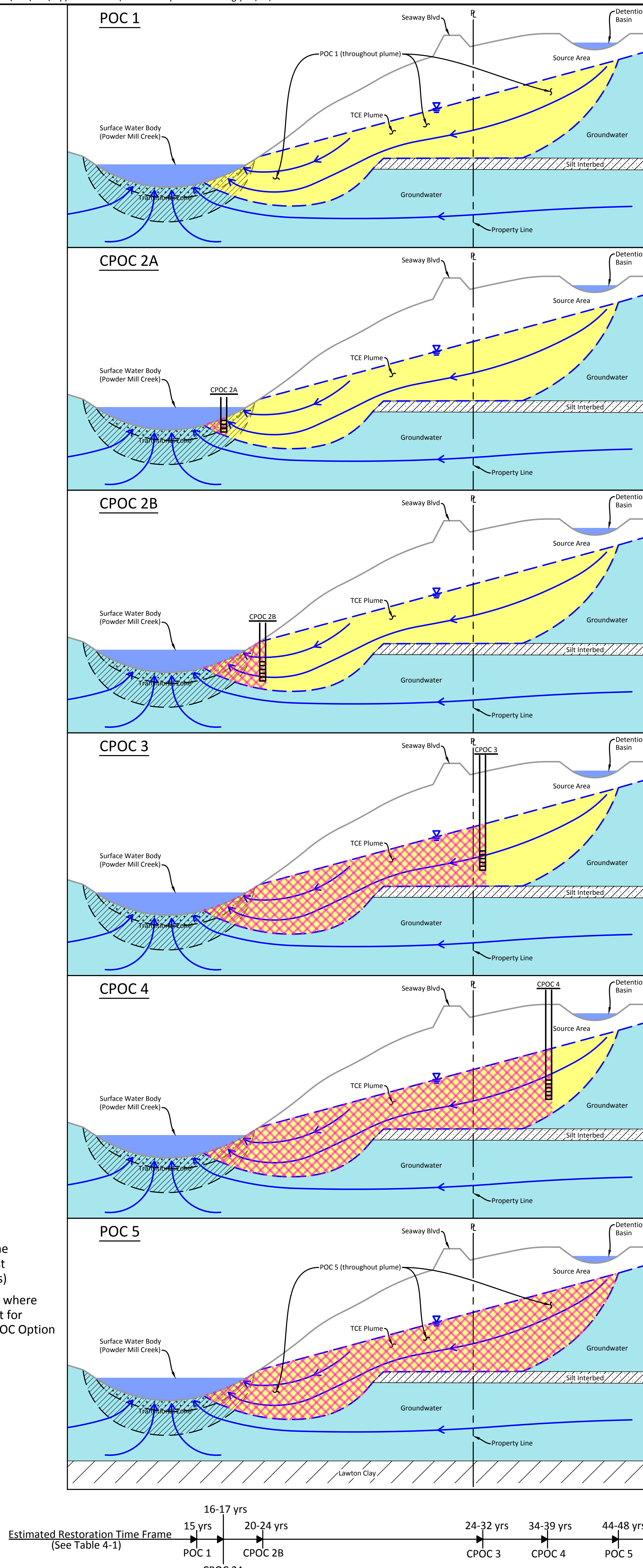
LANDAU ASSOCIATES

DRAFT

Supplemental Feasibility Study
Boeing Commercial Airplanes
Everett, Washington

Summary of POC Options

Figure
4-6a



Legend

- Extent of TCE Plume (where 4 µg/L must be met for all POCs)
- Groundwater Area where SWQS must be met for Compliance with POC Option
- Sediments
- Transitional Zone
- Silt Interbed
- Lawton Clay
- Groundwater Flow

Notes

1. Adapted from Ecology 2017 (Figure 5a).
2. This graphic is only a general representation to convey relative location and restoration time frame of each standard and conditional point of compliance (POC) option. Not drawn to scale.
3. All POC options also require meeting SWQS in Powder Mill Creek.
4. Black and white reproduction of this color original may reduce its effectiveness and lead to incorrect interpretation.

LANDAU ASSOCIATES

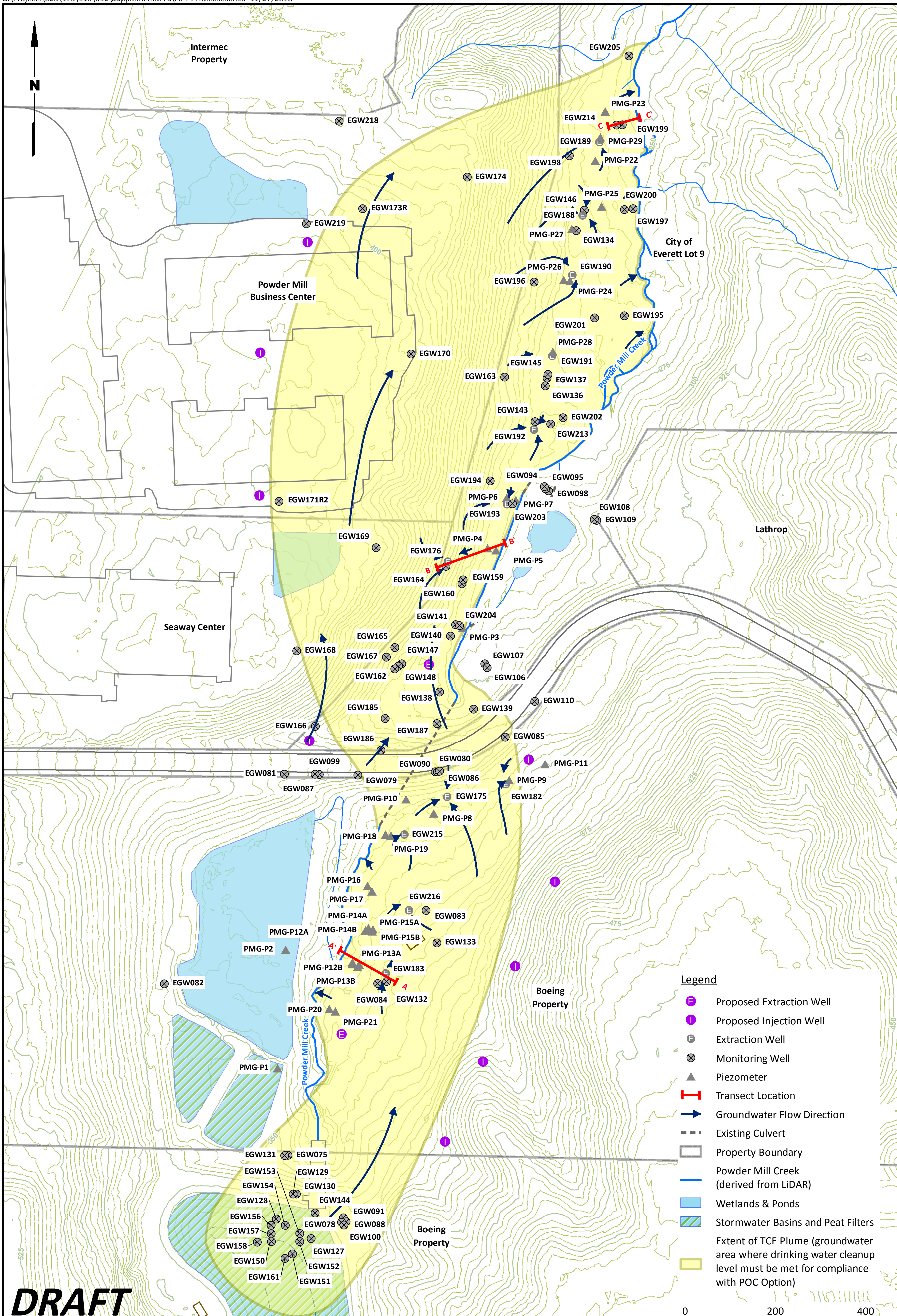
DRAFT

Supplemental Feasibility Study
Boeing Commercial Airplanes
Everett, Washington

Comparison of POC Options

Figure 4-6b

G:\Projects\025\175\118\012\Supplemental FS\F04-7Transects.mxd 11/27/2018

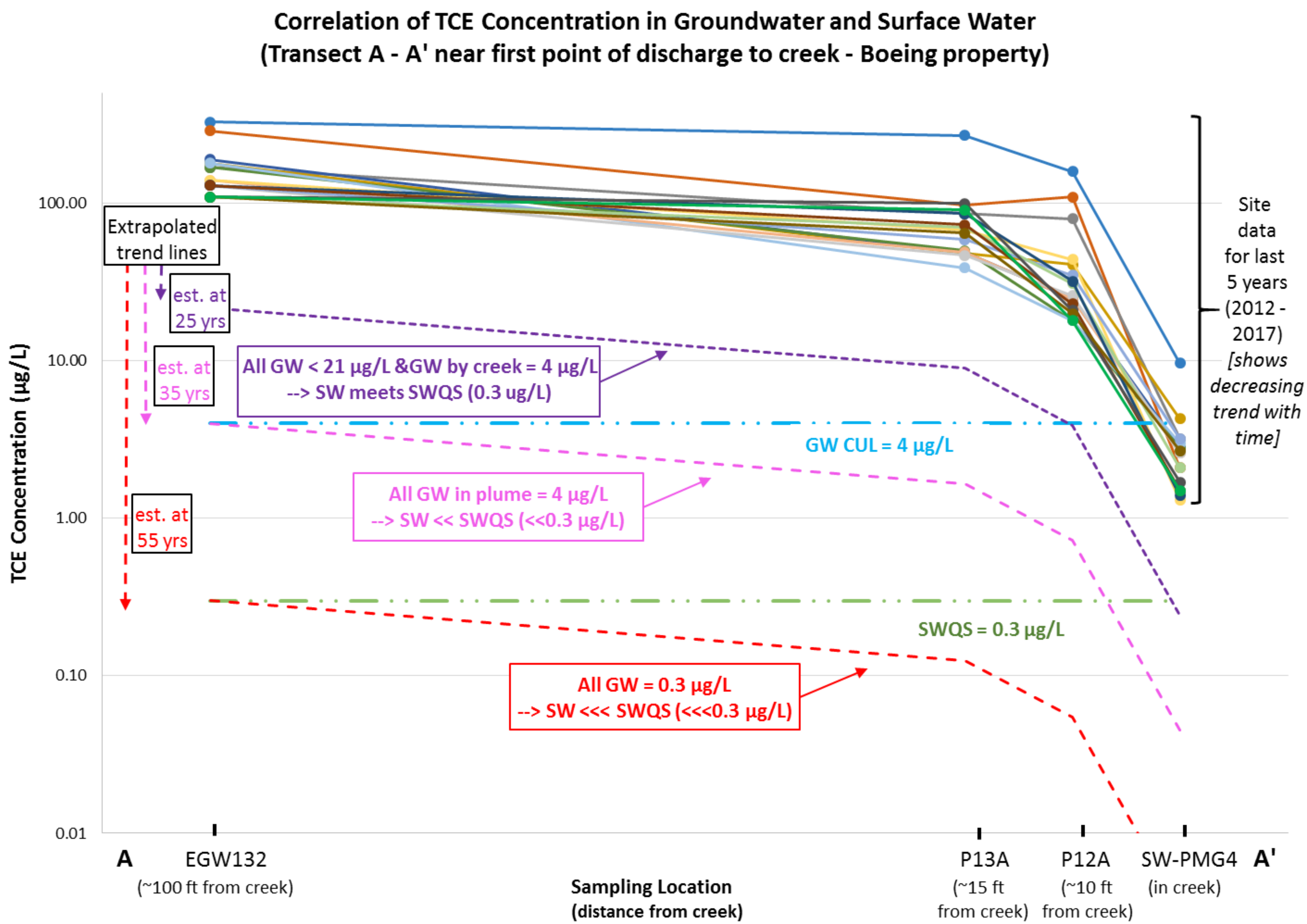


Note

1. Black and white reproduction of this color original may reduce its effectiveness and lead to incorrect interpretation.

LANDAU ASSOCIATES

Supplemental Feasibility Study Boeing Commercial Airplanes Everett, Washington	**Powder Mill Gulch Groundwater-Surface Water Transect Locations**	Figure **4-7**



LANDAU ASSOCIATES

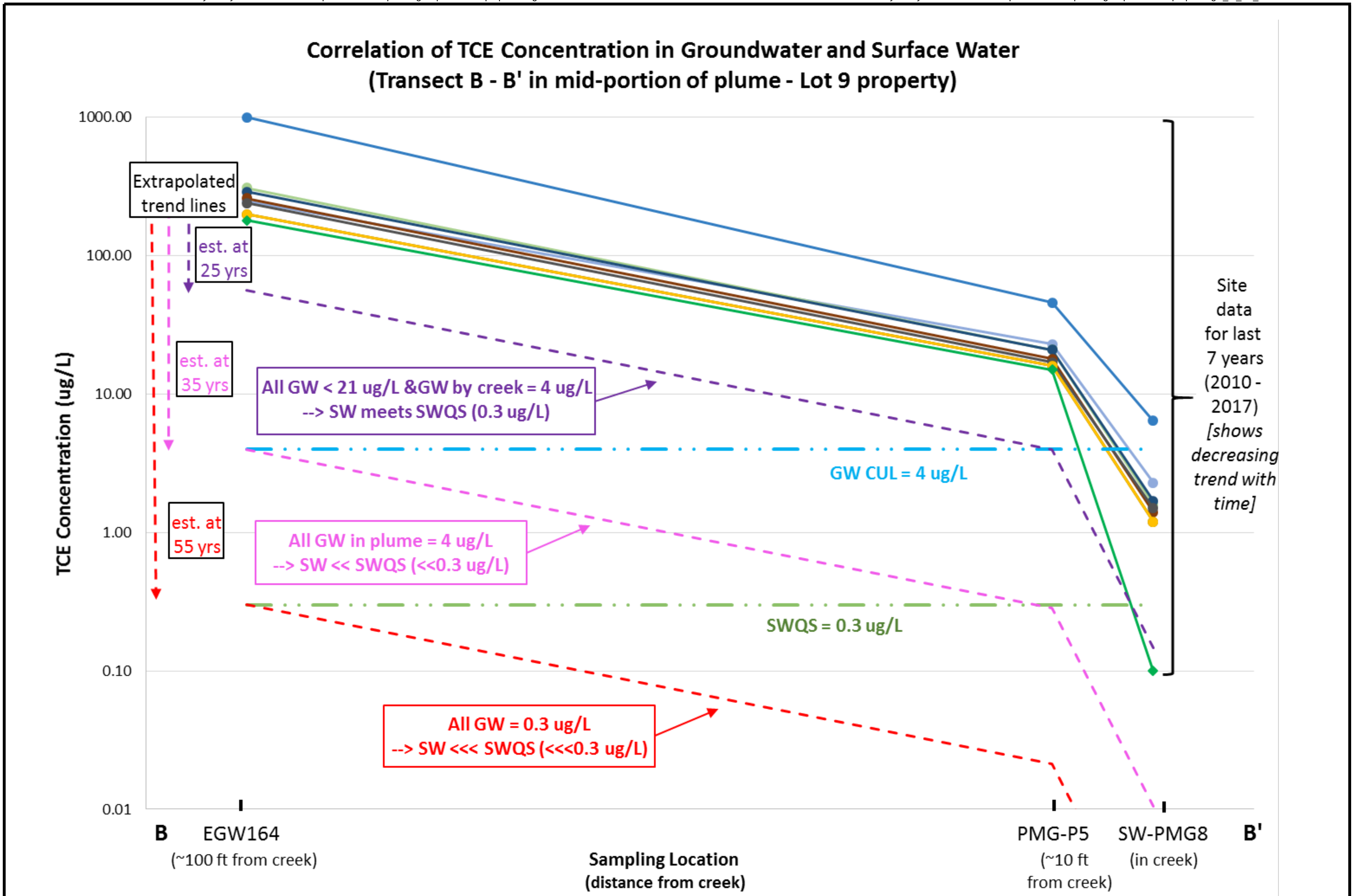
DRAFT

Powder Mill Gulch
Boeing Commercial Airplanes
Everett, Washington

Groundwater-Surface Water Transect A (South End of Plume)

Figure
4-7a

Source: P:\025\175\FileRm\R\Feasibility Study\2015 FS\Formal Dispute\FormalDisputeMtgPrep\Nov2016 proposal\gw_to_sw_correlation.xlsx



LANDAU ASSOCIATES

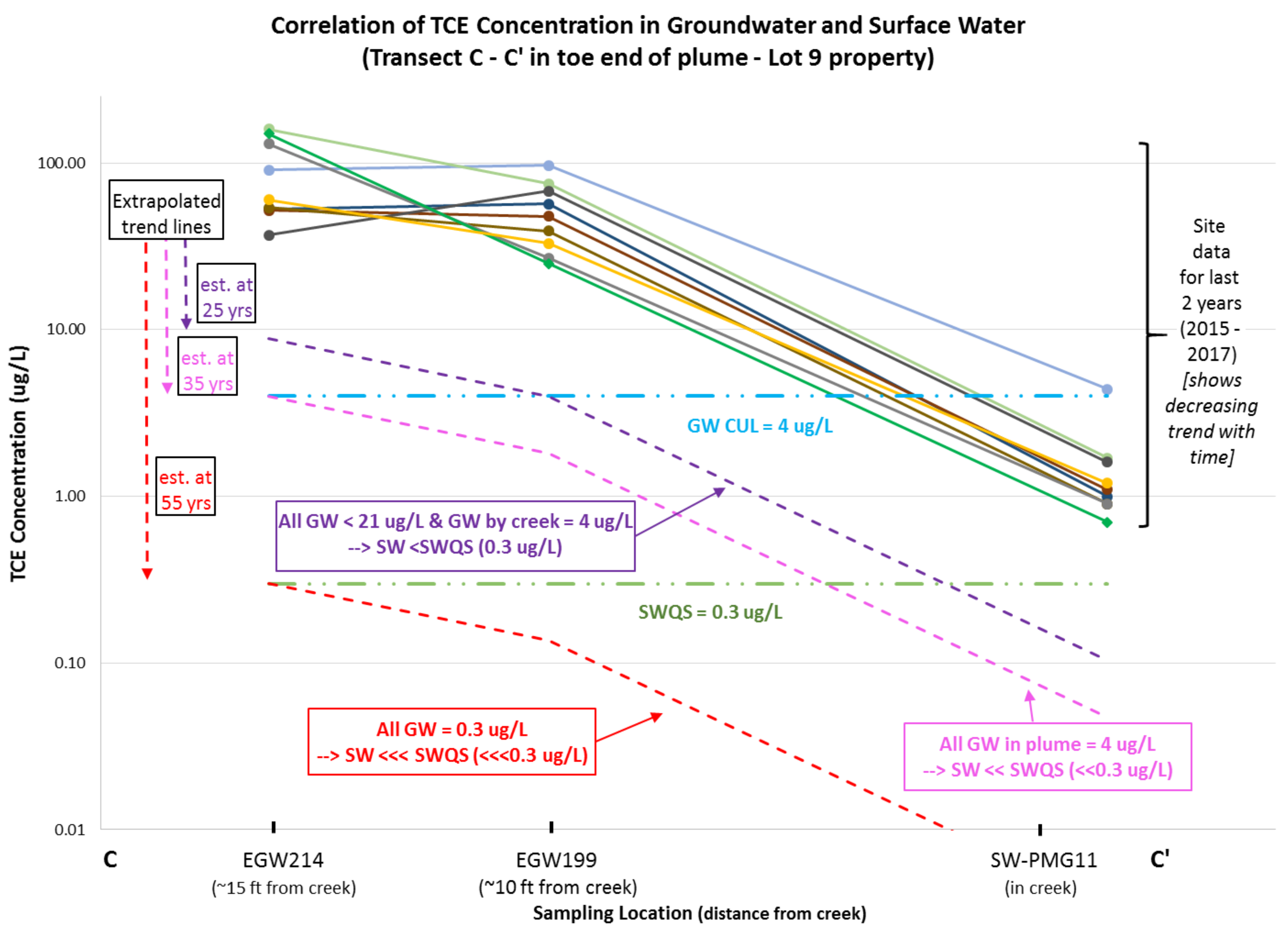
DRAFT

Powder Mill Gulch
Boeing Commercial Airplanes
Everett, Washington

Groundwater-Surface Water Transect B (Mid Portion of Plume)

Figure
4-7b

Source: P:\025\175\FileRm\R\Feasibility Study\2015 FS\Formal Dispute\FormalDisputeMtgPrep\Nov2016 proposal\gw_to_sw_correlation.xlsx



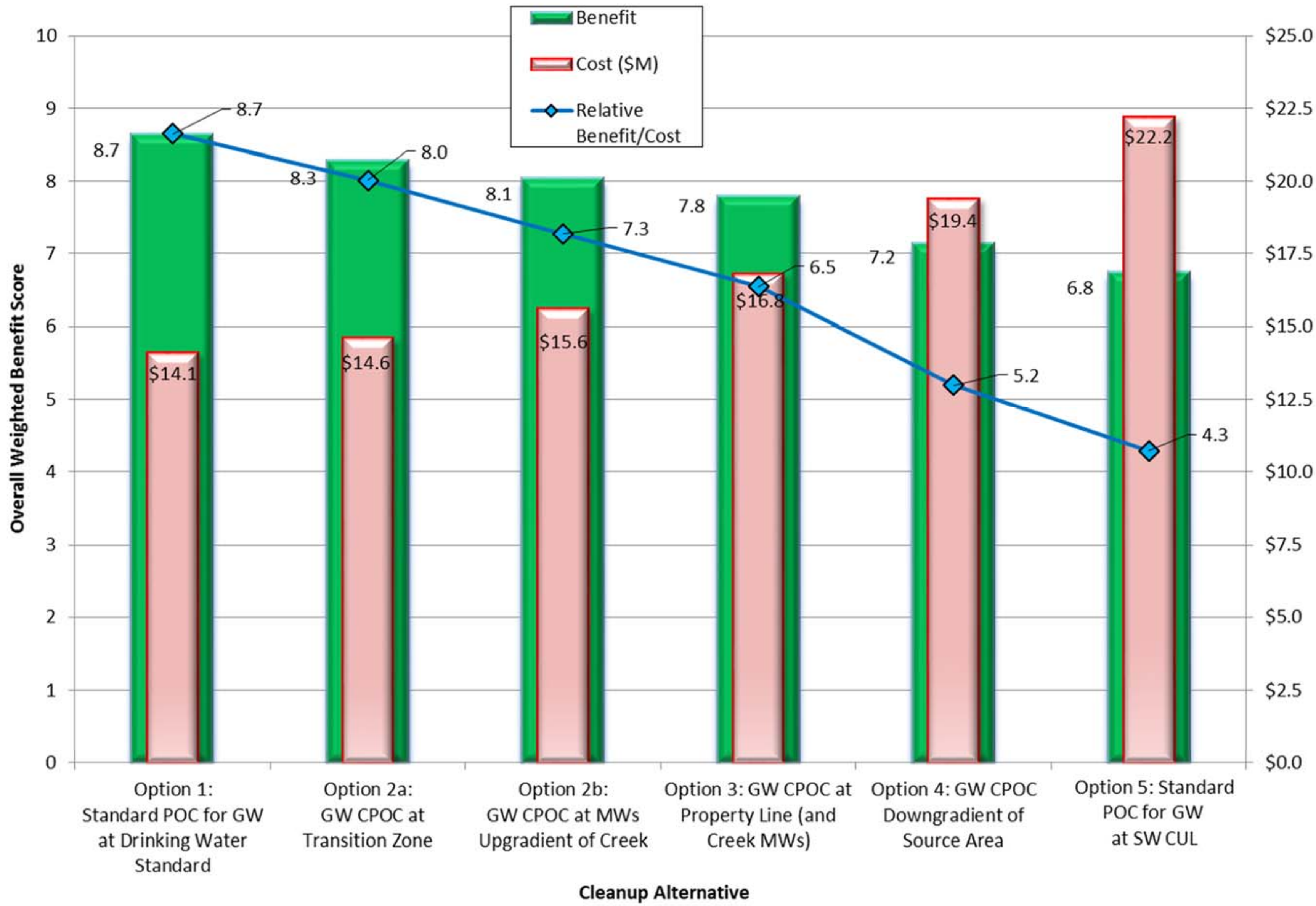
LANDAU ASSOCIATES

DRAFT

Powder Mill Gulch
Boeing Commercial Airplanes
Everett, Washington

Groundwater-Surface Water Transect C (North End of Plume)

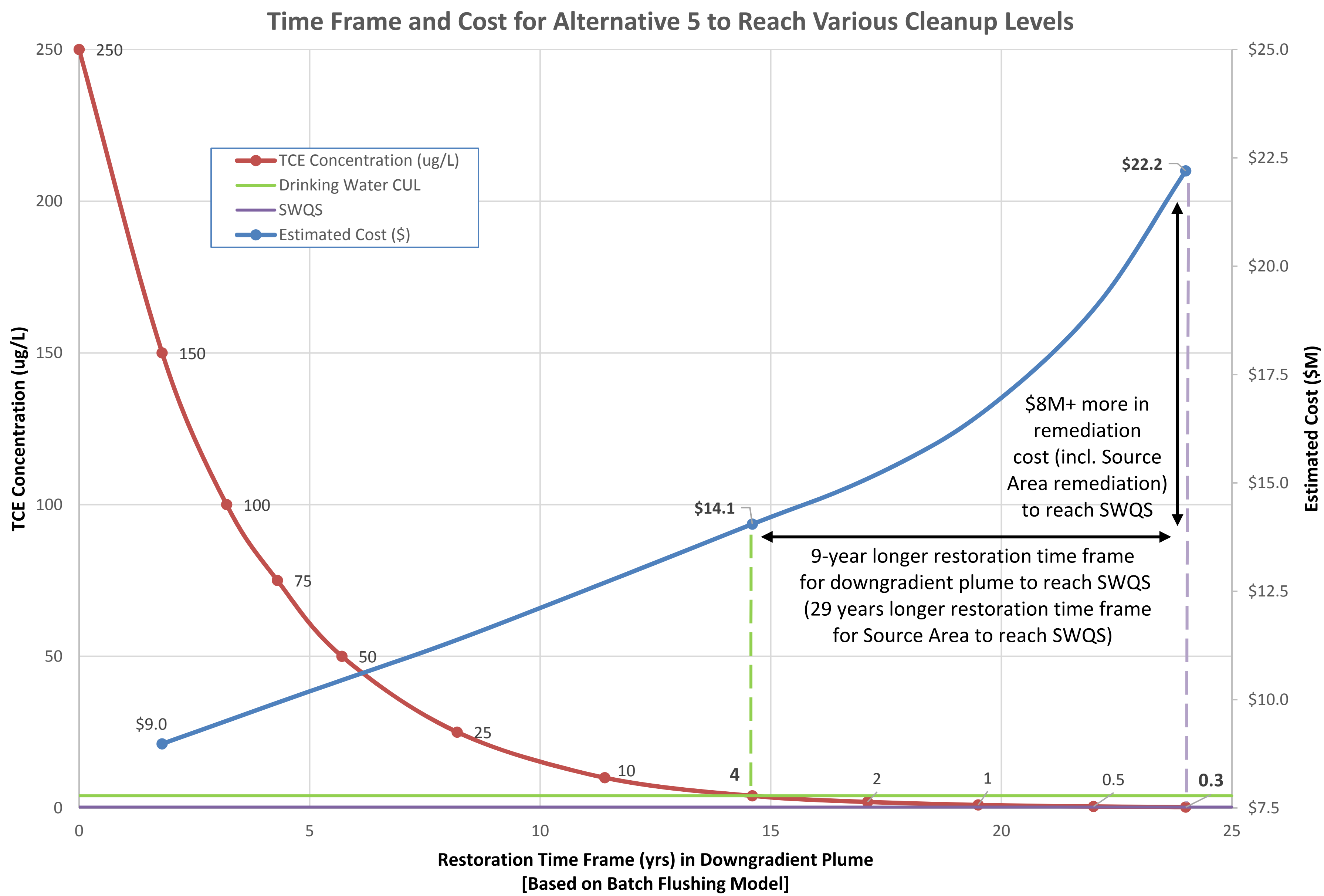
Figure 4-7c



LANDAU ASSOCIATES

DRAFT

Supplemental Feasibility Study Boeing Commercial Airplanes Everett, Washington	**Summary of Point of Compliance Relative Benefits Ranking – Alternative 5**	Figure 4-8



LANDAU ASSOCIATES

DRAFT

Supplemental Feasibility Study
Boeing Commercial Airplanes
Everett, Washington

Time Frame and Cost for Alternative 5 to Reach Various Cleanup Levels

Figure 4-9

DRAFT

Table 2-1
Restoration Time Frame Summary - All Remedial Alternatives
Boeing Everett - Powder Mill Gulch
Everett, Washington

Cleanup Alternative	Restoration Time Frame (years)				Comment
	Batch-Flushing	Biochlor	Average	Total*	
Alt 1 to GW CULs	28	45	37	**37**	GW CUL = 4 µg/L
Alt 1 to GW/SW CULs	45	73	59	59	SW CUL = 0.3 µg/L (SWQS as GW CUL)
Alt 2 to GW CULs	28	42	35	**35**	GW CUL = 4 µg/L
Alt 2 to GW/SW CULs	45	69	57	57	SW CUL = 0.3 µg/L (SWQS as GW CUL)
Alt 3 to GW CULs	21.5	33	27	**30**	GW CUL = 4 µg/L
Alt 3 to GW/SW CULs	39	60	50	53	SW CUL = 0.3 µg/L (SWQS as GW CUL)
Alt 4 to GW CULs	21.5	33	27	**30**	GW CUL = 4 µg/L
Alt 4 to GW/SW CULs	39	60	50	53	SW CUL = 0.3 µg/L (SWQS as GW CUL)
Alt 5 to GW CULs - Downgradient	15	N/A	N/A	**23**	GW CUL = 4 µg/L; Max. restoration time frame between downgradient plume and source area = 23 years
Alt 5 to GW CULs - Source Area	6	33	19		
Alt 5 to GW/SW CULs - Downgradient	35	N/A	N/A	38	SW CUL = 0.3 µg/L (SWQS as GW CUL); Max. restoration time frame between downgradient plume and source area = 38 years
Alt 5 to GW/SW CULs - Source Area	10	60	35		

Notes:

µg/L = micrograms per liter
Alt = Alternative
CAP = cleanup action plan
GW = groundwater
REL = remediation level
SW = surface water

N/A = not applicable, model results not applied to cleanup area

GW CUL = 4 µg/L Drinking water
SW CUL = 0.3 µg/L Drinking water and consumption of organisms

*Total restoration time frames start from assumed CAP implementation (currently assumed 2021). For Alternatives 2–5, assume restoration time frames where *in situ* treatment takes 3 years from CAP implementation start date for treatment to occur and achieve max TCE concentration in treatment areas = 100 µg/L (starting point of model degradation).

Table 3-1
Benefits Analysis and Ranking Considerations - Alternative 5
Boeing Everett - Powder Mill Gulch
Everett, Washington

Alternative Number:			Alternative 5
Description			Enhanced *In Situ* Bioremediation Source Area Treatment, Dynamic Groundwater Recirculation, and Institutional Controls
Relative Benefits Ranking for Disproportionate Cost Analysis			
Evaluation Criteria: WAC 173-340-360(3)(f)	**Weighting Factor**	**Benefit Score**	**Ranking Considerations (1)**
- Protectiveness	30%	9	**Superior** **• Existing risks minimal:** **- no current or likely future use of groundwater (GW) for drinking water** **- no current or likely future use of surface water (SW) for drinking water or consumption of organisms** **- current SW concentrations below ecological risk values** **• Dynamic groundwater recirculation (DGR) and Source Area enhanced in situ bioremediation (EISB) will be used separately, but complementary, to achieve cleanup levels (CULs) in GW and SW** **• Groundwater extraction and treatment (GET)/DGR system also used to minimize migration of contaminated GW to SW** **•Significantly shorter time frame required to achieve cleanup standards for GW and SW than all other alternatives:** **- Estimated 15 years for DGR to achieve drinking water standard in Downgradient Plume and SW standard in Powder Mill Creek** **- Estimated 23 years for EISB to achieve drinking water standard in Source Area** **• Attaining drinking water standards site-wide and protection of SW beneficial uses in the creek provide relatively high level of improvement of overall environmental quality** **• ICs, if necessary, will further reduce site risks until remedy completed.**
- Permanence	20%	9	**Superior** • Source Area EISB permanently destroys volatile organic compounds (VOCs)*in situ* , reduces contaminant toxicity, mass, and volume through stimulation of biological reductive dechlorination, ultimately irreversibly degrading the contaminants down to benign breakdown products. • DGR increases and enhances hydraulic control and capture through injection of treated groundwater along plume boundaries. • DGR enhances VOCs mass and volume removal from site GW through increased aquifer and pore volume flushing, and ultimately destroys the contaminant through treatment/disposal of VOCs sorbed to granular activated carbon (GAC). • ICs, if necessary, further prevent human exposure to contaminated media until implementation of cleanup achieves cleanup standards.
- Effectiveness over the Long-Term	20%	9	**Superior** • Highest degree of certainty that Alternative 5 will effectively and reliably achieve cleanup over the other alternatives. • Ability of DGR and EISB has been demonstrated to be successful in achieving cleanup of GW to federal drinking water standards. • Cleanup of GW to drinking water standard protective of potential future exposure and has been demonstrated to result in attainment of SW standards (protective of SW beneficial uses). • Exposure and risk during cleanup can be reliably mitigated by ICs, if necessary, and would be required for a significantly shorter duration than all the other alternatives.
- Management of Short-Term Risk	10%	8	**Excellent** • The ability to manage short-term risks associated with Alternative 5 is relatively high because of the low risks associated with worker safety during DGR system construction (expansion of existing GET system), injection well drilling, and electron donor injection events, which include the injection of nontoxic and nonhazardous substances. - Minimal worker health risk from contact with contaminated media during drilling. Drilling will be completed by qualified HAZWOPER-certified driller. - Minimal worker safety risk during drilling, DGR system construction, and EISB injections. Work will be completed by qualified HAZWOPER-certified contractor. • Long term operations and maintenance (O&M) of extraction/injection wells and treatment system present minor risks.
- Tech./Admin. Implementability	10%	8	**Excellent** • Technical implementation is relatively uncomplicated; proper installation of injection and extraction wells, treatment of GW and implementation of donor injection events in the source area provide limited technical challenges. Long-term O&M of extraction/injectio wells and treatment system present minor challenges, but duration will be shorter than for other alternatives resulting in lower likelihoo of major equipment problems/replacement. • Administration implementation challenges are very similar to other alternatives and include minor challenges such as modification of permitting for discharge of treated GW (National Pollutant Discharge Elimination System [NPDES] permit, and Underground Injection Control [UIC] permit), and filing ICs, if necessary.
- Consideration of Public Concerns	10%	10	**Superior (assumed equal for all alternatives)** • Protective of human health and the environment. • Provides at least the minimum level of protection under the Model Toxics Control Act (MTCA). • Public comments/concerns will be addressed during Remedial Investigation/Feasibility Study/Cleanup Action Plan (RI/FS/CAP) public comment period(s).
Estimated Cost ($)			**$14,100,000**
Overall Weighted Benefit Score (1)		8.9	**Excellent**
Comparative Overall Benefit/Cost Ratio (1,2)		7.8	**Excellent**

Notes:
(1) Ratings used: Poor (1-2), Fair (3-4), Good (5-6), Excellent (7-8), and Superior (9-10).
(2) Benefit/Cost Ratio scaled (divided) by cost of lowest cost alternative in order to compare ranges similar in scale to comparative overall benefit, as presented on Figure 3-1.

DRAFT

Table 3-2
Disproportionate Cost Analysis Summary - All Remedial Alternatives
Boeing Everett, Powder Mill Gulch
Everett, Washington

Alternative Number and Name	**Alternative 1 Continued Groundwater Extraction and Treatment (GET) System Operations and Institutional Controls**				**Alternative 2 Enhanced *In Situ* Bioremediation (EISB) Source Area Treatment w/GET System and Institutional Controls**				**Alternative 3 Focused *In Situ* Chemical Oxidation (ISCO) Treatment w/GET System and Institutional Controls**				**Alternative 4 Focused EISB Treatment w/GET System and Institutional Controls**				**Alternative 5 EISB Source Area Treatment, Dynamic Groundwater Recirculation (DGR), and Institutional Controls (if needed)**			
Relative Benefits Ranking for Disproportionate Cost Analysis (Washington Administrative Code [WAC] 173-340-360[2][b][i] and WAC 173-340-360[3][f])																				
***Comparative Overall Benefit* (a)**		Score	Weighting Factor	Weighted Score		Score	Weighting Factor	Weighted Score		Score	Weighting Factor	Weighted Score		Score	Weighting Factor	Weighted Score		Score	Weighting Factor	Weighted Score
- Protectiveness	Good	6	0.3	1.8	Excellent	7	0.3	2.1	Excellent	8	0.3	2.4	Excellent	7	0.3	2.1	Superior	9	0.3	2.7
- Permanence	Good	5	0.2	1	Excellent	7	0.2	1.4	Excellent	8	0.2	1.6	Excellent	7	0.2	1.4	Superior	9	0.2	1.8
- Effectiveness over the Long-Term	Good	6	0.2	1.2	Excellent	7	0.2	1.4	Excellent	8	0.2	1.6	Excellent	8	0.2	1.6	Superior	9	0.2	1.8
- Management of Short-Term Risks	Superior	10	0.1	1	Superior	9	0.1	0.9	Good	6	0.1	0.6	Excellent	7	0.1	0.7	Excellent	8	0.1	0.8
- Technical/Administrative Implementability	Superior	9	0.1	0.9	Excellent	8	0.1	0.7	Good	5	0.1	0.5	Good	5	0.1	0.5	Excellent	8	0.1	0.8
- Consideration of Public Concerns	Superior	10	0.1	1	Superior	10	0.1	1	Superior	10	0.1	1	Superior	10	0.1	1	Superior	10	0.1	1
Overall Weighted Benefit Score				**6.9**				**7.5**				**7.7**				**7.3**				**8.9**

Disproportionate Cost Analysis - Quantitative Evaluation

	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5
Overall Weighted Benefit Score	6.9	7.5	7.7	7.3	8.9
Estimated Remedy Cost	$12,300,000	$14,000,000	$21,600,000	$22,300,000	$14,100,000
Relative Benefit/Cost Ratio (b)	6.9	6.6	4.4	4.0	7.8
Most Permanent Solution	No	No	No	No	**Yes**
Lowest Cost Alternative	**Yes**	No	No	No	No
Costs Disproportionate to Incremental Benefits	Yes	Yes	Yes	Yes	**No**
Remedy that is Permanent to the Maximum Extent Practicable	No	No	No	No	Yes
Preferred Alternative	**No**	**No**	**No**	**No**	Yes

Notes:

(a) Ratings used: Poor (1-2), Fair (3-4), Good (5-6), Excellent (7-8), and Superior (9-10).

(b) Benefit/Cost Ratio scaled (multiplied) by lowest cost alternative score in order to compare ranges similar in scale to comparative overall benefit, as presented on Figure 3-1

Table 4-1
Restoration Time Frame Summary - Alternative 5 Point of Compliance Options
Boeing Everett - Powder Mill Gulch
Everett, Washington

Point of Compliance Option	Restoration Time Frame (years)						Comment	Restoration Timeframe 5) (years; if groundwater upgradient of CPOC not required to meet TCE = 4 ug/L)
	Batch-Flushing							
	Linear	Freundlich 1)	Biochlor	Average	Total 2)	Range 3)		
POC Option 1 - Downgradient	15	N/A	N/A	N/A	15	**15**	Standard POC: GW CUL = 4 µg/L (drinking water standard); SW CUL = 0.3 µg/L (SWQS)	N/A
POC Option 1 - Source Area	6	N/A	33	20	23	**23**		
POC Option 2a - Downgradient 5)	16	17	N/A	N/A	16	**16 - 17**	Conditional POC (Transition Zone): GW and SW CUL = 0.3 µg/L (SWQS)	9
POC Option 2a - Source Area	6	N/A	33	20	23	**23**		
POC Option 2b - Downgradient 4,5)	20	24	N/A	N/A	20	**20 - 24**	Conditional POC (Monitoring Wells Upgradient of Creek): GW and SW CUL = 0.3 µg/L (SWQS)	15
POC Option 2b - Source Area	6	N/A	33	20	23	**23**		
POC Option 3 - Downgradient	24	32	N/A	N/A	24	**24 - 32**	Conditional POC (Monitoring Wells at Boeing Property Line and Upgradient of Creek on Boeing Property): GW and SW CUL = 0.3 µg/L (SWQS)	24
POC Option 3 - Source Area	6	N/A	33	20	23	**23**		
POC Option 4 - Downgradient 6)	34	39	N/A	N/A	34	**34 - 39**	Conditional POC (Monitoring Wells Downgradient of Source Area): GW and SW CUL = 0.3 µg/L (SWQS)	34
POC Option 4 - Source Area	8	10	45	27	30	**30 - 31**		
POC Option 5 - Downgradient	44	48	N/A	N/A	44	**44 - 48**	Standard POC: GW CUL = 0.3 µg/L (SWQS); SW CUL = 0.3 µg/L (SWQS)	N/A
POC Option 5 - Source Area	10	14	59	35	38	**38 - 40**		

Abbreviations:

µg/L = micrograms per liter
CAP = cleanup action plan
CUL = cleanup level
GW = groundwater
SW = surface water
POC = point of compliance
SWQS = surface water quality standards
TCE = trichloroethene
N/A = not applicable, model results not applied to cleanup area

Notes:

GW CUL = 4 µg/L — Drinking water
SW CUL = 0.3 µg/L — Drinking water and consumption of organisms

1) Freundlich desorption isotherm used in Batch Flushing Model where linear isotherm do not apply (not in linear range of cleanup that apply at higher contaminant concentrations in groundwater) and Freundlich isotherm is a better predictor of groundwater cleanup time frames in low concentration ranges where controlled by desorption or back diffusion limited processes. Value shown includes additional time predicted for concentrations decreases from 4 µg/L to 0.3 µg/L.
2) Total restoration time frames start from assumed CAP implementation (currently assumed 2021). For Source Area, restoration timeframes assume *in situ* treatment takes 3 years from CAP implementation start date for treatment to occur and achieve max TCE concentration in treatment areas = 100 µg/L (starting point of model degradation).
3) Lower end of restoration time frame range use Batch Flushing model results where linear isotherm is applied. Upper end of restoration time frame range use Batch Flushing Model where Freundlich isotherm is applied. Restoration timeframes in downgradient plume for POC Options 1 through 3 do not include monitoring wells immediately downgradient of the source area which could take longer to reach SWQS because of residual TCE (and other CVOC) discharge from the source area (at concentrations >4 µg/L) during completion of source area cleanup.
4) Restoration timeframe for POC Option 2b assumes that additional time necessary to reduce concentrations from 4 µg/L to 0.3 µg/L at wells upgradient of the creek will be dependent upon shorter flow paths from the edge of a contracted plume located near the Lot 9 access road (i.e., not the current width of the plume) .
5) Downgradient plume restoration time frame for these POC options shown in "Batch Flushing" (linear) column for the downgradient plume are dependent upon reaching TCE concentrations of 4 µg/L (drinking water standard); if 0.3 µg/L (SWQS) were only required for CPOC compliance, restoration time frames would be reduced to 9 and 15 years for Options 2a and 2b, respectively, as shown on column on far right. I.e., the restoration time frames for these CPOCs are longer to achieve the drinking water cleanup level (4 µg/L TCE) upgradient of the CPOC than to the time needed to achieve the surface water cleanup level (0.3 µg/L TCE) at the CPOC itself.
6) Downgradient plume restoration time frame shown in "Batch Flushing" (linear) column for downgradient plume assumes that DGR cleanup time is dependent upon source area cleanup; value shown assumes source area TCE concentrations must be reduced to 1.2 µg/L before DGR cleanup can be completed to SWQS in dowgradient plume.

DRAFT

Table 4-2
Benefits Analysis and Ranking Considerations - Alternative 5 Point of Compliance Evaluation
Boeing Everett - Powder Mill Gulch
Everett, Washington

POC Option Number:			POC Option 1		POC Option 2a		POC Option 2b		POC Option 3		POC Option 4		POC Option 5
Point of Compliance Description (1):			Standard Point of Compliance - Drinking Water Standard (4 µg/L TCE) in GW, Surface Water Quality Standard (0.3 µg/L TCE) in SW		Groundwater Conditional Point of Compliance in Transitional Zone at Creek (0.3 µg/L TCE)		Groundwater Conditional Point of Compliance in Monitoring Wells Upgradient of Creek (0.3 µg/L TCE)		Groundwater Conditional Point of Compliance at Boeing Property Line and Upgradient of Creek on Boeing Property (0.3 µg/L TCE)		Groundwater Conditional Point of Compliance Downgradient of Source Area (0.3 µg/L TCE)		Standard Point of Compliance - Surface Water Quality Standard (0.3 µg/L TCE) throughout Groundwater and Surface Water at Powder Mill Gulch
Relative Benefits Ranking for Disproportionate Cost Analysis													
Evaluation Criteria: WAC 173-340-360(3)(f)	**Weighting Factor**	**Benefit Score**	**Ranking Considerations (1)**	**Benefit Score**	**Ranking Considerations (1)**	**Benefit Score**	**Ranking Considerations (1)**	**Benefit Score**	**Ranking Considerations (1)**	**Benefit Score**	**Ranking Considerations (1)**	**Benefit Score**	**Ranking Considerations (1)**
- Protectiveness	30%	9	**Superior** • Protective of human health and the environment; when CULs met in GW (drinking water standards) and SW (surface water quality standards), all potential human and ecological receptors protected • Existing risks minimal: - no current or likely future use of groundwater for drinking water (institutional controls [ICs] will be implemented to minimize future risk) - no current or likely future use of surface water (SW) for drinking water or consumption of organisms (ICs will be implemented to minimize future risk) - current SW concentrations below ecological risk values • Groundwater extraction and treatment (GET) to minimize migration of contaminated groundwater (GW) to SW • Dynamic groundwater recirculation (DGR) and Source Area enhanced *in situ* bioremediation (EISB) to achieve cleanup levels (CULs) in GW and SW • Shortest time required to achieve cleanup standards at this point of compliance: - Estimated 15 years for DGR to achieve drinking water standard in Downgradient Plume and surface water standard in Powder Mill Creek - Estimated 23 years for EISB to achieve drinking water standard in Source Area	8.5	**Excellent/Superior** • Protective of human health and the environment; when CULs met in GW and SW under Option 1, all potential human and ecological receptors protected • Existing risks minimal: - no current or likely future use of GW for drinking water (ICs will be implemented to minimize future risk) - no current or likely future use of SW for drinking water or consumption of organisms (ICs will be implemented to minimize future risk) - current SW concentrations below ecological risk values • GET to minimize migration of contaminated GW to SW • DGR and Source Area EISB to achieve CULs in GW and SW • Second shortest time required to achieve cleanup standards at this point of compliance: - Estimated 16 years for DGR to achieve SW standards in Downgradient Plume and surface water standard in monitoring points adjacent to/below Powder Mill Creek - Estimated 23 years for EISB to achieve drinking water standard in Source Area	8.5	**Excellent** • Protective of human health and the environment; when CULs met in GW and SW under Option 1, all potential human and ecological receptors protected • Existing risks minimal: - no current or likely future use of GW for drinking water (ICs will be implemented to minimize future risk) - no current or likely future use of SW for drinking water or consumption of organisms (ICs will be implemented to minimize future risk) - current SW concentrations below ecological risk values • GET to minimize migration of contaminated GW to SW • DGR and Source Area EISB to achieve CULs in GW and SW • Slightly longer time required to achieve cleanup standards at this point of compliance: - Estimated 20 years for DGR to achieve drinking water standard in Downgradient Plume and SW standard in wells upgradient of Powder Mill Creek - Estimated 23 years for EISB to achieve drinking water standard in Source Area • Attaining drinking water standards for Source Area majority of Downgradient Plume provide relatively high level of improvement of overall environmental quality.	8	**Excellent** • Protective of human health and the environment; when CULs met in GW and SW under Option 1, all potential human and ecological receptors protected • Existing risks minimal: - no current or likely future use of GW for drinking water (ICs will be implemented to minimize future risk) - no current or likely future use of SW for drinking water or consumption of organisms (ICs will be implemented to minimize future risk) - current SW concentrations below ecological risk values • GET to minimize migration of contaminated GW to SW • DGR and Source Area EISB to achieve CULs in GW and SW • Moderately long time required to achieve cleanup standards at this point of compliance: - Estimated 24 years for DGR to achieve SW standards in off-property plume - Estimated 23 years for EISB to achieve drinking water standards in Source Area	7	**Excellent** • Protective of human health and the environment; when CULs met in GW and SW under Option 1, all potential human and ecological receptors protected • Existing risks minimal: - no current or likely future use of GW for drinking water (ICs will be implemented to minimize future risk) - no current or likely future use of SW for drinking water or consumption of organisms (ICs will be implemented to minimize future risk) - current SW concentrations below ecological risk values • GET to minimize migration of contaminated GW to SW • DGR and Source Area EISB to achieve CULs in GW and SW • Relatively long time required to achieve cleanup standards at this point of compliance: - Estimated 34 years for DGR to achieve SW standards in Downgradient Plume (dependent on Source Area restoration) - Estimated 30 years for EISB to achieve drinking water standards and low enough concentrations in Source Area to achieve SW standards in monitoring wells immediately downgradient of Source Area	6	**Good** • Protective of human health and the environment; when CULs met in GW and SW under Option 1, all potential human and ecological receptors protected • Existing risks minimal: - no current or likely future use of GW for drinking water (ICs will be implemented to minimize future risk) - no current or likely future use of SW for drinking water or consumption of organisms (ICs will be implemented to minimize future risk) - current SW concentrations below ecological risk values • GET to minimize migration of contaminated GW to SW • DGR and Source Area EISB to achieve CULs in GW and SW • Longest time required to achieve cleanup standards at this point of compliance: - Estimated 44 years for DGR to achieve SW standards in Downgradient Plume (dependent on Source Area restoration) - Estimated 38 years for EISB to achieve SW standards in Source Area.
- Permanence	20%	8	**Excellent** • Source Area EISB permanently destroys volatile organic compounds (VOCs) *in situ*, reduces contaminant toxicity, mass, and volume. • DGR captures and removes VOC mass and volume from site GW and ultimately destroys the contaminant through treatment/disposal of VOCs sorbed to granular activated carbon (GAC). • Actual volume of TCE reduced from current conditions is approximately 90 percent	8	**Excellent** • Source Area EISB permanently destroys VOCs *in situ*, reduces contaminant toxicity, mass, and volume. • DGR captures and removes VOCs mass and volume from site GW and ultimately destroys the contaminant through treatment/disposal of VOCs sorbed to GAC. • Actual volume of TCE reduced from current conditions is approximately 90 percent	8	**Excellent** • Source Area EISB permanently destroys VOCs *in situ*, reduces contaminant toxicity, mass, and volume. • DGR captures and removes VOCs mass and volume from site GW and ultimately destroys the contaminant through treatment/disposal of VOCs sorbed to GAC. • Actual volume of TCE reduced from current conditions is approximately 90.3 percent • Quantity of treatment residuals marginally increased through additional TCE mass loading on GAC	8.5	**Excellent/Superior** • Source Area EISB permanently destroys VOCs *in situ*, reduces contaminant toxicity, mass, and volume. • DGR captures and removes VOCs mass and volume from site GW and ultimately destroys the contaminant through treatment/disposal of VOCs sorbed to GAC. • Actual volume of TCE reduced from current conditions is approximately 95 percent • Quantity of treatment residuals slightly increased through additional TCE mass loading on GAC	8.5	**Excellent/Superior** • Source Area EISB permanently destroys VOCs *in situ*, reduces contaminant toxicity, mass, and volume. • DGR captures and removes VOCs mass and volume from site GW and ultimately destroys the contaminant through treatment/disposal of VOCs sorbed to GAC. • Actual volume of TCE reduced from current conditions is approximately 97.9 percent • Quantity of treatment residuals moderately increased through additional TCE mass loading on GAC	9	**Superior** • Source Area EISB permanently destroys VOCs *in situ*, reduces contaminant toxicity, mass, and volume. • DGR captures and removes VOCs mass and volume from site GW and ultimately destroys the contaminant through treatment/disposal of VOCs sorbed to GAC. • Actual volume of TCE reduced from current conditions is approximately 99 percent • Quantity of treatment residuals moderately increased through additional TCE mass loading on GAC
- Effectiveness over the Long-Term	20%	8	**Excellent** • Cleanup of GW to drinking water standard is likely to be achieved and will be protective of potential future exposure and has been demonstrated to result in attainment of SW standards (protective of SW beneficial uses). • Relatively short time frame required to meet cleanup standards results in high degree of certainty that the remedy will continue to succesfully achieve cleanup goals and objectives while TCE concentrations are still above cleanup standards.	7.5	**Excellent** • Cleanup of GW to drinking water standard is likely to be achieved and will be protective of potential future exposure and has been demonstrated to result in attainment of SW standards (protective of SW beneficial uses). • Exposure and risk during cleanup can be reliably mitigated by ICs. • Minimally longer time frame required to meet cleanup standards results in very slightly lower degree of certainty that the remedy will continue to succesfully achieve cleanup goals and objectives while TCE concentrations are still above cleanup standards.	7	**Excellent** • Cleanup of GW to drinking water standard is likely to be achieved and will be protective of potential future exposure and has been demonstrated to result in attainment of SW standards (protective of SW beneficial uses). • Exposure and risk during cleanup can be reliably mitigated by ICs. • Slightly longer time frame required to meet cleanup standards results in lower degree of certainty that the remedy will continue to succesfully achieve cleanup goals and objectives while TCE concentrations are still above cleanup standards.	7	**Excellent** • Cleanup of GW to drinking water standard is likely to be achieved and will be protective of potential future exposure and has been demonstrated to result in attainment of SW standards (protective of SW beneficial uses). • Exposure and risk during cleanup can be reliably mitigated by ICs. • Slightly longer time frame required to meet cleanup standards results in lower degree of certainty that the remedy will continue to succesfully achieve cleanup goals and objectives while TCE concentrations are still above cleanup standards.	6.5	**Good/Excellent** • Cleanup of GW to drinking water standard is likely to be achieved and will be protective of potential future exposure and has been demonstrated to result in attainment of SW standards (protective of SW beneficial uses). • Exposure and risk during cleanup can be reliably mitigated by ICs. • Moderatly longer time frame required to meet cleanup standards results in moderately lower degree of certainty that the remedy will continue to succesfully achieve cleanup goals and objectives while TCE concentrations are still above cleanup standards due to increased risk of system failure or decreased efficiency due to issues with pumping systems, electronic monitoring and controls, or electrical system.	6.5	**Good/Excellent** • Cleanup of GW to drinking water standard is likely to be achieved and will be protective of potential future exposure and has been demonstrated to result in attainment of SW standards (protective of SW beneficial uses). • Exposure and risk during cleanup can be reliably mitigated by ICs. • Moderatly longer time frame required to meet cleanup standards results in moderately lower degree of certainty that the remedy will continue to succesfully achieve cleanup goals and objectives while TCE concentrations are still above cleanup standards due to increased risk of system failure or decreased efficiency due to issues with pumping systems, electronic monitoring and controls, or electrical system.
- Management of Short-Term Risk	10%	8.5	**Excellent/Superior** • Minimal worker health risk from contact with contaminated media during drilling. Drilling will be completed by qualified HAZWOPER-certified driller. • Minimal worker safety risk during drilling, DGR system construction, and EISB injections. Work will be completed by qualified HAZWOPER-certified contractor. • Long-term operations and maintenance (O&M) of extraction/injection wells and treatment system present minor risks. • Long-term sampling of monitoring wells in detention basin from a raft presents minor risks.	8.5	**Excellent/Superior** • Minimal worker health risk from contact with contaminated media during drilling. Drilling will be completed by qualified HAZWOPER-certified driller. • Minimal worker safety risk during drilling, DGR system construction, and EISB injections. Work will be completed by qualified HAZWOPER-certified contractor. • Long-term O&M of extraction/injection wells and treatment system present minor risks. • Long-term sampling of monitoring wells in detention basin from a raft presents minor risks.	8	**Excellent** • Minimal worker health risk from contact with contaminated media during drilling. Drilling will be completed by qualified HAZWOPER-certified driller. • Minimal worker safety risk during drilling, DGR system construction, and EISB injections. Work will be completed by qualified HAZWOPER-certified contractor. • Slightly longer long-term O&M period for extraction/injection wells and treatment system presents slightly higher risks to workers. • Slightly longer long-term sampling of monitoring wells in detention basin from a raft present slightly higher risks.	8	**Excellent** • Minimal worker health risk from contact with contaminated media during drilling. Drilling will be completed by qualified HAZWOPER-certified driller. • Minimal worker safety risk during drilling, DGR system construction, and EISB injections. Work will be completed by qualified HAZWOPER-certified contractor. • Slightly longer long-term O&M period for extraction/injection wells and treatment system presents slightly higher risks to workers. • Slightly longer long-term sampling of monitoring wells in detention basin from a raft present slightly higher risks.	7.5	**Excellent** • Minimal worker health risk from contact with contaminated media during drilling. Drilling will be completed by qualified HAZWOPER-certified driller. • Minimal worker safety risk during drilling, DGR system construction, and EISB injections. Work will be completed by qualified HAZWOPER-certified contractor. • Moderately longer long-term O&M period for extraction/injection wells and treatment system presents moderately higher risks to workers. • Moderately longer long-term sampling of monitoring wells in detention basin from a raft present moderately higher risks.	7.5	**Excellent** • Minimal worker health risk from contact with contaminated media during drilling. Drilling will be completed by qualified HAZWOPER-certified driller. • Minimal worker safety risk during drilling, DGR system construction, and EISB injections. Work will be completed by qualified HAZWOPER-certified contractor. • Moderately longer long-term O&M period for extraction/injection wells and treatment system presents moderately higher risks to workers. • Moderately longer long-term sampling of monitoring wells in detention basin from a raft present moderately higher risks.

Table 4-2
Benefits Analysis and Ranking Considerations - Alternative 5 Point of Compliance Evaluation
Boeing Everett - Powder Mill Gulch
Everett, Washington

POC Option Number:		POC Option 1		POC Option 2a		POC Option 2b		POC Option 3		POC Option 4		POC Option 5	
Point of Compliance Description (1):			Standard Point of Compliance - Drinking Water Standard (4 µg/L TCE) in GW, Surface Water Quality Standard (0.3 µg/L TCE) in SW		Groundwater Conditional Point of Compliance in Transitional Zone at Creek (0.3 µg/L TCE)		Groundwater Conditional Point of Compliance in Monitoring Wells Upgradient of Creek (0.3 µg/L TCE)		Groundwater Conditional Point of Compliance at Boeing Property Line and Upgradient of Creek on Boeing Property (0.3 µg/L TCE)		Groundwater Conditional Point of Compliance Downgradient of Source Area (0.3 µg/L TCE)		Standard Point of Compliance - Surface Water Quality Standard (0.3 µg/L TCE) throughout Groundwater and Surface Water at Powder Mill Gulch
Relative Benefits Ranking for Disproportionate Cost Analysis													
Evaluation Criteria: WAC 173-340-360(3)(f)	Weighting Factor	Benefit Score	Ranking Considerations (1)	Benefit Score	Ranking Considerations (1)	Benefit Score	Ranking Considerations (1)	Benefit Score	Ranking Considerations (1)	Benefit Score	Ranking Considerations (1)	Benefit Score	Ranking Considerations (1)
- Tech/Admin. Implementability	10%	9	**Excellent** • Ability of DGR and EISB has been widely demonstrated to be successful in achieving cleanup of groundwater to drinking water standards (i.e., two orders of magnitude [99%] reduction). • Technical implementation of system construction remedy implementation relatively uncomplicated; proper installation of injection and extraction wells, treatment of GW, and implementation of donor injection events provide limited technical challenges. Long-term O&M period is shortest of all options; O&M of extraction/injection wells and treatment system present minor challenges. • Administration implementation challenges include modification of permitting for discharge of treated groundwater (National Pollutant Discharge Elimination System [NPDES] permit, and Underground Injection Control [UIC] permit), and maintaining access agreements with offsite property owners; filing ICs and associated 5-year reviews not required. • Integration with existing site operations (detention basin O&M) and other current/future remedial actions (sediment/stormwater remediation work) presents some challenges.	8	**Excellent** • Ability of DGR and EISB has been widely demonstrated to be successful in achieving cleanup of GW to drinking water standards (i.e., two orders of magnitude [99%] reduction). Site data demonstrates high likelihood of reaching SW standards at point of groundwater discharge to SW due to attenuation in transition/hyporheic zone. • Technical implementation relatively uncomplicated; proper installation of injection and extraction wells, treatment of GW, and implementation of donor injection events provide limited technical challenges. Long-term O&M period is second shortest of all options; O&M of extraction/injection wells and treatment system present minor challenges. • Minor technical challenges may be encountered with installation of pore water samplers and monitoring of GW adjacent to or beneath creek. • Administration implementation challenges include modification of permitting for discharge of treated groundwater (NPDES permit, UIC permit), maintaining access agreements with ofsite property owners,and filing ICs/conducting 5-yr reviews. • Integration with existing site operations (detention basin O&M) and other current/future remedial actions (sediment/stormwater remediation work) presents some challenges.	7	**Excellent** • Ability of DGR and EISB has been widely demonstrated to be successful in achieving cleanup of GW to drinking water standards (i.e., two orders of magnitude [99%] reduction). However, success in achieving three-order of magnitude (99.9%) reductions in GW (to SWQS) have been shown to be technically infeasible through active remedial technologies; therefore, there is moderate uncertainty that the alternative will be successful in achieving cleanup standards in a reasonable restoration time frame at the monitoring wells upgradient of the creek for this CPOC. • Technical implementation is relatively uncomplicated; proper installation of injection and extraction wells, treatment of GW, and implementation of donor injection events provide limited technical challenges. Long-term O&M period slightly longer; O&M of extraction/injection wells and treatment system present minor challenges. • Administration implementation challenges include modification of permitting for discharge of treated groundwater (NPDES permit, UIC permit); challenges increase with longer remedial time frames for maintaining access agreements with ofsite property owners,and filing ICs/conducting 5-yr review. • Challenges increase with time for integration with existing site operations (detention basin O&M) and other current/future remedial actions (sediment/stormwater remediation work).	5	**Good** • Ability of DGR and EISB has not been widely demonstrated to be successful in achieving cleanup of GW to SWQS; i.e., achieving three-order of magnitude (99.9%) reductions in GW have been shown to be technically infeasible through active remedial meausres. Therefore, there is moderately high uncertainty that the alternative will be successful in achieving cleanup standards in the core of the plume at and downgradient of the Boeing property line. • Technical implementation is relatively uncomplicated; proper installation of injection and extraction wells, treatment of GW, and implementation of donor injection events provide limited technical challenges. Long-term O&M likely to extend into period requiring major equipment replacement; O&M of extraction/injection wells and treatment system may present more significant challenges with duration of remedy. • Greater technical challenges may be encountered with 9-year longer sampling of GW and SW , maintenance of detention basis injection wells, and O&M of DGR system. • Administration implementation challenges include modification of permitting for discharge of treated groundwater (NPDES permit, UIC permit); challenges increase more with longer remedial time frames for maintaining access agreements with ofsite property owners,and filing ICs. • Challenges increase more with time for integration with existing site operations (detention basin O&M) and other current/future remedial actions (sediment/stormwater remediation work).	3	**Fair** • Ability of DGR and EISB has not been widely demonstrated to be successful in achieving cleanup of GW to SWQS; i.e., achieving three-order of magnitude (99.9%) reductions in GW have been shown to be technically infeasible through active remedial meausres. Therefore, there is relatively high uncertainty that the alternative will be successful in achieving cleanup standards in the core of the plume and immediately downgradient of the Source Area. • Technical implementation is relatively uncomplicated; proper installation of injection and extraction wells, treatment of groundwater, and implementation of donor injection events provide limited technical challenges. Long-term O&M very likely to extend into period requiring major equipment replacement; O&M of extraction/injection wells and treatment system may present more significant challenges with duration of remedy. • Greater technical challenges may be encountered with 19-year longer sampling of GW and SW, maintenance of detention basis injection wells, and O&M of DGR system. • Administration implementation challenges include modification of permitting for discharge of treated groundwater (NPDES permit, UIC permit); challenges increase considerably more more with longer remedial time frames for maintaining access agreements with ofsite property owners,and filing ICs. • Challenges increase considerably more with time for integration with existing site operations (detention basin O&M) and other current/future remedial actions (sediment/stormwater remediation work).	1	**Poor** • Ability of DGR and EISB has not been widely demonstrated to be successful in achieving cleanup of GW to SWQS; i.e., achieving three-order of magnitude (99.9%) reductions in GW have been shown to be technically infeasible through active remedial meausres. Therefore, there is very high uncertainty that the alternative will be successful in achieving cleanup standards in the core of the plume and in the Source Area. • Technical implementation relatively uncomplicated; proper installation of injection and extraction wells, treatment of groundwater, and implementation of donor injection events provide limited technical challenges. Longest O&M period of all options, very likely to extend into period requiring major equipment replacement; O&M of extraction/injection wells and treatment system may present more significant challenges with duration of remedy. • Greater technical challenges may be encountered with 29-year longer sampling of GW and SW, maintenance of detention basis injection wells, and O&M of DGR system with likely major equipment replacement. • Administration implementation challenges include modification of permitting for discharge of treated groundwater (NPDES permit, UIC permit); challenges increase substantially more more with longer remedial time frames for maintaining access agreements with ofsite property owners,and filing ICs. • Challenges increase substantially more with time for integration with existing site operations (detention basin O&M) and other current/future remedial actions (sediment/stormwater remediation work).
- Consideration of Public Concerns	10%	10	**Superior (assumed equal for all alternatives)** • Protective of human health and the environment. • Provides at least the minimum level of protection under the Model Toxics Control Act (MTCA). • Public comments/concerns will be addressed during Remedial Investigation/Feasibility Study/Cleanup Action Plan (RI/FS/CAP) public comment period(s).	10	**Superior (assumed equal for all alternatives)** • Protective of human health and the environment. • Provides at least the minimum level of protection under MTCA. • Public comments/concerns will be addressed during RI/FS/CAP public comment period(s).	10	**Superior (assumed equal for all alternatives)** • Protective of human health and the environment. • Provides at least the minimum level of protection under MTCA. • Public comments/concerns will be addressed during RI/FS/CAP public comment period(s).	10	**Superior (assumed equal for all alternatives)** • Protective of human health and the environment. • Provides at least the minimum level of protection under MTCA. • Public comments/concerns will be addressed during RI/FS/CAP public comment period(s).	10	**Superior (assumed equal for all alternatives)** • Protective of human health and the environment. • Provides at least the minimum level of protection under MTCA. • Public comments/concerns will be addressed during RI/FS/CAP public comment period(s).	10	**Superior (assumed equal for all alternatives)** • Protective of human health and the environment. • Provides at least the minimum level of protection under MTCA. • Public comments/concerns will be addressed during RI/FS/CAP public comment period(s).
Estimated Cost ($)			$14,100,000		$14,600,000		$15,600,000		$16,800,000		$19,400,000		$22,200,000
Overall Weighted Benefit Score (2)		8.65	Excellent/Superior	8.3	Excellent	8.05	Excellent	7.8	Excellent	7.2	Good	6.8	Good
Comparative Overall Benefit/Cost Ratio (2,3)		8.65	Excellent/Superior	8.0	Excellent	7.3	Good/Excellent	6.5	Good	5.2	Fair/Good	4.3	Fair

Notes:
(1) POC Options 2a, 2b, 3, and 4 are modified from standard MTCA requirements in Option 1 to include meeting SWQS at location described
(2) Ratings used: Poor (1-2), Fair (3-4), Good (5-6), Excellent (7-8), and Superior (9-10).
(3) Benefit/Cost Ratio scaled (divided) by cost of lowest cost point of compliance in order to compare ranges similar in scale to comparative overall benefit, as presented on Figure 4-8.

DRAFT

Table 4-3
Disproportionate Cost Analysis Summary - Alternative 5 Point of Compliance Evaluation
Boeing Everett - Powder Mill Gulch
Everett, Washington

POC Option Number:	Option 1	Option 2a	Option 2b	Option 3	Option 4	Option 5
Point of Compliance Description (1):	Standard Point of Compliance - Drinking Water Standard (4 µg/L TCE) in GW, Surface Water Quality Standard (0.3 µg/L TCE) in SW	Groundwater Conditional Point of Compliance in Transitional Zone at Creek (0.3 µg/L TCE)	Groundwater Conditional Point of Compliance in Monitoring Wells Upgradient of Creek (0.3 µg/L TCE)	Groundwater Conditional Point of Compliance at Boeing Property Line and Upgradient of Creek on Boeing Property (0.3 µg/L TCE)	Groundwater Conditional Point of Compliance Downgradient of Source Area (0.3 µg/L TCE)	Standard Point of Compliance - Surface Water Quality Standard (0.3 µg/L TCE) throughout Groundwater and Surface Water at Powder Mill Gulch

Relative Benefits Ranking for Disproportionate Cost Analysis (Washington Administrative Code [WAC] 173-340-360[2][b][i] and WAC 173-340-360[3][f])

Options 1, 2a and 2b

Comparative Overall Benefit (2)	Option 1	Score	Weighting Factor	Weighted Score	Option 2a	Score	Weighting Factor	Weighted Score	Option 2b	Score	Weighting Factor	Weighted Score
- Protectiveness	Superior	9	0.3	2.7	Excellent/ Superior	8.5	0.3	2.55	Excellent/ Superior	8.5	0.3	2.55
- Permanence	Excellent	8	0.2	1.6	Excellent	8	0.2	1.6	Excellent	8	0.2	1.6
- Effectiveness over the Long-Term	Excellent	8	0.2	1.6	Excellent	7.5	0.2	1.5	Excellent	7	0.2	1.4
- Management of Short-Term Risks	Excellent/ Superior	8.5	0.1	0.85	Excellent/ Superior	8.5	0.1	0.85	Excellent	8	0.1	0.8
- Technical/Administrative Implementability	Superior	9	0.1	0.9	Excellent	8	0.1	0.8	Excellent	7	0.1	0.7
- Consideration of Public Concerns	Superior	10	0.1	1	Superior	10	0.1	1	Superior	10	0.1	1
Overall Weighted Benefit Score				**8.7**				**8.3**				**8.1**

Options 3, 4 and 5

Comparative Overall Benefit (2)	Option 3	Score	Weighting Factor	Weighted Score	Option 4	Score	Weighting Factor	Weighted Score	Option 5	Score	Weighting Factor	Weighted Score
- Protectiveness	Excellent	8	0.3	2.4	Excellent	7	0.3	2.1	Good	6	0.3	1.8
- Permanence	Excellent/ Superior	8.5	0.2	1.7	Excellent/ Superior	8.5	0.2	1.7	Superior	9	0.2	1.8
- Effectiveness over the Long-Term	Excellent	7	0.2	1.4	Good/ Excellent	6.5	0.2	1.3	Good/ Excellent	6.5	0.2	1.3
- Management of Short-Term Risks	Excellent	8	0.1	0.8	Excellent	7.5	0.1	0.75	Excellent	7.5	0.1	0.75
- Technical/Administrative Implementability	Good	5	0.1	0.5	Fair	3	0.1	0.3	Poor	1	0.1	0.1
- Consideration of Public Concerns	Superior	10	0.1	1	Superior	10	0.1	1	Superior	10	0.1	1
Overall Weighted Benefit Score				**7.8**				**7.2**				**6.8**

Disproportionate Cost Analysis - Quantitative Evaluation

	Option 1	Option 2a	Option 2b	Option 3	Option 4	Option 5
Overall Weighted Benefit Score	8.7	8.3	8.1	7.8	7.2	6.8
Estimated Remedy Cost at POC	$14,100,000	$14,600,000	$15,600,000	$16,800,000	$19,400,000	$22,200,000
Relative Benefit/Cost Ratio (3)	8.7	8.0	7.3	6.5	5.2	4.3
Lowest Cost POC	**Yes**	Yes	No	No	No	No
Costs Disproportionate to Incremental Benefits	**No**	Yes	Yes	Yes	Yes	Yes
POC that is Permanent to the Maximum Extent Practicable	Yes	No	No	No	No	No
Preferred POC	**Yes**	**No**	**No**	**No**	**No**	**No**

Notes:

(1) POC Options 2a, 2b, 3, and 4 are modified from standard MTCA requirements in Option 1 to include meeting SWQS at location described

(2) Ratings used: Poor (1-2), Fair (3-4), Good (5-6), Excellent (7-8), and Superior (9-10).

(3) Benefit/Cost Ratio scaled (multiplied) by lowest cost POC score in order to compare ranges similar in scale to comparative overall benefit, as presented on Figure 4-8.

APPENDIX A

Groundwater Modeling Technical Memorandum

Technical Memorandum

TO: Debbie Taege, The Boeing Company

FROM: Ben Lee, PE and Piper Roelen, PE

DATE: November 26, 2018

RE: **Preliminary Groundwater Modeling and Restoration Time Frame Modeling – Dynamic Groundwater Recirculation System**
Powder Mill Gulch – Boeing Everett Plant
Everett, Washington
Project No. 025175.118.012

Introduction and Objective

The Boeing Company (Boeing) operates a groundwater extraction and treatment (GET) system within Powder Mill Gulch (PMG), north of its Everett manufacturing plant, to mitigate for historical groundwater impacts by volatile organic compounds (VOCs), primarily trichloroethene (TCE). The groundwater system of PMG has been previously investigated and documented in the remedial investigation report (URS and Landau Associates, Inc. [LAI] 2011) that was approved by the Washington State Department of Ecology (Ecology; Ecology 2011). Groundwater flow at the site has been simulated with a three-dimensional numerical groundwater flow model (model; LAI 2011) using Groundwater Modeling System (GMS)/MODFLOW to better understand groundwater hydrology at the site and for use in design and placement of the various GET system extraction wells. The model was originally constructed for the site in 2009 and has been updated and calibrated with site data periodically as successive phases and expansions of the GET system have been designed, installed, and brought into operation (LAI 2012 and 2014). The GET system was designed by LAI, and has been in operation since 2012 (with expansions in 2015 and 2016). It currently consists of 12 extraction wells and an air stripper treatment system. Treated groundwater from the GET system is discharged to Powder Mill Creek under a National Pollutant Discharge Elimination System (NPDES) permit. Optionally, the treated effluent may also be discharged to the City of Everett sanitary sewer system under a discharge permit.

Four remedial alternatives for cleanup of the PMG TCE plume were originally evaluated in a feasibility study (FS) report (AECOM and LAI 2015) that was submitted to the Washington State Department of Ecology (Ecology) in 2015. During subsequent communications and correspondence with Ecology, it was determined that an additional remedial alternative proposed by Boeing should be evaluated as part of a supplemental FS (SFS). As a part of this fifth alternative (identified as "Alternative 5" for the purposes of the SFS and this memorandum), Boeing proposed modifying and upgrading the existing GET system by adding nine groundwater injection wells and two additional extraction wells to convert the system into a groundwater recirculation (GR) system. Through adaptive management and dynamic operation of the GR system, dynamic groundwater recirculation (DGR) will be used to address contamination in the downgradient portion of the groundwater plume.

LAI developed a conceptual plan for proposed extraction and injection wells for the DGR system as shown in Figure 1. The plan was based on the preliminary modeling results included in this memorandum as well as the current known TCE plume configuration; site topography, natural features (wetlands, surface water, vegetation), and infrastructure; and the location, spacing, and area of influence of the existing GET system extraction wells. The nine proposed injection wells will inject treated groundwater pumped from the existing GET system (and from the two new extraction wells).

The MODFLOW groundwater model for the site has been modified to better simulate current groundwater flow conditions and to simulate the effect of the proposed extraction and injection wells. This technical memorandum summarizes changes made to model boundary conditions as well as results of simulations including the proposed extraction and injection wells. This memorandum also serves as a support document to the SFS report for PMG by providing backup and input information related to two restoration time frame estimating models used to estimate restoration time frames for cleanup alternatives discussed in the SFS.

Model Recharge Modifications

Recent groundwater quality and elevation data within PMG suggest a slight northwesterly shift of the TCE plume boundary in the area of the Seaway Center property and Powder Mill Business Center (PMBC) property (north of Seaway Boulevard and west of Powder Mill Creek).[1] New commercial developments on the PMBC property (completed in 2015) and on the Seaway Center Property (completed in early 2018) appear to be the cause of this shift, most likely due to altered recharge patterns to the groundwater system of PMG. Specifically, precipitation recharge has been greatly reduced in areas newly covered with impervious material (i.e., buildings or pavement). These developments were constructed on previously forested areas and include impervious areas covering approximately 22.4 acres on the PMBC property and 11.3 acres on the Seaway Center property (approximately 34 total acres of new impervious area). Concurrently, precipitation recharge has likely been increased/concentrated in the location of a new stormwater infiltration pond on the north end of the PMBC property receiving runoff from the new impervious surfaces on that property. The stormwater pond located on the Seaway Center property is a lined detention pond that discharges to the City of Everett stormwater management system and does not infiltrate onsite.

Based on this new data, the following modifications to the model were implemented to simulate the recent changes in the recharge patterns near PMG noted above:

- Recharge to the approximately 22.4 acres of impervious ground surface at the PMBC property and the approximately 11.3 acres of impervious ground surface at the Seaway Center property

[1] Two new monitoring wells were installed in this area in late October 2018 that are now being used to better understand and further evaluate the extent of the TCE plume and groundwater flow in this area.

associated with the new commercial developments[2] north of Seaway Boulevard was set to zero (i.e., 0.0 feet [ft] per day). Recharge to a new 1.0-acre infiltration facility associated with the PMBC property development was set to 0.18 ft per day[3] under steady state conditions. The impervious surfaces and the infiltration facility are shown on Figure 2.

The simulated groundwater contours resulting from the modifications to the model recharge array noted above are shown on Figure 3. MODPATH particle tracking flow path lines originating from select model cells and based on the simulated head resulting from the recharge array modifications are shown on Figure 4.

Modeling of Proposed Injection and Extraction Wells

The two proposed extraction wells and nine proposed injection wells were each applied to model layer 1 as a well boundary condition (extraction wells were given negative discharge rates to indicate a withdrawal of water from the groundwater system; injection wells were given positive discharge rates to indicate an addition of water to the groundwater system). The proposed wells were applied to the model in locations shown on Figures 1 and 5. The extraction or injection rates applied to the proposed (and existing) wells are summarized in Table 1. The simulated steady state head under proposed additional extraction and injection conditions is shown on Figure 5.

Particle tracking was performed with MODPATH using the simulated steady state head under proposed extraction and injection conditions (along with extraction from existing extraction wells). The results of the particle tracking indicates that the proposed injection wells and extraction wells, in combination with the existing extraction wells, enhances containment and capture of the TCE plume, and enhances flushing of the plume by creating shorter groundwater flow paths between naturally occurring or injected clean groundwater outside the periphery of the plume and the extraction wells located inside the plume. Representative MODPATH particle flow path lines under proposed extraction and injection conditions are shown on Figure 6.[4]

Application of Groundwater Modeling and Methodology for Restoration Time Frame Analysis

As indicated in Section 2.3.6 of the SFS report, estimated restoration time frames for achieving the cleanup standards at various points of compliance for the conceptual DGR system and source area

[2] The impervious area of the new developments includes Buildings A, B, C, and D and the new parking lot on the PMBC property, and Buildings A and B and the new parking lots and the detention pond on the Seaway Center property.

[3] 0.18 ft per day recharge is based on an average annual precipitation rate of 36.1 inches, a contributing area of approximately 22.35 acres (assuming all stormwater from the new development is routed to the infiltration facility), and an infiltration facility area of 1.0 acre. This value assumes that 100 percent of the stormwater that is routed to the facility is infiltrated.

[4] Note that this figure represents steady state operation of the conceptual DGR system with all injection wells and extraction wells operating simultaneously at set flow rates (Table 1). Actual operation of the DGR system will result in multiple and varying flow directions depending on the configuration and flow rates for each injection and extraction well.

bioremediation (Alternative 5) were determined using groundwater GMS/MODFLOW modeling in combination with one or both of two restoration time frame estimating models, the Batch Flushing model (EPA 1988) and the BIOCHLOR Natural Attenuation Decision Support System model (BIOCHLOR, Version 2.2, 2002 release).[5] These models are both industry standard and EPA-accepted tools for this type of application (EPA 1988, 2018) and are the same models used for previous restoration time frame estimates provided in the FS and associated submittals prepared for Ecology for review.

The results from the particle tracking shown on Figure 6 were used to identify flow paths and distances/travel times that could be used as input parameters for the Batch Flushing and BIOCHLOR modeling to estimate restoration time frames associated with Alternative 5 in different areas of the site. Specifically, the flow paths between injection wells or the edge of the plume and extraction wells or identified point of compliance, as identified by the MODFLOW groundwater model, were used to identify flow path lengths/travel times for input into the Batch Flushing and/or BIOCHLOR models.

Consistent with the way restoration time frames were estimated for the four FS alternatives, an average of the results from the Batch Flushing model and BIOCHLOR was used for the restoration time frame for the source area. The rationale for using this average is based on the comparison of the results of the two models and the average of the two models to actual site data sets (LAI 2017). Existing site data at several locations within the core of the plume where groundwater TCE concentration reductions have been observed both before and after the influence of GET system operations showed a strong correlation with the average of the models under both pre- and post-extraction well pumping conditions, providing a greater degree of confidence and justification for using this average. For the source area, the estimate assumes that the highest TCE concentration remaining in the source area after implementation of enhanced *in situ* bioremediation (EISB) would be 100 micrograms per liter (µg/L).[6]

However, unlike the other four alternatives, only the Batch Flushing model was used to estimate the restoration time frame using Alternative 5, DGR, in the downgradient plume. The leading literature on DGR supports this use of the Batch Flushing model. Suthersan et al. (2015) reported that:

> "The underlying basis for the design of a DGR system is the volume of water contained within the plume, and the number of pore volume flushes (PVFs) required to achieve water quality goals set forth by the performance objectives. Simple equations can be applied within the context of the [conceptual site model] (CSM) to begin the design process. An estimate for the volume of water needed to achieve remedial goals can be

---

[5] Calculations, data assumptions, and input parameters for BIOCHLOR and Batch Flushing were the same as prior restoration time frame modeling (except as otherwise noted in this report) as detailed in the *Restoration Time Frame Evaluation—Modeling Inputs/Sensitivity Analysis* Technical Memorandum (LAI 2017).

[6] Achieving cleanup to levels at or below this concentration would mean that source area concentrations have been reduced to similar concentrations as the rest of the diluted TCE groundwater plume outside of the source area; performing active EISB to reduce concentrations below that of the rest of the plume provides no additional benefit and is not considered cost-effective.

developed from concepts of complete mixed reactors often referred to as batch flush…"

This statement, along with the results of case studies for sites where DGR systems have been employed where significantly more rapid restoration time frames have been realized in comparison to pump-and-treat systems (ITRC 2015, Suthersan et al. 2017), indicates that the results of the Batch Flushing model are more representative of the restoration time frames that can be anticipated from implementation of DGR systems.

Therefore, using the flow path distances/travel times between injection wells and extraction wells as identified by the MODFLOW groundwater model, the Batch Flushing model was applied for flow paths that cross TCE focus areas in the downgradient plume to identify the most conservative restoration time frames for the plume as a whole.

BIOCHLOR and Batch Flushing Model Inputs

Additional information on the background and theory of the Batch Flushing and BIOCHLOR models was included in LAI's restoration time frame modeling inputs and sensitivity analysis technical memorandum (LAI 2017). The inputs used for these two models are described below.

The inputs used for the BIOCHLOR and Batch Flushing Modeling were the same as those provided to Ecology in the restoration time frame memorandum (LAI 2017), except for the following:

Travel distances (*L*): The groundwater flow path distances, based on the MODFLOW groundwater model output, that were used for these two models for evaluation of Alternative 5 included the following approximate flow distances:

- From the upgradient edge of the source area to the downgradient edge, *L* = approximately 450 ft (same value used in previous source area modeling);[7]
- Across the TCE focus area south of Seaway Boulevard from proposed injection wells to extraction wells on the downgradient edge of the focus area, *L* = approximately 380 ft (or approximately 30 percent of the flow path length used for the other FS alternatives in this area of the site because of the effects of the DGR system);[8]
- Across the TCE focus area north of Seaway Boulevard from proposed injection wells to extraction wells on the downgradient edge of the focus area, *L* =approximately 450 ft (or approximately 50 percent of the flow path length used for the other FS alternatives in this area of the site because of the effects of the DGR system);[7]

[7] Applies to point of compliance (POC) Options 1 through 5 for source area restoration time frame (through enhanced *in situ* bioremediation).

[8] Applies to POC Options 1 through 5 for downgradient plume restoration time frame (through DGR); however, assumed Options 4 and 5 also reliant on source area restoration. Note that the restoration time frames for POC options 2a/2b are driven by the longer times necessary to meet drinking water standards upgradient of the actual POCs (see SFS Table 4-1).

- Across the plume south of Seaway Boulevard from proposed injection wells through monitoring wells adjacent to creek, *L* = approximately 420 ft;[9,10] and
- From west edge and across theoretical future contracted width of plume north of Seaway Boulevard through monitoring wells adjacent to creek, *L* =approximately 225 ft.[8]

Gradient (*i*):

- For the source area, *i* = 0.027 feet per foot (ft/ft), value used to reflect slightly flatter gradients measured for this area of the site.
- Although the gradients in the Phase 1 and Phase 2 Interim Action (IA) areas are likely to be steeper as a result of groundwater injection wells operating in these areas in conjunction with the DGR system, because these gradients will be shifted and altered frequently during DGR operations, as a conservative measure the gradient values used for the models in these areas were kept constant with values used for the restoration time frame modeling done for the other four FS alternatives.

The results and discussion of the restoration time frame modeling for Alternative 5 are included in Section 2.3.6 of the SFS report. The results and discussion of the restoration time frame modeling for the evaluation of POC options are included in Sections 4.2, 4.3.1, and 4.3.3 of the SFS report.

Freundlich Isotherm for Estimation of Restoration Time Frames for Low Concentrations

Section 4.1 of the SFS report includes discussion of restoration time frames that would be necessary based on a series of groundwater points of compliance. Several of these points of compliance include requirements for achieving very low TCE concentrations (i.e., 0.3 µg/L) within the TCE plume. Prominent research references related to the behavior of chlorinated solvents in the environment (e.g., Pankow and Cherry 1996, Stroo and Ward 2010) discuss sorption and desorption processes for chlorinated solvents in the aqueous environment. These references, which are based on both experimental and full-scale field application data, consistently indicate that experimentally derived isotherms for chlorinated solvents, including TCE, are often not well described by linear isotherms (which is what the Batch Flushing model uses for the retardation factor equation for calculating restoration time frames) for certain segments of the isotherm curve. Rather, the isotherms show that the retardation factor is dependent on the solution concentration and is often better predicted by non-linear isotherms, such as the Freundlich desorption isotherm. This non-linear behavior of the isotherm data appears to be primarily due to sorption/desorption or diffusion/back diffusion limited interactions of the contaminants between the aquifer solid and aqueous matrices.

[9] Applies to POC Option 2b for additional downgradient plume restoration time frame at monitoring wells adjacent to creek both north and south of Seaway Boulevard (through DGR).

[10] Applies to POC Option 3 for additional downgradient restoration time frame at monitoring wells adjacent to creek south of Seaway Boulevard.

Therefore, the Batch Flushing Model was run again to provide a more realistic estimate of restoration time frames for the cleanup of TCE to very low concentrations. In previous Batch Flushing Modeling performed to estimate the time frames required for all TCE concentration decreases, including those between 4 µg/L and 0.3 µg/L, the linear form of the retardation factor equation was used, namely:

$$R = 1 + K_{oc} \cdot f_{oc} \cdot \frac{\rho_b}{\theta_w} \qquad (1)$$

where,

R is the retardation coefficient for a specific contaminant

K_{oc} is the organic carbon partition coefficient (milliliters per gram [mL/g])

f_{oc} is the fraction organic carbon in the aquifer

ρ_b is the bulk density of the aquifer material (grams per milliliter [g/mL])

θ_w is the porosity (identified as "*n*" in the sensitivity analysis technical memorandum [LAI 2017]).

For updated Batch Flushing Modeling to estimate the time frames required for TCE concentration decreases between 4 µg/L and 0.3 µg/L, the retardation factor used was instead calculated using the Freundlich sorption/desorption isotherm equation:

$$R = 1 + \frac{\rho_b}{\theta_w} \cdot n_f \cdot K_f \cdot C_w^{(n_f - 1)} \qquad (2)$$

where,

K_f is the Freundlich constant indicative of the adsorptive capacity of the soil (micrograms per gram [µg/g])

n_f is the Freundlich constant describing the degree of deviation from linearity

C_w is the aqueous phase contaminant concentration.

Freundlich Constants (K_f and n_f):

The two Freundlich constants identified above are experimentally derived through batch and column studies. Based on a range of literature values (EPA 1996, Kret et al. 2015, Werth and Reinhard 1997, Zytner 2002) identified from experiments with TCE in fine to medium sand matrices, the following approximate mean values from these experiments (along with the aqueous phase TCE concentration) were used to determine the calculated retardation factor values used in the Batch Flushing Model runs:

K_f = 0.5

n_f = 0.9

C_w = 0.3 µg/L TCE.

The resulting restoration time frame values—calculated by the Batch Flushing Model for the various point of compliance options evaluated in Section 4 of the SFS—typically defined the upper end of the time frame ranges shown in Table 4-1 of the SFS. These values are shown to provide a frame of reference to show that restoration time frames for lower cleanup levels are likely to be substantially longer than predicted by the Batch Flushing Model using retardation factors based on linear isotherm equations.[11]

Use of This Report

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

This document has been prepared under the supervision and direction of the following key staff.

LANDAU ASSOCIATES, INC.

Ben Lee, PE
Senior Engineer

Piper Roelen, PE
Principal

BDL/PMR/JRN/ljl
[P:\025\175\FILERM\R\FEASIBILITY STUDY\2018 FS SUPPLEMENT\APPA_GW MODEL MEMO\APPA GW MODELING TM FINAL_112618.DOCX]

[11] Note that using both the high and both the low values found in literature for K_f (0.1 to 1.5 µg/g) and n_f (0.65 to 1.1) in Equation 2 yielded restoration time frames for reducing TCE concentrations from 4 to 0.3 µg/L from approximately 60 percent lower to 127 percent higher than the difference of time between the results of the linear and Freundlich estimates shown in SFS Table 4-1.

Attachments

Figure 1. Groundwater Recirculation System – Conceptual Layout
Figure 2. Modified Recharge Areas
Figure 3. Simulated Head – Model Modifications
Figure 4. Simulated Head and Flow Path Lines – Model Modifications
Figure 5. Simulated Head – Proposed Extraction and Injection Wells
Figure 6. Simulated Head and Flow Path Lines – Injection Wells
Table 1. Well Extraction/Injection Rates (Simulated)

References

AECOM and LAI. 2015. Draft Report: Feasibility Study for Upland Areas and Powder Mill Gulch, Boeing Commercial Airplanes Everett Plant, Everett, Washington. AECOM and Landau Associates, Inc. November 16.

Ecology. 2011. Letter RE: Ecology Contingent Approved Uplands Remedial investigation (RI) Report. Washington State Department of Ecology, Hazardous Waste & Toxics Reduction Program. November 21.

EPA. 1988. Guidance on Remedial Actions for Contaminated Ground Water at Superfund Sites. EPA/540/G-88/003. Office of Research and Development Publication. US Environmental Protection Agency. December.

EPA. 1996. Soil Screening Guidance: Technical Background Document; Appendix K, Table K-2. Collected K_{oc} Values (Hydrophobic Organics). EPA/540/R95/128. Office of Solid Waste and Emergency Response, US Environmental Protection Agency. May.

EPA. 2018. "BIOCHLOR, Natural Attenuation Decision Support System." US Environmental Protection Agency. https://www.epa.gov/water-research/biochlor-natural-attenuation-decision-support-system . Accessed November 1.

ITRC. 2015. "Integrated DNAPL Site Characterization and Tools Selection (ISC-1), Appendix B." Interstate Technology & Regulatory Council, DNAPL Site Characterization Team. www.itrcweb.org/DNAPL-ISC_tools-selection.

Kret, E., A. Kiecak, G. Malina, I. Nijenhuis, and A. Postawa. 2015. Identification of TCE and PCE Sorption and Biodegradation Parameters in a Sandy Aquifer for Fate and Transport Modelling: Batch and Column Studies. Environmental Science and Pollution Research International 22.13 (2015): 9877–9888. PMC. Web. 17. October.

LAI. 2011. Work Plan, Phase 1 Downgradient Plume Interim Action, Powder Mill Gulch, Boeing Everett Plant, Washington. Appendix C – Numerical Groundwater Modeling Technical Memoranda. Landau Associates, Inc. October 14.

LAI. 2012. Conceptual Design Report, Phase 2 Downgradient Plume Interim Action, Powder Mill Gulch, Everett, Washington. Appendix B – Groundwater Modeling Report. Landau Associates, Inc. December 3.

LAI. 2014. Technical Memorandum: Powder Mill Gulch Phase 1 Downgradient Plume Interim Action Optimization, Numerical Groundwater Flow modeling – Extraction Optimization, Boeing Everett Facility, Everett, Washington. Landau Associates, Inc. September 12.

LAI. 2017. Technical Memorandum: Restoration Time Frame Evaluation—Modeling Inputs/Sensitivity Analysis, Powder Mill Gulch, Boeing Everett Facility, Everett, Washington. Landau Associates, Inc. September 20.

Pankow, J.F., and J.A. Cherry. 1996. *Dense Chlorinated Solvents and Other DNAPLs in Groundwater: History, Behavior, and Remediation*. Portland, OR: Waterloo Press.

Stroo, H.F., and C.H. Ward. 2010. *In Situ Remediation of Chlorinated Solvent Plumes*. New York, NY: Springer.

Suthersan, S.S., J. Horst, M. Schonbrich, N. Welty, and J. McDonough. 2017. *Remediation Engineering: Design Concepts; Chapter 5 - Dynamic Groundwater Recirculation*. Second ed. Boca Raton, FL: CRC Press.

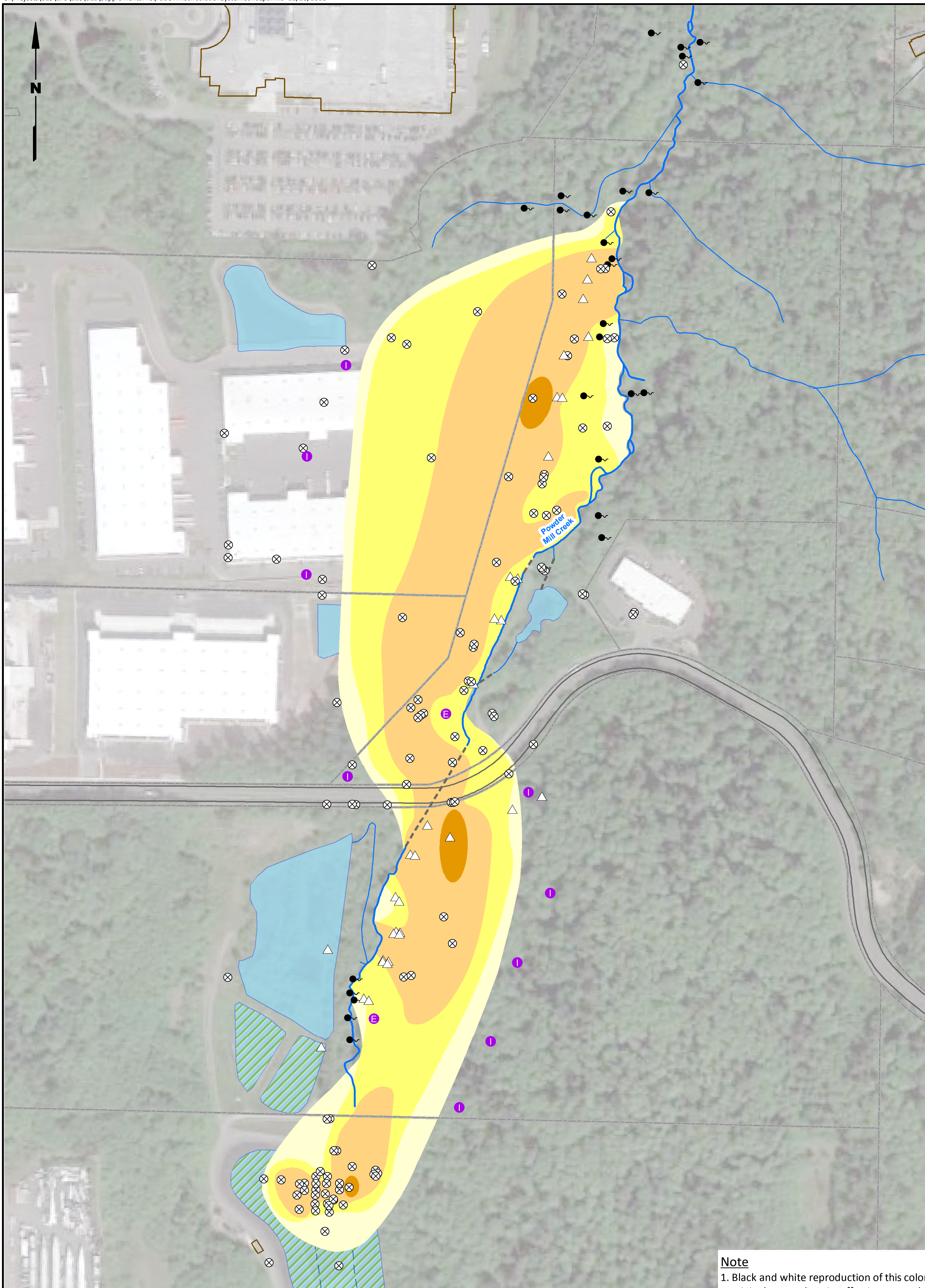
Suthersan, S.S., E. Killenbeck, S. Potter, C. Divine, and M. Lefrancois. 2015. "Resurgence of Pump and Treat Solutions: Directed Groundwater Recirculation." *National Ground Water Association, Groundwater Monitoring & Remediation* 35 (2).

URS and LAI. 2011. Final: Remedial Investigation Report, BCA Everett Plant, Everett, Washington. URS Corporation and Landau Associates, Inc. November 4.

Werth, C. and M. Reinhard. 1997. Effects of Temperature on Trichloroethylene Desorption from Silica Gel and Natural Sediments. 1. Isotherms. Environmental Science & Technology, Vol. 31, No. 3, 689-696.

Zytner, R. 2002. Organic Compounds in Unsaturated Soil. School of Engineering. University of Guelph.

G:\Projects\025\175\118\012\Supplemental FS\F01GWRecirculationSystemConcept.mxd 11/28/2018



Note
1. Black and white reproduction of this color original may reduce its effectiveness and lead to incorrect interpretation.

Legend

Samples Collected in October 2017
- Monitoring Well
- Piezometer
- Seep

Other Monitoring Locations
- Monitoring Well
- Piezometer
- Seep
- Extraction Well

- Proposed Extraction Well
- Proposed Injection Well

- 0.49 ≤ TCE <4μg/L
- 4 ≤ TCE <25 μg/L
- 25 ≤ TCE <250 μg/L
- 250 ≤ TCE <500 μg/L

0 250 500
Scale in Feet

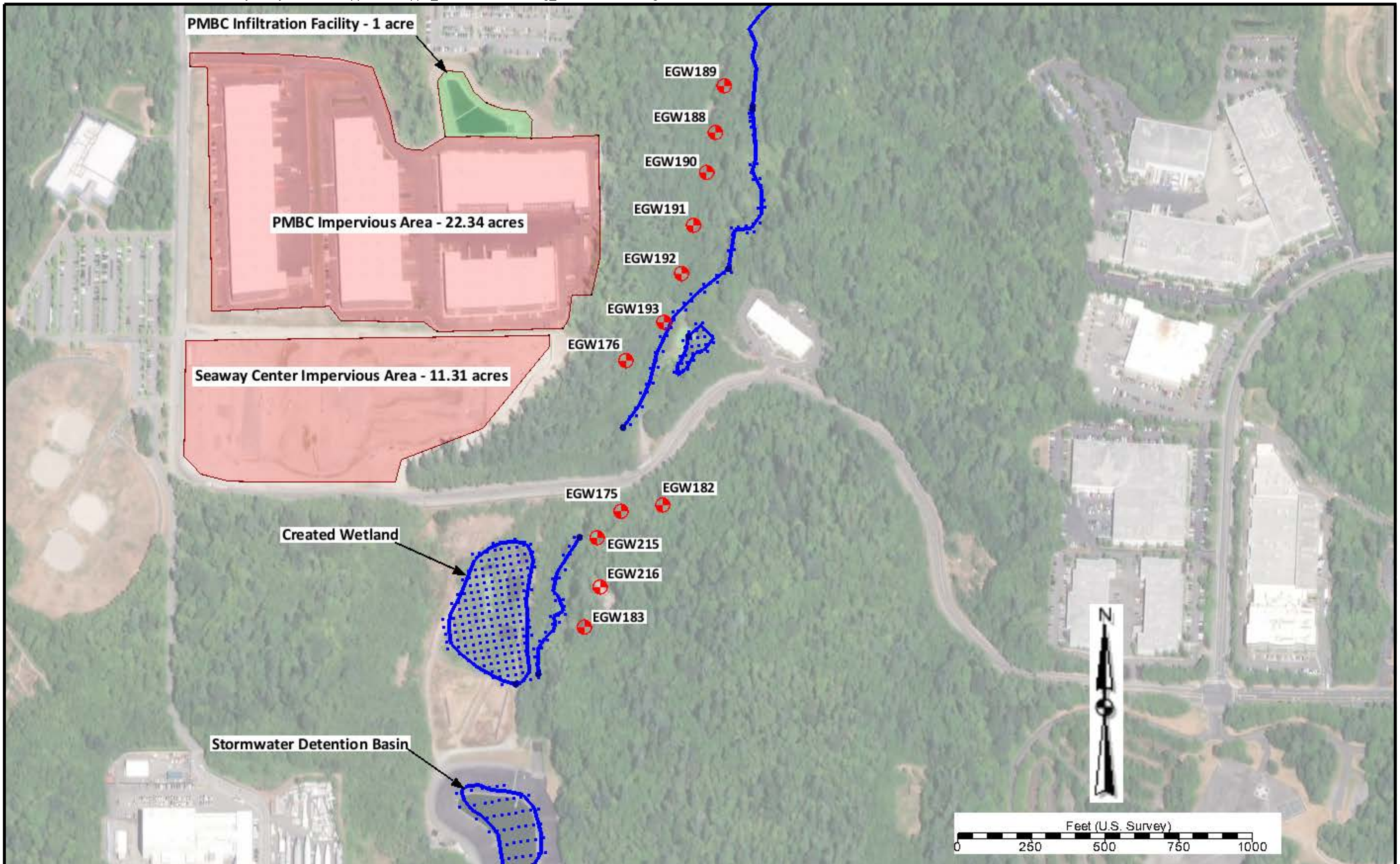
Data Sources: Google Earth Pro. Aerial Photo Date: 5/18.

Landau Associates

Supplemental Feasibility Study
Boeing Commercial Airplanes
Everett, Washington

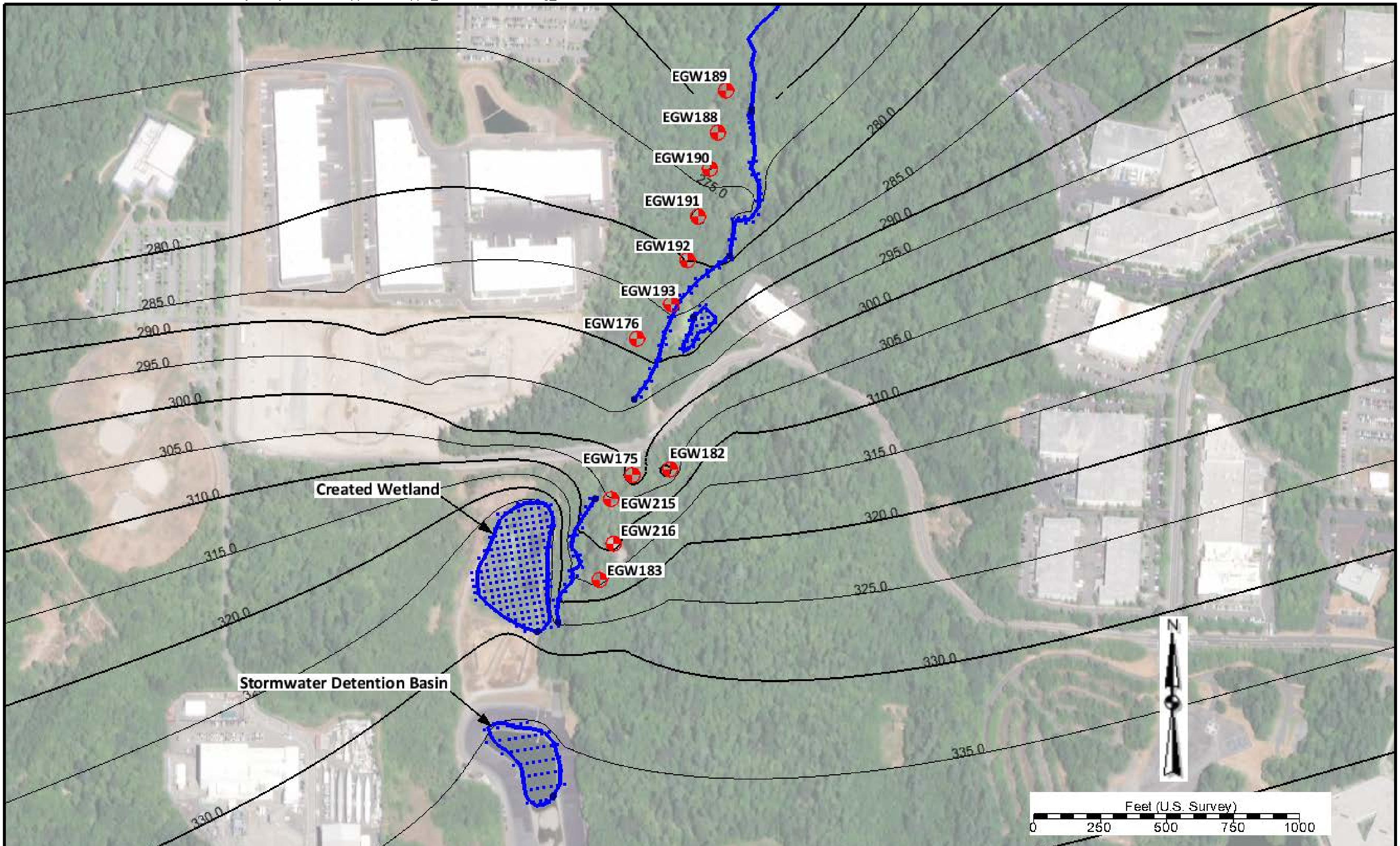
Groundwater Recirculation System - Conceptual Layout

Figure 1



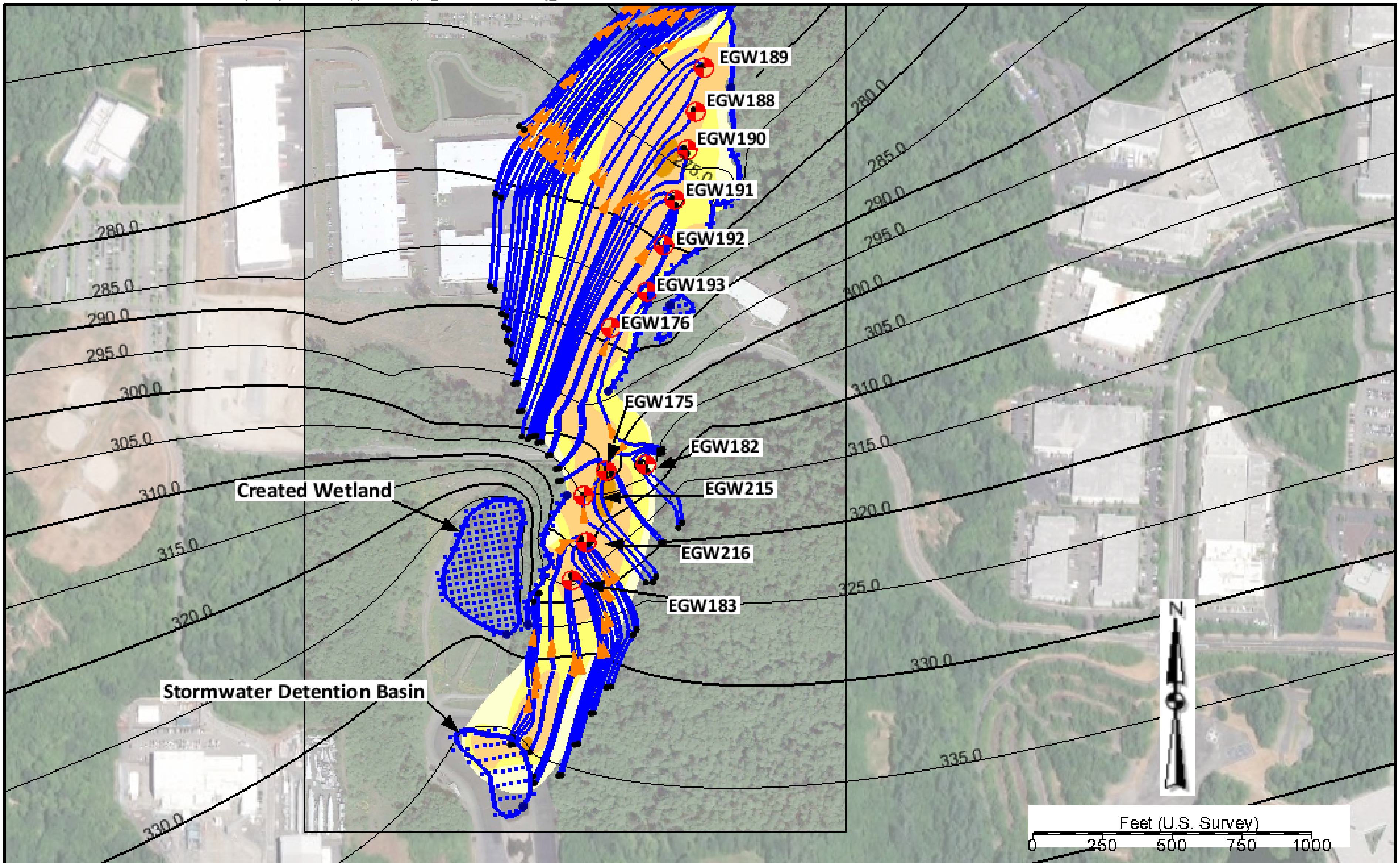
LANDAU ASSOCIATES

Boeing – Powder Mill Gulch Everett, Washington	**Modified Recharge Areas**	Figure 2



LANDAU ASSOCIATES

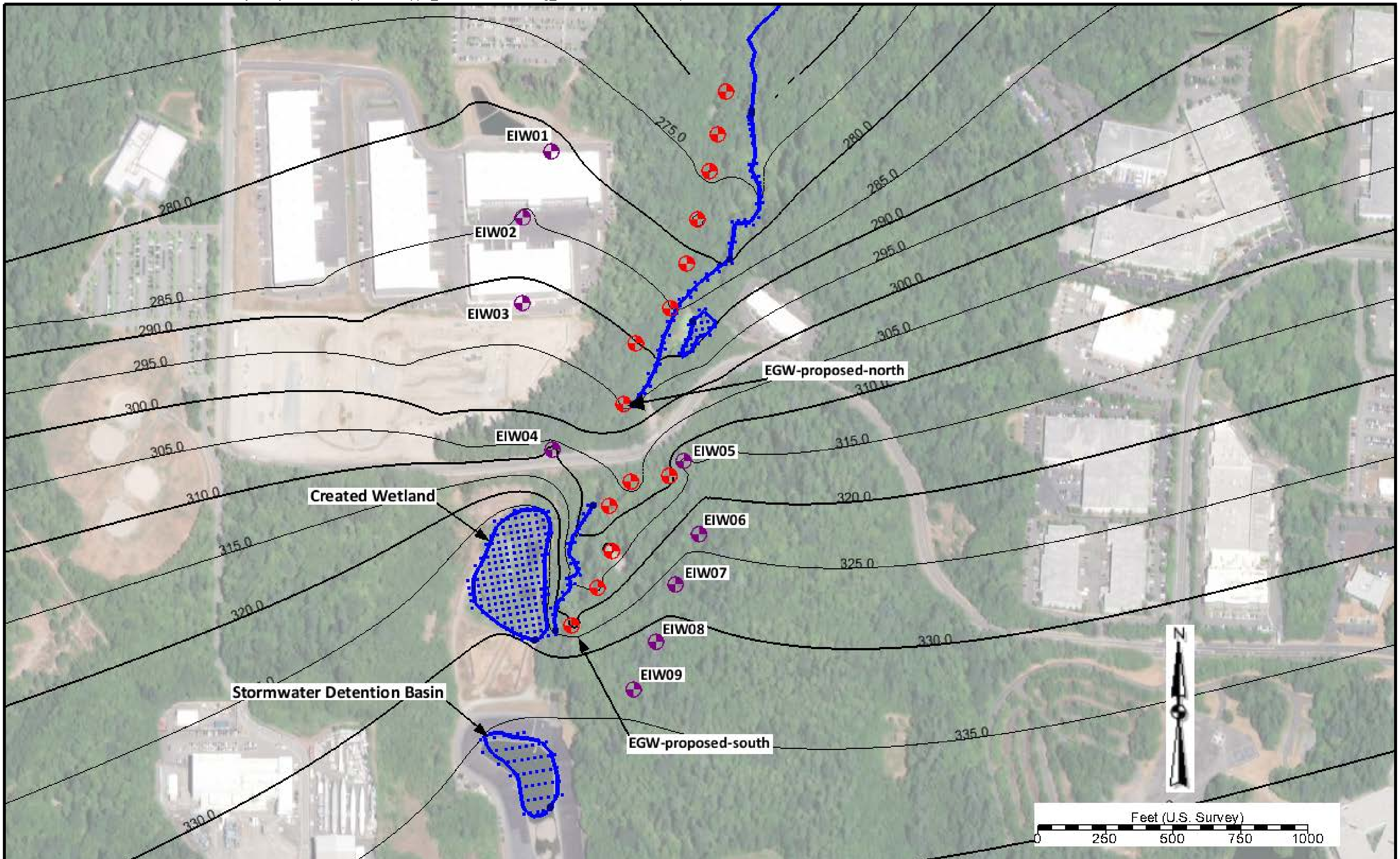
Boeing – Powder Mill Gulch Everett, Washington	**Simulated Head – Model Modifications**	Figure 3



Note: MODPATH particle tracks originating from select locations are overlaid on the TCE plume (separate figure) from LAI (2018).

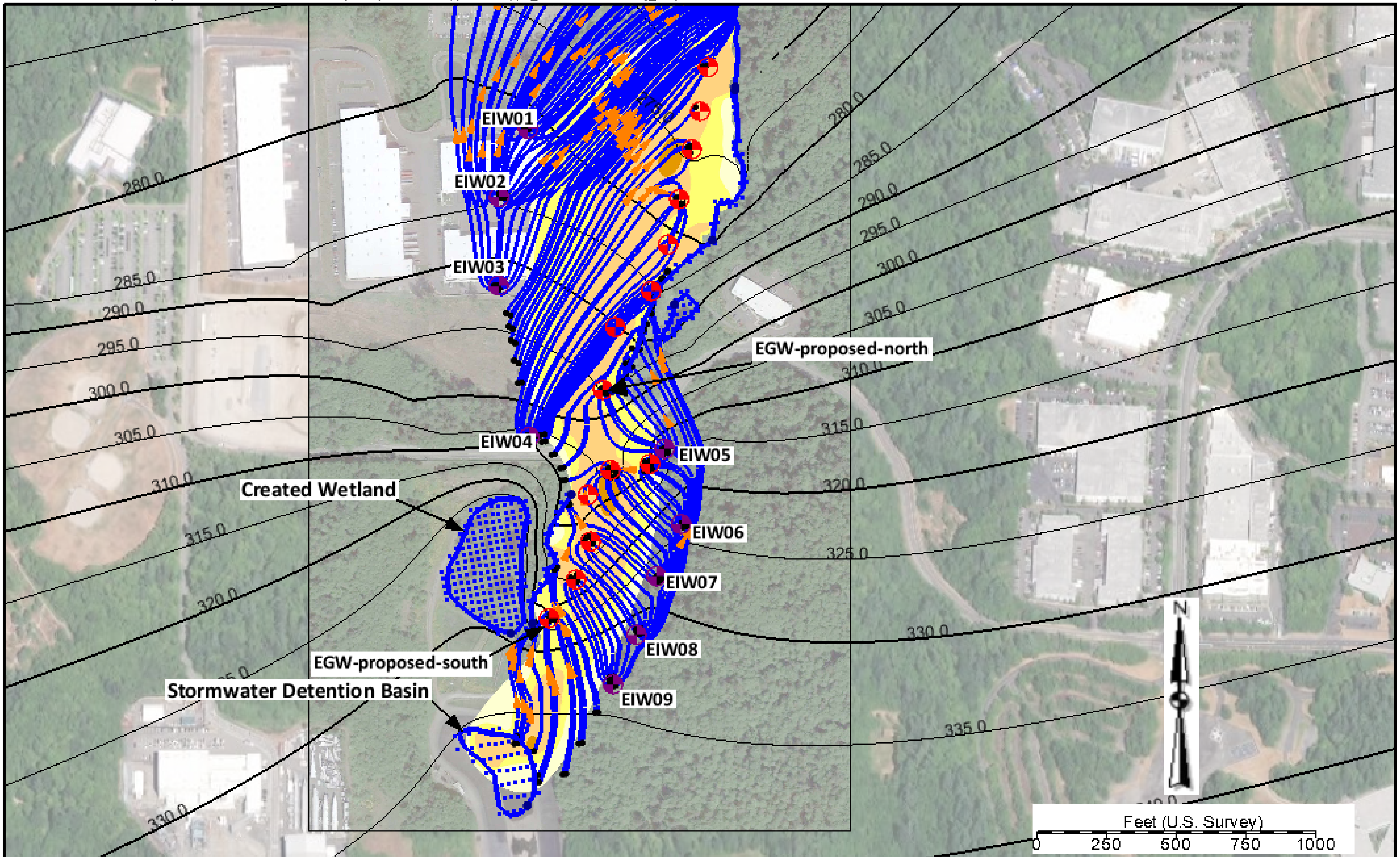
LANDAU ASSOCIATES

Boeing – Powder Mill Gulch Everett, Washington	**Simulated Head and Flow Path Lines – Model Modifications**	Figure 4



LANDAU ASSOCIATES

Boeing – Powder Mill Gulch Everett, Washington	**Simulated Head – Proposed Extraction and Injection Wells**	Figure 5



Note: MODPATH particle tracks originating from simulated proposed injection wells and other select locations are overlaid on the TCE plume (separate figure) from LAI (2018).

LANDAU ASSOCIATES

Boeing – Powder Mill Gulch Everett, Washington	**Simulated Head and Flow Path Lines – Injection Wells**	Figure 6

Table 1
Well Extraction/Injection Rates (Simulated)
Boeing - Powder Mill Gulch
Everett, Washington

Location	IA Area	Well ID	Extraction Rate (gpm)
Extraction Wells	Phase 1	EGW175	24
		EGW182	27
		EGW183	22
		EGW215	2
		EGW216	21
	Phase 2	EGW176	1
		EGW188	18
		EGW189	14
		EGW190	26
		EGW191	32
		EGW192	3
		EGW193	3
	Proposed	EGW-proposed-north	15
		EGW-proposed-south	25

Location	IA Area	Well ID	Injection Rate (gpm)
Injection Wells	Proposed	EIW01	25
		EIW02	25
		EIW03	25
		EIW04	25
		EIW05	25
		EIW06	25
		EIW07	25
		EIW08	25
		EIW09	25

Abbreviations and Acronyms:

gpm = gallons per minute

IA = interim action

ID = identification

APPENDIX B

Remedial Cost Estimates

Table B-1a
Comparison of Alternative Costs
Exposure Pathway Model: EPM K
Esperance Sand, North Complex, PMG SWMU

ALTERNATIVE 1 **CONTINUED OPERATION OF EXISTING GET SYSTEM AND INSTITUTIONAL CONTROLS**

Client	Boeing	**EPM Group**	K
Location	BCA Everett Plant	**Site Name**	Esperance Sand/Powder Mill Gulch
Project	Upland Area Feasibility Study	**Building**	N/A
Estimator	Piper Roelen	**Media**	Groundwater
Report Date	10/30/15	**Plume Length**	2,800 FT
Last Updated */**	8/17/18	**Max Plume Width**	700 FT
QA Reviewer	Jerry Ninteman	**Saturated Thickness**	10 to 60 FT

* highlighted cells indicate inputs modified from original 2015 FS estimates
** highlighted cells indicate inputs modified from 2016 revised estimates

Site/Problem Description Chlorinated solvents in groundwater within the Esperance Sand Aquifer beneath Powder Mill Gulch and chlorinated solvents in surface water in Powder Mill Creek at concentrations exceeding MTCA cleanup standards.

Proposed Remedial Action Continued operation of GET system for hydraulic control of chlorinated solvents in groundwater, minimizing migration of chlorinated solvents in groundwater to surface water, groundwater flushing and restoration, and protection of human and ecological receptors.

Alternative Specific Assumptions
1. Costs presented have an accuracy of +50% to -30% and are suitable for comparing alternatives
2. Washington State Sales Tax is applied to Direct Costs only
3. 30-year real discount rate of 0.6% per Office of Management and Budget, Circular A-94 Appendix C, Rev. Feb. 2018
4. Operation of existing GET system with 12 extraction wells.
5. Assumes GET system operation for 38 years to reach TCE CUL of 4 μg/L
6. Assumes major equipment replacement at 20-year intervals
7. Annual groundwater and surface water monitoring
8. Six quarters of confirmation groundwater and surface water sampling

DETAILED COST ESTIMATE

Cost Type	Category	Item #	Description	Quantity	Unit	Unit Cost	Total
IMPLEMENTATION	**REMEDIAL DESIGN, PLANNING, AND GENERAL (Indirect Costs)**						
		1	Engineering/Proj Mgmt/Const Mgmt/Reporting				
		2	Cleanup action plan	1	LS	$ 30,000	$ 30,000
		3	Permits	1	LS	$ 10,000	$ 10,000
		4	Negotiate and implement institutional controls	1	LS	$ 10,000	$ 10,000
		5	Cleanup action construction report	0	LS	$ 20,000	$ -
		6	Engineering/Remedial Design	8%	pct	$ 50,000	$ 4,000
		7	Construction management/oversight	6%	pct	$ 50,000	$ 3,000
		8	Project management	5%	pct	$ 11,071,000	$ 553,550
		9	Ecology oversight	5%	pct	$ 11,071,000	$ 553,550
	Subtotal Remedial Design, Planning, and General Costs						*$ 1,164,100*
	Indirect Contingency and Unlisted Engineering Services (%)			**15%**	pct	$1,164,100	$ 174,600
	TOTAL INDIRECT COST						**$1,339,000**
	Category	**Item #**	**Description**	**Quantity**	**Unit**	**Unit Cost**	**Total**
	REMEDIAL ACTION CONSTRUCTION - NOT APPLICABLE (Direct Costs)						
		1	No New Construction Required				
		2	Construction	0	LS	$ -	$ -
	Subtotal Remedial Action Construction Costs						$ -
	Direct Cost Contingency and Unlisted Engineering Services (%)			**25%**	pct	$0	$ -
	Contractor Bond Fee, Overhead, and Profit (%)			**20%**	pct	$0	$ -
	Washington State Sales Tax (%)			**9.2%**	pct	$0	$0
	TOTAL DIRECT COST						**$0**
	Category	**Item #**	**Description**	**Quantity**	**Unit**	**Unit Cost**	**Total**
OM&M	**ANNUAL OPERATION, MAINTENANCE, MONITORING, AND REPORTING**						
		1	Electrical usage	1	yr	$ 36,500	$ 36,500
		2	Cell phone/GET system remote access charges	12	mo	$ 369	$ 4,428
		3	Carbon usage	1	ea	$ 9,600	$ 9,600
		4	System monitoring/NPDES reporting	1	yr	$ 20,000	$ 20,000
		5	O&M labor and cost	1	yr	$ 80,000	$ 80,000
		6	NPDES annual renewal fee	1	yr	$ 20,137	$ 20,137
		7	Groundwater sampling	1	yrs	$ 65,000	$ 65,000
		8	Groundwater elevation monitoring	1	yrs	$ 8,000	$ 8,000
		9	Surface water sampling	1	yrs	$ 8,000	$ 8,000
		10	Reporting	1	yr	$ 15,000	$ 15,000
	Subtotal Annual OM&M and Reporting Cost						$ 266,700
	Annual Monitoring Cost Contingency and Unlisted Items (%)			**20%**	pct	$266,700	$ 53,300
			Years of Annual Monitoring	***36***	yrs	$320,000	$ 11,520,000
	TOTAL ANNUAL OM&M AND REPORTING COST						***$11,520,000***
	Present-Worth Annual OM&M and Reporting Cost		Presumed Discount Rate	***0.6%***	pct		**$10,333,000**
	Category	**Item #**	**Description**	**Quantity**	**Unit**	**Unit Cost**	**Total**
	NON-ROUTINE OPERATION, MAINTENANCE, MONITORING, AND REPORTING						
		1	Baseline groundwater/surface water sampling	1	event	$ 73,000	$ 73,000
		2	GET system replacement cost	1	event	$ 150,000	$ 150,000
		3	1.5 years quarterly confirmation sampling	6	event	$ 73,000	$ 438,000
		4	Cleanup completion report	1	LS	$ 20,000	$ 20,000
	Subtotal Non-Routine OM&M and Reporting Cost						$ 681,000
	Annual Monitoring Cost Contingency and Unlisted Items (%)			**20%**	pct	$681,000	$ 136,200
	TOTAL NON-ROUTINE OM&M AND REPORTING COST						***$817,000***
	Present-Worth Non-Routine OM&M and Reporting Cost		Presumed Discount Rate	***0.6%***	pct		**$681,000**
TOTAL	**ALTERNATIVE COST SUMMARY**						
	TOTAL PRESENT-WORTH REMEDIAL DESIGN, PLANNING, AND GENERAL COST (INDIRECT)						**$1,339,000**
	TOTAL PRESENT-WORTH REMEDIATION IMPLEMENTATION COST (DIRECT)						**$0**
	TOTAL PRESENT-WORTH OM&M COST (ANNUAL & NON-ROUTINE)						**$11,014,000**
	TOTAL PRESENT-WORTH COST						**$12,350,000**
			Appropriate Cost Range (-30% - +50%)		**TOTAL**	**$ 8,650,000**	**$ 18,530,000**

Table B-1b
Comparison of Alternative Costs
Exposure Pathway Model: EPM K
Esperance Sand, North Complex, PMG SWMU

ALTERNATIVE 2 **SOURCE AREA EISB CONTINUED OPERATION OF GET SYSTEM, AND INSTITUTIONAL CONTROL**

Client		Boeing	**EPM Group**	K	
Location		BCA Everett Plant	**Site Name**	Esperance Sand/Powder Mill Gulch	
Project		Upland Area Feasibility Study	**Building**	N/A	
Estimator		Piper Roelen	**Media**	Groundwater	
Report Date		10/30/15	**Plume Length**	2,800	FT
Last Updated	*/**	8/17/18	**Max Plume Width**	700	FT
QA Reviewer		Jerry Ninteman	**Saturated Thickness**	10 to 60	FT

* highlighted cells indicate inputs modified from original 2015 FS estimates
** highlighted cells indicate inputs modified from 2016 revised estimates

Site/Problem Description Chlorinated solvents in groundwater within the Esperance Sand Aquifer beneath Powder Mill Gulch and chlorinated solvents in surface water in Powder Mill Creek at concentrations exceeding MTCA cleanup standards.

Proposed Remedial Action Injection of electron donor for enhanced bioremediation of groundwater in detention basin source area (TCE > 100 µg/L) in combination with continued operation of GET system for hydraulic control of chlorinated solvents in groundwater, minimizing migration of chlorinated solvents in groundwater to surface water, groundwater flushing and restoration, and protection of human and ecological receptors.

Alternative Specific Assumptions

1. Costs presented have an accuracy of +50% to -30% and are suitable for comparing alternatives
2. Washington State Sales Tax is applied to Direct Costs only
3. 30-year real discount rate of 0.6% per Office of Management and Budget, Circular A-94 Appendix C, Rev. Feb. 2018
4. Installation of injection wells at 8 locations (3 depth interval wells each location)
5. Assume all wells installed to a depths of 30, 50, and 70 ft bgs (20 ft screen each)
6. Well spacing at 15 ft OC crossgradient and 100 ft downgradient
7. Assume 3 injection events of electron donor over 3-year period
8. Operation of existing GET system with 12 extraction wells
9. Assumes GET system operation for 37 years (including 3 years of injection events) to reach TCE CUL of 4 µg/L
10. Assumes major equipment replacement at 20-year intervals
11. Annual groundwater and surface water monitoring
12. Six quarters of confirmation groundwater and surface water sampling

DETAILED COST ESTIMATE

Cost Type	Category	Item #	Description	Quantity	Unit	Unit Cost	Total
IMPLEMENTATION	**REMEDIAL DESIGN, PLANNING, AND GENERAL (Indirect Costs)**						
		1	Engineering/Proj Mgmt/Const Mgmt/Reporting				
		2	Cleanup action plan	1	LS	$ 30,000	$ 30,000
		3	Permits	1	LS	$ 15,000	$ 15,000
		4	Negotiate and implement institutional controls	1	LS	$ 10,000	$ 10,000
		5	Contract documents and contractor bidding/procurement	1	LS	$ 20,000	$ 20,000
		6	Cleanup action construction report	1	LS	$ 20,000	$ 20,000
		7	Engineering/Remedial Design	8%	pct	$ 797,000	$ 63,760
		8	Construction management/oversight	6%	pct	$ 797,000	$ 47,820
		9	Project management	5%	pct	$ 12,531,580	$ 626,579
		10	Ecology oversight	5%	pct	$ 12,531,580	$ 626,579
	Subtotal Remedial Design, Planning, and General Costs						*$ 1,459,700*
	Indirect Contingency and Unlisted Engineering Services (%)			**15%**	pct	$1,459,700	$ 219,000
	TOTAL INDIRECT COST						**$1,679,000**
	Category	**Item #**	**Description**	**Quantity**	**Unit**	**Unit Cost**	**Total**
	REMEDIAL ACTION CONSTRUCTION - ELECTRON DONOR INJECTIONS (Direct Costs)						
		1	Install injection wells, wells/distribution				
		2	Utility locate/clearing	1	LS	$ 2,500	$ 2,500
		3	Driller mobilization/demobilization	1	LS	$ 20,000	$ 20,000
		6	Drilling - injection wells (detention basin hotspot)	24	wells	$ 4,000	$ 96,000
		7	Well development	24	wells	$ 500	$ 12,000
		8	IDW disposal	70	Drums	$ 200	$ 14,000
		9	Injection of Electron Donor				
		10	Injection crew/labor	75	days	$ 3,000	$ 225,000
		11	Purchase equipment/supplies for injection system setup	1	LS	$ 25,000	$ 25,000
		12	Materials and rentals for injection events	3	event	$ 20,000	$ 60,000
		13	Water for injection events	285,000	gal	$ 0.03	$ 8,550
		14	Donor for injection events	36,000	lbs	$ 1.50	$ 54,000
	Subtotal Remedial Action Construction Costs						*$ 517,100*
	Direct Cost Contingency and Unlisted Engineering Services (%)			**25%**	pct	$ 517,100	$ 129,300
	Contractor Bond Fee, Overhead, and Profit (%)			**20%**	pct	$ 180,625	$ 36,100
	Washington State Sales Tax (%)			**9.2%**	pct	$ 216,725	$ 19,900
	TOTAL DIRECT COST						**$702,000**
OM&M	**Category**	**Item #**	**Description**	**Quantity**	**Unit**	**Unit Cost**	**Total**
	ANNUAL OPERATION, MAINTENANCE, MONITORING, AND REPORTING						
		1	Electrical usage	1	yr	$ 36,500	$ 36,500
		2	Cell phone/GET system remote access charges	12	mo	$ 369	$ 4,428
		3	Carbon usage	1	ea	$ 9,600	$ 9,600
		4	System monitoring/NPDES reporting	1	yr	$ 20,000	$ 20,000
		5	O&M labor and cost	1	yr	$ 80,000	$ 80,000
		6	NPDES annual renewal fee	1	yr	$ 20,137	$ 20,137
		7	Groundwater sampling	1	yrs	$ 65,000	$ 65,000
		8	Groundwater elevation monitoring	1	yrs	$ 8,000	$ 8,000
		9	Surface water sampling	1	yrs	$ 8,000	$ 8,000
		10	Reporting	1	yr	$ 15,000	$ 15,000
	Subtotal Annual OM&M and Reporting Cost						$ 266,700
	Annual Monitoring Cost Contingency and Unlisted Items (%)			**20%**	pct	$266,700	$ 53,300
			Years of Annual Monitoring	***35***	yrs	$320,000	$ 11,200,000
	TOTAL ANNUAL OM&M AND REPORTING COST						***$11,200,000***
	Present-Worth Annual OM&M and Reporting Cost		Presumed Discount Rate	***0.6%***	pct		**$10,075,000**
	Category	**Item #**	**Description**	**Quantity**	**Unit**	**Unit Cost**	**Total**
	NON-ROUTINE OPERATION, MAINTENANCE, MONITORING, AND REPORTING						
		1	Baseline groundwater/surface water sampling	1	event	$ 73,000	$ 73,000
		2	Quarterly groundwater sampling	9	event	$ 65,000	$ 585,000
		3	Quarterly groundwater elevation monitoring	9	event	$ 8,000	$ 72,000
		4	Quarterly surface water sampling	9	event	$ 8,000	$ 72,000
		5	GET system replacement cost	1	event	$ 150,000	$ 150,000
		6	1.5 years quarterly confirmation sampling	6	event	$ 73,000	$ 438,000
		7	Cleanup completion report	1	LS	$ 20,000	$ 20,000
	Subtotal Non-Routine OM&M and Reporting Cost						$ 1,410,000
	Annual Monitoring Cost Contingency and Unlisted Items (%)			**20%**	pct	$1,410,000	$ 282,000
	TOTAL NON-ROUTINE OM&M AND REPORTING COST						***$1,692,000***
	Present-Worth Non-Routine OM&M and Reporting Cost		Presumed Discount Rate	***0.6%***	pct		**$1,548,000**
TOTAL	**ALTERNATIVE COST SUMMARY**						
	TOTAL PRESENT-WORTH REMEDIAL DESIGN, PLANNING, AND GENERAL COST (INDIRECT						**$1,679,000**
	TOTAL PRESENT-WORTH REMEDIATION IMPLEMENTATION COST (DIRECT						**$702,000**
	TOTAL PRESENT-WORTH OM&M COST (ANNUAL & NON-ROUTINE						**$11,623,000**
	TOTAL PRESENT-WORTH COST						**$14,000,000**
			Appropriate Cost Range (-30% - +50%)		**TOTAL**	**$ 9,800,000**	**$ 21,000,000**

Table B-1c
Comparison of Alternative Costs
Exposure Pathway Model: EPM K
Esperance Sand, North Complex, PMG SWMU

ALTERNATIVE 3 **FOCUSED ISCO, CONTINUED OPERATION OF GET SYSTEM, AND INSTITUTIONAL CONTROLS**

Client	Boeing	**EPM Group**	K	
Location	BCA Everett Plant	**Site Name**	Esperance Sand/Powder Mill Gulch	
Project	Upland Area Feasibility Study	**Building**	N/A	
Estimator	Piper Roelen	**Media**	Groundwater	
Report Date	10/30/15	**Plume Length**	2,800	FT
Last Updated */**	8/17/18	**Max Plume Width**	700	FT
QA Reviewer	Jerry Ninteman	**Saturated Thickness**	10 to 60	FT

* highlighted cells indicate inputs modified from original 2015 FS estimates
** highlighted cells indicate inputs modified from 2016 revised estimates

Site/Problem Description Chlorinated solvents in groundwater within the Esperance Sand Aquifer beneath Powder Mill Gulch and chlorinated solvents in surface water in Powder Mill Creek at concentrations exceeding MTCA cleanup standards.

Proposed Remedial Action Injection of chemical oxidant (sodium persulfate) for contaminant oxidation in groundwater in TCE focus areas (TCE > 250 µg/L) in in combination with continued operation of GET system for hydraulic control of chlorinated solvents in groundwater, minimizing migration of chlorinated solvents in groundwater to surface water, groundwater flushing and restoration, and protection of human and ecological receptors.

Alternative Specific Assumptions

1 Costs presented have an accuracy of +50% to -30% and are suitable for comparing alternatives
2 Washington State Sales Tax is applied to Direct Costs only
3 30-year real discount rate of 0.6% per Office of Management and Budget, Circular A-94 Appendix C, Rev. Feb. 2018
4 Installation of injection wells at 27 locations in detention basin (3 depth interval wells each location)
5 Installation of injection wells at 53 locations in South of Seaway (2 depth interval wells each location)
6 Installation of injection wells at 70 locations in North of Seaway (2 depth interval wells each location)
7 Assume wells installed to depths of 30, 50, and 70 ft bgs in detention basin (20-ft screen each)
8 Assume wells installed to depths of 40 and 60 ft bgs South of Seaway (20-ft screen each)
9 Assume wells installed to depths of 45 and 60 ft bgs North of Seaway (15-ft screen each)
10 Well spacing at 15 ft OC crossgradient and 30 ft downgradient
11 Assume 6 injection events of sodium persulfate and activating agent over 3–5-year period
12 Assume construction of iron/iron bacteria pretreatment system for extracted groundwater with iron from ISCO
13 Quarterly groundwater and surface water monitoring during injection period
14 Operation of existing GET system with 12 extraction wells
15 Assumes GET system operation for 30 years (including 3–5 years of injection events) to reach TCE CUL of 4 µg/L
16 Assume O&M of iron/iron bacteria pretreatment facility and biofouling maintenance of wells for 7 years
17 Annual groundwater and surface water monitoring
18 Six quarters of confirmation groundwater and surface water sampling

DETAILED COST ESTIMATE

Cost Type	Category	Item #	Description	Quantity	Unit	Unit Cost	Total
IMPLEMENTATION	**REMEDIAL DESIGN, PLANNING, AND GENERAL (Indirect Costs)**						
		1	Engineering/Proj Mgmt/Const Mgmt/Reporting				
		2	Cleanup action plan	1	LS	$ 30,000	$ 30,000
		3	Permits	1	LS	$ 20,000	$ 20,000
		4	Negotiate and implement institutional controls	1	LS	$ 10,000	$ 10,000
		5	Contract documents and contractor bidding/procurement	1	LS	$ 20,000	$ 20,000
		6	Cleanup action construction report	1	LS	$ 20,000	$ 20,000
		7	Engineering/Remedial Design	6%	pct	$ 6,600,000	$ 396,000
		8	Construction management/oversight	6%	pct	$ 6,600,000	$ 396,000
		9	Project management	5%	pct	$ 19,313,000	$ 965,650
		10	Ecology oversight	5%	pct	$ 19,313,000	$ 965,650
	Subtotal Remedial Design, Planning, and General Costs						*$ 2,823,300*
	Indirect Contingency and Unlisted Engineering Services (%)			**15%**	pct	$2,823,300	$ 423,500
	TOTAL INDIRECT COST						**$3,247,000**
	Category	**Item #**	**Description**	**Quantity**	**Unit**	**Unit Cost**	**Total**
	REMEDIAL ACTION CONSTRUCTION - OXIDANT INJECTIONS (Direct Costs)						
		1	ISCO treatability study/pilot test	1	LS	$ 150,000	$ 150,000
		2	Install injection wells, wells/distribution				
		3	Utility locates	1	LS	$ 7,500	$ 7,500
		4	Site prep/clearing/grubbing	1	LS	$ 350,000	$ 350,000
		5	Driller mobilization/demobilization	1	LS	$ 20,000	$ 20,000
		6	Drilling - injection wells (Lot 9 TCE focus area)	140	wells	$ 3,500	$ 490,000
		7	Drilling - injection wells (Boeing Seaway TCE focus area)	106	wells	$ 3,750	$ 397,500
		8	Drilling - injection wells (detention basin TCE focus area)	81	wells	$ 4,000	$ 324,000
		9	Well development	327	wells	$ 500	$ 163,500
		10	IDW disposal	660	Drums	$ 200	$ 132,000
		11	ISCO materials/Injection of oxidants				
		12	Injection crew/labor	480	days	$ 3,000	$ 1,440,000
		13	Purchase equipment/supplies for injection system setup	1	LS	$ 25,000	$ 25,000
		14	Materials and rentals for injection events	6	event	$ 20,000	$ 120,000
		15	Water for injection events	3120000	gal	$ 0.03	$ 93,600
		16	Oxidant for injection events	312000	lbs	$ 2.05	$ 639,600
		17	Construct Iron/Iron Bacteria Pre-treatment Facility	1	LS	$ 200,000	$ 200,000
	Subtotal Remedial Action Construction Costs						*$ 4,552,700*
	Direct Cost Contingency and Unlisted Engineering Services (%)			**25%**	pct	$4,552,700	$ 1,138,200
	Contractor Bond Fee, Overhead, and Profit (%)			**20%**	pct	$2,605,625	$ 521,100
	Washington State Sales Tax (%)			**9.2%**	pct	$ 3,126,725	$287,700
	TOTAL DIRECT COST						**$6,500,000**
	Category	**Item #**	**Description**	**Quantity**	**Unit**	**Unit Cost**	**Total**
OM&M	**ANNUAL OPERATION, MAINTENANCE, MONITORING, AND REPORTING**						
		1	Electrical usage	1	yr	$ 36,500	$ 36,500
		2	Cell phone/GET system remote access charges	12	mo	$ 369	$ 4,428
		3	Carbon usage	1	ea	$ 9,600	$ 9,600
		4	System monitoring/NPDES reporting	1	yr	$ 20,000	$ 20,000
		5	O&M labor and cost	1	yr	$ 80,000	$ 80,000
		6	NPDES annual renewal fee	1	yr	$ 20,137	$ 20,137
		7	Groundwater sampling	1	yrs	$ 65,000	$ 65,000
		8	Groundwater elevation monitoring	1	yrs	$ 8,000	$ 8,000
		9	Surface water sampling	1	yrs	$ 8,000	$ 8,000
		10	Reporting	1	yr	$ 15,000	$ 15,000
	Subtotal Annual OM&M and Reporting Cost						$ 266,700
	Annual Monitoring Cost Contingency and Unlisted Items (%)			**20%**	pct	$266,700	$ 53,300
			Years of Annual Monitoring	***30***	yrs	$320,000	$ 9,600,000
	TOTAL ANNUAL OM&M AND REPORTING COST						***$9,600,000***
	Present-Worth Annual OM&M and Reporting Cost		Presumed Discount Rate	***0.6%***	pct		**$8,762,000**
	Category	**Item #**	**Description**	**Quantity**	**Unit**	**Unit Cost**	**Total**
	NON-ROUTINE OPERATION, MAINTENANCE, MONITORING, AND REPORTING						
		1	Baseline groundwater/surface water sampling	1	event	$ 73,000	$ 73,000
		2	GET System Replacement Cost	1	event	$ 150,000	$ 150,000
		3	Iron/Biofouling Maintenance/Equipment Replacement	7	yr	$ 60,000	$ 420,000
		4	Iron Pretreatment System O&M	7	yr	$ 40,000	$ 280,000
		2	Quarterly groundwater sampling	9	event	$ 65,000	$ 585,000
		3	Quarterly groundwater elevation monitoring	9	event	$ 8,000	$ 72,000
		4	Quarterly surface water sampling	9	event	$ 8,000	$ 72,000
		5	1.5 years quarterly confirmation sampling	6	event	$ 73,000	$ 438,000
		6	Cleanup completion report	1	LS	$ 20,000	$ 20,000
	Subtotal Non-Routine OM&M and Reporting Cost						$ 2,110,000
	Annual Monitoring Cost Contingency and Unlisted Items (%)			**20%**	pct	$2,110,000	$ 422,000
	TOTAL NON-ROUTINE OM&M AND REPORTING COST						***$2,532,000***
	Present-Worth Non-Routine OM&M and Reporting Cost		Presumed Discount Rate	***0.6%***	pct		**$3,159,000**
TOTAL	**ALTERNATIVE COST SUMMARY**						
	TOTAL PRESENT-WORTH REMEDIAL DESIGN, PLANNING, AND GENERAL COST (INDIRECT						**$3,247,000**
	TOTAL PRESENT-WORTH REMEDIATION IMPLEMENTATION COST (DIRECT)						**$6,500,000**
	TOTAL PRESENT-WORTH OM&M COST (ANNUAL & NON-ROUTINE)						**$11,921,000**
	TOTAL PRESENT-WORTH COST						**$21,670,000**
			Appropriate Cost Range (-30% - +50%)		**TOTAL**	**$ 15,170,000**	**$ 32,510,000**

Table B-1d
Comparison of Alternative Costs
Exposure Pathway Model: EPM K
Esperance Sand, North Complex, PMG SWMU

ALTERNATIVE 4 **FOCUSED EISB, CONTINUED OPERATION OF GET SYSTEM, AND INSTITUTIONAL CONTROLS**

Client	Boeing	**EPM Group**	K
Location	BCA Everett Plant	**Site Name**	Esperance Sand/Powder Mill Gulch
Project	Upland Area Feasibility Study	**Building**	N/A
Estimator	Piper Roelen	**Media**	Groundwater
Report Date	10/30/15	**Plume Length**	2,800 FT
Last Updated */**	8/17/18	**Max Plume Width**	700 FT
QA Reviewer	Jerry Ninteman	**Saturated Thickness**	10 to 60 FT

* highlighted cells indicate inputs modified from original 2015 FS estimates
** highlighted cells indicate inputs modified from 2016 revised estimates

Site/Problem Description Chlorinated solvents in groundwater within the Esperance Sand Aquifer beneath Powder Mill Gulch and chlorinated solvents in surface water in Powder Mill Creek at concentrations exceeding MTCA cleanup standards.

Proposed Remedial Action Injection of electron donor for enhanced bioremediation of groundwater in TCE source area (TCE >100 µg/L) and downgradient focus areas (TCE > 250 µg/L or as needed to reach cleanup standards) in combination with continued operation of GET system for hydraulic control of chlorinated solvents in groundwater, minimizing migration of chlorinated solvents in groundwater to surface water, groundwater flushing and restoration, and protection of human and ecological receptors.

Alternative Specific Assumptions

1 Costs presented have an accuracy of +50% to -30% and are suitable for comparing alternatives
2 Washington State Sales Tax is applied to Direct Costs only
3 30-year real discount rate of 0.6% per Office of Management and Budget, Circular A-94 Appendix C, Rev. Feb. 2018
4 Installation of injection wells at 14 locations in detention basin (3 depth interval wells each location)
5 Installation of injection wells at 11 locations in South of Seaway (2 depth interval wells each location)
6 Installation of injection wells at 22 locations in North of Seaway (2 depth interval wells each location)
7 Assume wells installed to depths of 30, 50, and 70 ft bgs in detention basin (20-ft screen each)
8 Assume wells installed to depths of 40 and 60 ft bgs South of Seaway (20-ft screen each)
9 Assume wells installed to depths of 45 and 60 ft bgs North of Seaway (15-ft screen each)
10 Well spacing at 15 ft OC crossgradient and 100 ft downgradient
11 Assume 3 injection events of electron donor over 3-year period
12 Assume construction of TOC and metals pretreatment system for extracted groundwater with TOC from EISB
13 Operation of existing GET system with 12 extraction wells
14 Assumes GET system operation for 30 years (including 3 years of injection events) to reach TCE CUL of 4 µg/L
15 Assume O&M of TOC pretreatment facility and biofouling maintenance of wells for 13 years
16 Assumes major equipment replacement at 20-year intervals
17 Annual groundwater and surface water monitoring
18 Six quarters of confirmation groundwater and surface water sampling

DETAILED COST ESTIMATE

Cost Type	Category	Item #	Description	Quantity	Unit	Unit Cost	Total
IMPLEMENTATION	**REMEDIAL DESIGN, PLANNING, AND GENERAL (Indirect Costs)**						
		1	Engineering/Proj Mgmt/Const Mgmt/Reporting				
		2	Cleanup action plan	1	LS	$ 30,000	$ 30,000
		3	Permits	1	LS	$ 30,000	$ 30,000
		4	Negotiate and implement institutional controls	1	LS	$ 10,000	$ 10,000
		5	Contract documents and contractor bidding/procurement	1	LS	$ 20,000	$ 20,000
		6	Cleanup action construction report	1	LS	$ 20,000	$ 20,000
		7	Engineering/Remedial Design	6%	pct	$ 6,018,000	$ 361,080
		8	Construction management/oversight	6%	pct	$ 6,018,000	$ 361,080
		9	Project management	5%	pct	$ 19,973,160	$ 998,658
		10	Ecology oversight	5%	pct	$ 19,973,160	$ 998,658
	Subtotal Remedial Design, Planning, and General Costs						*$ 2,829,500*
	Indirect Contingency and Unlisted Engineering Services (%)			**15%**	pct	$2,829,500	$ 424,400
	TOTAL INDIRECT COST						**$3,254,000**
	Category	**Item #**	**Description**	**Quantity**	**Unit**	**Unit Cost**	**Total**
	REMEDIAL ACTION CONSTRUCTION - ELECTRON DONOR INJECTIONS (Direct Costs)						
		1	EISB tracer study/pilot test	1	LS	$ 150,000	$ 150,000
		2	Install injection wells, wells/distribution				
		3	Utility locate	1	LS	$ 2,500	$ 2,500
		4	Site prep/clearing/grubbing	1	LS	$ 150,000	$ 150,000
		5	Driller mobilization/demobilization	1	LS	$ 20,000	$ 20,000
		6	Drilling - injection wells (Lot 9 TCE focus area)	44	wells	$ 3,500	$ 154,000
		7	Drilling - injection wells (Boeing Seaway TCE focus area	22	wells	$ 3,750	$ 82,500
		8	Drilling - injection wells (detention basin TCE focus area)	42	wells	$ 4,000	$ 168,000
		9	Well development	108	wells	$ 500	$ 54,000
		10	IDW disposal	240	Drums	$ 200	$ 48,000
		11	Injection of Electron Donor				
		12	Injection crew/labor	150	days	$ 3,000	$ 450,000
		13	Purchase equipment/supplies for injection system setup	1	LS	$ 25,000	$ 25,000
		14	Materials and rentals for injection events	3	event	$ 20,000	$ 60,000
		15	Water for injection events	########	gal	$ 0.03	$ 36,000
		16	Donor for injection events	330,000	lbs	$ 1.50	$ 495,000
		17	Construct TOC and Metals Pre-treatment Facility	1	LS	$ 2,000,000	$ 2,000,000
	Subtotal Remedial Action Construction Costs						*$ 3,895,000*
	Direct Cost Contingency and Unlisted Engineering Services (%)			**25%**	pct	$3,895,000	$ 973,800
	Contractor Bond Fee, Overhead, and Profit (%)			**20%**	pct	$3,348,750	$ 669,800
	Washington State Sales Tax (%)			**9.2%**	pct	$ 4,018,550	$369,700
	TOTAL DIRECT COST						**$5,908,000**
	Category	**Item #**	**Description**	**Quantity**	**Unit**	**Unit Cost**	**Total**
OM&M	**ANNUAL OPERATION, MAINTENANCE, MONITORING, AND REPORTING**						
		1	Electrical usage	1	yr	$ 36,500	$ 36,500
		2	Cell phone/GET system remote access charges	12	mo	$ 369	$ 4,428
		3	Carbon usage	1	ea	$ 9,600	$ 9,600
		4	System monitoring/NPDES reporting	1	yr	$ 20,000	$ 20,000
		5	GET system O&M labor and cost	1	yr	$ 85,000	$ 85,000
		6	NPDES annual renewal fee	1	yr	$ 20,137	$ 20,137
		7	Groundwater sampling	1	yrs	$ 65,000	$ 65,000
		8	Groundwater elevation monitoring	1	yrs	$ 8,000	$ 8,000
		9	Surface water sampling	1	yrs	$ 8,000	$ 8,000
		10	Reporting	1	yr	$ 15,000	$ 15,000
	Subtotal Annual OM&M and Reporting Cost						$ 271,700
	Annual Monitoring Cost Contingency and Unlisted Items (%)			**20%**	pct	$271,700	$ 54,300
			Years of Annual Monitoring	***30***	yrs	$326,000	$ 9,780,000
	TOTAL ANNUAL OM&M AND REPORTING COST						***$9,780,000***
	Present-Worth Annual OM&M and Reporting Cost		Presumed Discount Rate	***0.6%***	pct		**$8,926,000**
	Category	**Item #**	**Description**	**Quantity**	**Unit**	**Unit Cost**	**Total**
	NON-ROUTINE OPERATION, MAINTENANCE, MONITORING, AND REPORTING						
		1	Baseline groundwater/surface water sampling	1	event	$ 73,000	$ 73,000
		2	GET System Replacement Cost	1	event	$ 150,000	$ 150,000
		3	Biofouling Maintenance/Equipment Replacement	13	yr	$ 60,000	$ 780,000
		4	TOC/Metals Pretreatment System O&M	13	yr	$ 100,000	$ 1,300,000
		5	Quarterly groundwater sampling (EISB parameters)	13	yr	$ 95,000	$ 1,235,000
		6	Quarterly groundwater sampling	9	event	$ 65,000	$ 585,000
		7	Quarterly groundwater elevation monitoring	9	event	$ 8,000	$ 72,000
		8	Quarterly surface water sampling	9	event	$ 8,000	$ 72,000
		9	1.5 years quarterly confirmation sampling	6	event	$ 73,000	$ 438,000
		10	Cleanup completion report	1	LS	$ 20,000	$ 20,000
	Subtotal Non-Routine OM&M and Reporting Cost						$ 4,725,000
	Annual Monitoring Cost Contingency and Unlisted Items (%)			**20%**	pct	$4,725,000	$ 945,000
	TOTAL NON-ROUTINE OM&M AND REPORTING COST						***$5,670,000***
	Present-Worth Non-Routine OM&M and Reporting Cost		Presumed Discount Rate	***0.6%***	pct		**$4,307,000**
TOTAL	**ALTERNATIVE COST SUMMARY**						
	TOTAL PRESENT-WORTH REMEDIAL DESIGN, PLANNING, AND GENERAL COST (INDIRECT)						**$3,254,000**
	TOTAL PRESENT-WORTH REMEDIATION IMPLEMENTATION COST (DIRECT)						**$5,908,000**
	TOTAL PRESENT-WORTH OM&M COST (ANNUAL & NON-ROUTINE)						**$13,233,000**
	TOTAL PRESENT-WORTH COST						**$22,400,000**
			Appropriate Cost Range (-30% - +50%)		**TOTAL**	**$ 15,680,000**	**$ 33,600,000**

Table B-1e
Comparison of Alternative Costs
Exposure Pathway Model: EPM K
Esperance Sand, North Complex, PMG SWMU

ALTERNATIVE 5 **DYNAMIC GROUNDWATER RECIRUCLATION AND SOURCE AREA EISB**

Client	Boeing	**EPM Group**	K
Location	BCA Everett Plant	**Site Name**	Esperance Sand/Powder Mill Gulch
Project	Upland Area Feasibility Study	**Building**	N/A
Estimator	Piper Roelen	**Media**	Groundwater
Report Date	11/21/18	**Plume Length**	2,800 FT
Last Updated	10/5/18	**Max Plume Width**	700 FT
QA Reviewer	Jerry Ninteman	**Saturated Thickness**	10 to 60 FT

Site/Problem Description Chlorinated solvents in groundwater within the Esperance Sand Aquifer beneath Powder Mill Gulch and chlorinated solvents in surface water in Powder Mill Creek at concentrations exceeding MTCA cleanup standards.

Proposed Remedial Action Conversion of existing GET system into dynamic groundwater recirculation (DGR) system for enhanced flushing and restoration of the downgradient plume, hydraulic capture and control of chlorinated solvents in groundwater, and minimizing migration of chlorinated solvents in groundwater to surface water. Injection of electron donor for enhanced bioremediation of groundwater in detention basin source area (TCE > 100 µg/L) .

Alternative Specific Assumptions

1. Costs presented have an accuracy of +50% to -30% and are suitable for comparing alternatives
2. Washington State Sales Tax is applied to Direct Costs only
3. 30-year real discount rate of 0.6% per Office of Management and Budget, Circular A-94 Appendix C, Rev. Feb. 201
4. Installation of groundwater injection at 9 locations along perimeter of downgradient plume (up to 65 ft deep)
5. Installation of 2 new extraction wells in the downgradient plume locations in South of Seaway (up to 65 ft deep)
6. Installation of bio injection wells at 14 locations in detention basin (3 depth interval wells each location)
7. Assume EISB injection wells installed to depths of 30, 50, and 70 ft bgs in detention basin (20-ft screen each)
8. Assume 4 new monitoring wells to monitor DGR performance
9. Assume 3 injection events of electron donor over 3-year period
10. Assume DGR pilot study costs included into final remedy costs, except for additional labor/reporting/lab costs
11. Assume drinking water standards to be met at standard point of compliance
12. Assume 3 injection events of electron donor over 3-year period
13. Assume construction of TOC and metals pretreatment system for extracted groundwater with TOC from EISB
14. Operation of DGR system with 14 extraction wells and 9 injection wells, with potential addition of 5 additional well
15. Assumes 23 years for EISB injections and subsequent monitoring to reach TCE CUL of 4 µg/L in the source area
16. Assumes DGR system operation for 15 years to reach TCE CUL of 4 µg/L in downgradient plume
17. Assumes major equipment replacement at 20-year intervals
18. Annual groundwater and surface water monitoring
19. Six quarters of confirmation groundwater and surface water sampling

DETAILED COST ESTIMATE

Cost Type	Category	Item #	Description	Quantity	Unit	Unit Cost	Total
IMPLEMENTATION	**REMEDIAL DESIGN, PLANNING, AND GENERAL (Indirect Costs)**						
		1	Engineering/Proj Mgmt/Const Mgmt/Reporting				
		2	Cleanup action plan	1	LS	$ 30,000	$ 30,000
		3	Permits	1	LS	$ 30,000	$ 30,000
		4	Negotiate and implement institutional controls	0	LS	$ 10,000	$ -
		5	Contract documents and contractor bidding/procurement	1	LS	$ 20,000	$ 20,000
		6	Cleanup action construction report/O&M manual	1	LS	$ 30,000	$ 30,000
		7	Engineering/Remedial Design	8%	pct	$ 4,033,000	$ 322,640
		8	Construction management/oversight	6%	pct	$ 4,033,000	$ 241,980
		9	Project management	5%	pct	$ 12,526,620	$ 626,331
		10	Ecology oversight	5%	pct	$ 12,526,620	$ 626,331
	Subtotal Remedial Design, Planning, and General Costs						*$ 1,927,300*
	Indirect Contingency and Unlisted Engineering Services (%)			**15%**	pct	$1,927,300	$ 289,100
	TOTAL INDIRECT COST						**$2,216,000**
	Category	**Item #**	**Description**	**Quantity**	**Unit**	**Unit Cost**	**Total**
	REMEDIAL ACTION CONSTRUCTION - DGR SYSTEM AND ELECTRON DONOR INJECTIONS (Direct Costs)						
		1	Contractor mobilization/demobilization	1	LS	$ 30,000	$ 30,000
		2	DGR Pilot Study	1	LS	$ 80,000	$ 80,000
			Install injection and extraction wells/distribution systen				
		3	Utility locate	1	LS	$ 2,500	$ 2,500
		4	Site prep/clearing/grubbing	1	LS	$ 75,000	$ 75,000
		5	Driller mobilization/demobilization	1	LS	$ 3,000	$ 3,000
		6	Drilling - DGR extraction well installatior	4	well	$ 20,000	$ 80,000
		7	Drilling - DGR injection well installation (shallow	4	well	$ 26,000	$ 104,000
		8	Drilling - DGR injection well installation (deep)	8	well	$ 15,000	$ 120,000
		9	Drilling - Monitoring wells for DGR monitoring	4	well	$ 12,000	$ 48,000
		10	IDW disposal	60	Drums	$ 200	$ 12,000
		11	Well vaults, pumps, air vac assemblies	1	LS	$ 210,000	$ 210,000
		12	Transfer tank, valving, and pump with controls	1	LS	$ 18,000	$ 18,000
		13	Directional drilling for pipe/conduit up to ridge	1	LS	$ 100,000	$ 100,000
		14	Water line, electrical, communications trenching	4200	LF	$ 16	$ 67,200
		15	Water piping	4200	LF	$ 60	$ 252,000
		16	Electrical conduit and cable	2400	LF	$ 45	$ 108,000
		17	Communications conduit and cable	4200	LF	$ 65	$ 273,000
		18	Trench repaving/restoration	20000	SF	$ 5	$ 100,000
		19	Electrical equipment upgrades/transformer/electrician	1	LS	$ 70,000	$ 70,000
		20	Instrumentation and controls; control panels	1	LS	$ 150,000	$ 150,000
		21	GAC polishing vessels	2	each	$ 12,500	$ 25,000
		22	DGR system startup and testing	1	LS	$ 20,000	$ 20,000
			EISB Injection Well Installation				
		23	Utility locate/clearing	1	LS	$ 1,000	$ 1,000
		24	Driller mobilization/demobilization	1	LS	$ 3,000	$ 3,000
		25	Drilling - injection wells (detention basin hotspot)	24	wells	$ 4,000	$ 96,000
		26	Well development	24	wells	$ 1,000	$ 24,000
		27	IDW disposal	70	Drums	$ 200	$ 14,000
			Injection of Electron Donor				
		28	Injection crew/labor	75	days	$ 3,000	$ 225,000
		29	Purchase equipment/supplies for injection system setup	1	LS	$ 25,000	$ 25,000
		30	Materials and rentals for injection events	3	event	$ 20,000	$ 60,000
		31	Water for injection events	285,000	gal	$ 0.03	$ 8,550
		32	Donor for injection events	36000	lbs	$ 2	$ 54,000
		33	Site Restoration - slope/buffer plantings, general cleanup	1	LS	$ 25,000	$ 25,000
	Subtotal Remedial Action Construction Costs						*$ 2,483,300*
	Direct Cost Contingency and Unlisted Engineering Services (%			**25%**	pct	$2,483,300	$ 620,800
	Contractor Bond Fee, Overhead, and Profit (%)			**20%**	pct	$2,638,375	$ 527,700
	Washington State Sales Tax (%)			**9.2%**	pct	$ 3,166,075	$291,300
	TOTAL DIRECT COST						**$3,923,000**
	Category	**Item #**	**Description**	**Quantity**	**Unit**	**Unit Cost**	**Total**
OM&M	**ANNUAL OPERATION, MAINTENANCE, MONITORING, AND REPORTING**						
		1	Electrical usage	1	yr	$ 44,500	$ 44,500
		2	Cell phone/GET system remote access charges	12	mo	$ 369	$ 4,428
		3	Carbon usage	1	yr	$ 9,600	$ 9,600
		4	System monitoring/NPDES reporting	1	yr	$ 20,000	$ 20,000
		5	DGR system O&M labor and cost	1	yr	$ 95,000	$ 95,000
		6	NPDES annual renewal fee	1	yr	$ 20,137	$ 20,137
		7	Groundwater sampling (during DGR)	1	yr	$ 65,000	$ 65,000
		8	Groundwater elevation monitoring (during DGR)	1	yr	$ 8,000	$ 8,000
		9	Surface water sampling (during DGR)	1	yr	$ 8,000	$ 8,000
		10	Reporting	1	yr	$ 15,000	$ 15,000
	Subtotal Annual OM&M and Reporting Cost						$ 289,700
	Annual Monitoring Cost Contingency and Unlisted Items (%			**20%**	pct	$289,700	$ 57,900
			Years of Annual Monitoring	***15***	yrs	$347,600	$ 5,214,000
	TOTAL ANNUAL OM&M AND REPORTING COST						***$5,214,000***
	Present-Worth Annual OM&M and Reporting Cost		Presumed Discount Rate	***0.6%***	pct		**$4,972,000**
	Category	**Item #**	**Description**	**Quantity**	**Unit**	**Unit Cost**	**Total**
	NON-ROUTINE OPERATION, MAINTENANCE, MONITORING, AND REPORTING						
		1	Baseline groundwater/surface water sampling	1	event	$ 73,000	$ 73,000
		2	DGR system replacement cost	1	event	$ 200,000	$ 200,000
		3	Quarterly groundwater sampling (EISB parameters)	3	yrs	$ 95,000	$ 285,000
		4	Quarterly groundwater sampling	12	event	$ 65,000	$ 780,000
		5	Quarterly groundwater elevation monitoring	12	event	$ 8,000	$ 96,000
		6	Quarterly surface water sampling	12	event	$ 8,000	$ 96,000
		7	Annual groundwater sampling (EISB parameters post DG	8	yrs	$ 65,000	$ 520,000
		8	Annual groundwater elevation monitoring (post DGR)	8	yrs	$ 8,000	$ 64,000
		9	Annual surface water sampling (post DGR)	8	yrs	$ 8,000	$ 64,000
		10	1.5 years quarterly confirmation sampling	6	event	$ 73,000	$ 438,000
		11	Cleanup completion report	1	LS	$ 20,000	$ 20,000
	Subtotal Non-Routine OM&M and Reporting Cost						$ 2,636,000
	Annual Monitoring Cost Contingency and Unlisted Items (%			**20%**	pct	$2,636,000	$ 527,200
	TOTAL NON-ROUTINE OM&M AND REPORTING COST						***$3,163,000***
	Present-Worth Non-Routine OM&M and Reporting Cost		Presumed Discount Rate	***0.6%***	pct		**$2,957,000**
TOTAL	**ALTERNATIVE COST SUMMARY**						
	TOTAL PRESENT-WORTH REMEDIAL DESIGN, PLANNING, AND GENERAL COST (INDIRECT)						**$2,216,000**
	TOTAL PRESENT-WORTH REMEDIATION IMPLEMENTATION COST (DIRECT)						**$3,923,000**
	TOTAL PRESENT-WORTH OM&M COST (ANNUAL & NON-ROUTINE)						**$7,929,000**
	TOTAL PRESENT-WORTH COST						**$14,070,000**
			Appropriate Cost Range (-30% - +50%)		**TOTAL**	**$ 9,850,000**	**$ 21,110,000**

APPENDIX C

Point of Compliance Cost Estimates

ALTERNATIVE 5 **DYNAMIC GROUNDWATER RECIRUCLATION AND SOURCE AREA EISB**

POINT OF COMPLIANCE OPTION: **OPTION 1 - GROUNDWATER AND SURFACE WATER STANDARD POCS**

Explanation of POC Option: Drinking water standard (4 µg/L TCE) to be met in monitoring wells throughout the groundwater TCE plume and the SWQS (0.3 µg/L TCE) to be met in creek water sampling points immediately above the creek bed.

POC Option Specific Assumptions

1. Existing monitoring well network sufficient for monitoring groundwater POC
2. Existing surface water sampling locations will be used for monitoring surface water POC
3. DGR system will be operated for 15 years for downgradient plume cleanup
4. EISB in source area will require 23 years for source area cleanup (including 3 injection events over 3-year period)

DETAILED COST ESTIMATE

Cost Type	Category	Item #	Description	Quantity	Unit	Unit Cost	Total
IMPLEMENTATION	**REMEDIAL DESIGN, PLANNING, AND GENERAL (Indirect Costs)**						
		1	Engineering/Proj Mgmt/Const Mgmt/Reporting				
		2	Cleanup action plan	1	LS	$ 30,000	$ 30,000
		3	Permits	1	LS	$ 30,000	$ 30,000
		4	Negotiate and implement institutional controls	0	LS	$ 10,000	$ -
		5	Contract documents and contractor bidding/procurement	1	LS	$ 20,000	$ 20,000
		6	Cleanup action construction report/O&M manual	1	LS	$ 30,000	$ 30,000
		7	Engineering/Remedial Design	8%	pct	$ 4,033,000	$ 322,640
		8	Construction management/oversight	6%	pct	$ 4,033,000	$ 241,980
		9	Project management	5%	pct	$ 12,513,620	$ 625,681
		10	Ecology oversight	5%	pct	$ 12,513,620	$ 625,681
	Subtotal Remedial Design, Planning, and General Costs						*$ 1,926,000*
	Indirect Contingency and Unlisted Engineering Services (%)			**15%**	pct	$1,926,000	$ 288,900
	TOTAL INDIRECT COST						**$2,215,000**
	Category	**Item #**	**Description**	**Quantity**	**Unit**	**Unit Cost**	**Total**
	REMEDIAL ACTION CONSTRUCTION - DGR SYSTEM AND ELECTRON DONOR INJECTIONS (Direct Costs)						
		1	Contractor mobilization/demobilization	1	LS	$ 30,000	$ 30,000
		2	DGR pilot study	1	LS	$ 80,000	$ 80,000
			Install injection and extraction wells/distribution system				
		3	Utility locate	1	LS	$ 2,500	$ 2,500
		4	Site prep/clearing/grubbing	1	LS	$ 75,000	$ 75,000
		5	Driller mobilization/demobilization	1	LS	$ 3,000	$ 3,000
		6	Drilling - DGR extraction well installation	4	well	$ 20,000	$ 80,000
		7	Drilling - DGR injection well installation (shallow)	4	well	$ 26,000	$ 104,000
		8	Drilling - DGR injection well installation (deep)	8	well	$ 15,000	$ 120,000
		9	Drilling - monitoring wells for DGR monitoring	4	well	$ 12,000	$ 48,000
		10	IDW disposal	60	Drums	$ 200	$ 12,000
		11	Well vaults, pumps, air vac assemblies	1	LS	$ 210,000	$ 210,000
		12	Transfer tank, valving, and pump with controls	1	LS	$ 18,000	$ 18,000
		13	Directional drilling for pipe/conduit up to ridge	1	LS	$ 100,000	$ 100,000
		14	Water line, electrical, communications trenching	4200	LF	$ 16	$ 67,200
		15	Water piping	4200	LF	$ 60	$ 252,000
		16	Electrical conduit and cable	2400	LF	$ 45	$ 108,000
		17	Communications conduit and cable	4200	LF	$ 65	$ 273,000
		18	Trench repaving/restoration	20000	SF	$ 5	$ 100,000
		19	Electrical equipment upgrades/transformer/electrician	1	LS	$ 70,000	$ 70,000
		20	Instrumentation and controls; control panels	1	LS	$ 150,000	$ 150,000
		21	GAC polishing vessels	2	each	$ 12,500	$ 25,000
		22	DGR system startup and testing	1	LS	$ 20,000	$ 20,000
			EISB injection well installation				
		23	Utility locate/clearing	1	LS	$ 1,000	$ 1,000
		24	Driller mobilization/demobilization	1	LS	$ 3,000	$ 3,000
		25	Drilling - injection wells (detention basin hotspot)	24	wells	$ 4,000	$ 96,000
		26	Well development	24	wells	$ 1,000	$ 24,000
		27	IDW disposal	70	Drums	$ 200	$ 14,000
			Injection of Electron Donor				
		28	Injection crew/labor	75	days	$ 3,000	$ 225,000
		29	Purchase equipment/supplies for injection system setup	1	LS	$ 25,000	$ 25,000
		30	Materials and rentals for injection events	3	event	$ 20,000	$ 60,000
		31	Water for injection events	285,000	gal	$ 0.03	$ 8,550
		32	Donor for injection events	36000	lbs	$ 2	$ 54,000
		33	Site Restoration - slope/buffer plantings, general cleanup	1	LS	$ 25,000	$ 25,000
	Subtotal Remedial Action Construction Costs						*$ 2,483,300*
	Direct Cost Contingency and Unlisted Engineering Services (%)			**25%**	pct	$2,483,300	$ 620,800
	Contractor Bond Fee, Overhead, and Profit (%)			**20%**	pct	$2,638,375	$ 527,700
	Washington State Sales Tax (%)			**9.2%**	pct	$ 3,166,075	$291,300
	TOTAL DIRECT COST						**$3,923,000**
	Category	**Item #**	**Description**	**Quantity**	**Unit**	**Unit Cost**	**Total**
OM&M	**ANNUAL OPERATION, MAINTENANCE, MONITORING, AND REPORTING**						
		1	Electrical usage	1	yr	$ 44,500	$ 44,500
		2	Cell phone/GET system remote access charges	12	mo	$ 369	$ 4,428
		3	Carbon usage	1	yr	$ 9,600	$ 9,600
		4	System monitoring/NPDES reporting	1	yr	$ 20,000	$ 20,000
		5	DGR system O&M labor and cost	1	yr	$ 95,000	$ 95,000
		6	NPDES annual renewal fee	1	yr	$ 20,137	$ 20,137
		7	Groundwater sampling (during DGR)	1	yr	$ 65,000	$ 65,000
		8	Groundwater elevation monitoring (during DGR)	1	yr	$ 8,000	$ 8,000
		9	Surface water sampling (during DGR)	1	yr	$ 8,000	$ 8,000
		10	Reporting	1	yr	$ 15,000	$ 15,000
	Subtotal Annual OM&M and Reporting Cost						$ 289,700
	Annual Monitoring Cost Contingency and Unlisted Items (%)			**20%**	pct	$289,700	$ 57,900
			Years of Annual Monitoring	***15***	yrs	$347,600	$ 5,214,000
	TOTAL ANNUAL OM&M AND REPORTING COST						***$5,214,000***
	Present-Worth Annual OM&M and Reporting Cost		Presumed Discount Rate	***0.6%***	pct		**$4,972,000**
	Category	**Item #**	**Description**	**Quantity**	**Unit**	**Unit Cost**	**Total**
	NON-ROUTINE OPERATION, MAINTENANCE, MONITORING, AND REPORTING						
		1	Baseline groundwater/surface water sampling	1	event	$ 73,000	$ 73,000
		2	DGR system replacement cost	1	event	$ 200,000	$ 200,000
		3	Quarterly groundwater sampling (EISB parameters)	3	yr	$ 95,000	$ 285,000
		4	Quarterly groundwater sampling	12	event	$ 65,000	$ 780,000
		5	Quarterly groundwater elevation monitoring	12	event	$ 8,000	$ 96,000
		6	Quarterly surface water sampling	12	event	$ 8,000	$ 96,000
		7	Annual groundwater sampling (EISB parameters post DGI	8	yrs	$ 65,000	$ 520,000
		8	Annual groundwater elevation monitoring (post DGR)	8	yrs	$ 8,000	$ 64,000
		9	Annual surface water sampling (post DGR)	8	yrs	$ 8,000	$ 64,000
		10	1.5 years quarterly confirmation sampling	6	event	$ 73,000	$ 438,000
		11	Cleanup completion report	1	LS	$ 20,000	$ 20,000
	Subtotal Non-Routine OM&M and Reporting Cost						$ 2,636,000
	Annual Monitoring Cost Contingency and Unlisted Items (%)			**20%**	pct	$2,636,000	$ 527,200
	TOTAL NON-ROUTINE OM&M AND REPORTING COST						***$3,163,000***
	Present-Worth Non-Routine OM&M and Reporting Cost		Presumed Discount Rate	***0.6%***	pct		**$2,944,000**
TOTAL	**ALTERNATIVE COST SUMMARY**						
	TOTAL PRESENT-WORTH REMEDIAL DESIGN, PLANNING, AND GENERAL COST (INDIRECT						**$2,215,000**
	TOTAL PRESENT-WORTH REMEDIATION IMPLEMENTATION COST (DIRECT						**$3,923,000**
	TOTAL PRESENT-WORTH OM&M COST (ANNUAL & NON-ROUTINE						**$7,916,000**
	TOTAL PRESENT-WORTH COST						**$14,050,000**
			Appropriate Cost Range (-30% - +50%)		**TOTAL**	**$ 9,840,000**	**$ 21,080,000**

Table C-1b
Comparison of Point of Compliance Costs
Boeing Everett - PMG SWMU

ALTERNATIVE 5 — **DYNAMIC GROUNDWATER RECIRUCLATION AND SOURCE AREA EISB**

POINT OF COMPLIANCE OPTION: **OPTION 2A - GROUNDWATER CPOC IN TRANSITION ZONE BENEATH THE CREEK**

Explanation of POC Option: SWQS (0.3 µg/L TCE) to be met in transition zone water sampling points below the creek bed or immediately adjacent to the creek (off property) and "within the surface water as close as technically possible to the point or points where groundwater flows into the surface water" (on Boeing property).
Drinking water standard (4 µg/L TCE) to be met in monitoring wells throughout the groundwater TCE plume.

POC Option Specific Assumptions

1. Pore water samplers or drive point wells will be installed at approximately 100-ft intervals in or adjacent to creek fo groundwater CPOC (assume 28 locations). Existing monitoring well network sufficient for monitoring groundwater throughout plume.
2. Existing surface water sampling locations will be used for monitoring surface water POC
3. Pore water samplers or drive point wells must be replaced every 3 years due to damage from storms/creek meander
4. DGR system will be operated for 16 years for downgradient plume cleanup
5. EISB in source area will require 23 years for source area cleanup (including 3 injection events over 3-year period)

DETAILED COST ESTIMATE

Cost Type	Category	Item #	Description	Quantity	Unit	Unit Cost	Total
IMPLEMENTATION	**REMEDIAL DESIGN, PLANNING, AND GENERAL (Indirect Costs)**						
		1	Engineering/Proj Mgmt/Const Mgmt/Reporting				
		2	Cleanup action plan	1	LS	$ 30,000	$ 30,000
		3	Permits	1	LS	$ 30,000	$ 30,000
		4	Negotiate and implement institutional controls	0	LS	$ 10,000	$ -
		5	Contract documents and contractor bidding/procurement	1	LS	$ 20,000	$ 20,000
		6	Cleanup action construction report/O&M manual	1	LS	$ 30,000	$ 30,000
		7	Engineering/Remedial Design	8%	pct	$ 4,033,000	$ 322,640
		8	Construction management/oversight	6%	pct	$ 4,033,000	$ 241,980
		9	Project management	5%	pct	$ 12,983,620	$ 649,181
		10	Ecology oversight	5%	pct	$ 12,983,620	$ 649,181
	Subtotal Remedial Design, Planning, and General Costs						*$ 1,973,000*
	Indirect Contingency and Unlisted Engineering Services (%)			**15%**	pct	$1,973,000	$ 296,000
	TOTAL INDIRECT COST						**$2,269,000**
	Category	**Item #**	**Description**	**Quantity**	**Unit**	**Unit Cost**	**Total**
	REMEDIAL ACTION CONSTRUCTION - DGR SYSTEM AND ELECTRON DONOR INJECTIONS (Direct Costs)						
		1	Contractor mobilization/demobilization	1	LS	$ 30,000	$ 30,000
		2	DGR pilot study	1	LS	$ 80,000	$ 80,000
			Install injection and extraction wells/distribution system				
		3	Utility locate	1	LS	$ 2,500	$ 2,500
		4	Site prep/clearing/grubbing	1	LS	$ 75,000	$ 75,000
		5	Driller mobilization/demobilization	1	LS	$ 3,000	$ 3,000
		6	Drilling - DGR extraction well installation	4	well	$ 20,000	$ 80,000
		7	Drilling - DGR injection well installation (shallow	4	well	$ 26,000	$ 104,000
		8	Drilling - DGR injection well installation (deep)	8	well	$ 15,000	$ 120,000
		9	Drilling - monitoring wells for DGR monitoring	4	well	$ 12,000	$ 48,000
		10	IDW disposal	60	Drums	$ 200	$ 12,000
		11	Well vaults, pumps, air vac assemblies	1	LS	$ 210,000	$ 210,000
		12	Transfer tank, valving, and pump with controls	1	LS	$ 18,000	$ 18,000
		13	Directional drilling for pipe/conduit up to ridge	1	LS	$ 100,000	$ 100,000
		14	Water line, electrical, communications trenching	4200	LF	$ 16	$ 67,200
		15	Water piping	4200	LF	$ 60	$ 252,000
		16	Electrical conduit and cable	2400	LF	$ 45	$ 108,000
		17	Communications conduit and cable	4200	LF	$ 65	$ 273,000
		18	Trench repaving/restoration	20000	SF	$ 5	$ 100,000
		19	Electrical equipment upgrades/transformer/electrician	1	LS	$ 70,000	$ 70,000
		20	Instrumentation and controls; control panels	1	LS	$ 150,000	$ 150,000
		21	GAC polishing vessels	2	each	$ 12,500	$ 25,000
		22	DGR system startup and testing	1	LS	$ 20,000	$ 20,000
			EISB Injection Well Installation				
		23	Utility locate/clearing	1	LS	$ 1,000	$ 1,000
		24	Driller mobilization/demobilization	1	LS	$ 3,000	$ 3,000
		25	Drilling - injection wells (detention basin hotspot)	24	wells	$ 4,000	$ 96,000
		26	Well development	24	wells	$ 1,000	$ 24,000
		27	IDW disposal	70	Drums	$ 200	$ 14,000
			Injection of Electron Donor				
		28	Injection crew/labor	75	days	$ 3,000	$ 225,000
		29	Purchase equipment/supplies for injection system setup	1	LS	$ 25,000	$ 25,000
		30	Materials and rentals for injection events	3	event	$ 20,000	$ 60,000
		31	Water for injection events	285,000	gal	$ 0.03	$ 8,550
		32	Donor for injection events	36000	lbs	$ 2	$ 54,000
		33	Site Restoration - slope/buffer plantings, general cleanup	1	LS	$ 25,000	$ 25,000
	Subtotal Remedial Action Construction Costs						*$ 2,483,300*
	Direct Cost Contingency and Unlisted Engineering Services (%			**25%**	pct	$2,483,300	$ 620,800
	Contractor Bond Fee, Overhead, and Profit (%)			**20%**	pct	$2,638,375	$ 527,700
	Washington State Sales Tax (%)			**9.2%**	pct	$ 3,166,075	$291,300
	TOTAL DIRECT COST						**$3,923,000**
	Category	**Item #**	**Description**	**Quantity**	**Unit**	**Unit Cost**	**Total**
OM&M	**ANNUAL OPERATION, MAINTENANCE, MONITORING, AND REPORTING**						
		1	Electrical usage	1	yr	$ 44,500	$ 44,500
		2	Cell phone/GET system remote access charges	12	mo	$ 369	$ 4,428
		3	Carbon usage	1	yr	$ 9,600	$ 9,600
		4	System monitoring/NPDES reporting	1	yr	$ 20,000	$ 20,000
		5	DGR system O&M labor and cost	1	yr	$ 95,000	$ 95,000
		6	NPDES annual renewal fee	1	yr	$ 20,137	$ 20,137
		7	Install pore water samplers or drive point wells	18	unit	$ 250	$ 4,500
		8	Groundwater sampling (during DGR)	1	yr	$ 70,000	$ 70,000
		9	Groundwater elevation monitoring (during DGR)	1	yr	$ 8,000	$ 8,000
		10	Surface water sampling (during DGR)	1	yr	$ 8,000	$ 8,000
		11	Reporting	1	yr	$ 15,000	$ 15,000
	Subtotal Annual OM&M and Reporting Cost						$ 299,200
	Annual Monitoring Cost Contingency and Unlisted Items (%			**20%**	pct	$299,200	$ 59,800
			Years of Annual Monitoring	***16***	yrs	$359,000	$ 5,744,000
	TOTAL ANNUAL OM&M AND REPORTING COST						***$5,744,000***
	Present-Worth Annual OM&M and Reporting Cost		Presumed Discount Rate	***0.6%***	pct		**$5,461,000**
	Category	**Item #**	**Description**	**Quantity**	**Unit**	**Unit Cost**	**Total**
	NON-ROUTINE OPERATION, MAINTENANCE, MONITORING, AND REPORTING						
		1	Baseline groundwater/surface water sampling	1	event	$ 75,000	$ 75,000
		2	DGR system replacement cost	1	event	$ 200,000	$ 200,000
		3	Replace pore water samplers or drive point wells	5	event	$ 4,500	$ 22,500
		4	Quarterly groundwater sampling (EISB parameters)	3	yr	$ 95,000	$ 285,000
		5	Quarterly groundwater sampling	12	event	$ 70,000	$ 840,000
		6	Quarterly groundwater elevation monitoring	12	event	$ 8,000	$ 96,000
		7	Quarterly surface water sampling	12	event	$ 8,000	$ 96,000
		8	Annual groundwater sampling (EISB parameters post DGR	7	yrs	$ 65,000	$ 455,000
		9	Annual groundwater elevation monitoring (post DGR	7	yrs	$ 8,000	$ 56,000
		10	Annual surface water sampling (post DGR	7	yrs	$ 8,000	$ 56,000
		11	1.5 years quarterly confirmation sampling	6	event	$ 75,000	$ 450,000
		12	Cleanup completion report	1	LS	$ 20,000	$ 20,000
	Subtotal Non-Routine OM&M and Reporting Cost						$ 2,651,500
	Annual Monitoring Cost Contingency and Unlisted Items (%			**20%**	pct	$2,651,500	$ 530,300
	TOTAL NON-ROUTINE OM&M AND REPORTING COST						***$3,182,000***
	Present-Worth Non-Routine OM&M and Reporting Cost		Presumed Discount Rate	***0.6%***	pct		**$2,925,000**
TOTAL	**ALTERNATIVE COST SUMMARY**						
	TOTAL PRESENT-WORTH REMEDIAL DESIGN, PLANNING, AND GENERAL COST (INDIRECT)						**$2,269,000**
	TOTAL PRESENT-WORTH REMEDIATION IMPLEMENTATION COST (DIRECT)						**$3,923,000**
	TOTAL PRESENT-WORTH OM&M COST (ANNUAL & NON-ROUTINE)						**$8,386,000**
	TOTAL PRESENT-WORTH COST						**$14,580,000**
			Appropriate Cost Range (-30% - +50%)		**TOTAL**	**$ 10,210,000**	**$ 21,870,000**

Table C-1c
Comparison of Point of Compliance Costs
Boeing Everett - PMG SWMU

ALTERNATIVE 5 — **DYNAMIC GROUNDWATER RECIRUCLATION AND SOURCE AREA EISB**

POINT OF COMPLIANCE OPTION: **OPTION 2B - GROUNDWATER CPOC IN MONITORING WELLS UPGRADIENT OF CREEK**

Explanation of POC Option: SWQS (0.3 µg/L TCE) to be met in monitoring wells in "buffer zone" upgradient of the creek. Drinking water standard (4 µg/L TCE) to be met in monitoring wells throughout the groundwater TCE plume

POC Option Specific Assumptions

1. Existing monitoring wells adjacent to creek sufficient for monitoring groundwater CPOC; monitoring well network sufficient for monitoring groundwater throughout plume.
2. Existing surface water sampling locations will be used for monitoring surface water POC
3. DGR system will be operated for 20 years for downgradient plume cleanup
4. EISB in source area will require 23 years for source area cleanup (including 3 injection events over 3-year period)
5. Major equipment replacement for DGR system will be required during 20-year operational time frame

DETAILED COST ESTIMATE

Cost Type	Category	Item #	Description	Quantity	Unit	Unit Cost	Total
IMPLEMENTATION	**REMEDIAL DESIGN, PLANNING, AND GENERAL (Indirect Costs)**						
		1	Engineering/Proj Mgmt/Const Mgmt/Reporting				
		2	Cleanup action plan	1	LS	$ 30,000	$ 30,000
		3	Permits	1	LS	$ 30,000	$ 30,000
		4	Negotiate and implement institutional controls	0	LS	$ 10,000	$ -
		5	Contract documents and contractor bidding/procurement	1	LS	$ 20,000	$ 20,000
		6	Cleanup action construction report/O&M manual	1	LS	$ 30,000	$ 30,000
		7	Engineering/Remedial Design	8%	pct	$ 4,148,000	$ 331,840
		8	Construction management/oversight	6%	pct	$ 4,148,000	$ 248,880
		9	Project management	5%	pct	$ 13,870,720	$ 693,536
		10	Ecology oversight	5%	pct	$ 13,870,720	$ 693,536
	Subtotal Remedial Design, Planning, and General Costs						*$ 2,077,800*
	Indirect Contingency and Unlisted Engineering Services (%)			**15%**	pct	$2,077,800	$ 311,700
	TOTAL INDIRECT COST						**$2,390,000**
	Category	**Item #**	**Description**	**Quantity**	**Unit**	**Unit Cost**	**Total**
	REMEDIAL ACTION CONSTRUCTION - DGR SYSTEM AND ELECTRON DONOR INJECTIONS (Direct Costs)						
		1	Contractor mobilization/demobilization	1	LS	$ 30,000	$ 30,000
		2	DGR pilot study	1	LS	$ 80,000	$ 80,000
			Install injection and extraction wells/distribution system				
		3	Utility locate	1	LS	$ 2,500	$ 2,500
		4	Site prep/clearing/grubbing	1	LS	$ 75,000	$ 75,000
		5	Driller mobilization/demobilization	1	LS	$ 3,000	$ 3,000
		6	Drilling - DGR extraction well installation	4	well	$ 20,000	$ 80,000
		7	Drilling - DGR injection well installation (shallow)	4	well	$ 26,000	$ 104,000
		8	Drilling - DGR injection well installation (deep)	8	well	$ 15,000	$ 120,000
		9	Drilling - Monitoring wells for DGR monitoring	4	well	$ 12,000	$ 48,000
		10	Drilling - Monitoring wells for CPOC monitoring	7	well	$ 10,000	$ 70,000
		11	IDW disposal	60	Drums	$ 200	$ 12,000
		12	Well vaults, pumps, air vac assemblies	1	LS	$ 210,000	$ 210,000
		13	Transfer tank, valving, and pump with controls	1	LS	$ 18,000	$ 18,000
		14	Directional drilling for pipe/conduit up to ridge	1	LS	$ 100,000	$ 100,000
		15	Water line, electrical, communications trenching	4200	LF	$ 16	$ 67,200
		16	Water piping	4200	LF	$ 60	$ 252,000
		17	Electrical conduit and cable	2400	LF	$ 45	$ 108,000
		18	Communications conduit and cable	4200	LF	$ 65	$ 273,000
		19	Trench repaving/restoration	20000	SF	$ 5	$ 100,000
		20	Electrical equipment upgrades/transformer/electrician	1	LS	$ 70,000	$ 70,000
		21	Instrumentation and controls; control panels	1	LS	$ 150,000	$ 150,000
		22	GAC polishing vessels	2	each	$ 12,500	$ 25,000
		23	DGR system startup and testing	1	LS	$ 20,000	$ 20,000
			EISB Injection Well Installation				
		24	Utility locate/clearing	1	LS	$ 1,000	$ 1,000
		25	Driller mobilization/demobilization	1	LS	$ 3,000	$ 3,000
		26	Drilling - injection wells (detention basin hotspot)	24	wells	$ 4,000	$ 96,000
		17	Well development	24	wells	$ 1,000	$ 24,000
		28	IDW disposal	70	Drums	$ 200	$ 14,000
			Injection of Electron Donor				
		30	Injection crew/labor	75	days	$ 3,000	$ 225,000
		31	Purchase equipment/supplies for injection system setup	1	LS	$ 25,000	$ 25,000
		32	Materials and rentals for injection events	3	event	$ 20,000	$ 60,000
		32	Water for injection events	285,000	gal	$ 0.03	$ 8,550
		33	Donor for injection events	36000	lbs	$ 2	$ 54,000
		34	Site Restoration - slope/buffer plantings, general cleanup	1	LS	$ 25,000	$ 25,000
	Subtotal Remedial Action Construction Costs						*$ 2,553,300*
	Direct Cost Contingency and Unlisted Engineering Services (%)			**25%**	pct	$2,553,300	$ 638,300
	Contractor Bond Fee, Overhead, and Profit (%)			**20%**	pct	$2,725,875	$ 545,200
	Washington State Sales Tax (%)			**9.2%**	pct	$ 3,271,075	$300,900
	TOTAL DIRECT COST						**$4,038,000**
	Category	**Item #**	**Description**	**Quantity**	**Unit**	**Unit Cost**	**Total**
OM&M	**ANNUAL OPERATION, MAINTENANCE, MONITORING, AND REPORTING**						
		1	Electrical usage	1	yr	$ 44,500	$ 44,500
		2	Cell phone/GET system remote access charges	12	mo	$ 369	$ 4,428
		3	Carbon usage	1	yr	$ 9,600	$ 9,600
		4	System monitoring/NPDES reporting	1	yr	$ 20,000	$ 20,000
		5	DGR system O&M labor and cost	1	yr	$ 95,000	$ 95,000
		6	NPDES annual renewal fee	1	yr	$ 20,137	$ 20,137
		7	Groundwater sampling (during DGR)	1	yr	$ 67,000	$ 67,000
		8	Groundwater elevation monitoring (during DGR)	1	yr	$ 8,000	$ 8,000
		9	Surface water sampling (during DGR)	1	yr	$ 8,000	$ 8,000
		10	Reporting	1	yr	$ 15,000	$ 15,000
	Subtotal Annual OM&M and Reporting Cost						$ 291,700
	Annual Monitoring Cost Contingency and Unlisted Items (%)			**20%**	pct	$291,700	$ 58,300
			Years of Annual Monitoring	***20***	yrs	$350,000	$ 7,000,000
	TOTAL ANNUAL OM&M AND REPORTING COST						***$7,000,000***
	Present-Worth Annual OM&M and Reporting Cost		Presumed Discount Rate	***0.6%***	pct		**$6,578,000**
	Category	**Item #**	**Description**	**Quantity**	**Unit**	**Unit Cost**	**Total**
	NON-ROUTINE OPERATION, MAINTENANCE, MONITORING, AND REPORTING						
		1	Baseline groundwater/surface water sampling	1	event	$ 75,000	$ 75,000
		2	DGR system equipment replacement cost	1	event	$ 200,000	$ 200,000
		3	Quarterly groundwater sampling (EISB parameters)	3	yr	$ 95,000	$ 285,000
		4	Quarterly groundwater sampling	12	event	$ 67,000	$ 804,000
		5	Quarterly groundwater elevation monitoring	12	event	$ 8,000	$ 96,000
		6	Quarterly surface water sampling	12	event	$ 8,000	$ 96,000
		7	Annual groundwater sampling (EISB parameters post DGR)	3	yrs	$ 65,000	$ 195,000
		8	Annual groundwater elevation monitoring (post DGR)	3	yrs	$ 8,000	$ 24,000
		9	Annual surface water sampling (post DGR)	3	yrs	$ 8,000	$ 24,000
		10	1.5 years quarterly confirmation sampling	6	event	$ 75,000	$ 450,000
		11	Cleanup completion report	1	LS	$ 20,000	$ 20,000
	Subtotal Non-Routine OM&M and Reporting Cost						$ 2,269,000
	Annual Monitoring Cost Contingency and Unlisted Items (%)			**20%**	pct	$2,269,000	$ 453,800
	TOTAL NON-ROUTINE OM&M AND REPORTING COST						***$2,723,000***
	Present-Worth Non-Routine OM&M and Reporting Cost		Presumed Discount Rate	***0.6%***	pct		**$2,564,000**
TOTAL	**ALTERNATIVE COST SUMMARY**						
	TOTAL PRESENT-WORTH REMEDIAL DESIGN, PLANNING, AND GENERAL COST (INDIRECT)						**$2,390,000**
	TOTAL PRESENT-WORTH REMEDIATION IMPLEMENTATION COST (DIRECT)						**$4,038,000**
	TOTAL PRESENT-WORTH OM&M COST (ANNUAL & NON-ROUTINE)						**$9,142,000**
	TOTAL PRESENT-WORTH COST						**$15,570,000**
			Appropriate Cost Range (-30% - +50%)		**TOTAL**	**$ 10,900,000**	**$ 23,360,000**

Table C-1d
Comparison of Point of Compliance Costs
Boeing Everett - PMG SWMU

ALTERNATIVE 5 — **DYNAMIC GROUNDWATER RECIRCULATION AND SOURCE AREA EISB**

POINT OF COMPLIANCE OPTION: **OPTION 3 - GROUNDWATER CPOC AT PROPERTY LINE/UPGRADIENT OF CREEK ON BOEING PROPI**

Explanation of POC Option: SWQS (0.3 µg/L TCE) to be met in monitoring wells along Boeing Property Line (and all points downgradient) and in "buffer zone" upgradient (or in transition zone as allowable by MTCA for properties abutting surface water) of the creek on Boeing property. Drinking water standard (4 µg/L TCE) to be met in monitoring wells throughout the groundwater TCE plume on Boeing property.

POC Option Specific Assumptions

1. Existing monitoring wells along property line and adjacent to creek sufficient for monitoring groundwater CPOC; however, monitoring well network sufficient for monitoring groundwater throughout plume.
2. Existing surface water sampling locations will be used for monitoring surface water POC
3. DGR system will be operated for 24 years for downgradient plume cleanup
4. EISB in source area will require 23 years for source area cleanup (including 3 injection events over 3-year period)
5. Major and minor equipment replacements for DGR system will be required during 24-year operational time frame

DETAILED COST ESTIMATE

Cost Type	Category	Item #	Description	Quantity	Unit	Unit Cost	Total
IMPLEMENTATION	**REMEDIAL DESIGN, PLANNING, AND GENERAL (Indirect Costs)**						
		1	Engineering/Proj Mgmt/Const Mgmt/Reporting				
		2	Cleanup action plan	1	LS	$ 30,000	$ 30,000
		3	Permits	1	LS	$ 30,000	$ 30,000
		4	Negotiate and implement institutional controls	0	LS	$ 10,000	$ -
		5	Contract documents and contractor bidding/procurement	1	LS	$ 20,000	$ 20,000
		6	Cleanup action construction report/O&M manual	1	LS	$ 30,000	$ 30,000
		7	Engineering/Remedial Design	8%	pct	$ 4,033,000	$ 322,640
		8	Construction management/oversight	6%	pct	$ 4,033,000	$ 241,980
		9	Project management	5%	pct	$ 14,922,620	$ 746,131
		10	Ecology oversight	5%	pct	$ 14,922,620	$ 746,131
	Subtotal Remedial Design, Planning, and General Costs						*$ 2,166,900*
	Indirect Contingency and Unlisted Engineering Services (%)			**15%**	pct	$2,166,900	$ 325,000
	TOTAL INDIRECT COST						**$2,492,000**
	Category	**Item #**	**Description**	**Quantity**	**Unit**	**Unit Cost**	**Total**
	REMEDIAL ACTION CONSTRUCTION - DGR SYSTEM AND ELECTRON DONOR INJECTIONS (Direct Costs)						
		1	Contractor mobilization/demobilization	1	LS	$ 30,000	$ 30,000
		2	DGR pilot study	1	LS	$ 80,000	$ 80,000
			Install injection and extraction wells/distribution system				
		3	Utility locate	1	LS	$ 2,500	$ 2,500
		4	Site prep/clearing/grubbing	1	LS	$ 75,000	$ 75,000
		5	Driller mobilization/demobilization	1	LS	$ 3,000	$ 3,000
		6	Drilling - DGR extraction well installation	4	well	$ 20,000	$ 80,000
		7	Drilling - DGR injection well installation (shallow)	4	well	$ 26,000	$ 104,000
		8	Drilling - DGR injection well installation (deep)	8	well	$ 15,000	$ 120,000
		9	Drilling - monitoring wells for DGR monitoring	4	well	$ 12,000	$ 48,000
		10	IDW disposal	60	Drums	$ 200	$ 12,000
		11	Well vaults, pumps, air vac assemblies	1	LS	$ 210,000	$ 210,000
		12	Transfer tank, valving, and pump with controls	1	LS	$ 18,000	$ 18,000
		13	Directional drilling for pipe/conduit up to ridge	1	LS	$ 100,000	$ 100,000
		14	Water line, electrical, communications trenching	4200	LF	$ 16	$ 67,200
		15	Water piping	4200	LF	$ 60	$ 252,000
		16	Electrical conduit and cable	2400	LF	$ 45	$ 108,000
		17	Communications conduit and cable	4200	LF	$ 65	$ 273,000
		18	Trench repaving/restoration	20000	SF	$ 5	$ 100,000
		19	Electrical equipment upgrades/transformer/electrician	1	LS	$ 70,000	$ 70,000
		20	Instrumentation and controls; control panels	1	LS	$ 150,000	$ 150,000
		21	GAC polishing vessels	2	each	$ 12,500	$ 25,000
		22	DGR system startup and testing	1	LS	$ 20,000	$ 20,000
			EISB Injection Well Installation				
		23	Utility locate/clearing	1	LS	$ 1,000	$ 1,000
		24	Driller mobilization/demobilization	1	LS	$ 3,000	$ 3,000
		25	Drilling - injection wells (detention basin hotspot)	24	wells	$ 4,000	$ 96,000
		26	Well development	24	wells	$ 1,000	$ 24,000
		27	IDW disposal	70	Drums	$ 200	$ 14,000
			Injection of Electron Donor				
		28	Injection crew/labor	75	days	$ 3,000	$ 225,000
		29	Purchase equipment/supplies for injection system setup	1	LS	$ 25,000	$ 25,000
		30	Materials and rentals for injection events	3	event	$ 20,000	$ 60,000
		31	Water for injection events	285,000	gal	$ 0.03	$ 8,550
		32	Donor for injection events	36000	lbs	$ 2	$ 54,000
		33	Site Restoration - slope/buffer plantings, general cleanup	1	LS	$ 25,000	$ 25,000
	Subtotal Remedial Action Construction Costs						*$ 2,483,300*
	Direct Cost Contingency and Unlisted Engineering Services (%)			**25%**	pct	$2,483,300	$ 620,800
	Contractor Bond Fee, Overhead, and Profit (%)			**20%**	pct	$2,638,375	$ 527,700
	Washington State Sales Tax (%)			**9.2%**	pct	$ 3,166,075	$291,300
	TOTAL DIRECT COST						**$3,923,000**
	Category	**Item #**	**Description**	**Quantity**	**Unit**	**Unit Cost**	**Total**
OM&M	**ANNUAL OPERATION, MAINTENANCE, MONITORING, AND REPORTING**						
		1	Electrical usage	1	yr	$ 44,500	$ 44,500
		2	Cell phone/GET system remote access charges	12	mo	$ 369	$ 4,428
		3	Carbon usage	1	yr	$ 9,600	$ 9,600
		4	System monitoring/NPDES reporting	1	yr	$ 20,000	$ 20,000
		5	DGR system O&M labor and cost	1	yr	$ 95,000	$ 95,000
		6	NPDES annual renewal fee	1	yr	$ 20,137	$ 20,137
		7	Groundwater sampling (during DGR)	1	yrs	$ 65,000	$ 65,000
		8	Groundwater elevation monitoring (during DGR)	1	yrs	$ 8,000	$ 8,000
		9	Surface water sampling (during DGR)	1	yrs	$ 8,000	$ 8,000
		10	Reporting	1	yr	$ 15,000	$ 15,000
	Subtotal Annual OM&M and Reporting Cost						$ 289,700
	Annual Monitoring Cost Contingency and Unlisted Items (%)			**20%**	pct	$289,700	$ 57,900
			Years of Annual Monitoring	***24***	yrs	$347,600	$ 8,342,400
	TOTAL ANNUAL OM&M AND REPORTING COST						***$8,342,000***
	Present-Worth Annual OM&M and Reporting Cost		Presumed Discount Rate	***0.6%***	pct		**$7,748,000**
	Category	**Item #**	**Description**	**Quantity**	**Unit**	**Unit Cost**	**Total**
	NON-ROUTINE OPERATION, MAINTENANCE, MONITORING, AND REPORTING						
		1	Baseline groundwater/surface water sampling	1	event	$ 73,000	$ 73,000
		2	DGR system equipment replacement cost	1.5	event	$ 200,000	$ 300,000
		3	Quarterly groundwater sampling (EISB parameters)	3	yr	$ 95,000	$ 285,000
		4	Quarterly groundwater sampling	12	event	$ 65,000	$ 780,000
		5	Quarterly groundwater elevation monitoring	12	event	$ 8,000	$ 96,000
		6	Quarterly surface water sampling	12	event	$ 8,000	$ 96,000
		7	Annual groundwater sampling (EISB parameters post DGR)	0	yrs	$ 65,000	$ -
		8	Annual groundwater elevation monitoring (post DGR)	0	yrs	$ 8,000	$ -
		9	Annual surface water sampling (post DGR)	0	yrs	$ 8,000	$ -
		10	1.5 years quarterly confirmation sampling	6	event	$ 73,000	$ 438,000
		11	Cleanup completion report	1	LS	$ 20,000	$ 20,000
	Subtotal Non-Routine OM&M and Reporting Cost						$ 2,088,000
	Annual Monitoring Cost Contingency and Unlisted Items (%)			**20%**	pct	$2,088,000	$ 417,600
	TOTAL NON-ROUTINE OM&M AND REPORTING COST						***$2,506,000***
	Present-Worth Non-Routine OM&M and Reporting Cost		Presumed Discount Rate	***0.6%***	pct		**$2,577,000**
TOTAL	**ALTERNATIVE COST SUMMARY**						
	TOTAL PRESENT-WORTH REMEDIAL DESIGN, PLANNING, AND GENERAL COST (INDIRECT)						**$2,492,000**
	TOTAL PRESENT-WORTH REMEDIATION IMPLEMENTATION COST (DIRECT)						**$3,923,000**
	TOTAL PRESENT-WORTH OM&M COST (ANNUAL & NON-ROUTINE)						**$10,325,000**
	TOTAL PRESENT-WORTH COST						**$16,740,000**
			Appropriate Cost Range (-30% - +50%)		**TOTAL**	**$ 11,720,000**	**$ 25,110,000**

Table C-1e
Comparison of Point of Compliance Costs
Boeing Everett - PMG SWMU

ALTERNATIVE 5 **DYNAMIC GROUNDWATER RECIRUCLATION AND SOURCE AREA EISB**

POINT OF COMPLIANCE OPTION: **OPTION 4 - GROUNDWATER CPOC IMMEDIATELY DOWNGRADIENT OF SOURCE AREA**

Explanation of POC Option: SWQS (0.3 µg/L TCE) to be met in monitoring wells downgradient of source area/detention basin (and all points downgradient). Drinking water standard (4 µg/L TCE) to be met in monitoring wells throughout the groundwater TCE plume on Boeing property.

POC Option Specific Assumptions

1 New monitoring wells (assume 3) will be necessary downgradient of detention basin to monitor groundwater CPOC; monitoring well network sufficient for monitoring groundwater throughout plume.
2 Existing surface water sampling locations will be used for monitoring surface water POC
3 DGR system will be operated for 24 years for downgradient plume cleanup
4 EISB in source area will require 30 years for source area cleanup (including 3 injection events over 3-year period)
5 GET system extraction wells will continue to be operated until compliance at groundwater CPOC (6 years after DGR)
6 Major and minor equipment replacements for DGR/GET system will be required during 24-year operational time frame

DETAILED COST ESTIMATE

Cost Type	Category	Item #	Description	Quantity	Unit	Unit Cost	Total
IMPLEMENTATION	**REMEDIAL DESIGN, PLANNING, AND GENERAL (Indirect Costs)**						
		1	Engineering/Proj Mgmt/Const Mgmt/Reporting				
		2	Cleanup action plan	1	LS	$ 30,000	$ 30,000
		3	Permits	1	LS	$ 30,000	$ 30,000
		4	Negotiate and implement institutional controls	0	LS	$ 10,000	$ -
		5	Contract documents and contractor bidding/procurement	1	LS	$ 20,000	$ 20,000
		6	Cleanup action construction report/O&M manual	1	LS	$ 30,000	$ 30,000
		7	Engineering/Remedial Design	8%	pct	$ 4,095,000	$ 327,600
		8	Construction management/oversight	6%	pct	$ 4,095,000	$ 245,700
		9	Project management	5%	pct	$ 17,287,300	$ 864,365
		10	Ecology oversight	5%	pct	$ 17,287,300	$ 864,365
	Subtotal Remedial Design, Planning, and General Costs						*$ 2,412,000*
	Indirect Contingency and Unlisted Engineering Services (%)			**15%**	pct	$2,412,000	$ 361,800
	TOTAL INDIRECT COST						**$2,774,000**
	Category	**Item #**	**Description**	**Quantity**	**Unit**	**Unit Cost**	**Total**
	REMEDIAL ACTION CONSTRUCTION - DGR SYSTEM AND ELECTRON DONOR INJECTIONS (Direct Costs)						
		1	Contractor mobilization/demobilization	1	LS	$ 30,000	$ 30,000
		2	DGR pilot study	1	LS	$ 80,000	$ 80,000
			Install injection and extraction wells/distribution system				
		3	Utility locate	1	LS	$ 2,500	$ 2,500
		4	Site prep/clearing/grubbing	1	LS	$ 75,000	$ 75,000
		5	Driller mobilization/demobilization	1	LS	$ 3,000	$ 3,000
		6	Drilling - DGR extraction well installation	4	well	$ 20,000	$ 80,000
		7	Drilling - DGR injection well installation (shallow	4	well	$ 26,000	$ 104,000
		8	Drilling - DGR injection well installation (deep)	8	well	$ 15,000	$ 120,000
		9	Drilling - monitoring wells for DGR monitoring	7	well	$ 12,000	$ 84,000
		10	IDW disposal	70	Drums	$ 200	$ 14,000
		11	Well vaults, pumps, air vac assemblies	1	LS	$ 210,000	$ 210,000
		12	Transfer tank, valving, and pump with controls	1	LS	$ 18,000	$ 18,000
		13	Directional drilling for pipe/conduit up to ridge	1	LS	$ 100,000	$ 100,000
		14	Water line, electrical, communications trenching	4200	LF	$ 16	$ 67,200
		15	Water piping	4200	LF	$ 60	$ 252,000
		16	Electrical conduit and cable	2400	LF	$ 45	$ 108,000
		17	Communications conduit and cable	4200	LF	$ 65	$ 273,000
		18	Trench repaving/restoration	20000	SF	$ 5	$ 100,000
		19	Electrical equipment upgrades/transformer/electrician	1	LS	$ 70,000	$ 70,000
		20	Instrumentation and controls; control panels	1	LS	$ 150,000	$ 150,000
		21	GAC polishing vessels	2	each	$ 12,500	$ 25,000
		22	DGR system startup and testing	1	LS	$ 20,000	$ 20,000
			EISB Injection Well Installation				
		23	Utility locate/clearing	1	LS	$ 1,000	$ 1,000
		24	Driller mobilization/demobilization	1	LS	$ 3,000	$ 3,000
		25	Drilling - injection wells (detention basin hotspot)	24	wells	$ 4,000	$ 96,000
		26	Well development	24	wells	$ 1,000	$ 24,000
		27	IDW disposal	70	Drums	$ 200	$ 14,000
			Injection of Electron Donor				
		28	Injection crew/labor	75	days	$ 3,000	$ 225,000
		29	Purchase equipment/supplies for injection system setup	1	LS	$ 25,000	$ 25,000
		30	Materials and rentals for injection events	3	event	$ 20,000	$ 60,000
		31	Water for injection events	285,000	gal	$ 0.03	$ 8,550
		32	Donor for injection events	36000	lbs	$ 2	$ 54,000
		33	Site Restoration - slope/buffer plantings, general cleanup	1	LS	$ 25,000	$ 25,000
	Subtotal Remedial Action Construction Costs						*$ 2,521,300*
	Direct Cost Contingency and Unlisted Engineering Services (%			**25%**	pct	$2,521,300	$ 630,300
	Contractor Bond Fee, Overhead, and Profit (%)			**20%**	pct	$2,685,875	$ 537,200
	Washington State Sales Tax (%)			**9.2%**	pct	$ 3,223,075	$296,500
	TOTAL DIRECT COST						**$3,985,000**
OM&M	**Category**	**Item #**	**Description**	**Quantity**	**Unit**	**Unit Cost**	**Total**
	ANNUAL OPERATION, MAINTENANCE, MONITORING, AND REPORTING						
		1	Electrical usage	1	yr	$ 44,500	$ 44,500
		2	Cell phone/GET system remote access charges	12	mo	$ 369	$ 4,428
		3	Carbon usage	1	yr	$ 9,600	$ 9,600
		4	System monitoring/NPDES reporting	1	yr	$ 20,000	$ 20,000
		5	DGR system O&M labor and cost	1	yr	$ 95,000	$ 95,000
		6	NPDES annual renewal fee	1	yr	$ 20,137	$ 20,137
		7	Groundwater sampling (during DGR)	1	yrs	$ 65,000	$ 65,000
		8	Groundwater elevation monitoring (during DGR)	1	yrs	$ 8,000	$ 8,000
		9	Surface water sampling (during DGR)	1	yrs	$ 8,000	$ 8,000
		10	Reporting	1	yr	$ 15,000	$ 15,000
	Subtotal Annual OM&M and Reporting Cost						$ 289,700
	Annual Monitoring Cost Contingency and Unlisted Items (%			**20%**	pct	$289,700	$ 57,900
			Years of Annual Monitoring	***24***	yrs	$347,600	$ 8,342,400
	TOTAL ANNUAL OM&M AND REPORTING COST						***$8,342,000***
	Present-Worth Annual OM&M and Reporting Cost		Presumed Discount Rate	***0.6%***	pct		**$7,748,000**
	Category	**Item #**	**Description**	**Quantity**	**Unit**	**Unit Cost**	**Total**
	NON-ROUTINE OPERATION, MAINTENANCE, MONITORING, AND REPORTING						
		1	Baseline groundwater/surface water sampling	1	event	$ 73,000	$ 73,000
		2	DGR/GET system equipment replacement cos	2	event	$ 200,000	$ 400,000
		3	Quarterly groundwater sampling (EISB parameters)	3	yr	$ 95,000	$ 285,000
		4	Quarterly groundwater sampling	12	event	$ 65,000	$ 780,000
		5	Quarterly groundwater elevation monitoring	12	event	$ 8,000	$ 96,000
		6	Quarterly surface water sampling	12	event	$ 8,000	$ 96,000
		7	Annual groundwater sampling (EISB parameters post DGR	6	yrs	$ 65,000	$ 390,000
		8	Annual groundwater elevation monitoring (post DGR	10	yrs	$ 8,000	$ 80,000
		9	Annual surface water sampling (post DGR	10	yrs	$ 8,000	$ 80,000
		10	Annual operation of GET system (post DGR)	10	yrs	$ 185,000	$ 1,850,000
		11	1.5 years quarterly confirmation sampling	6	event	$ 73,000	$ 438,000
		12	Cleanup completion report	1	LS	$ 20,000	$ 20,000
	Subtotal Non-Routine OM&M and Reporting Cost						$ 4,588,000
	Annual Monitoring Cost Contingency and Unlisted Items (%			**20%**	pct	$4,588,000	$ 917,600
	TOTAL NON-ROUTINE OM&M AND REPORTING COST						***$5,506,000***
	Present-Worth Non-Routine OM&M and Reporting Cost		Presumed Discount Rate	***0.6%***	pct		**$4,871,000**
TOTAL	**ALTERNATIVE COST SUMMARY**						
	TOTAL PRESENT-WORTH REMEDIAL DESIGN, PLANNING, AND GENERAL COST (INDIRECT						**$2,774,000**
	TOTAL PRESENT-WORTH REMEDIATION IMPLEMENTATION COST (DIRECT)						**$3,985,000**
	TOTAL PRESENT-WORTH OM&M COST (ANNUAL & NON-ROUTINE)						**$12,619,000**
	TOTAL PRESENT-WORTH COST						**$19,380,000**
			Appropriate Cost Range (-30% - +50%)		**TOTAL**	**$ 13,570,000**	**$ 29,070,000**

Table C-1f
Comparison of Point of Compliance Costs
Boeing Everett - PMG SWMU

ALTERNATIVE 5 — **DYNAMIC GROUNDWATER RECIRCULATION AND SOURCE AREA EISB**

POINT OF COMPLIANCE OPTION: **OPTION 5 - GROUNDWATER STANDARD POC USING SWQS**

Explanation of POC Option: SWQS (0.3 µg/L TCE) to be met in monitoring wells throughout the groundwater TCE plume (and surface water).

POC Option Specific Assumptions

1. Existing monitoring well network sufficient for monitoring groundwater POC; however, new monitoring wells (assume 3) will be necessary to monitor EISB performance downgradient of detention basin.
2. Existing surface water sampling locations will be used for monitoring surface water POC
3. DGR system will be operated for 24 years for downgradient plume cleanup
4. EISB in source area will require 38 years for source area cleanup (including 3 injection events over 3-year period)
5. GET system extraction wells will continue to be operated until compliance at groundwater CPOC (4 years after DGR)
6. Major and minor equipment replacements for DGR/GET system will be required during 24-year operational time frame

DETAILED COST ESTIMATE

Cost Type	Category	Item #	Description	Quantity	Unit	Unit Cost	Total
IMPLEMENTATION	**REMEDIAL DESIGN, PLANNING, AND GENERAL (Indirect Costs)**						
		1	Engineering/Proj Mgmt/Const Mgmt/Reporting				
		2	Cleanup action plan	1	LS	$ 30,000	$ 30,000
		3	Permits	1	LS	$ 30,000	$ 30,000
		4	Negotiate and implement institutional controls	0	LS	$ 10,000	$ -
		5	Contract documents and contractor bidding/procurement	1	LS	$ 20,000	$ 20,000
		6	Cleanup action construction report/O&M manual	1	LS	$ 30,000	$ 30,000
		7	Engineering/Remedial Design	8%	pct	$ 4,095,000	$ 327,600
		8	Construction management/oversight	6%	pct	$ 4,095,000	$ 245,700
		9	Project management	5%	pct	$ 19,853,300	$ 992,665
		10	Ecology oversight	5%	pct	$ 19,853,300	$ 992,665
	Subtotal Remedial Design, Planning, and General Costs						*$ 2,668,600*
	Indirect Contingency and Unlisted Engineering Services (%)			**15%**	pct	$2,668,600	$ 400,300
	TOTAL INDIRECT COST						**$3,069,000**
	Category	**Item #**	**Description**	**Quantity**	**Unit**	**Unit Cost**	**Total**
	REMEDIAL ACTION CONSTRUCTION - DGR SYSTEM AND ELECTRON DONOR INJECTIONS (Direct Costs)						
		1	Contractor mobilization/demobilization	1	LS	$ 30,000	$ 30,000
		2	DGR pilot study	1	LS	$ 80,000	$ 80,000
			Install injection and extraction wells/distribution system				
		3	Utility locate	1	LS	$ 2,500	$ 2,500
		4	Site prep/clearing/grubbing	1	LS	$ 75,000	$ 75,000
		5	Driller mobilization/demobilization	1	LS	$ 3,000	$ 3,000
		6	Drilling - DGR extraction well installation	4	well	$ 20,000	$ 80,000
		7	Drilling - DGR injection well installation (shallow)	4	well	$ 26,000	$ 104,000
		8	Drilling - DGR injection well installation (deep)	8	well	$ 15,000	$ 120,000
		9	Drilling - monitoring wells for DGR monitoring	7	well	$ 12,000	$ 84,000
		10	IDW disposal	70	Drums	$ 200	$ 14,000
		11	Well vaults, pumps, air vac assemblies	1	LS	$ 210,000	$ 210,000
		12	Transfer tank, valving, and pump with controls	1	LS	$ 18,000	$ 18,000
		13	Directional drilling for pipe/conduit up to ridge	1	LS	$ 100,000	$ 100,000
		14	Water line, electrical, communications trenching	4200	LF	$ 16	$ 67,200
		15	Water piping	4200	LF	$ 60	$ 252,000
		16	Electrical conduit and cable	2400	LF	$ 45	$ 108,000
		17	Communications conduit and cable	4200	LF	$ 65	$ 273,000
		18	Trench repaving/restoration	20000	SF	$ 5	$ 100,000
		19	Electrical equipment upgrades/transformer/electrician	1	LS	$ 70,000	$ 70,000
		20	Instrumentation and controls; control panels	1	LS	$ 150,000	$ 150,000
		21	GAC polishing vessels	2	each	$ 12,500	$ 25,000
		22	DGR system startup and testing	1	LS	$ 20,000	$ 20,000
			EISB Injection Well Installation				
		23	Utility locate/clearing	1	LS	$ 1,000	$ 1,000
		24	Driller mobilization/demobilization	1	LS	$ 3,000	$ 3,000
		25	Drilling - injection wells (detention basin hotspot)	24	wells	$ 4,000	$ 96,000
		26	Well development	24	wells	$ 1,000	$ 24,000
		27	IDW disposal	70	Drums	$ 200	$ 14,000
			Injection of Electron Donor				
		28	Injection crew/labor	75	days	$ 3,000	$ 225,000
		29	Purchase equipment/supplies for injection system setup	1	LS	$ 25,000	$ 25,000
		30	Materials and rentals for injection events	3	event	$ 20,000	$ 60,000
		31	Water for injection events	285,000	gal	$ 0.03	$ 8,550
		32	Donor for injection events	36000	lbs	$ 2	$ 54,000
		33	Site Restoration - slope/buffer plantings, general cleanup	1	LS	$ 25,000	$ 25,000
	Subtotal Remedial Action Construction Costs						*$ 2,521,300*
	Direct Cost Contingency and Unlisted Engineering Services (%)			**25%**	pct	$2,521,300	$ 630,300
	Contractor Bond Fee, Overhead, and Profit (%)			**20%**	pct	$2,685,875	$ 537,200
	Washington State Sales Tax (%)			**9.2%**	pct	$ 3,223,075	$296,500
	TOTAL DIRECT COST						**$3,985,000**
	Category	**Item #**	**Description**	**Quantity**	**Unit**	**Unit Cost**	**Total**
OM&M	**ANNUAL OPERATION, MAINTENANCE, MONITORING, AND REPORTING**						
		1	Electrical usage	1	yr	$ 44,500	$ 44,500
		2	Cell phone/GET system remote access charges	12	mo	$ 369	$ 4,428
		3	Carbon usage	1	yr	$ 9,600	$ 9,600
		4	System monitoring/NPDES reporting	1	yr	$ 20,000	$ 20,000
		5	DGR system O&M labor and cost	1	yr	$ 95,000	$ 95,000
		6	NPDES annual renewal fee	1	yr	$ 20,137	$ 20,137
		7	Groundwater sampling (during DGR)	1	yrs	$ 65,000	$ 65,000
		8	Groundwater elevation monitoring (during DGR)	1	yrs	$ 8,000	$ 8,000
		9	Surface water sampling (during DGR)	1	yrs	$ 8,000	$ 8,000
		10	Reporting	1	yr	$ 15,000	$ 15,000
	Subtotal Annual OM&M and Reporting Cost						$ 289,700
	Annual Monitoring Cost Contingency and Unlisted Items (%)			**20%**	pct	$289,700	$ 57,900
			Years of Annual Monitoring	***24***	yrs	$347,600	$ 8,342,400
	TOTAL ANNUAL OM&M AND REPORTING COST						***$8,342,000***
	Present-Worth Annual OM&M and Reporting Cost		Presumed Discount Rate	***0.6%***	pct		**$7,748,000**
	Category	**Item #**	**Description**	**Quantity**	**Unit**	**Unit Cost**	**Total**
	NON-ROUTINE OPERATION, MAINTENANCE, MONITORING, AND REPORTING						
		1	Baseline groundwater/surface water sampling	1	event	$ 73,000	$ 73,000
		2	DGR/GET system equipment replacement cost	2.5	event	$ 200,000	$ 500,000
		3	Quarterly groundwater sampling (EISB parameters)	3	yr	$ 95,000	$ 285,000
		4	Quarterly groundwater sampling	12	event	$ 65,000	$ 780,000
		5	Quarterly groundwater elevation monitoring	12	event	$ 8,000	$ 96,000
		6	Quarterly surface water sampling	12	event	$ 8,000	$ 96,000
		7	Annual groundwater sampling (EISB parameters post DGR)	14	yrs	$ 65,000	$ 910,000
		8	Annual groundwater elevation monitoring (post DGR)	20	yrs	$ 8,000	$ 160,000
		9	Annual surface water sampling (post DGR)	20	yrs	$ 8,000	$ 160,000
		10	Annual operation of GET system (post DGR)	20	yrs	$ 185,000	$ 3,700,000
		11	1.5 years quarterly confirmation sampling	6	event	$ 73,000	$ 438,000
		12	Cleanup completion report	1	LS	$ 20,000	$ 20,000
	Subtotal Non-Routine OM&M and Reporting Cost						$ 7,218,000
	Annual Monitoring Cost Contingency and Unlisted Items (%)			**20%**	pct	$7,218,000	$ 1,443,600
	TOTAL NON-ROUTINE OM&M AND REPORTING COST						***$8,662,000***
	Present-Worth Non-Routine OM&M and Reporting Cost		Presumed Discount Rate	***0.6%***	pct		**$7,437,000**
TOTAL	**ALTERNATIVE COST SUMMARY**						
	TOTAL PRESENT-WORTH REMEDIAL DESIGN, PLANNING, AND GENERAL COST (INDIRECT)						**$3,069,000**
	TOTAL PRESENT-WORTH REMEDIATION IMPLEMENTATION COST (DIRECT)						**$3,985,000**
	TOTAL PRESENT-WORTH OM&M COST (ANNUAL & NON-ROUTINE)						**$15,185,000**
	TOTAL PRESENT-WORTH COST						**$22,240,000**
			Appropriate Cost Range (-30% - +50%)		**TOTAL**	**$ 15,570,000**	**$ 33,360,000**