Engineering Evaluation/Cost Analysis Report
EMF Site
Revision 3
December 2015

Prepared for:
The Boeing Company
Engineering Operations and Technology
EHS Remediation

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List of Acronyms

ARARs	Applicable or Relevant and Appropriate Requirements
AWQC	Ambient Water Quality Criteria
bgs	below ground surface
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CSGWPP	Comprehensive State Ground Water Protection Program
cis-1,2-DCE	cis-1,2-dichloroethene
COC	chemicals of concern
CVOC	chlorinated volatile organic compound
DGSWP	Data Gaps Sampling Work Plan
DNAPL	dense non-aqueous phase liquid
DQO	Data Quality Objective
Ecology	Washington Department of Ecology
EE/CA	Engineering Evaluation/Cost Analysis
EMF	Electronics Manufacturing Facility
EPA	Environmental Protection Agency
ERD	enhanced reductive dechlorination
Foc	fraction organic carbon
FS	Feasibility Study
ft	feet
IAS	in-situ air sparge
ISCO	in-situ chemical oxidation
IDSR	Investigation Data Summary Report
IWS	in-well stripping
KCIA	King County International Airport
LDW	Lower Duwamish Waterway
L/kg	liter per kilogram
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
MNA	monitored natural attenuation
MSL	mean sea level
MTCA	Model Toxics Control Act
MW	monitoring well
NAPL	non-aqueous phase liquids
NCP	National Contingency Plan
NGVD29	National Geodetic Vertical Datum 1929
NOV	Notice of Violation
NPV	Net present value
RA	Removal Action
RAO	Removal Action Objectives
RCRA	Resource Conservation and Recovery Act
Rd	retardation coefficient
RI	Remedial Investigation
SVE	soil vapor extraction
TCE	trichloroethene
TMCL	target media cleanup level
trans-1,2-DCE	trans-1,2-dichloroethene

ug/L	micrograms per liter
VOC	volatile organic compound
VCP	Voluntary Cleanup Program
WAC	Washington Administrative Code

Executive Summary

Engineering Evaluation/Cost Analysis Report, EMF Site

August 2015

This report has been prepared for The Boeing Company (Boeing) in response to an Administrative Settlement Agreement and Order on Consent For Removal Action (Settlement Agreement) entered into by Boeing and the U.S. Environmental Protection Agency (EPA) on February 2, 2007. The Settlement Agreement has been issued under the Comprehensive Environmental Response, Compensation, and Liability Act of 1980, as amended (CERCLA). This report presents an Engineering Evaluation/Cost Analysis (EE/CA) for the former Electronics Manufacturing Facility (EMF) located at Boeing Field/King County International Airport (KCIA) in Seattle, Washington. The EMF site has been the subject of investigations and removal actions since a hazardous materials release was identified in 1982.

The EMF property is located on the east side of KCIA. The VOC plume has been transported by natural groundwater movement southwest from the EMF property, across KCIA, passing under Boeing Plant 2 towards the Lower Duwamish Waterway (LDW) located approximately 3,600 feet southwest of the former EMF property. The site consists of the EMF property and the portions of KCIA, North Boeing Field, and Boeing Plant 2 impacted by the EMF VOC plume that are located in a west to southwest direction from the EMF property. The down-gradient boundary of the site is the LDW. The contaminants of concern (COCs) that have been identified in the EMF VOC plume are trichloroethene (TCE), cis-1,2-dichloroethene (cis-1,2-DCE), trans-1,2-dichloroethene (trans-1,2-DCE), vinyl chloride (VC), and toluene.

A release of hazardous substances at the EMF property was identified and reported in 1982. Removal actions were initiated in the fall of 1982 and expanded site characterization was implemented in 1985 with continued monitoring through 1993. In 1996 and 1997, a Model Toxics Control Act (MTCA) Remedial Investigation / Feasibility Study (RI/FS) was conducted under the MTCA Voluntary Cleanup Program (VCP, Weston 1997). Additional investigation data has been collected and remedial actions implemented between 1997 and 2014 to characterize the site conditions and optimize removal actions for site restoration. Under the Settlement Agreement, EPA determined that an actual or threatened release of hazardous substances from the EMF site may present endangerment to public health and the environment. Based on that determination, a removal action may be required and, if carried out in compliance with the terms of the Settlement Agreement, would be considered consistent with the NCP, as provided in Section 300.700(c)(3)(ii) of the National Contingency Plan (NCP). Through evaluation, and subsequent selection of proposed cleanup actions presented in this EE/CA, actions will be implemented to minimize and further reduce any potential harm to public health and the environment.

The EMF property is owned by King County and was previously leased to Boeing. The long-term lease was terminated at the request of King County with Boeing retaining responsibility for continued environmental restoration. Details of previous removal actions at the site are summarized in the EMF Historical Data Report (CALIBRE 2008). Briefly, the following removal actions have been performed at the site (and the last item noted, voluntary ERD full-scale implementation, is ongoing):

1982 to 1985: Removal actions at the source area for soil and groundwater
1997: Removal action for TPH and PCBs in soil, DNAPL recovery
1997–2006: Operation of an in-well stripping system (groundwater treatment)
2000-2001: Chemical oxidation of groundwater (and saturated soil) at the source area
2003-2004: ERD pilot study, and
2005-2014: ERD full-scale implementation throughout VOC plume.

The EE/CA guidance (USEPA 1993) requires a streamlined risk evaluation that should focus on the specific problem that the removal action is intended to address. The Settlement Agreement and Order on Consent identifies the intent of the EMF removal action as; "..primary objective of this removal activity is the removal, treatment and/or containment of the EMF plume and sources of hazardous substances thereto to mitigate or prevent further releases into the environment, and specifically into the LDW". A significant amount of prior characterization work has been completed and a large body of environmental, hydrogeologic, and geochemical data has been collected throughout the characterization and MTCA remedial actions implemented. A Conceptual Site Model (CSM) has been developed and revised in the EMF Historical Data Summary Report, Data Gaps Sampling Work Plan, and Investigation Data Sampling Report (CALIBRE 2008, 2010, and 2012). The COCs identified at the EMF site and groundwater plume are VOCs; specifically TCE, cis-1,2-DCE, trans-1,2-DCE, VC, and toluene. Other potential COCs evaluated have included TPH in soil, PCBs in soil, and priority pollutant metals in soil and groundwater. Historical removal actions and site-wide sampling for these other analytes have resulted in remaining levels which are below applicable criteria (AWQC and MTCA Method A standards for residential land use, inclusive of both human and ecological exposure criteria). These other potential COCs have been investigated (samples collected and results compared with chemical-specific risk-based ARARs) and are no longer considered COCs for this project.

The VOC plume from the EMF property extends from the EMF site to the Duwamish Waterway. The COCs identified in the EMF groundwater plume include TCE, and its degradation daughter products of trans-1,2-DCE, cis-1,2-DCE, and (VC). Near the EMF property TCE remains a COC in groundwater but in the down gradient areas, chlorinated solvents have been either completely destroyed or converted to one or more of the daughter products. The vertical and lateral extent of the VOC plume have been mapped in multiple transects (throughout the 3,600 foot length of the plume).

One of the key questions in the EMF Data Gaps Report was the impact of the VOC plume at the Duwamish Waterway (i.e., Does the impact of the VOC plume result in concentrations that cause a potential exposure risk exceeding NCP risk standards or Ambient Water Quality Criteria (AWQC) for the COCs at the discharge point?). All monitoring wells and probe samples collected near the LDW between October 2010 and February 2011 were below AWQC for all VOCs. Recent sampling results (through 2014) are consistent with the multiple sampling events conducted over the last several years (all below AWQC for all VOCs). Key data gaps for risk evaluation (as well as other site characterization concerns) were identified through a Data Quality Objectives (DQO) process in the Historical Data Summary Report (CALIBRE 2008) and Data Gaps Sampling Work Plan (CALIBRE 2010). The data gaps were related to the evaluation of other specific exposure pathways that were considered plausible (indoor air, storm drains, stream channels, etc.). Further investigations were completed to determine if these potential pathways were complete. The results and conclusions are summarized in the Investigation Data Summary Report (CALIBRE 2012) and are summarized below.

<u>Indoor Air</u>

Under current conditions and land use, the indoor air pathway is either not complete or concentrations are at levels below the conservative MTCA screening levels for protection of indoor air. Any future building development on the EMF property will require appropriate measures to mitigate this potential exposure pathway (such as a soil-vapor barrier).

<u>Storm Drains</u>

Sampling has been completed from the storm drain systems connected to the EMF property, based on these site data, migration of VOCs in the storm drainage system is not a complete pathway.

Exposure to Soil

Prior removal of impacted soil (in the initial remedial actions to MTCA levels for unrestricted future use) addressed this pathway in the vadose zone. The groundwater removal action is expected to address the remaining VOC contamination in saturated zone soils. The surface is paved and any future development on the EMF property will require appropriate measures to mitigate the potential exposure pathways (such as avoiding or limiting soil excavation in the saturated zone near former source areas where possible).

Groundwater

As noted above, groundwater containing VOCs from the release area is the primary transport pathway for potential exposure to COCs from the site. Historically, site groundwater has not been considered a source of potable water by Boeing and human exposure through drinking water ingestion has not been considered a complete pathway. The groundwater discharges to the LDW and this discharge represents a potential exposure pathway for human and ecological receptors.

EMF site groundwater east of the Boeing Plant 2 Facility will be treated as potable until the EPA and Ecology accept a nonpotability determination for EMF. For the portion of the EMF plume beneath the Boeing Plant 2 RCRA Facility, a Plant 2 determination of potability or non-potability will apply once it is accepted by the EPA and has been subjected to a public comment period.

Identification and Assessment of Discharges to Lower Duwamish Waterway

The EMF Investigation Data Summary Report (IDSR) notes that all monitoring wells and probes near the LDW monitored between October 2010 and February 2011 were below AWQC for all VOCs (CALIBRE 2012). These prior results are also consistent with the multiple sampling events conducted over the last several years (as of February 2014). Based on the current data, the COCs in the EMF VOC plume are at levels which do not exceed the applicable AWQC at the discharge point.

As the basic objective of the EE/CA, potential Removal Action Alternatives have been developed based on the nature and extent of contamination, exposure pathways and human health/ecological risk evaluation, and ARARs. The Removal Action Alternatives evaluated in this EE/CA include:

1. No action
2. Monitored Natural Attenuation (MNA)
3. In-situ Air Sparging with Soil Vapor Extraction (IAS/SVE)
4. In Well Stripping (IWS), and
5. Enhanced Reductive Dechlorination (ERD).

Most of the proposed removal actions are expected to include active operation for several years and monitoring. The alternatives are also expected to include specific Institutional Controls (ICs) required as residual contamination may remain which would not allow for unrestricted future land use. The ICs are presented as an integral part of each of the alternatives evaluated. Institutional controls (or covenants defined under RCW 64.70.040 and WAC 173-340-440) are measures that prohibit or restrict activities that may disturb or interfere with a sites cleanup action, or that may result in exposure to hazardous substances at a site. The ICs anticipated for the EMF site include:

1. Prohibit the use of groundwater from the site for drinking or domestic purposes or demonstrate that sufficient protections are in-place to ensure that groundwater cannot be used for domestic purposes
2. Restrict the property for industrial/commercial use only.
3. If re-development of the EMF property includes an occupied structure to be constructed in an area above the EMF plume, then the plans will include evaluation of the need for, and applying appropriate engineering controls as necessary to mitigate the potential for vapor intrusion.

The general framework for these ICs is outlined in the lease termination agreement between King County and Boeing (January 2009).

The Removal Action Objectives (RAOs) have been developed based on a Conceptual Site Model (CSM), which includes the source of contamination, the nature and extent of contamination, exposure pathways and human health/ecological risk evaluation and the applicable or relevant and appropriate requirements (ARARs) that have been identified. The RAOs have been developed to control or eliminate the potential for exposure by human and ecological receptors due to contamination at the EMF Site. The RAOs are to:

- Prevent or reduce human exposure to VOCs present in site groundwater in excess of established criteria.
- Prevent or reduce ecological exposure to VOCs present in site groundwater in excess of established criteria.
- Restore groundwater to be in compliance with applicable water quality parameters (ARARs for groundwater).

All alternatives, with the exception of No Action and Monitored Natural Attenuation (MNA), evaluated in this EE/CA include an active phase followed by an MNA phase. Performance monitoring from past and current remedial actions has provided data to allow for optimization of remedial actions; all planned and future actions will be implemented in a manner taking advantage of site-specific experience and it is expected that the selected alternative implemented will be modified/optimized as performance monitoring data dictate. For the purposes of this EE/CA, a recent date was chosen to use as the "current plume condition" (based on the EMF plume conditions at the end of the data gaps investigation). In order to allow for a rational comparison of technology alternatives, each of the alternatives is applied at the same target treatment areas based on the "current plume condition".

No Action
The No-Action alternative is a scenario where no site activities are performed either in remediation efforts or in compliance monitoring. This alternative is included for the purpose of relative comparison.

Monitored Natural Attenuation
For the Monitored Natural Attenuation alternative, no active remediation efforts would be implemented and the site would be continued to be monitored for natural attenuation of the chemicals present. Institutional Controls (ICs) would be required for this alternative. The ICs would include the implementation of Deed Restrictions to establish land-use restrictions and Five-Year Reviews throughout the project duration. The MNA alternative, coupled with appropriate ICs, is expected to meet the RAOs (partially because of the prior actions already implemented) within a reasonable time frame.

In-situ Air Sparging with Soil Vapor Extraction (IAS/SVE)
This (IAS/SVE) alternative involves treatment of groundwater by in-situ air sparging (IAS) using air injection wells and soil vapor extraction (SVE) using vapor extraction wells with treatment of the off gas. Institutional Controls would be required for this alternative. The ICs would include the implementation of Deed Restrictions to establish land-use restrictions and Five-Year Reviews throughout the project duration. The IAS/SVE alternative, coupled with appropriate ICs, is expected to meet the RAOs within a reasonable time frame.

In-well Stripping
This alternative (IWS) involves treatment of groundwater by in-well stripping (IWS) using recirculating wells with treatment of off gas from the wells. Institutional Controls would be required for this alternative. The ICs would include the implementation of Deed Restrictions to establish land-use restrictions and Five-Year Reviews throughout the project duration. The IWS alternative, coupled with appropriate ICs, is expected to meet the RAOs within a reasonable time frame.

Enhanced Reductive Dechlorination
Enhanced reductive dechlorination (ERD) is a proposed in-situ technology for the removal action based on the prior experience at this site. Anaerobic reductive dechlorination is a naturally occurring biodegradation process whereby microbes can degrade chlorinated VOCs in groundwater when conditions are favorable. Institutional Controls will be required for this alternative. The ICs would include the implementation of Deed Restrictions to establish land-use restrictions and Five-Year Reviews throughout the project duration. Based on existing results from the site, the ERD alternative, coupled with appropriate ICs, is expected to meet the RAOs within a reasonable time frame (existing performance data are available).

<u>Comparative Analysis of Alternatives</u>
The criteria used to evaluate and compare Removal Action Alternatives in an EE/CA are defined in the NCP and associated EPA guidance documents. The three general evaluation criteria are Effectiveness, Implementability, and Cost. The specific components of the criteria are defined as follows:

1) Effectiveness Evaluation
    - Overall Effectiveness;
    - Protection of Human Health;
    - Protection of the Environment;
    - Compliance with ARARs;
    - Short-term Effectiveness;
    - Long-term Effectiveness; and
    - Reduction in Toxicity, Mobility, and Volume of Waste.

2) Implementability Evaluation
    - Overall Implementability;
    - Technical Feasibility;
    - Administrative Feasibility;
    - Availability of Services and Materials; and
    - Community Acceptability.

3) Cost Evaluation
    - Capital Cost; and

- Operation and Maintenance Cost.

The EE/CA provides the details of the comparative analysis of each removal alternative based on the established criteria. In order to develop a comparative ranking, each criterion is assigned a relative score from 0 to 5; with a score of 0 reflecting a very low score and 5 a very high score. Tabular data (within the EE/CA) present a breakdown relative ranking and cost elements for each alternative.

Recommended Alternative

The relative score/ranking for the five alternatives are presented in Table E-1; this ranking reflects the individual scores assigned to each criterion with the exception of the Community Acceptability (to be determined by EPA through public comment). A relative comparison of the estimated costs for the alternatives is presented in Figure E-1. Based on the rankings in Table E-1, treatment with Enhanced Reductive Dechlorination (ERD) is the recommended cleanup alternative.

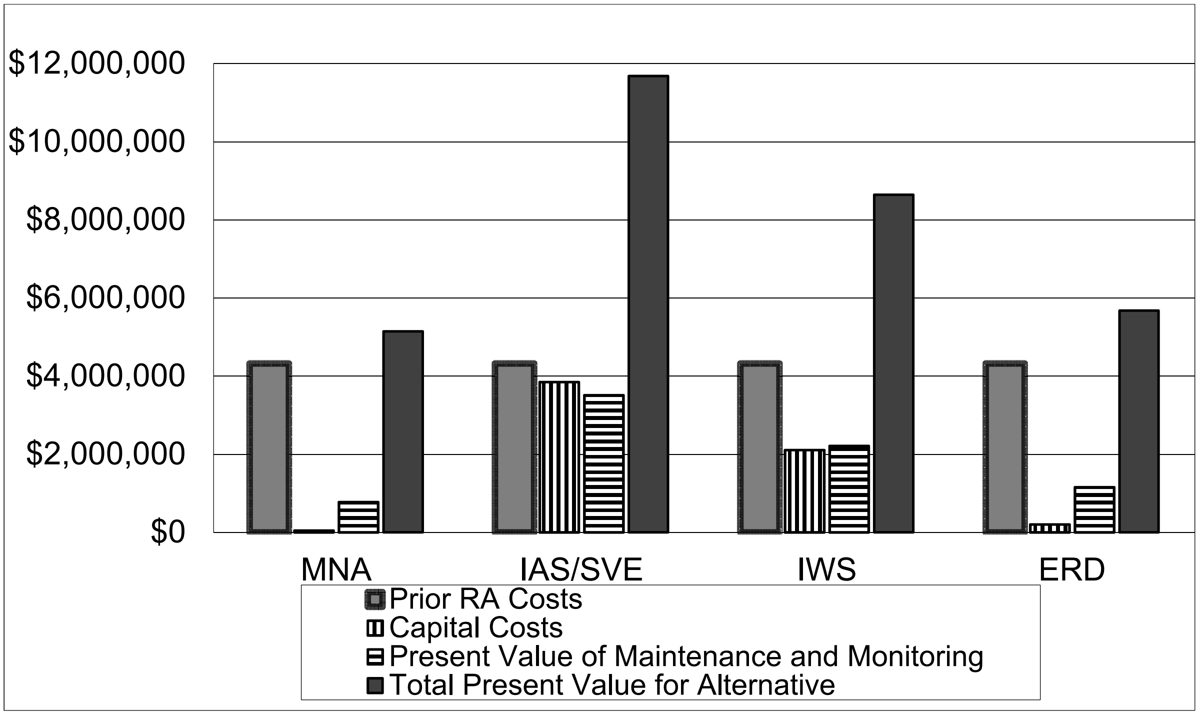
The sum of the scores (in Table E-1) is intended to assist in a decision making process on a preferred alternative. A higher total score (a numerical number) reflects a higher comparative ranking (i.e., a preferred remedy based on the required criteria).

Table E-1 Comparison of Relative Scoring for All Alternatives Considered

Criteria	**No Action**	**MNA**	**IAS/SVE**	**IWS**	**ERD**
Effectiveness	3	11	21	24	28
Implementability	12	16	12	12	20
Total Cost	5	4	2	3	4
Total Score*	**20**	**31**	**35**	**39**	**52**

*A higher total score reflects a higher comparative ranking (i.e., a preferred remedy based on the required criteria).

Figure E-1 Comparison of Estimated Cost for the Alternatives



1.0 Introduction

This report has been prepared by CALIBRE Systems, Inc. (CALIBRE) for The Boeing Company (Boeing) in response to an Administrative Settlement Agreement and Order on Consent For Removal Action (Settlement Agreement) entered into by Boeing and the U.S. Environmental Protection Agency (EPA) on February 2, 2007. The Settlement Agreement has been issued under the Comprehensive Environmental Response, Compensation, and Liability Act of 1980, as amended (CERCLA).

This report presents an Engineering Evaluation/Cost Analysis (EE/CA) for the former Electronics Manufacturing Facility (EMF) located at Boeing Field/King County International Airport (KCIA) in Seattle, Washington. Starting in 1982, investigations (and subsequent remedial actions) initially focused on the EMF property near the identified location of hazardous material spills. In 1999, a larger volatile organic compound (VOC) plume in groundwater was identified (i.e., larger than the EMF property). Based on that data, subsequent investigations and removal actions have been implemented in the down-gradient areas impacted by the VOC plume from the EMF property.

Within the CERCLA process under the Settlement Agreement, applicable regulatory standards (i.e., cleanup criteria) have not yet been established by EPA for this site and are the subject of ongoing work/negotiations.

For the purpose of this project, the term “EMF property” is used to define the physical location of the former EMF building and immediate surrounding area (parking areas for the facility). The terms EMF site, site, and VOC plume are used to describe any areas impacted by the VOC plume from the EMF property.

2.0 Background

2.1 Site Location and Description

The EMF property is located on the east side of KCIA. The facility is situated between the active runways/taxiways and Perimeter Road located to the east, which forms the eastern boundary of the airport and ancillary support operations (see Figure 2-1). Past industrial activities at the EMF property resulted in the release of trichloroethene (TCE) to the ground and to groundwater beneath the property. The VOC plume has been transported by natural groundwater movement southwest from the EMF property, across KCIA, passing under Boeing Plant 2 towards the Lower Duwamish Waterway (LDW) located approximately 3,600 feet southwest of the former EMF property.

The site consists of the EMF property and the portions of KCIA, North Boeing Field, and Boeing Plant 2 impacted by the EMF VOC plume that are located in a west to southwest direction from the EMF property. The down-gradient boundary of the site is the LDW. The contaminants of concern (COCs) that have been identified in the EMF VOC plume are trichloroethene (TCE), cis-1,2-dichloroethene (cis-1,2-DCE), trans-1,2-dichloroethene (trans-1,2-DCE), and vinyl chloride (VC).

Toluene is also a contaminant of concern. Relatively large concentrations of toluene that have been historically detected in some of the injection wells is believed to have been biologically generated from toluene precursors in some of the waste beverage solutions used for ERD injections.

2.2 Overview of EMF Cleanup Activities

A release of hazardous substances at the EMF property was identified and reported in 1982. Removal actions were initiated in the fall of 1982 and expanded site characterization was implemented in 1985 with continued monitoring through 1993. In 1996 and 1997, a MTCA RI/FS was conducted under the MTCA Voluntary Cleanup Program (VCP, Weston 1997). Additional investigation data has been collected and remedial actions implemented between 1997 and 2014 to characterize the site conditions and implement removal actions for site restoration (work prior to 2007 was under the MTCA VCP and after 2007 was either voluntary or required under a CERCLA Settlement Agreement with EPA). Additional details are summarized in section 2.4 and are presented in further detail within multiple reports in the administrative record.

2.3 Statutory Basis for Action

As part of the Settlement Agreement, EPA determined that an actual or threatened release of hazardous substances from the EMF site may present endangerment to public health and the environment. Based on that determination, a removal action may be required by the Settlement Agreement and, if carried out in compliance with the terms of the Settlement Agreement, would be considered consistent with the NCP, as provided in Section 300.700(c)(3)(ii) of the NCP. Through evaluation, and subsequent selection of proposed cleanup actions presented in this EE/CA, actions will be implemented to minimize and further reduce any potential harm to public health and the environment.

2.4 Previously Prepared Documents and Environmental Investigations

The following table provides a chronological list of major investigations, deliverables and actions performed at the EMF site. The table is highlighted with shaded colors to depict the regulatory involvement as follows;

Salmon shading is used for pre-MTCA and MTCA activities;
Blue shading is used for activities required under the Agreement related to the EE/CA; and
Green shading is used for voluntary actions completed subsequent to the Agreement.

Table 2-1 History for EMF Project

Date/Year	Scope
May 1982	Initial identification and regulatory notification of release
Fall 1982	Ecology issues Notice of Violation (NOV, Aug) and Order DE 82-469 (Oct). Remedial actions implemented: well points installed and soil removal; TCE contamination identified.
Apr 1985	Ecology amends original Order to include defining nature, extent and source of contamination
Spring 1985	Landau conducts site characterization; EMF groundwater monitoring program initiated
Nov 1985	Identification and regulatory notification of chromium contamination in area of pipe chase; Boeing meets with Ecology to discuss appropriate remedial action. Soil removal action implemented.
Dec 1985	Ecology rescinds Order
1986-1993	Groundwater monitoring of wells at EMF property
Jan-Apr 1996	Building at EMF property removed, and property re-graded/paved
Spring 1996	EMF MTCA RI/FS initiated
Fall 1997	MTCA RA implemented; 2 in-well stripping wells in VOC plume, DNAPL encountered/recovered, removal actions for soil above residential standards
May-July 1999	Expanded investigation down gradient and deeper intervals (to western edge of EMF property)
Nov 1999	Conceptual plan and data requirements for chemical oxidation
Feb 2000	Expanded investigation of DNAPL source area and down gradient area
Apr 2000	Expanded investigation of EMF property site-wide area

Date/Year	Scope
Mar 2000	Focused MTCA Feasibility Study for source control
May 2000	Chemical oxidation bench and pilot tests
June 2000 – 2001	Chemical oxidation of source area (continued from pilot through fall 2000 and again spring 2001 to fall 2001), plus rebound monitoring thereafter
Nov 2000	Expanded investigation into KCIA/Boeing field (center of field)
Feb 2001	Expanded investigation across KCIA/Boeing field (taxiway on west side of KCIA)
Mar-Aug 2001	Expanded investigation to East Marginal Way (at fire station)
Sep 2001	Aquifer pumping test (at East Marginal Way, fire station)
Jan 2002	Summary MTCA RI report (for all up gradient characterization)
Mar 2002	Expanded investigation into Plant 2 (2-40 Parking Area)
Mar 2002	Expanded investigation in Plant 2 (2-40/41 Transportation Aisle)
May 2002	Expanded investigation in Plant 2 (west side of 2-41 Building near LDW)
Aug 2002	EMF plume wells installed in Plant 2 (EMFWF-30, EMFWF- 31, EMFWF- 32)
Dec 2002	EMF Site and VOC Plume Data Summary Report Addendum (MTCA RI summary for all 2002 work, transects and wells in Plant 2)
Dec 2002	Chemical Oxidation Summary with rebound monitoring
July 2003	Enhanced Reductive Dechlorination (ERD) Pilot Test Work Plan
Fall 2003 – Winter 2004	ERD substrate injection (at 2-40 pilot test area in Sept 03; at 2-40 pilot test area in Feb 04)
Aug 2004	Technical Memorandum, ERD Pilot Test for EMF VOC Plume Under Plant 2
Sept 2004	Work Plan for Implementing ERD in EMF Plume (includes preparation of MTCA FS and additional bench tests beyond pilot test). Start of MTCA RA construction: wells in 2-41, ERD pilot area, 2-40 parking lot, and fire station
Apr 2005	ERD substrate injection implementation at Area 1 (2-41 bldg.), Area 2 (2-40 bldg. at pilot test area expanded) and Area 4 (fire station)
Jun 2005	EPA request to stop ERD injections within Plant 2 to evaluate regulatory oversight options for continuing cleanup actions.
Jul - Nov 2005	ERD substrate injection implementation (at EMF site in Jul 05 and Oct 05, at Fire station in Nov 05)
Aug 2006	Technical Memorandum, Remedial Action Implementation of Enhanced Reductive Dechlorination in EMF VOC Plume, evaluation of ERD performance
Sep 2006	Substrate injection (emulsified vegetable oil) implemented in mid-field grassy strip (implemented at a time with airport closure)
Oct 2006	Remedial optimization and expansion along injection transect at fire station, substrate injection and Technical Memorandum, Remedial Optimization of EMF Plume
Dec 2006 – Jan 2007	ERD substrate injection at Area 1 (2-41 bldg.), Area 2 (2-40 bldg. at pilot test area expanded), Area 3 (2-40 parking lot), and Area 4 (fire station)
Sept 2007	Groundwater Monitoring Report
April 2008	Groundwater Monitoring Report
May 2008	Groundwater Monitoring Report
June 2008	Historical Data Summary Report, REV 2
Aug 2008	Groundwater Monitoring Report
Oct 2008	Expansion of ERD Injection Wells Within Plant 2
May 2009	Groundwater Monitoring Report
Nov 2009	EMF Source Area ERD Expansion (including NV-1 and NV-2)
Oct 2009	Groundwater Monitoring Report
Febr 2010	Groundwater Monitoring Report

Date/Year	Scope
Aug 2010	Groundwater Monitoring Report
Oct 2010	Data Gaps Sampling Work Plan, REV 3, this approved plan started the Data Gaps Investigation pursuant the Settlement Agreement
Febr 2011	Groundwater Monitoring Report
May 2011	EMF Investigation Data Summary Report (Draft)
Aug 2011	Groundwater Monitoring Report
Febr 2012	Groundwater Monitoring Report
Febr 2012	Expanded ERD injection Network at EMF Property (including shallow zone)
Mar 2012	EMF Investigation Data Summary Report (Rev 2)
Aug 2012	Groundwater Monitoring Report
Nov 2012	EMF Investigation Data Summary Report Final (from Data Gaps Sampling)
Febr 2013	Groundwater Monitoring Report
Aug 2013	Groundwater Monitoring Report
Jan 2014	Expanded Investigation EMF Property Source Area and South End of Fire Station
Febr 2014	Groundwater Monitoring Report

3.0 Site Characterization

3.1 Site Location and Description

The EMF property is owned by King County and was previously leased to Boeing. The long-term lease was voluntarily terminated (at the request of King County) with Boeing retaining responsibility for continued environmental restoration. The facility was originally used for prototype aircraft testing during the 1940s and 1950s, and was converted for use as an electronics manufacturing facility in 1962. A circuit board plating line at the EMF facility was in operation from 1962 until 1982, at which time electronics manufacturing operations were discontinued. From 1982 through 1996 the property was used for various non-manufacturing operations and the building was subsequently demolished in 1996.

A release of hazardous substances at the EMF property was identified and reported in 1982. Removal actions were initiated in the fall of 1982 and expanded site characterization was implemented in 1985 with monitoring through 1993. In 1996 and 1997, a MTCA RI/FS was conducted under the MTCA Voluntary Cleanup Program [(VCP), Weston 1997]. Additional investigation data have been collected and removal actions were implemented between 1997 and 2014 to characterize the site conditions and the down-gradient VOC plume in groundwater (conducted under the MTCA VCP through 2006 and conducted voluntarily through the EPA Settlement Agreement from 2007 to date). Table 2-1 presents a chronology of investigation and remedial activities at the site since 1982. The chronology of site investigation and removal action activities is shown on a timeline in Figure 2-2.

3.2 Demographic Setting

The EMF property is paved as are most of the down-gradient areas, with the exception of grass strips between the airport runways, and the train tracks and landscape strip that parallel East Marginal Way South. The buildings in the area of the EMF property include the Terminal building for KCIA to the north and an operations building for United Parcel Service's air cargo activities located to the south. On the west side of KCIA the buildings include the Boeing Fire Station (Building 3-840), a guard station, and several smaller support structures associated with Boeing's 737/757 flight delivery center. The EMF VOC plume has been identified under the central areas of two buildings within Plant 2 (Buildings 2-40 and 2-41). The Plant 2 buildings were demolished in 2011, and this area of Plant 2 has been repaved with asphalt.

3.3 Site Geology and Hydrogeology

The nearest surface water body to the site is the LDW, which is located approximately 3,600 feet to the southwest of the EMF property (approximately 1,200 feet from the west side of KCIA). The entire area is served with storm water collection and conveyance systems; therefore, there are no natural drainage patterns or areas of erosion or sediment deposition on site. Precipitation falling on the site is either collected by storm sewers that discharge to the LDW or infiltrates within unpaved areas.

Throughout the project history, the primary potential impacts of concern have been related to the discharge of shallow groundwater from the VOC plume to surface water and sediments of the LDW.

The site is located in the Duwamish Valley in an area that includes surficial fill material from historical land reclamation and dredging within the valley. The Duwamish Waterway was dredged to its present course in the early 1900s and the ancestral channel and tide flat areas were filled with materials sluiced from the present day channel and nearby upland areas. The site lies within this area of fill and areas of ancestral river channels. Based on descriptions of numerous borings in the area, the materials appear to be nearly homogeneous at different spatial locations, although some vertical layering is present.

The site soils generally consist of approximately 5 to 10 feet of fill material (primarily sands), a thin layer (typically 10 feet or less) of sandy silt/silty sand, and a layer of fine to medium fluvial sand extending to a depth of approximately 40 to 50 feet below ground surface (bgs). Underlying the sand unit is a relatively fine-grained sandy silt layer of variable thickness.

Samples for geologic characterization and evaluation of grain-size distribution have been collected at locations throughout the site. The grain-size distributions typically indicate a well-sorted soil throughout the vertical profile of the aquifer where the VOC plume is encountered.

An aquifer pump test was conducted in the zone where the plume has been identified and the hydraulic conductivity is approximately 1.1×10^{-1} centimeters per second or 300 feet per day. The grain-size data have also been used with the Hazen equation to provide a relative estimate of the hydraulic conductivity based on the grain-size distribution (specifically using D_{10}). The Hazen formula is $K \approx F\ (D_{10}^{2})$ where K = hydraulic conductivity, and D_{10} is grain size in millimeters, and F() is an empirical relation (Freeze and Cherry 1979). Using this formula, the relative hydraulic conductivity of the zone where the plume has been identified is higher than that of the underlying and overlying stratigraphic units.

The fraction organic carbon (foc) in several soil samples from the site have been tested in a laboratory by the method of Plumb (1981). The data were collected to evaluate the adsorption of organic compounds (present in water) to aquifer soils. The measured fraction organic carbon ranges from 0.07% to 0.39 % with an average value of 0.2%. These data represent the more permeable sandy layers present in the site stratigraphy. Other lower permeability layers are present, some of which contain abundant organic matter from the historical tide flats. The lower permeability layers are expected to have a higher fraction organic carbon.

The following description of the relevant site geology and hydrogeology is focused first on the regional setting (i.e., the Duwamish River Valley) that defines the general boundaries, recharge areas, discharge areas, flow directions, and geochemical conditions within the area. A subsequent description is provided for the specific hydrogeologic conditions that have been determined from the investigations within and around the EMF VOC plume.

The regional geology and hydrogeology of the Duwamish River valley has been studied in a number of investigations with the most complete summary provided in the Duwamish Hydrogeologic Pathways Project funded by the City of Seattle (Booth and Herman 1998). General characteristics of the relevant hydrostratigraphic units in the area include:

Fill Fill is generally encountered within the top 20 feet (often much less except near the river channel) and thought to be derived from dredging and re-channelization of the Duwamish River.

Younger Alluvium The younger alluvial deposits contain wood and other organic materials (plant matter from the tide flats) in a silt and sand matrix. The alluvial deposits have a relatively constant thickness and depth and are located near the present day sea level.

Older Alluvium Older alluvium are estuarine deposits present throughout the area beneath the younger alluvium with variable basal depth (up to 100 feet in the center of the valley and appreciable thinner near the valley edges). The older alluvium are typically identified as sandy silt in the lower portions and sand and silty sand in the upper portions.

The aquifer system within the Duwamish valley is typically considered a single unit within the younger and older alluvium stratigraphic units present. General estimates of the hydraulic conductivity range from 10^{-1} to 10^{-3} cm/sec (280 to 2.8 ft/day) with the range highly dependent on the silt content of the specific area and stratigraphic unit (Booth and Herman 1998).

Within the alluvial aquifer (defined above as a single unit) further distinction is made between “upper” and “lower” groundwater zones, which are typically differentiated based on locally-continuous silt aquitards, upward vertical gradients, and/or the occurrence of saline groundwater. Brackish groundwater conditions are encountered in the lower groundwater zone throughout much of the valley. The data for locations distant from the waterway suggest that the deeper water is connate, in other words, the brackish groundwater was emplaced during the original deposition in an estuarine environment. The brackish water is expected to have a significant impact on groundwater flow (Booth and Herman 1998). The fresh groundwater (from recent recharge) will tend to migrate above the higher density saline water with the density contrast limiting the amount of mixing between the fresh water and brackish zones.

The groundwater flow direction within the alluvial aquifer has been mapped at a regional scale and in numerous local areas. As expected in an alluvial river valley, the flow direction is from the valley edges (sources of recharge) towards the LDW (discharge point). In general, regional flow patterns appear nearly perpendicular to the LDW with local variations due to changes in subsurface materials. Near the LDW, tidal influences are observed which indicate temporary changes in the apparent groundwater flow direction. The overall groundwater flux generally appears unchanged when the tidal variations are averaged over the short-term tidal cycles.

Based on historical maps and the results of previous investigations, ancestral river channels are present in the Duwamish Valley, including one near the western edge of the EMF property. The data indicate that the VOC plume follows the regional groundwater flow direction (unchanged flow path) as it passes under the known ancestral river channel. As such, there is no evidence suggesting the channel serves as a preferential pathway for contaminant migration.

The existing site data (both regional and local) indicate that groundwater flow is towards the Duwamish Waterway, essentially perpendicular to the Waterway. Data collected at the EMF property indicate a hydraulic conductivity that is somewhat lower relative to the measured value on the west side of KCIA (based on soil texture and grain-size distributions).

Based on groundwater elevations measured in wells installed near the Boeing Fire Station on the west side of KCIA, the hydraulic gradient in this area is 0.0011 ft/ft. This gradient and the measured hydraulic conductivity results in an estimated groundwater pore water velocity in the range of 450 feet/year, assuming a porosity of 0.33. This estimate of groundwater velocity is generally consistent with the observed length and estimated age of the contaminant plume (PPC, 2002).

3.4 Topography

The surface topography in the area is essentially flat with minor variations (less than 1 foot) constructed for storm water collection systems. The EMF property on the east side of KCIA is at an elevation of 14.1 feet and the elevation on the west side of KCIA near the Boeing Fire Station is 13.2 feet. The elevation on the east side of Boeing Plant 2 is 13.1 feet and the elevation on the west side of Boeing Plant 2 is 13.3 feet. All of the elevations noted above are based on the National Geodetic Vertical Datum 1929 (NGVD29).

3.5 History

A hazardous substance release at the EMF property was identified in 1982 and removal actions were initiated in the fall of 1982 with expanded site characterization implemented in 1985. In 1996 and 1997, a MTCA RI/FS was conducted under the MTCA Voluntary Cleanup Program (VCP, Weston 1997). Additional investigation data has been collected and removal actions implemented between 1997 and 2014 to characterize the site conditions and implement removal actions for site restoration (work prior to 2007 was under the MTCA VCP and after 2007 almost all work was completed with notification to EPA).

3.6 Nature and Extent of Contamination

3.6.1 Soil

The 1997 MTCA RI included soil sampling in all suspect areas in and around the EMF property including all transformer pads, USTs, and locations in and around the plating bath operations (where chromic acid was used). In the areas around former transformer pads PCBs were detected, but all levels were below MTCA Method B soil cleanup levels for unrestricted use.

All UST areas were investigated and the results indicated TPH in vadose zone soils in the vicinity of two former USTs (UST-203 and UST-206) at concentrations in excess of MTCA Method A cleanup levels. TPH was not detected in groundwater. Removal actions were implemented at the UST areas and all confirmation samples (at the final depth of the excavation) met all MTCA Method A criteria.

The total metal concentrations that were detected in soils were within natural background concentrations for Washington State or below MTCA Method B cleanup levels for soil. The 1997 soil investigation included multiple samples in and around the locations where a release from the chromic acid lines was identified and removed previously (in 1982 and 1985). All laboratory results for hexavalent and total chromium analysis were less than the MTCA Method B criteria (for unrestricted use).

All of the soil sampling data noted above pertain to vadose zone soil samples (for evaluation of exposure risk via soil contact and vapor intrusion pathways). Based on the prior remedial actions, the data summarized above, the EMF Historical Data Summary report, and the EMF Data Gaps sampling plan no remaining areas have been identified where COCs in soil exceed ARARs (or represented appreciable risk). No impacted areas or chemical plumes in soil were identified (no extent above ARARs).

Saturated zone soil samples were also collected in the 1997 MTCA RI and Remedial Action (in multiple locations and specifically at the location/interval where DNAPL was suspected. These 1997 soil samples identified elevated VOCs in soil (at the DNAPL area) which exceeded MTCA criteria for leaching impacts to groundwater and they represent the well-documented source for the VOC plume in groundwater. These samples are saturated zone soil collected at depths of 25 to 40 feet below ground surface and do not represent a soil contact or vapor intrusion risk (they are too deep). Planned removal actions for site groundwater plume will address this area.

3.6.2 Groundwater

The VOC plume from the EMF property extends from the EMF site to the discharge point within the Duwamish Waterway. The COCs identified in the EMF groundwater plume include TCE, and its degradation daughter products of trans-1,2-DCE, cis-1,2-DCE, and VC. Near the EMF property TCE is still detected in groundwater but in the down gradient areas it is fully converted to one or more of the daughter products. Toluene is also a COC at and downgradient of some of the injection wells. The vertical and lateral extent of the VOC plume have been mapped in multiple transects (throughout the 3,600 foot length of the plume). Based on the site investigations, the lower boundary of the plume is at a depth of approximately 50-55 feet bgs (typically). The upper boundary of the plume is within the upper sand layer at a depth of approximately 30 feet bgs. These data are consistent with all historical sampling data throughout the plume (including multiple transects in down-gradient locations, and multiple shallow wells on the EMF property and in Plant 2).

The lateral edges of the VOC plume at the EMF property (the east side of the airport) are defined by specific monitoring wells where groundwater monitoring results reveal very low or non-detect concentrations of TCE, 1,2-DCE and VC. The lateral edges of the plume at the west side of the airport (near the Boeing Fire Station) are defined by specific monitoring wells where groundwater monitoring results have typically been very low or non-detect concentrations of 1,2-DCE and VC. However the southern boundary of the EMF plume near the Fire Station showed an increasing VOC trend over recent years (and actions have been taken to treat the plume in this area). The initial width of the plume is estimated to have ranged between 500 and 200 feet (depending on location). The existing remedial actions have largely removed the plume beneath Boeing Plant 2 area.

For current plume maps (February 2014) refer to Figures 3-1 through 3-5. These iso-concentration contours are approximate and are expected to change as current voluntary actions continue to remove/destroy VOCs.

One of the key questions in the EMF Data Gaps Report was the impact of the VOC plume at the Duwamish Waterway (i.e., Does the impact of the VOC plume result in concentrations that cause a potential exposure risk exceeding NCP risk standards or Ambient Water Quality Criteria (AWQC) for the COCs at the discharge point?). All monitoring wells and probe samples collected near the LDW between October 2010 and February 2011 were below AWQC for all VOCs. Recent sampling results (through 2014) are consistent with the multiple sampling events conducted over the last several years (all below AWQC for all VOCs).

Many monitoring and treatment wells have been installed throughout the investigation and voluntary remedial action phases of the EMF site. These wells, historical uses, and sampling data have been discussed in prior reports (e.g., EMF Historical Data Summary Report and the EMF Investigation Summary Report [CALIBRE 2008 and 2012]). A summary of all current EMF site wells is provided in Attachment A. The summary includes; a current complete well list, a list of frequently monitored wells, and cross sections of frequently monitored wells.

3.7 Previous Removal Actions

Details of previous removal actions at the site are summarized in the EMF Historical Data Report (CALIBRE 2008). Briefly, the following removal actions have been performed at the site (and the last item noted, ERD full-scale implementation, is ongoing):

1982 to 1985: Removal actions at the source area for soil and groundwater
1997: Removal action for TPH and PCBs in soil, DNAPL recovery
1997–2006: Operation of in-well stripping system (groundwater treatment)
2000-2001: Chemical oxidation of groundwater (and saturated soil) at the source area
2003-2004: ERD pilot study, and
2005-2014: ERD full-scale implementation throughout VOC plume.

The general removal actions for all vadose zone soils in excess of ARARs has been excavation and offsite disposal with confirmational sampling. Several different types of removal actions for groundwater have been implemented over the life of the project and in different areas of the VOC plume (NAPL recovery, In-well Stripping, ISCO, and biological treatment through ERD).

3.8 Risk Evaluation

The EE/CA guidance (USEPA 1993) requires a streamlined risk evaluation that is "…intermediate in scope between the limited risk evaluation undertaken for emergency removal actions and the conventional baseline risk assessment normally conducted for remedial actions". The guidance also indicates the risk evaluation "…should focus on the specific problem that the removal action is intended to address". EPA's Settlement Agreement and Order on Consent indicates that EPA intends the EMF removal action to address; "..primary objective of this removal activity is the removal, treatment and/or containment of the EMF plume and sources of hazardous substances thereto to mitigate or prevent further releases into the environment, and specifically into the LDW".

The hazardous substance release at the EMF site was initially identified in 1982. Since that time, a significant amount of work has been completed and a large body of environmental, hydrogeologic, and geochemical data has been collected throughout the characterization and remedial actions implemented. A Conceptual Site Model (CSM) has been developed and revised in the EMF Historical Data Summary Report, Data Gaps Sampling Work Plan, and Investigation Data Sampling Report (CALIBRE 2008, 2010, and 2012). The following information summarizes key details of the CSM specifically related to consideration of exposure pathways and risk evaluation.

3.8.1 Chemicals of Concern

The chemicals of concern (COCs) identified at the EMF site and groundwater plume are VOCs; specifically trichloroethene (TCE), cis-1,2-dichloroethene (cis-1,2-DCE), trans-1,2-dichloroethene (trans-1,2-DCE), VC, and toluene. Other potential COCs evaluated have included TPH in soil, PCBs in soil, and priority pollutant metals in soil and groundwater. Historical removal actions and site-wide sampling for these other analytes have resulted in remaining levels which are below applicable criteria (AWQC and MTCA Method A standards for residential land use, inclusive of both human and ecological exposure criteria). These other potential COCs have been investigated (samples collected and results compared with chemical-specific risk-based ARARs) and are no longer considered COCs for this project.

3.8.2 Contaminant Transport Pathways

The primary transport mechanism of the VOC plume is groundwater flow. Multiple site studies have shown that shallow groundwater (<50 feet deep) flows toward the LDW through the most permeable alluvial sediments. Key processes related to this transport pathway include:

Groundwater velocity (~450 ft/yr)
Adsorption/retardation:

TCE	K_d = 0.3 L/kg, retardation factor, R_d = 2.4
cis-1,2-DCE	K_d =0.07 L/kg, R_d = 1.4
VC	K_d =0.04 L/kg, R_d = 1.2

Degradation via reductive dechlorination (degradation rate expressed as half-life):
Baseline conditions before ERD treatment, $T_{½}$= 19 months
After ERD treatment; $T_{½}$= 0.7 months

The vertical and lateral extents of the VOC plume are generally well understood. Plume characterization data indicate that the EMF VOC plume remains as a discrete, stratified plume present between depths of approximately 30 and 50 feet bgs with very little spreading or dispersion in the vertical and horizontal directions as it migrates towards the LDW.

Key data gaps for risk evaluation (as well as other site characterization concerns) were identified through a Data Quality Objectives (DQO) process in the Historical Data Summary Report (CALIBRE 2008) and Data Gaps Sampling Work Plan (CALIBRE 2010). The data gaps were related to the evaluation of other specific exposure pathways that were considered plausible (indoor air, storm drains, stream channels, etc.). Further investigations were completed to determine if these potential pathways were complete. The results and conclusions are summarized in the Investigation Data Summary Report (CALIBRE 2012) and are summarized in the following sections.

3.8.3 Indoor Air

On the EMF property, shallow contamination is present (VOCs in groundwater) however no structures exist above the plume in this area. Near the KCIA Arrivals Building (the closest structure) all measured values of VOCs (in the shallow zone) are less than the screening levels published by Ecology for protection of indoor air. Monitoring has demonstrated that VOC concentrations near the closest structures (groundwater data) are less than the conservative MTCA screening criteria. In down-gradient plume areas (Boeing Fire station) where structures are present, the VOCs in shallow groundwater are non-detect and/or below MTCA screening levels used for evaluating the potential for an indoor air pathway. Under current conditions and land use, the indoor air pathway is either not complete or concentrations are at levels below the conservative MTCA screening levels for protection of indoor air.

3.8.4 Storm Drains

Sampling has been completed from the storm drain systems connected to the EMF property (the only area of the plume with shallow groundwater contamination). All VOCs (TCE, cis 1,2-DCE, trans 1,2-DCE and VC) are reported as less than the Method 8260C detection limit (0.2 ug/L) for all seven sampling events. Based on these site data, migration of VOCs in the storm drainage system is not a complete pathway.

3.8.5 Impacts of Stream Channels

Existing data demonstrate little (if any) impacts of former stream channels on the VOC plume migration path; the historic stream channels are at an elevation above mean sea level (MSL) and the primary EMF plume migration path is at an elevation approximately -27 ft MSL. Based on these site data, former stream channels are not a preferential pathway.

3.8.6 Exposure to Soil

Exposure to contaminated soil has not been considered a significant exposure pathway because of the prior removal of impacted soil in the initial remedial actions (to MTCA levels for unrestricted future use) and the site is paved. It is expected that soil contamination remains in saturated soil (within the source area where DNAPL was previously present). The surface is paved and any future development on the EMF property will require appropriate measures to mitigate the potential exposure pathways (such as a soil-vapor barrier).

3.8.7 Groundwater

As noted above, groundwater containing VOCs from the release area is the primary transport pathway for potential exposure to COCs from the site. Historically, site groundwater has not been considered a source of potable water by Boeing and human exposure through drinking water ingestion has not been considered a complete pathway. The groundwater discharges to the LDW and this discharge represents a potential exposure pathway for human and ecological receptors. All existing work on this project has used the ambient water quality criteria (AWQC, based on the ARARs defined under the MTCA, and also consistent with the National Contingency Plan) as the threshold criteria for evaluating potential impacts to human and ecological receptors. Based on EPA's direction, this EE/CA considers that groundwater will be considered as a potable resource until EPA and Ecology accept a nonpotability determination for EMF. The five year review can be used to evaluate the status of EMF groundwater potability and any effect upon the removal action. Potential future risk from hypothetical potable water use will be mitigated by institutional controls[1] as described in Section 3.9.

Under CERCLA, cleanup goals are derived for any potential exposure pathway for which the risk assessment identified an unacceptable risk. For EMF, groundwater cleanup levels will be protective of drinking water ingestion, organisms exposed to adjacent surface water and people who consume fish and shellfish harvested from the LDW. Potential future risk from vapor intrusion will be mitigated by institutional controls as described in Section 3.9.

3.8.8 Identification and Assessment of Discharges to Lower Duwamish Waterway

The EMF Investigation Data Summary Report (IDSR) notes that all monitoring wells and probes near the LDW monitored between October 2010 and February 2011 were below AWQC for all VOCs (CALIBRE 2012). These prior results are consistent with the multiple sampling events conducted over the last several years. Based on the data described in the IDSR, the present interpretation of the data is that the EMF VOC plume is at levels which do not exceed the applicable AWQC at the discharge point.

As described above, the EMF VOC plume discharges to the LDW and this discharge to surface water is believed to be the primary exposure pathway by which a potential risk is derived from the EMF site. Other pathways have been considered, but the prior assessment performed under the project (based on the CSM, and data gaps/site characterization data) has been that those other pathways are incomplete. The assessment of risks associated with the EMF plume discharge to the LDW has included pathways for which there are both human and ecological receptors. Based on the data presented in the Investigation

[1] In the EMF lease termination, the County agrees to make reasonable efforts to seek approvals necessary to record documents necessary to effect institutional controls as long as such institutional controls do not interfere with or impair the use of the EMF Site for Airport-related purposes. The institutional controls include a restrictive covenant prohibiting the use of groundwater at the Airport for drinking or domestic purposes and restricting the property for industrial\commercial use.

Data Summary Report (CALIBRE 2012) and data collected since that time, remedial actions implemented throughout the plume have resulted in reductions of the EMF VOC plume concentrations to levels which do not exceed the applicable AWQC at the discharge point.

3.9 Institutional Controls

As the basic objective of the EE/CA, potential Removal Action Alternatives have been developed based on the nature and extent of contamination, exposure pathways and human health/ecological risk evaluation, and ARARs. The Removal Action Alternatives evaluated include: No action, Monitored Natural Attenuation (MNA), In-situ Air Sparging with Soil Vapor Extraction (IAS/SVE), In Well Stripping (IWS), and Enhanced Reductive Dechlorination (ERD). The basic requirement is to control or eliminate the potential for exposure of human and ecological receptors to Site contamination. Most of the proposed removal actions are expected to include active operation for several years and monitoring. The alternatives are also expected to include specific Institutional Controls (ICs) required for as long as residual contamination may remain which would not allow for unrestricted future land use. The ICs are presented as an integral part of each of the alternatives evaluated.

Institutional controls, or covenants defined under RCW 64.70.040 and WAC 173-340-440, are measures that prohibit or restrict activities that may disturb or interfere with a sites cleanup action, or that may result in exposure to hazardous substances at a site. The ICs anticipated for the EMF site include:

1. Prohibit the use of groundwater from the site for drinking or domestic purposes or demonstrate that sufficient protections are in-place to ensure that drinking water cannot be used for domestic purposes.
2. Restrict the property for industrial/commercial use only.
3. If re-development of the EMF property includes an occupied structure to be constructed in an area above the EMF plume, then the plans will include evaluation of the need for, and applying appropriate engineering controls as necessary to mitigate the potential for vapor intrusion.

The general framework for these ICs is outlined in the lease termination agreement between King County and Boeing (January 2009). In the lease termination agreement, Boeing is obligated to perform cleanup and remediation activities for the Site and long-term management is expected to include ICs. The lease termination agreement also states that any ICs placed on the EMF property may not interfere with, or impair, the use of the EMF site for airport-related purposes.

Future groundwater use as a potable supply is considered unlikely by Boeing based on the existing site conditions, reasonable future site uses (i.e., as a regional airport), and existing State and local regulations. Existing laws prohibit installation of groundwater supply wells, and Boeing considers the area to meet the definition of non-potable (as the term is defined in WAC 173-340-720(2)). This could change in the future, and if so, a five-year review process to re-evaluate groundwater cleanup levels would be implemented to address any future risks at that time.

The planned future use of the property is to remain an industrial/commercial site. Currently, no structures are present at the site and groundwater containing VOCs from the release area is the primary transport pathway for potential exposure to contaminants of concern from the site. The EMF property area is part of an International/Commercial Airport. Existing access controls include an asphalt/concrete cover and security fences (with full-time patrol; 24/7) which presently prohibit public access.

As stated in the lease termination agreement, future development of the property should avoid occupied underground structures such as parking garages, basements, or pedestrian tunnels within areas contaminated with VOCs if a reasonable alternative is available. If a reasonable alternative is not available, the redevelopment will be planned with the known contamination issues. If subsurface work will be performed within areas containing VOCs, the crews performing the work will utilize appropriate personal protective equipment and have appropriate training for working in hazardous locations.

If the construction of structures are planned, and a potential for migration of VOCs into buildings exist, the plans would require the installation, operation, and monitoring of engineered controls to prevent the migration of VOCs into buildings and avoid unacceptable risk from vapor intrusion. These may include vapor barriers, active or passive depressurization systems, and clean fill capping.

The ICs described above have been agreed upon in the lease termination agreement between King County and Boeing, and the County has agreed to seek approvals for such ICs that may be required as part of the removal action or cleanup remedy. It is expected that these ICs will be will be described in a restrictive covenant on the property and that the covenant will be executed by the property owners and recorded with the King County register of deeds.

The Department of Ecology maintains a registry identifying all environmental covenants established within the state (RCW 64.70.120). Property owners that must agree to all restrictive covenants include King County and Boeing. Figure 3-6 show the EMF plume and the property parcels impacted by the EMF plume, Table 3-1 provides parcel details below. Institutional control requirements for specific parcels may be reduced or eliminated if groundwater monitoring demonstrates that all COCs have been sufficiently remediated such that remaining exposure pathways are permanently closed.

Table 3-1 Property Parcel Numbers Associated with the EMF Site

Property Name	Property Owner	Parcel Number
King County International Airport	King County	2824049007
Boeing Plant 2	Boeing	2824049009
Boeing Plant 2	Boeing	3320409002

4.0 Removal Action Goals and Objectives

The Removal Action Objectives (RAOs) discussed below have been developed based on the Conceptual Site Model (including source of contamination, the nature and extent of contamination, exposure pathways and human health/ecological risk evaluation) and the applicable or relevant and appropriate requirements (ARARs) that have been identified. The RAOs have been developed to control or eliminate the potential for exposure by human and ecological receptors due to contamination at the EMF Site.

The general evaluation criteria for the analysis of potential removal actions defined in EPA guidance are effectiveness, implementability, and cost (EPA 1993); these criteria are discussed in detail in Section 5. The effectiveness evaluation needs to be based on criteria which are defined through the RAOs. The RAOs are to:

- Prevent or reduce human exposure to VOCs present in site groundwater in excess of established criteria.
- Prevent or reduce ecological exposure to VOCs present in site groundwater in excess of established criteria.

The proposed removal action at the Site must address the RAOs, in addition future use of the property must be consistent with the RAOs.

4.1 Removal Action Schedule

EPA has determined that a non-time-critical removal action (NTCRA) is appropriate at the Site. The initial removal/response actions at the EMF Site started in 1982 and remedial actions have continued through to the current date (2014), see Table 2-1 and Figure 2-2. For the purpose of this EE/CA, the "schedule" reference is intended to describe the time when new/revised/modified removal actions are implemented following EPA's decision on a NTCRA. The removal action could commence within twelve months following approval of this EE/CA. Based on past experience with the technologies similar to those proposed in this EE/CA, it is estimated that removal actions would need to operate for several years.

4.2 Applicable or Relevant and Appropriate Requirements

The following section/table present the major Federal and State environmental laws, but may not be entirely inclusive. The process of identifying additional ARARs or modifying this initial determination will continue as removal action alternatives are selected. Applicable requirements are defined as those cleanup standards, standards of control, or other substantive environmental protection requirements, criteria, or limitations promulgated under Federal or State environmental law that specifically addresses a hazardous substance, pollutant, contaminant, remedial action, location or other circumstance at a CERCLA site.

If a requirement is not applicable, it still may be considered relevant and appropriate. Relevant and appropriate requirements are those same standards mentioned above that while not "applicable", address problems or situations sufficiently similar to those encountered at the site that their use is well suited to the particular site. For this EE/CA, ARARs have been identified on a preliminary basis during the planning phases and investigation phases, and may be further refined (as necessary) during the identification and evaluation of removal action alternatives.

The list of identified ARARs for the EMF Site is presented in Table 4-1.

Table 4-1 Identification of ARARs

Requirement	ARAR?	Rationale
Federal		
National Pollution Discharge Elimination System (NPDES) 40 CFR Part 122 The NPDES establishes permitting requirements, technology based limitations and standards, control of toxic pollutants, and monitoring of effluents to assure discharge permit conditions and limits are not exceeded.	**NO**	All alternatives considered include in-situ groundwater treatment. No effluents are to be discharged from the proposed removal actions.
Safe Drinking Water Act (National Primary and Secondary Drinking Water Regulations) (42 U.S.C. 300f, 40 CFR Part 141, 40 CFR Part 143) The Safe Drinking Water Act (SDWA) established to ensure the quality and safety of drinking water, sets the primary standards maximum contaminant levels (MCL) and maximum contaminant level goals (MCLG) for chemical constituents in drinking water. Secondary standards pertain primarily to the aesthetic qualities of drinking water.	**YES**	The standards set under the SDWA apply to drinking water but do not apply to non-potable water. The NCP references to the applicability of MCLs as ARARs also include the qualification that they are ARAR to water resources "that are current or potential sources of drinking water".
Clean Water Act (CWA) 33 USC 1251-1387 Chapter 26 The purpose of the Clean Water Act is to restore and maintain the quality of surface waters by restricting discharges of all designated pollutants, which include 126 priority toxic pollutants, various conventional pollutants, and certain non-conventional pollutants.	**YES**	The primary exposure pathway identified is through surface water; AWQCs are set to protect surface water; and the removal action is being implemented to meet the AWQC.
Clean Air Act, as amended (42 U.S.C. 7401) The Federal Clean Air Act is designed to regulate any activities that affect air quality, and provide a framework for controlling air pollution. The National Primary and Secondary Ambient Air Quality Standards (40 CFR Part 50) set standards for ambient pollutants which are regulated within a region. The National Emissions Standards for Hazardous Air Pollutants (40 CFR Part 61) establishes numerical standards for hazardous air pollutants. Locally the Puget Sound Clean Air Agency implements regulations to control the emission of air contaminants from all sources within the jurisdiction of the Agency (and thereby carry out the requirements and purposes of	**YES**	The Clean Air Act is implemented in the area by Puget Sound Clean Air Agency (PSCAA). PSCAA Regulation 1 applies to any remedial alternative that may generate an air discharge.

Table 4-1 Identification of ARARs

Requirement	ARAR?	Rationale
the Federal Clean Air Act under the Washington Clean Air Act, see further discussion under State Laws).		
Endangered Species Act Prohibits jeopardizing federal threatened or endangered species, or adversely modifying habitats essential to their survival.	**NO**	Threatened or endangered species are not known to inhabit the Site. Site activities will not jeopardize threatened or endangered species.
National Historic Preservation Act, Archeological Resources Protection (16 U.S.C. 470 et seq.) The National Historic Preservation Act requires that historically significant properties be protected. Establishes requirements for the preservation of historic sites, buildings or objects of significance. Undesirable impacts to such areas must be mitigated.	**NO**	No historically significant structures are found at the Site. All site activities will occur in a previously developed industrial areas.
Floodplains/Wetlands Environmental Review Requires Federal agencies to avoid, to the extent possible, adverse effects associated with the development of a flood plain or the destruction or loss of wetlands. Pertinent if remedial activities take place in the vicinity of a floodplain or wetland.	**NO**	The removal action will not be conducted within wetland or floodplain areas.
Resource Conservation and Recovery Act (RCRA) Provides the governing regulations for owners and operators of hazardous waste treatment, storage, and disposal facilities; and for the generators and transporters of hazardous waste. In the State of Washington, RCRA is implemented by the Dangerous Waste Regulations (WAC Chapter 173-303).	**YES**	Any waste generated during the removal action will be characterized and handled per RCRA regulation, as implemented by WAC 173-303.
Occupational Safety and Health Act (OSHA) (29 CFR 1910) Establishes the worker health and safety requirements for operations at hazardous waste sites.	**YES**	All site activities will be conducted under appropriate OSHA standards.
Rules for Transport of Hazardous Waste (49 CFR 107, 171)	**YES**	Hazardous waste generated (if any) during site activities will be characterized as needed to determine

Table 4-1 Identification of ARARs

Requirement	ARAR?	Rationale
The U.S. Department of Transportation (DOT) establishes requirements for packaging, handling, and manifesting hazardous waste.		packaging, handling and transport requirements.
State		
Model Toxics Control Act (MTCA) RCW 70.105D The act gives Ecology authority to apply administrative processes and standards to all facilities in the State of Washington where there has been a release, or a threatened release, of a hazardous substance that may pose a threat to human health or the environment. This act is implemented by: **Model Toxics Control Act, Cleanup Regulation, Chapter 173-340 WAC**. MTCA provides a means of evaluating levels of contamination, and establishing site cleanup requirements. ARARs for the conduct of the removal action under MTCA are: WAC 173-340-720, Groundwater Cleanup Standards (where applicable).	**YES**	ARARs defining cleanup standards are goals for the removal action, will be met when practicable.
Dangerous Waste Regulations (WAC 173-303) The State of Washington Dangerous Waste Regulations implement the federal hazardous waste regulations pursuant to RCRA. These regulations establish requirements for the generation, treatment, and disposal of dangerous waste. These requirements might be applicable as chemical specific ARARs, depending on the chosen remedial action. WAC 173-303 may be applicable if dangerous wastes are generated by the chosen remedial alternative.	**YES**	WAC 173-303 will be followed for all generation, and off-site treatment, and disposal of hazardous waste (if generated during the removal action).
Minimum Standards for Construction and Maintenance of Wells, Regulation and Licensing of Well Contractors and Operators RCW 18.104, WAC 173-160, 162) Establishes standards for the design, construction, and maintenance of water wells in the State of Washington.	**YES**	Wells installed to implement the removal action will be constructed in a manner meeting these regulations.
Air Pollution Control Regulations (WAC 173-400), Control of New Sources of Air Toxics (WAC 173-600), and Ambient Air Quality Standards for Particulate Matter (WAC 173-470)	**YES**	The Washington Clean Air Act is implemented in the area by the PSCAA. PSCAA Regulation 1 applies

Table 4-1 Identification of ARARs

Requirement	ARAR?	Rationale
The Washington clean air regulations were enacted to comply with the federal clean air act, as amended. The intent of this act is to ensure the protection of public health and the air resources of the State. The regulation is applicable to remedial activities and establishes technical and procedural standards for the control of air contaminant sources. Limits have been established for hazardous air emissions.		to any removal alternative that may generate an air discharge.
Washington Industrial Safety and Health Act (WISHA),Chapter 296-62 WAC Regulations guiding worker safety during the implementation of sampling efforts and/or remedial actions.	**YES**	Site activities will be conducted under appropriate WISHA standards.
Water Pollution Control Act, Chapter 90.48 RCW This act prohibits the discharge of pollutants into water.	**NO**	Ground water will be treated in-situ. No effluents are to be discharged from the proposed removal actions.
Water Quality Standards for Surface Waters of the State of Washington, Chapter 173-201A WAC The State of Washington has adopted the Federal Water Quality Criteria for Toxic Substances. These criteria are applied to all surface waters, regardless of the designated use of the water body.	**YES**	The removal actions are planned to restore groundwater so that AWQCs are met.
Underground Injection Control (WAC 173-218) Limits injection into aquifers to protect ground water for beneficial uses.	**YES**	UIC registration is required for wells used for ERD substrate injection.
Water Quality Standards for Ground Water of the State of Washington (WAC 173-200) The State of Washington has adopted these standards to ensure groundwater is protected.	**YES**	Establishes maximum contaminant levels for discharge to groundwater.

4.3 Interim Cleanup Level Goals

The cleanup levels presented below address multiple exposure scenarios for all media (groundwater, indoor air, and soil in Tables 4.2a, 4.2b and 4.3c). Pursuant to CERCLA (and MTCA) requirements, the cleanup goals used throughout the project have been based on the AWQCs which are identified as existing state/federal standards (ARARs). Under Section 304(a)(1) of the Clean Water Act (CWA), EPA has developed and published criteria for water quality that are numerical values establishing ambient water concentrations protective of human health from harmful effects of pollutants. These criteria are based solely on data and scientific judgments about the relationship between pollutant concentrations and environmental and human health effects (i.e., the AWQCs do not reflect consideration of social or economic impacts or the technological feasibility of meeting the target concentrations in ambient water). The interim cleanup level goals are presented in Table 4-2 (as parts 4.2a, 4.2b and 4.2c for groundwater, indoor air, and soil).

Table 4-2a Interim Cleanup Levels Groundwater

EMF COCs in Groundwater	National Recommended Water Quality Criteria (1) CWA §304(a)	Modified MTCA Method B Surface Water (2) (if applicable) WAC 173-340-730	State Primary Drinking Water Standards (5)(6)(7) Washington MCLs	EPA Proposed TMCL for Surface Water and Groundwater Discharging to Surface Water in the LDW
	Groundwater Criteria	Groundwater Criteria	Groundwater Criteria	Groundwater Criteria
Constituents	ug/L	ug/L	ug/L	ug/L
Trichloroethene	7	12.7 (3)	5	1.4
cis-1,2-dichloroethene		4,500 (4)	70	130
trans-1,2-dichloroethene	4,000	6,300 (4)	100	940
Vinyl chloride	1.6	3.7	2	2.4
Toluene	520	8,700 (4)	1,000	1,300

Water

(1) Human health criteria set for consumption of organisms only (based on saline water and does not include water ingestion, LDW surface water is not designated for domestic water supply use by the State of Washington). EPA Ambient Water Quality Criteria (AWQCs), as updated June 2015.

(2) MTCA risk-based formula for fish consumption, but only applies if other protective ARARs have not been established (i.e., AWQCs do not exist or are not considered protective).

(3) The MTCA risk-based formula for TCE is based on an oral cancer potency factor of 0.0046 kg-dy/mg, per 2012 Ecology Guidance (from 2011 updates in IRIS). The MTCA TCE criteria considers 3 types of cancer endpoints (kidney, non-Hodgkin lymphoma, and liver) but does not consider early life exposure (from fish ingestion) and a fish-diet fraction of 0.5, from 2012 Ecology Guidance.

(4) Modified MTCA Method B (surface water based on consumption of fish/organisms) modified to use the BCF from The Hazardous Waste Companion Database to the Human Health Risk Assessment Protocol (HHRAP) for Hazardous Waste Combustion Facilities, Final. (EPA 520-R-05-006).

(5) The prior information in this footnote has been deleted.

(6) The standards are potentially applicable to groundwater that may be used for drinking water supplies. Ecology determines the maximum beneficial use of groundwater, which may or may not include drinking.

(7) Washington Primary Drinking Water Standards WAC 246-290-130, Maximum Contaminant Levels (MCLs), which are equivalent to Federal MCLs.

Table 4-2b Interim Cleanup Levels Air

EMF COCs in Air	MTCA Method C (8)(9)(10)	MTCA Method C without ELE (8)(9)(10)	MTCA Method B (8)(13)	EPA Proposed Ambient Air TMCLs - Industrial (Restricted) (14)(15)	EPA Proposed Ambient Air TMCLs - Residential (Unrestricted)	Immediate Action Concentrations - TCE from OEA Memo Industrial (Restricted)	Immediate Action Concentrations - TCE from OEA Memo Residential (Unrestricted)
	Indoor Air Criteria	Indoor Air Criteria	Indoor Air Criteria	Indoor Air Criteria	Indoor Air Criteria	Indoor Air Action level	Indoor Air Action level
Constituents	ug/m^3	ug/m^3	ug/m^3	ug/m^3	ug/m^3	ug/m^3	ug/m^3
Trichloroethene	2	6.3[11]	0.37	30	0.59	8.4	2
cis-1,2-dichloroethene	-	-	-	-[16]	[16]		-
trans-1,2-dichloroethene	70	-	32	-[16]	[16]		-
Vinyl chloride	2.8	5.5[12]	0.28	28[17]	0.16[17]		-
Toluene	4,900	-	2,200	22,000	5,200		-

Air

(8) MTCA levels posted based on comparison of EPA (IRIS) and MTCA Cancer/Non Cancer criteria. Values for TCE include updated toxicity information (in IRIS) including oral cancer potency factors (CPFo's) and inhalation (CPFi's) unit risks for three types of cancer: kidney tumors, non-Hodgkin lymphoma, and liver cancer.

(9) MTCA Method C risk threshold of 10^{-5} for excess cancer risks or a Hazard Index of 1 for non-cancer risks for indoor air and industrial exposure of 24 hours/day, 350 days/year for 30 years as per the MTCA Method C assumptions.

(10) The source area of the EMF Site meets the MTCA criteria for an industrial site (WAC 173-340-200 and 173-340-345) and the regional airport is expected to remain an industrial setting for the foreseeable future.

(11) MTCA Method C (cancer-TCE) air CUL calculated using equation 750-2, a cancer risk of 10^{-5}, and a CPFi = 1.435E-02 $(mg/kg\text{-}day)^{-1}$, (sum of 3 CPFi's with no Early Life Exposure (ELE) adjustment).

(12) MTCA Method C (cancer-VC) air CUL calculated using equation 750-2, a cancer risk of 10^{-5}, and a CPF = 1.6E-02 per mg/kg-day (rather than 3.1E-02 per mg/kg-day if children and pregnant women were exposed).

(13) MTCA Method B risk threshold of 10^{-6} for excess cancer risks or a Hazard Index of 1 for non-cancer risks for indoor air.

(14) EPA Region 10 (R10) has made a risk management decision to use a 1 in 100,000 excess individual lifetime risk for cancer for workers at Boeing Plant 2. Calculations are based on the EPA Regional Screening Level (RSL) equations modified for a total risk of 1.0E-5.

(15) Ecology worker exposure was modified from full time (365 days/year x 24 hours/day) to the work week allowed under industrial soil exposure (10 hours/day x 7 days/week x 50 weeks/year).

(16) No inhalation toxicity factors are available.

(17) Vinyl chloride is considered mutagenic by EPA; its values are from the May 2012 EPA RSL Tables for residential exposure; http://www.epa.gov/reg3hwmd/risk/human/rb-concentration_table/Generic_Tables/pdf/resair_sl_table_run_MAY2012.pdf.

Table 4-2c Interim Cleanup Levels Soil

EMF COCs in Soil	MTCA Method C Industrial (Restricted) Land Use Includes CLARC Toxicity Factors [18]	MTCA Method B Residential (Unrestricted) Land Use Includes CLARC Toxicity Factors [18]	EPA RSL Industrial (Restricted) Includes Ingestion, Dermal, and Inhalation [19]	EPA RSL Residential (Unrestricted) Includes Ingestion, Dermal, and Inhalation [20]	EPA Proposed Soil TMCL to Protect All Pathways
	Soil Criteria	Soil Criteria	Soil Criteria	Soil Criteria	Soil Criteria
Constituents	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
Trichloroethene	1.7E+03	2.2E+01	1.9E+01	1.7E+00	0.05
cis-1,2-dichloroethene	7.0E+03	1.6E+02	1.0E+03	1.6E+02	2.5
trans-1,2-dichloroethene	7.0E+04	1.6E+03	1.0E+04	1.6E+03	19
Vinyl chloride	8.8E+01	6.7E-01	1.2E+01	6.0E-02	0.034
Toluene	2.8E+05	6.4E+03	2.9E+04	5.0E+03	100

Soil

(18) MTCA Method C uses WAC-173-340-745, equations 745-1 and 745-2; MTCA Method B uses WAC 173-340-740, equations 740-1 and 740-2 (Ecology 2007).

(19) EPA RSL Worker scenario has been modified to a 1 in 100,000 excess individual lifetime cancer risk and a soil ingestion rate of 200 mg/kg-day by an EPA Region 10 risk management decision.

(20) EPA RSL calculations using EPA toxicity factors and exposure parameters as presented in http://www.epa.gov/reg3hwmd/risk/human/rb-concentration_table/usersguide.htm

5.0 Identification and Analysis of Removal Action Alternatives

Based on the objectives defined in the NCP (40 CFR § 300.415), the purpose of an EE/CA is to analyze potential Removal Action Alternatives to address contamination present at the Site. The alternatives are evaluated and developed through the criteria suggested in the NCP and EPA guidance documents (EPA, 1993). More specifically, the Removal Action Alternatives have been developed and analyzed separately against the RAOs and evaluation criteria. Evaluation criteria are presented in Section 5.2.

The alternatives are screened in Section 5.3 based on multiple criteria consisting of Effectiveness categories, Implementability categories, and Cost. Cost estimates for all removal action alternatives are summarized in Section 5.3 and presented in detail in Attachment B. Section 5.3 presents further details on the recommended removal action.

Voluntary remedial actions have been implemented throughout the EMF site for the last 17 years. The remedial actions have included several stages/sequences in different areas of the source/plume footprint. Initial groundwater remediation efforts began in 1997 with the installation of an In Well Stripping (IWS) system in the source area of the EMF property. Expanded source-area treatment has included in-situ chemical oxidation (ISCO) in a portion of the EMF property (completed in 2000 and 2001). Biological treatment through enhanced reductive dechlorination (ERD) has been implemented in the source area and throughout the plume (starting as a pilot test in late 2003 and expanded throughout the plume between 2005 and 2014). The remedial actions implemented include several different remedial technologies including aggressive source-area treatment and plume-wide treatment.

Most alternatives evaluated in this EE/CA include an active phase followed by a monitored natural attenuation (MNA) phase. As presented in this EE/CA , the selected alternatives for the decisions moving forward are single technology approaches (coupled with MNA in later project years). In reality, all alternatives represent multiple technologies because of the prior work already implemented throughout the site (as part of the existing voluntary cleanup actions). Further consideration of dual-technology approaches are not presented in this EE/CA due to:

1. Multiple treatment technologies have already been implemented and all alternatives presented in this EE/CA represent the combined application of multiple technologies.
2. Specific technologies such as In-Situ Air Sparging and In-Well Stripping introduce oxygen to the groundwater and the oxidizing conditions would have a negative impact on the performance an enhanced reductive dechlorination alternative (an anaerobic process).
3. The enhanced reductive dechlorination alternative is an anaerobic process and can cause increased ferrous iron concentrations (although the entire Duwamish Valley has been documented to have naturally high iron levels). Experience has demonstrated that technologies which introduce dissolved oxygen (such as In-Situ Air Sparging and In-Well Stripping) will immediately create iron precipitates which may plug/foul the treatment wells. Combining these technologies could have a negative impact on the performance either approach.

Performance monitoring from past and current remedial actions has provided data to allow for optimization of remedial actions. All planned and future actions will be implemented in a similar manner and it is expected that the selected alternative implemented will be modified/optimized as performance monitoring data dictate.

As discussed in section 3 (Nature and Extent of Contamination), the soil sampling completed within the EMF property has been previously summarized in the Historical Data Summary Report (CALIBRE 2008). Most of the sampling was completed as part of the 1997 MTCA RI and the soil sampling was focused on vadose zone soil (above the water table). All areas with soil exceeding the MTCA criteria (using a default residential exposure scenario) were excavated and removed in the 1997 MTCA remedial actions. Additional soil samples were collected later with well installation (as part of the MTCA remedial action). These added soil samples were in the DNAPL source area and were collected at depths 25 to 40 ft below ground surface (saturated zone soil samples). The ongoing remedial actions in this area (and all active alternatives considered in this EE/CA) are addressing the TCE residues in this area (treating both groundwater and soil which are in equilibrium in the saturated zone). The removal actions proposed in this EE/CA will address the RAOs for both soil and groundwater in this area.

5.1 Removal Action Objective

The objective for removal activities at this site is to protect human health and the environment by reducing concentrations of chemicals of concern to levels below applicable ARARs. Any removal actions undertaken at this site will encounter access challenges based on current land use (an active airport) and existing infrastructure. The site encompasses active runways servicing commercial, private, and occasionally military planes. Access is not available in the runway and buffer areas; there is intermittent access to the apron areas. The primary objective is the protection of the Duwamish Waterway where the plume discharges to the Waterway.

5.2 Development of Removal Action Alternatives

Prior to evaluating individual technologies for this EE/CA, varying removal approaches were considered including; an in-situ treatment technology, a plume-containment technology, and extraction technology. For in-situ technologies two choices were considered; in-situ chemical oxidation (ISCO) and Enhanced Reductive Dechlorination (ERD), the ISCO technology was rejected as current concentrations of VOCs in groundwater are low enough to preclude efficient use of this technology. In addition, relevant experience within the Duwamish Valley aquifer (both at the EMF site and other nearby sites) has demonstrated that the natural oxidant demand soil matrix is quite high and this condition limits the effectiveness of ISCO approaches. The ERD technology also has been/currently being used on various other sites in the near vicinity with success.

For the plume containment type approaches, the options included both in-well air stripping (IWS) and permeable treatment barriers. Preliminary comparisons precluded the use of a permeable treatment barrier due to access constraints and current land use (an active airport). Plume extraction technologies considered included pump and treat extraction and in-situ air sparging/soil vapor extraction. The pump and treat technology was rejected due to the infrastructure required to successfully deploy the technology for a VOC plume of this size given the access and logistical restrictions of this property.

For the purposes of this EE/CA a recent date was chosen to use as the “current plume condition” (based on the EMF plume conditions at the end of the data gaps investigation). The first draft of this EE/CA was submitted in late 2012. Since that time ongoing voluntary remediation efforts have continued to reduce VOC concentrations in the groundwater plume and most recent data reflect conditions as of February 2014. In order to allow for a rational comparison of technology alternatives, each of the alternatives is applied at the target treatment areas based on the date (and corresponding groundwater data) selected as the “current plume conditions”. Each alternative analyzed with the exception of No Action, is expected to transition to Monitored Natural Attenuation (MNA) phase once COC concentrations in groundwater have decreased to levels where remediation is not cost effective. In order to provide a consistent comparison of alternatives, the EE/CA assumes seven years of active remediation using the specified technology (with monitoring during this seven-year period), followed by six years of monitoring. The actual duration of active treatment and monitoring may change depending on the effectiveness and future conditions encountered during removal operations.

The EE/CA also assumes that each alternative is applied at each target treatment area based on the “current plume conditions”. The target treatment areas are based on expected actions required to meet the RAOs, and the target treatment areas are applied consistently for each alternative considered. Conditions are expected to change as the project progresses and the final treatment areas/configurations may change as conditions change (due to continued voluntary remedial actions). Each alternative considers the same treatment areas and current/future changes in the VOC plume will not impact the relative comparison between alternatives for the EE/CA (each alternative considers the areas requiring treatment consistently). Performance monitoring has been used for optimization of the remedial actions and all planned/future actions will be implemented in a similar manner.

For each alternative it is expected that Institutional Controls (ICs) will be required. The ICs would include the implementation of Deed Restrictions to establish land-use restrictions and Five-Year Reviews throughout the project duration. For the purpose of the EE/CA cost estimates, three Five-Year reviews are included in the project life-cycle costs.

5.2.1 No Action

The No-Action alternative is a scenario where no site activities are performed either in remediation efforts or in compliance monitoring. This alternative does not provide added protection to human health or the environment and is included for the purpose of relative comparison with the alternatives.

5.2.2 Monitored Natural Attenuation

For the Monitored Natural Attenuation alternative, no active remediation efforts would be implemented and the site would be continued to be monitored for natural attenuation of the chemicals present. For the purposes of this analysis, a period of 13 years is used for monitoring to be generally consistent with the other alternatives evaluated. However, if this alternative were selected it would may require a longer duration when compared to the other alternatives. For this EE/CA comparison, each alternative was considered to have a 13-year life cycle. For this estimate, an assumed 55 wells would be sampled annually with an additional 5 quality assurance samples, for a total of 60 samples. All monitoring wells would be sampled for volatile organic compounds and select wells for natural attenuation parameters such as dissolved gases and iron. For the MNA alternative the only capital costs include the installation of an estimated ten new monitoring wells (specific locations have not been identified but some new wells may be needed).

Institutional Controls (ICs) will be required for this alternative. The ICs would include the implementation of Deed Restrictions to establish land-use restrictions and Five-Year Reviews throughout the project duration. The MNA alternative, coupled with appropriate ICs, is expected to meet the RAOS (partially because of the prior actions already implemented).

5.2.3 In-situ Air Sparging with Soil Vapor Extraction (IAS/SVE)

This alternative involves treatment of groundwater by in-situ air sparging (IAS) using air injection wells and soil vapor extraction (SVE) using vapor extraction wells with treatment of the off gas using vapor-phase granular activated carbon (GAC) and other media (zeolite impregnated with permanganate). The vapor phase zeolite treatment (permanganate) is used to oxidize the highly volatile chemicals that GAC is less effective at adsorbing.

The IAS/SVE system operates by blowing air into the groundwater via air-sparge wells, the air then bubbles through the porous media and volatile compounds volatilize from the water into a vapor phase (in the bubbles). The vapors are then extracted with the SVE vent wells and treated in above-ground processes.

Assuming treatment is required at each accessible area within the EMF plume, air sparge (injection) wells would be installed across that portion of the plume at the EMF property, the Fire Station, an area in the 2-40 parking lot, and an area in the location of the former 2-41 Building. The air sparge wells would be installed approximately 40 feet below ground surface (bgs) at the EMF site and 50 ft bgs at the Fire Station and 2-40/2-41 areas. The SVE vent wells would be installed in the vadose zone at approximately 10 ft bgs. One hundred three (103) air sparge wells are included along with another 103 SVE wells. The estimate of 206 wells (103 air sparge wells and 103 SVE wells) is based on observed soil conditions at the site and professional experience resulting in a radius of influence of approximately 20 feet, see Figures 5-1 and 5-2 for assumed well locations. SVE wells would be constructed using 4-inch PVC and sparge wells would be constructed with 2-inch PVC. In order to operate the IAS/SVE wells it is assumed 11 equipment packages would be required, with each equipment system operating no more than 12 wells. One equipment system would be placed in the 2-41 and 2-40 areas, two at the Fire Station area, and seven at the EMF area.

Required air handling and treatment equipment would be housed in semi-permanent structures (portable trailers with power service). Injection air would be provided to the wells using positive-displacement blowers and air would be extracted from the wells using blowers. Air would be conveyed to and from the wells through underground piping. Off-gas from each SVE system would be treated using two 1,800-pound capacity GAC adsorbers operated in series, followed by two 700-pound capacity permanganate media vessels, also in series after each equipment package. The GAC and permanganate media vessels would be located in a structure near the equipment packages for each system. After vapor treatment (VOC removal), the air would be discharged to the atmosphere through a stack.

For the purposes of this EE/CA the estimated project duration for IAS/SVE operation would be seven years with an additional six years of monitoring after the IAS/SVE systems were shutdown. The actual operating duration may differ from this estimate but for the purposes of comparison, all alternatives in this evaluation have been adjusted to the same project duration. Lower capital costs could potentially be achieved through sequential treatment at each area with fewer equipment packages. However, the project duration would substantially increase with a phased approach.

O&M requirements for this alternative would include the following:

- Process monitoring of off gas;
- Compliance monitoring of groundwater potentially including the installation of (an) additional MW(s) as necessary to provide bounding data;
- Preparation and submission of monitoring reports;
- Periodic inspections, repairs, and adjustments;
- Replacement and disposal of spent GAC and permanganate media.

Institutional Controls (ICs) will be required for this alternative. The ICs would include the implementation of Deed Restrictions to establish land-use restrictions and Five-Year Reviews throughout the project duration. The IAS/SVE alternative, coupled with appropriate ICs, is expected to meet the RAOs.

5.2.4 In-well Stripping

This alternative involves treatment of groundwater by in-well stripping (IWS) using recirculating wells with treatment of off gas from the wells using vapor-phase GAC and permanganate-impregnated media.

The recirculating well technology operates as an in-well stripping system. Recirculating wells are installed with two well screen intervals; one screen is below groundwater level and serves as the release point for the injected airflow (still contained with the well casing). The second screen interval is typically within the vadose zone and serves as the return for groundwater flow that is pumped up the well via the pressure differential created by bubbling water near the lower screen interval. Based on Henry's law, the bubbled water within the well column removes a portion of the volatiles within the groundwater phase into a vapor phase. The wells are under vacuum and the vapors are then removed and treated in an above-ground equipment package (typically). The VOCs vapor are removed and treated using both granulated activated carbon and permanganate impregnated zeolite. The vapor phase zeolite treatment (permanganate) is used to oxidize the highly volatile chemicals that GAC is less effective at adsorbing.

For this alternative, recirculating wells would be installed across that portion of the plume at the EMF property, the Fire Station, in an area of the 2-40 parking lot and in an area of the former 2-41 Building containing VOCs in excess of cleanup standards. Fifty-eight (58) recirculating wells are included based upon an assumed radius of influence of 30 feet per well, see Figures 5-3 and 5-4 for well locations. The IWS wells would be installed to a depth of 40 ft at the EMF area and 50 ft at the Fire Station and 2-40/2-41 areas. These wells would be installed with extraction screens located at the bottom of the plume. Recharge screens would be located within infiltration galleries installed in the vadose zone. The infiltration galleries would be constructed by excavating the native soil from around the well and backfilling with coarse material (e.g., pea gravel). The infiltration galleries would increase the infiltration capacity and enhance the recharge capacity of the wells. The infiltration galleries would be covered with pavement and the well head would be completed below grade in a flush-mount vault. Equipment packages servicing wells are required and are expected to be capable of operating no more than 12 wells per package, resulting in one equipment system at the 2-41 and 2-40 parking lot areas, one at the Fire Station, and 3 at the EMF area. Addition of chemicals at the well head may be required in order to control iron fouling. Bench-scale tests would be performed during detailed design in order to determine the required chemicals and dosage.

Required air handling and treatment equipment would be housed in semi-permanent structures (enclosed equipment trailers with power service). Injection air would be provided to the wells using positive-displacement blowers and air would be extracted from the wells using blowers. Air would be conveyed to and from the wells through underground piping. Off-gas would be treated using two 1,800-pound capacity GAC adsorbers operated in series, followed by two 700-pound capacity permanganate media vessels, also in series after each equipment package. The GAC and permanganate media vessels would be located in a structure nearby the blower equipment packages. After treatment, the air would be discharged to the atmosphere through a stack.

For the purposes of this analysis, estimated project duration for IWS operation would be seven years with an additional six years of monitoring after the IWS systems were shutdown. The actual required duration may differ from this timeline but for the purposes of comparison, all alternatives in this evaluation have been adjusted to the same project duration periods.

O&M requirements for this alternative would include the following:

- Process monitoring of off gas;
- Compliance monitoring of groundwater potentially including the installation of (an) additional MW(s) as necessary to provide bounding data;
- Preparation and submission of monitoring reports;
- Periodic inspections, repairs, and adjustments;
- Replacement and disposal of spent GAC and permanganate media;
- Supply of iron control chemicals.

Institutional Controls (ICs) will be required for this alternative. The ICs would include the implementation of Deed Restrictions to establish land-use restrictions and Five-Year Reviews throughout the project duration. The IWS alternative, coupled with appropriate ICs, is expected to meet the RAOs.

5.2.5 Enhanced Reductive Dechlorination

Enhanced reductive dechlorination (ERD) is an in-situ technology for the removal action based on the prior experience at this site. Anaerobic reductive dechlorination is a naturally occurring biodegradation process whereby microbes can degrade chlorinated VOCs in groundwater. The process name of reductive dechlorination comes from the method by which these reactions strip chlorine atoms from VOC molecules. To facilitate their respiration while they metabolize available carbon-energy source material, microbes must utilize electron acceptors. As electron acceptors are depleted, the groundwater environment becomes increasingly reduced (lower oxidation-reduction potential [ORP]) and the microbes are forced to use alternative electron acceptors, ultimately using the chlorinated compounds as the electron acceptor.

In order to promote increased bioactivity a series of groundwater injection wells are required throughout the portion of the plume at the EMF property, Fire Station area, and areas of Plant 2 with VOCs in groundwater above ARARs. These wells would serve to inject substrate to groundwater. The bulk of these wells have been installed and are presently in use as part of the existing voluntary cleanup actions. Additional wells may be necessary in selected areas. Injection wells would be constructed of 4-inch PVC to the targeted injection depths, see Figures 5-5 thru 5-7 for well locations. An organic carbon source (a substrate solution) would be injected periodically throughout the plume to maintain reducing conditions in groundwater. Substrate injection equipment would be mobilized to the site prior to each injection event and removed after the completion of each event. For the purposes of this analysis, a project duration of seven years is used (for consistency in comparison with other alternatives), with six years of monitoring to be completed after the final year of injections.

The actual operating duration for ERD injections would be determined based on performance monitoring and may be shorter than seven years (at least in portions of the plume) based on the prior actions started over the last several years. Initially substrate injections will occur at an interval of once per year. However, injection frequency may be modified, based on results of groundwater quality sampling and with agreement from the agencies, to optimize the efficiency of the treatment and adhere to a desirable removal timeline.

The O&M requirements for this alternative would include the following:

- Completion of substrate injections events;
- Completion of bio-augmentation (where necessary) as part of remedial optmimization in accordance with an EPA approved work plan;
- Compliance monitoring of groundwater potentially including the installation of (an) additional MW(s) as necessary to provide bounding data;
- Preparation and submission of biannual groundwater monitoring reports including a calculation of degradation rate constant.

Institutional Controls (ICs) will be required for this alternative. The ICs would include the implementation of Deed Restrictions to establish land-use restrictions and Five-Year Reviews throughout the project duration. The ERD alternative, coupled with appropriate ICs, is expected to meet the RAOs (existing performance data are available).

Boeing wants to conduct bio-augmentation using EMF Site groundwater as part of the anticipated remedial optimization. A work plan has been prepared and submitted to EPA related to this work element (CALIBRE 2015). EPA has indicated that the extracted groundwater contains a listed waste and must be managed accordingly (meet the requirements under RCRA Subtitle C). There are multiple regulatory options available to evaluate and manage groundwater associated with treatment and re-injection (for bio-augmentation) at the EMF site. The options include:

1) Boeing petitions EPA for delisting groundwater (environmental media) that meets current drinking water standards.
2) Contained-out determination by EPA.
3) RCRA Section 3020(b) Exemption for Reinjection of Contaminated Ground Water; this requires a conversion of existing Class V wells to Class IV injection wells (within the UIC registration program).

Each of these options are summarized below and described/evaluated in more detail in the draft work plan.

Delisting a CERCLA/RCRA remediation waste (and thus removing it from regulation under RCRA Subtitle C) is an EPA recommended option (EPA 1990) for addressing wastes or treatment residuals containing hazardous constituents in low concentrations (i.e., at or near health-based levels). Delisting requires a demonstration that a listed waste, or a mixture containing listed hazardous wastes, no longer meets any of the criteria under which the waste was listed and no other factors are known that would make the waste hazardous. In order to implement this option, Boeing would prepare a delisting petition pursuant to the substantive requirements of 40 CFR 260.20 and .22. All proposed actions for the EMF site are on-site response actions so meeting the substantive requirements should be sufficient. Pending EPA's acceptance of this approach and subsequent review and approval of the delisting petition, the delisting may be granted when the EPA issues the CERCLA decision document.

In a contained-out determination, EPA (or an authorized State) determines that the low levels of listed wastes remaining in the environmental media no longer require regulation under RCRA (this is sometimes called a *no longer contain-in* determination). Contained-out determinations are site-specific and EPA generally makes conservative assumptions based on residential or unrestricted exposure. EPA cannot make a contained-out determination for the EMF project until after a decision memorandum is finalized.

RCRA Section 3020(a) bans the disposal of hazardous waste by underground injection into a formation which contains an underground source of groundwater within one-quarter mile of the injection well. Section 3020(b) exempts reinjection of treated contaminated groundwater from the Section 3020(a) ban (and the land disposal restrictions, LDRs) if:

1) The reinjection is a CERCLA response action, or part of a RCRA corrective action remedy, intended to clean up the contamination;
2) The contaminated groundwater is treated to substantially reduce hazardous constituents prior to such reinjection, and
3) The response action or corrective action is part of a legitimate effort to cleanup contamination and is sufficient to protect human health and the environment upon completion.

An exemption can be considered and granted if EPA has a basis to determine that the three criteria listed above are satisfied. Re-injection of treated listed waste contaminated water pursuant to a RCRA Section 3020(b) exemption would change the injection wells to Class IV wells.

All of the options listed above (delisting, contained-out determination, and Section 3020[b] exemption) meet the ARARs. Depending on other EPA policy directions and schedule, Boeing is prepared to initate one or more of these options at EPA's direction.

5.3 Comparative Analysis of Alternatives

The criteria which are used to evaluate and compare Removal Action Alternatives in an EE/CA are defined in the NCP and associated EPA guidance documents. The three general evaluation criteria are Effectiveness, Implementability, and Cost. The specific components of the criteria are defined as follows:

4) Effectiveness Evaluation
    - Overall Effectiveness;
    - Protection of Human Health;
    - Protection of the Environment;
    - Compliance with ARARs;
    - Short-term Effectiveness;
    - Long-term Effectiveness; and
    - Reduction in Toxicity, Mobility, and Volume of Waste.

5) Implementability Evaluation
    - Overall Implementability;
    - Technical Feasibility;
    - Administrative Feasibility;
    - Availability of Services and Materials; and
    - Community Acceptability.

6) Cost Evaluation
    - Capital Cost; and
    - Operation and Maintenance Cost.

The following sections provide the details of the comparative analysis of each removal alternative based on the established criteria. In order to develop a comparative ranking, each criterion is assigned a relative score from 0 to 5; with a score of 0 reflecting a very low score and 5 a very high score. In some cases different alternatives may be given the same score for a specific criterion, administrative feasibility for instance. To compare and evaluate the alternatives, each individual criterion is scored and summed under the three primary criteria categories; Total Effectiveness, Implementability, and Total Cost. This approach assumes that within each of the three general categories (Effectiveness, Implementability and Cost) each of the sub-criterion are equally weighted. The scoring of the Cost Evaluation is provided as a single score/rank including the sum of historic costs, new capital costs and future costs (converted to a net present) value) rather than a score/rank for each sub- criterion. Tabular data provide a breakdown of these cost elements for each alternative.

The sum of these scores is intended to assist in a decision making process on a preferred alternative. A higher total score (a numerical number) reflects a higher comparative ranking (i.e., a preferred remedy based on the required criteria).

This section provides a summary of the evaluation findings and Section 5.4 presents a recommended removal action alternative based on the comparative ranking.

5.3.1 No Action Evaluation

Overall Effectiveness

The overall effectiveness rating for the no-action alternative is zero (0); this alternative does not provide any reduction of chemical constituents other than that which occurs naturally. In addition without monitoring, any reductions that may occur naturally will not be recorded. As such, this alternative is also scored at zero (0) for protection of human health and protection of the environment (although natural degradation is occurring, no monitoring to verify is included in this no-action alternative). This alternative is also scored at zero (0) for Compliance with ARARs and Short-term Effectiveness. This alternative is scored at two (2) for long-term effectiveness as natural attenuation will slowly reduce VOC concentrations and scored at one (1) for the Reduction on Toxicity, Mobility, and Volume of Waste. The no-action alternative does not actively treat the concentrations and relies solely on existing attenuation processes which may be a long process for this site (assuming that existing remedial actions were to be discontinued).

Table 5-1 Scoring of No-Action Alternative in the Effectiveness Category

Criteria	**Score**
Overall Effectiveness	0
Protection of Human Health	0
Protection of the Environment	0
Compliance with ARARs	0
Short-term Effectiveness	0
Long-term Effectiveness	2
Reduction in Toxicity, Mobility, and Volume of Waste	1
Total Effectiveness Score	3

Implementability

The overall Implementability for the no-action alternative scores high; solely because it does not require any additional construction activities or monitoring. The technical feasibility score for this alternative is scored at one (1); it is unlikely that the no-action alternative is acceptable. The administrative feasibility score is low at one (1); it is assumed that a no-action alternative would be difficult to justify. The score for the Community Acceptability will be determined by EPA during the public review process.

Table 5-2 Scoring of No-Action Alternative in the Implementability Category

Criteria	Score
Overall Implementability	5
Technical Feasibility	1
Administrative Feasibility	1
Availability of Services and Materials	5
Community Acceptability	TBD[1]
Implementability Total	12

Note: TBD = to be determined.

Cost Analysis

The new capital costs associated with this alternative are assumed to be zero ($0); as stated no actions or monitoring would be taken.

Table 5-3 No-Action Alternative Estimated Costs Summary and Scoring

Criteria	Estimated Cost	Score
Historic Costs (prior remedial actions)	$4,324,559	---
Capital Cost	$0	---
Operations and Maintenance	$0	---
Institutional Controls	$0	---
Cost Analysis Total	$4,324,559	5

5.3.2 Monitored Natural Attenuation

Overall Effectiveness

The overall effectiveness rating for the MNA alternative is two (2); this alternative provides the slowest method of removing the constituents of concern. This alternative also is scored at two (2) for protection of human health and protection of the environment. This alternative is scored at one (1) for the remaining effectiveness criteria (Compliance with ARARs, Short-term Effectiveness, and Reduction on Toxicity, Mobility, and Volume of Waste). This alternative is scored at two (2) for long-term effectiveness VOC concentrations will be reduced (via natural attenuation). The MNA alternative does not actively reduce concentrations and relies on existing attenuation processes which may be a long process for this site (assuming that all existing remedial measures were to be discontinued).

Table 5-4 Scoring of MNA Alternative in the Effectiveness Category

Criteria	**Score**
Overall Effectiveness	2
Protection of Human Health	2
Protection of the Environment	2
Compliance with ARARs	1
Short-term Effectiveness	1
Long-term Effectiveness	2
Reduction in Toxicity, Mobility, and Volume of Waste	1
Total Effectiveness Score	11

Implementability

The overall Implementability for the MNA alternative scores high at five (5) , the site would not require any additional removal construction activities. The site includes an extensive monitoring well network in place that would require periodic monitoring until site concentrations fall below the ARARs. The technical feasibility score for this alternative is scored at two (2), as a result of the longer timeline required for VOC concentrations to meet ARARs. The administrative feasibility score is higher, four (4), as the site currently is being monitored. The score for the Community Acceptability will be determined by EPA during the public review process.

Table 5-5 Scoring of MNA Alternative in the Implementability Category

Criteria	**Score**
Overall Implementability	5
Technical Feasibility	2
Administrative Feasibility	4
Availability of Services and Materials	5
Community Acceptability	TBD[1]
Implementability Total	16

Note: TBD = to be determined.

Cost Analysis

The capital costs associated with this alternative include the installation of 10 new monitoring wells, these new wells have been included in the costs for all alternatives. For this alternative the capital costs total is $44,022. As stated previously there is an extensive monitoring well network currently in place bounding the EMF plume. These existing wells would be used to monitor VOC concentrations until ARARs are achieved. The monitoring and maintenance costs for this alternative are estimated at $71,610 per year ($683,567 as a net present value including periodic replacement costs), this estimate is based on a monitoring duration of 13 years. In addition to monitoring and maintenance, Institutional Controls will be put in place. The ICs are estimated at $91,553 (as a net present value) for the project life cycle.

A detailed cost estimate for this alternative is presented in Attachment B.

Table 5-6 MNA Alternative Estimated Costs Summary and Scoring

Criteria	Estimated Cost	Score
Historic Costs (prior remedial actions)	$4,324,559	---
Capital Cost	$44,022	---
Monitoring and Maintenance (as NPV)	$683,567	---
Institutional Controls (as NPV)	$91,553	---
Cost Analysis Total	$5,143,700	4

5.3.3 In-situ Air Sparging with Soil Vapor Extraction Evaluation

Overall Effectiveness

The IAS/SVE alternative has an overall effectiveness rating of three (3); this alternative provides protection to human health and the environment by removing VOCs from groundwater. This alternative may take longer than the IWS alternative to remove VOCs concentrations in groundwater resulting in the lower score for short-term effectiveness (2). Long-term this alternative will reduce concentrations and should result in effectively reducing concentrations to ARAR levels resulting in a score of four (4). This alternative is scored at three (3) for the reduction of toxicity, mobility, and volume of wastes. Introduction of air into the aquifer is likely to slow natural anaerobic degradation processes in the vicinity of (and down gradient of) the air sparging wells. A portion of the plume lies under the active runway with no access, full treatment is dependent on groundwater velocities and the plume migration to the accessible treatment area.

Table 5-7 Scoring of IAS/SVE Alternative in the to Effectiveness Category

Criteria	Score
Overall Effectiveness	3
Protection of Human Health	3
Protection of the Environment	3
Compliance with ARARs	3
Short-term Effectiveness	2
Long-term Effectiveness	4
Reduction in Toxicity, Mobility, and Volume of Waste	3
Total Effectiveness Score	21

Implementability

The overall Implementability for the IAS/SVE alternative is scored at three (3). The technical feasibility is scored at three (3); this is a proven technology that has been used successfully on other sites however the large nature of this site and the presence of an area that will not allow access for treatment wells precludes a higher score. Due to the size of this site and current operations (an active airport), the administrative feasibility is scored at two (2). Current operations in the area include daily loading and unloading of cargo airplanes, an active and busy runway, and the Boeing Fire Station (used for emergency response). With these constraints, it may prove difficult to place all wells and equipment packages where needed. For the Availability of Services and Materials criteria this alternative scored a four (4); drilling and construction services are available and the IAS/SVE systems are a common equipment package with different options available.

The score for the Community Acceptability will be determined by EPA during the public review process.

Table 5-8 Scoring of IAS/SVE Alternative in the Implementability Category

Criteria	Score
Overall Implementability	3
Technical Feasibility	3
Administrative Feasibility	2
Availability of Services and Materials	4
Community Acceptability	TBD[1]
Implementability Total	12

Note: TBD = to be determined.

Cost Analysis

The capital costs associated with this alternative have been estimated at $3.8 million ($3,847,450), as stated previously there is an extensive monitoring well network currently in place bounding the EMF plume. These existing wells would be used to monitor VOC concentrations until ARARs are achieved. New construction would also be required, for the purpose of this estimate, it is assumed 103 air sparge wells and 103 soil vapor extraction wells would be required. Additional costs for 10 new monitoring wells have been included (specific locations have not been defined but some may be necessary).

In addition to the well drilling, eleven equipment systems would be required; seven at the EMF source area, two at the Fire Station area, one at the 2-40 parking lot area, and one near the former 2-41 area. All equipment packages consist of a positive displacement blower system used for the IAS injection and regenerative blower system that is used to induce the vacuum for the SVE lines, a moisture knockout drum, process control systems, and off-gas treatment vessels.

The Operations and Maintenance and monitoring for this alternative are estimated to start at $537,938 per year, reduce in later years and result in a net present value of $3,420,321 over the estimated project duration of 13 years (this includes 7 years of O&M plus monitoring followed by an additional 6 years of monitoring). Operations and Maintenance for these systems include costs for power to run the equipment systems, replacement costs for GAC/other media, routine inspections of the equipment including various repairs to equipment, compliance monitoring on a semi-annual basis, and periodic reporting. In addition to monitoring and maintenance, Institutional Controls will be put in place. The ICs are estimated at $91,553 (as a net present value) for the project life cycle.

Further details for this cost estimate are provided in Attachment B.

Table 5-9 IAS/SVE Alternative Estimated Costs Summary and Scoring

Criteria	Estimated Cost	Score
Historic Costs (prior remedial actions)	$4,324,559	---
Capital Cost	$3,847,450	---
Monitoring and Maintenance (as NPV)	$3,420,321	---
Institutional Controls (as NPV)	$91,553	---
Cost Analysis Total	$11,683,882	2

5.3.4 In-well Stripping

Overall Effectiveness

The IWS alternative has an overall effectiveness rating of three (3); this alternative provides protection to human health and the environment by effectively removing VOCs from groundwater. This alternative is expected to be more effective at reducing VOC concentrations than the IAS/SVE and No-Action alternatives, resulting in a slightly higher score. This alternative has a short-term effectiveness score of three (3), the alternative is effective at removing constituents but will take a period of time before significant VOC reductions occur. The long-term effectiveness is scored at three (3). This technology is proven and will successfully reduce VOC concentrations in the area treated. A portion of the plume lies under the active runway with no access, full treatment is dependent on groundwater velocities and the plume migration to the accessible treatment area.

This alternative is scored at four (4) for the categories of protection of human health, protection of environment, and compliance with ARARs. For this EE/CA, the IWS technology is scored at three (3) for the reduction of toxicity, mobility, and volume of waste due to the limited accessibility to the plume as previously stated. This technology is effective at treating concentrations within a specific area of influence, but does not provide a means to effectively treat VOCs present under the runway area. The IWS process adds dissolved oxygen into the groundwater which is likely to slow natural anaerobic degradation processes in the vicinity of (and down gradient of) the IWS wells.

Table 5-10 Scoring of IWS Alternative in the Effectiveness Category

Criteria	**Score**
Overall Effectiveness	3
Protection of Human Health	4
Protection of the Environment	4
Compliance with ARARs	4
Short-term Effectiveness	3
Long-term Effectiveness	3
Reduction in Toxicity, Mobility, and Volume of Waste	3
Total Effectiveness Score	24

Implementability

The overall Implementability for the IWS alternative is scored as three (3). The technical feasibility is scored as three (3); this is a proven technology that has been used successfully at other sites however the large nature of this site and the presence of an area that is inaccessible for treatment wells precludes a higher score. Due to the size of this site and current activities, the administrative feasibility is scored slightly lower at two (2). This area has many current operations including the daily loading and unloading of cargo airplanes, an active and busy runway, and the Boeing Fire Station (used for emergency response). With these constraints it may prove difficult to place all wells and equipment packages where needed. For the Availability of Services and Materials criteria this alternative is scored at four (4); drilling and construction services are available and the IWS systems are standard equipment package with different options available.

The score for the Community Acceptability will be determined by EPA during the public review process.

Table 5-11 Scoring of IWS Alternative in the Implementability Category

Criteria	Score
Overall Implementability	3
Technical Feasibility	3
Administrative Feasibility	2
Availability of Services and Materials	4
Community Acceptability	TBD[1]
Implementability Total	12

Note: TBD = to be determined.

Cost Analysis

The capital costs associated with this alternative have been estimated at $2.1 million ($2,106,106), as stated previously there is an extensive monitoring well network currently in place bounding the EMF plume. These existing wells would be used to monitor VOC concentrations until ARARs are achieved. New construction would also be required. For the purpose of this estimate it is assumed 58 in-well stripping wells would be installed. Additional costs for 10 new monitoring wells have also been included (specific locations are unknown but some may be necessary).

In addition to the well drilling, multiple equipment systems would be required; three (minimum) at the EMF source area, one at the Fire Station area, one at the 2-40 parking lot area, and one in the area of the former 2-41 building. Each equipment package would consist of a positive displacement blower system used for the injected air supply, a regenerative blower used to induce the vacuum return from the wells, a moisture knockout drum, process control systems, and two vapor GAC vessels connected in series and permanganate impregnated zeolite vessels.

The Operations and Maintenance and monitoring for this alternative are estimated at $316,557 per year, reduce in later years and result in a net present value of $2,119,739 over the estimated project duration of 13 years (this includes 7 years of O&M plus monitoring followed by an additional 6 years of monitoring). Operations and Maintenance for these systems include costs for power to run the equipment systems, replacement costs for GAC, routine inspections of the equipment including various repairs to equipment, compliance monitoring on a semi-annual basis, and periodic reporting. In addition to monitoring and maintenance, Institutional Controls will be put in place. The ICs are estimated at $91,553 (as a net present value) for the project life cycle.

Further details for this cost estimate are provided in Attachment B.

Table 5-12 IWS Alternative Estimated Costs Summary and Summary

Criteria	Estimated Cost	Score
Historic Costs (prior remedial actions)	$4,324,559	---
Capital Cost	$2,106,106	---
Monitoring and Maintenance (as NPV)	$2,119,739	---
Institutional Controls (as NPV)	$91,553	---
Cost Analysis Total	$8,641,957	3

As noted in Section 2.4, IWS was initially implemented to treat groundwater at the source area at the EMF property. Although IWS was found to be effective in removing VOCs from source areas, it is expected to be much less efficient in treating lower levels of VOCs that are now present in the plume. By 2005, IWS operation at the EMF property was terminated in favor of ERD.

5.3.5 Enhanced Reductive Dechlorination

Overall Effectiveness

The ERD alternative has an overall effectiveness score of four (4); this alternative provides protection to human health and the environment by effectively destroying VOC concentrations in soil and in groundwater. This alternative has been demonstrated to be effective at this site based on results from the existing voluntary remedial actions. This technology has also been proven to be effective at reducing VOC concentrations to non-detect levels. In contrast, the other technologies may not achieve these levels (near non-detect) or the efficiency of systems is drastically reduced at the lower concentrations. This alternative is scored at four (4) for the short-term effectiveness (the prior voluntary actions at the site have already implemented this remedy).

Long-term effectiveness for this technology is scored at four (4); the treatment technology is demonstrated in the site-specific conditions. This alternative is scored at four (4) for the reduction of toxicity, mobility, and volume of waste. The biological treatment process reduces concentrations of TCE and daughter products and this alternative generates virtually no waste during the treatment process (an in-situ technology).

Table 5-13 Scoring of ERD Alternative in the Effectiveness Category

Criteria	**Score**
Overall Effectiveness	4
Protection of Human Health	4
Protection of the Environment	4
Compliance with ARARs	4
Short-term Effectiveness	4
Long-term Effectiveness	4
Reduction in Toxicity, Mobility, and Volume of Waste	4
Total Effectiveness Score	28

Implementability

The overall Implementability for the ERD alternative is scored as five (5). The ERD alternative scores high because the majority of the system is currently in place, even if this were not the case the nature of this technology requires minimal infrastructure in comparison to the other alternatives (with the exception of MNA and No Action). Injection wells are the only permanent portion of the system, injection equipment is mobilized and demobilized for each injection event providing an alternative that does not disrupt ongoing site activities (within an active airport).

This technology scores high in all criteria in the Implementability category based on the limited infrastructure that is required and the ability to mobilize equipment solely for injection events. The Community Acceptability will be determined by EPA during the public review process.

Table 5-14 Scoring of ERD Alternative in the Implementability Category

Criteria	Score
Overall Implementability	5
Technical Feasibility	5
Administrative Feasibility	5
Availability of Services and Materials	5
Community Acceptability	TBD[1]
Implementability Total	20

Note: TBD = to be determined.

Cost Analysis

The capital costs associated with this alternative are estimated at approximately two hundred thousand ($199,884). As noted previously, an extensive monitoring well network is currently in place bounding the EMF plume and these existing wells would be used to monitor VOC concentrations until ARARs are achieved assuming that the plume does not change shape, direction, or grow in size. In addition for this ERD alternative, there is an extensive injection well network currently in place throughout the EMF plume and there are very limited additional removal construction activities required. The prior expenditures for the site-wide ERD injection well network are not included as new capital costs (i.e., they represent prior historical costs already incurred). New capital costs include the installation of an estimated four deep and four shallow wells. These limited well installation costs are included to cover potential costs for added wells or replacement of wells closed during recent demolition work in the Plant 2 area (if necessary). Additional costs for 10 new monitoring wells have been included (the specific locations have not been established but some may be necessary). The initial capital costs include a one-time substrate injection, after which future substrate injections are captured in the Operations and Maintenance costs.

The Operations and Maintenance and monitoring for this alternative are estimated at $139,265 per year, reduce in later years and result in a net present value of $1,062,099 for the estimated project duration of 13 years (this includes 7 years of O&M plus monitoring followed by an additional 6 years of monitoring). Operations and Maintenance for this system include costs for periodic substrate injections to ensure continued bioactivity, replacement costs for injection and compliance wells, compliance monitoring on a semi-annual basis, and semi-annual reporting. In addition to monitoring and maintenance, Institutional Controls will be put in place. The ICs are estimated at $91,553 (as a net present value) for the project life cycle.

Further details for this cost estimate are provided in Attachment B.

Table 5-15 ERD Alternative Estimated Costs Summary and Scoring

Criteria	Estimated Cost	Score
Historic Costs (prior remedial actions)	$4,324,559	---
Capital Cost	$199,884	---
Monitoring and Maintenance (as NPV)	$1,062,099	---
Institutional Controls (as NPV)	$91,553	---
Cost Analysis Total	$5,678,096	4

5.4 Recommended Alternative

The relative score/ranking for the five alternatives are presented in Table 5-16; this ranking reflects the individual scores assigned to each criterion with the exception of the Community Acceptability (to be determined by EPA through public comment). A relative comparison of the estimated costs for the alternatives is summarized in Table 5-17 and presented in Figure 5-8. Based on the rankings below, ERD is the recommended cleanup alternative. The ranking as a single numerical score (as presented in this approach) inherently provides a higher weighting to the Effectiveness category because a larger number of sub-criterion (7) are included when compared to the number of sub-criterion for the Implementability (5) and Cost (1) categories. The Effectiveness category incorporates several critical criterion (Protection of Human Health, Protection of the Environment, Compliance with ARARs, and Reduction in Toxicity/ Mobility/Volume of Waste) so it is prudent to assign a higher relative weight to this overall category. Other options for weightings/ranking between the three primary categories (Effectiveness, Implementability, and Total Cost) can be easily derived from the relative scoring presented in Table 5-16.

Table 5-16 Comparison of Relative Scoring for All Alternatives Considered

Criteria	**No Action**	**MNA**	**IAS/SVE**	**IWS**	**ERD**
Effectiveness	3	11	21	24	28
Implementability	12	16	12	12	20
Total Cost	5	4	2	3	4
Total Score	**20**	**31**	**35**	**39**	**52**

Table 5-17 Summary of Costs for All Alternatives Considered

Alternative	**Costs**
No-action Alternative [(1)]	$4,324,559
MNA Alternative [(2)]	$5,143,700
IAS/SVE Alternative [(2)]	$11,683,882
IWS Alternative [(2)]	$8,641,957
ERD Alternative [(2)]	$5,678,096

[(1)] The costs listed for No-action alternative are the historic remedial costs

[(2)] The costs listed for all other alternatives include; Historic remedial costs, Capital costs for construction, 7-years of O&M costs, 13 years of monitoring costs, and costs for ICs.

5.5 EPA Clean and Green Policy

The Green Cleanups program in EPA Region 10 states that "Green cleanups (also called green remediation) are about considering all environmental impacts of our work and incorporating practices that maximize the overall environmental benefit. Region 10's Clean & Green Policy does not change how or why cleanup decisions are made, but supports greener cleanups by promoting sustainable technologies and practices in our cleanup programs" (EPA 2009). Consistent with the EPA Region 10 "Clean and Green Policy" to enhance the environmental benefits and sustainability of remediation programs at Superfund sites, the following demonstrates how the ERD alternative meets EPA's Clean and Green Policy:

1) 100% use of renewable energy (green power), and energy conservation and efficiency approaches including EnergyStar equipment – Minimal power requirements are needed for implementing ERD; a very limited amount of power is needed to pump substrates from tanks into injection wells on a short-term, discontinuous basis. No continuous source of power is needed to implement ERD and the total energy consumed is less than 0.1% of the other alternatives (other than MNA).
2) Industrial material reuse or recycling within regulatory requirements – Most of the substrates used for ERD on this project are reclaimed sugar products that do not meet specifications (or packaging requirements) for use in food products. These sugar mixtures would otherwise require long-haul trucking to a disposal site, or treatment prior to composting or disposal. The use of sugar not able to be used as a food product meets the recycling objectives of the Green Cleanup policy. Use of alternative substrates (e.g., emulsified vegetable oil and several other substrates) has been evaluated in the ERD Workplan (CALIBRE 2004), and will continue to be evaluated and considered.
3) Recycling of materials generated at or removed from the site – Implementation of ERD generates virtually no waste. Any residual waste sugar products from the mixing tanks are typically insignificant and quantities are small enough to allow disposal to the sanitary sewer system. Totes used to transport sugar solutions are reused for subsequent injection events.
4) Environmentally Preferable Purchasing – Only local sources of sugar substrates are used for ERD, minimizing the transportation requirements needed to supply sugar to the site. All injection pumps, piping and equipment are re-used.
5) Greenhouse gas emission reduction technologies– Greenhouse gas emissions are minimized with the ERD alternative. Small amounts of greenhouse gas emissions result from the local transportation of equipment and sugar products to the site for ERD, but no ongoing operation of electrical or motorized equipment is needed to sustain cleanup operations. Although some methane is produced as sugar is degraded, the amount is considered negligible compared to equivalent emissions of continuously operating equipment.

6.0 References

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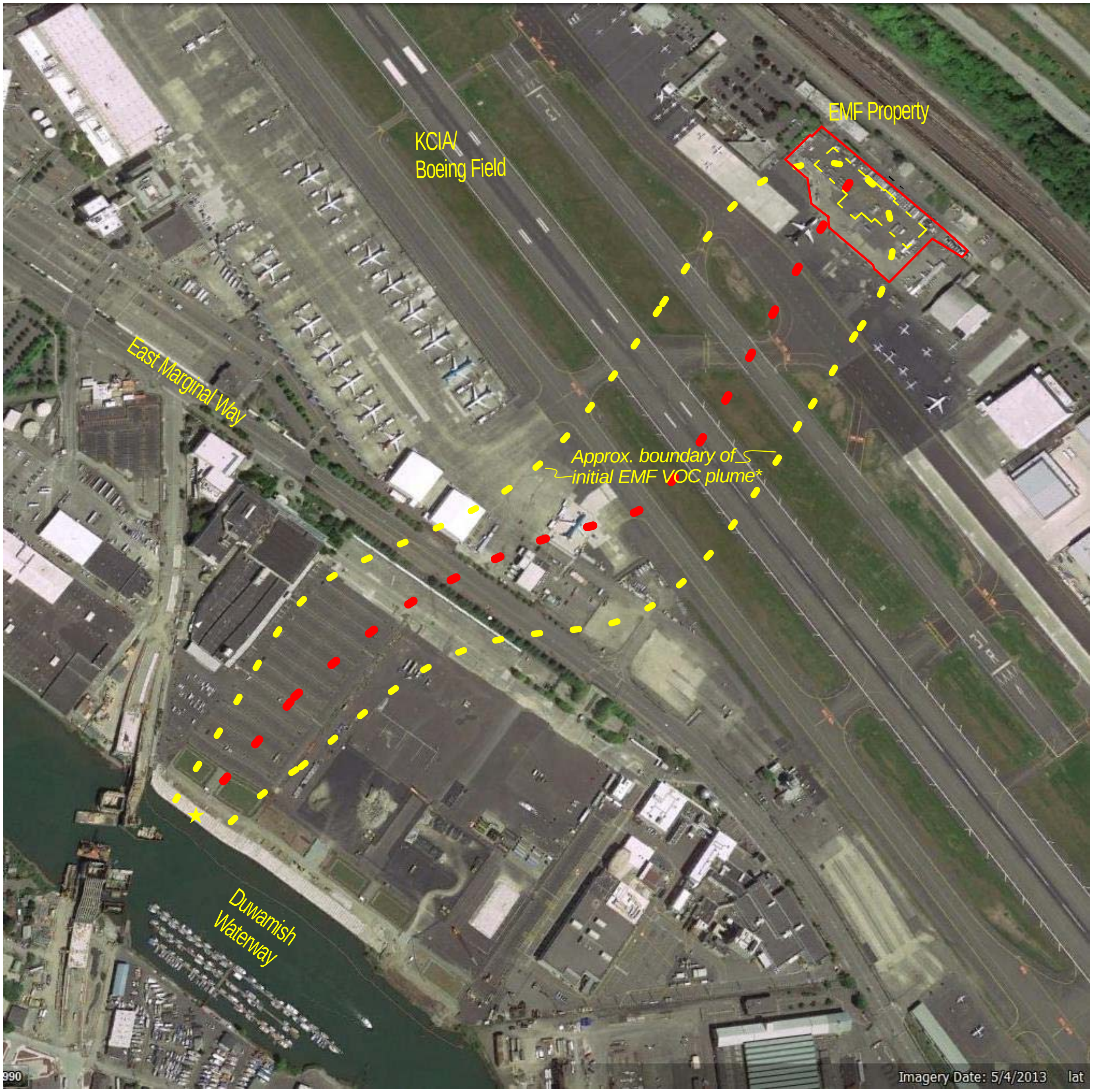
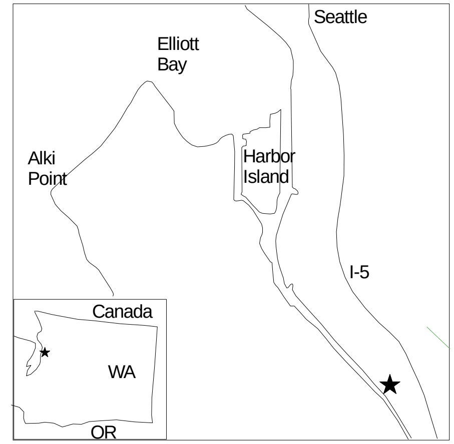
Figures





*The initial VOC plume boundaries depicted are based primarily on historicaldata (~ 2000). Remedial actions have been implemented throughout the plume over the last 15 years and the current footprint (plume boundary) is expected to be reduced.

N

APPROXIMATE SCALE IN FEET

0 250 500 1000

BOEING® CALIBRE Systems

REVISION NO.: 0 | DATE: 1/31/2014 | FILE: Fig 2-1 Site Location

Figure 2-1 EMF Property Location

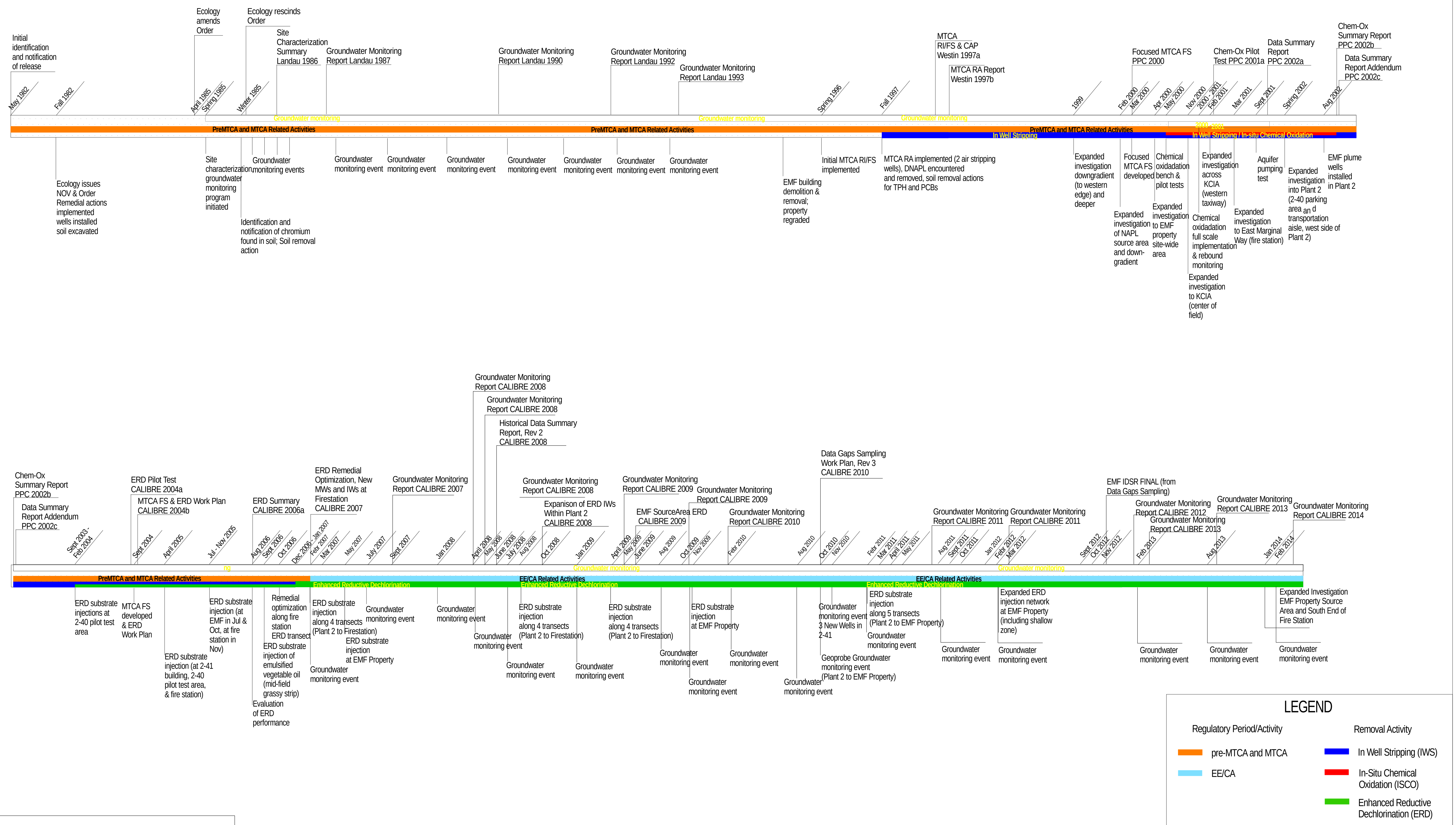


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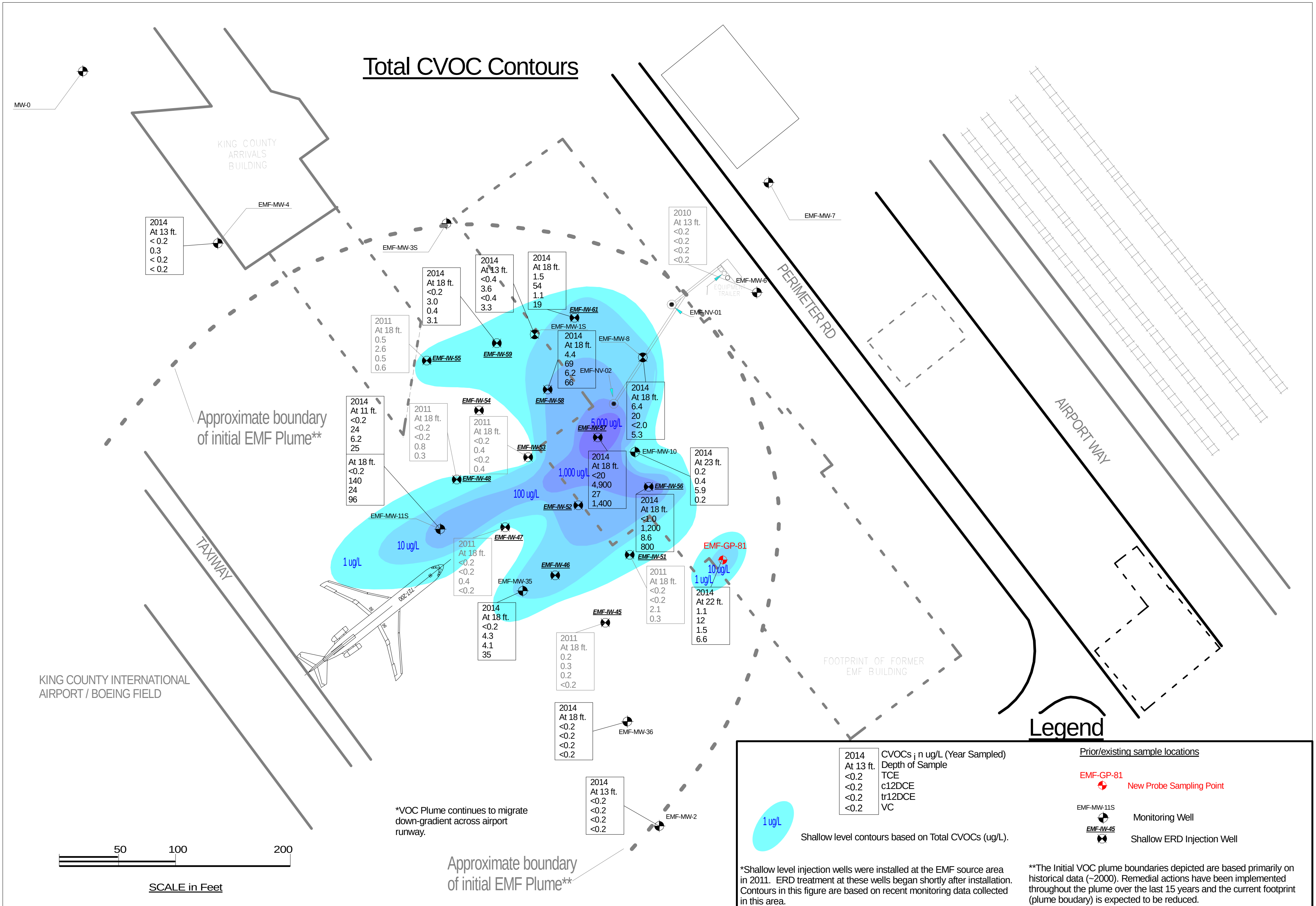
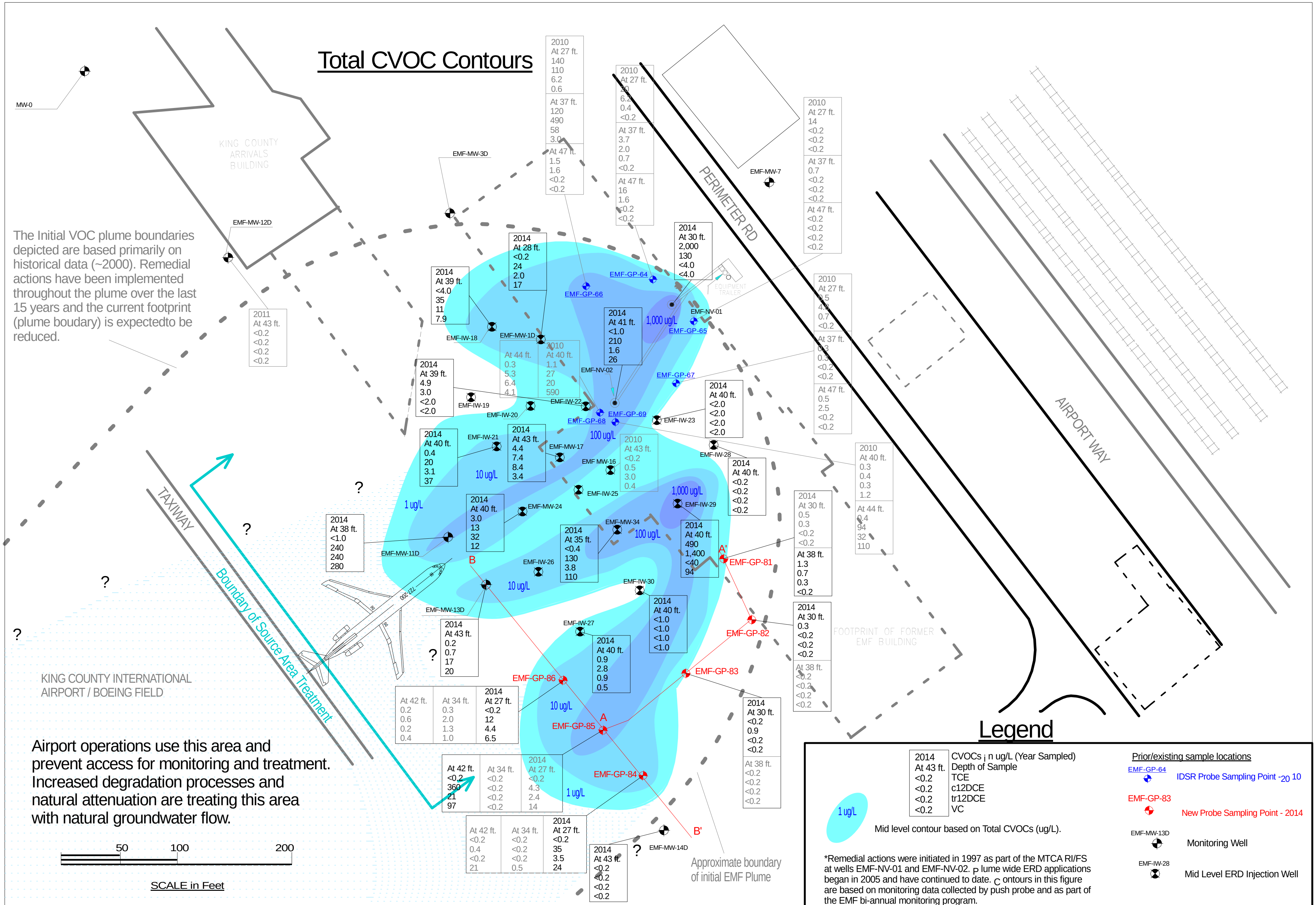
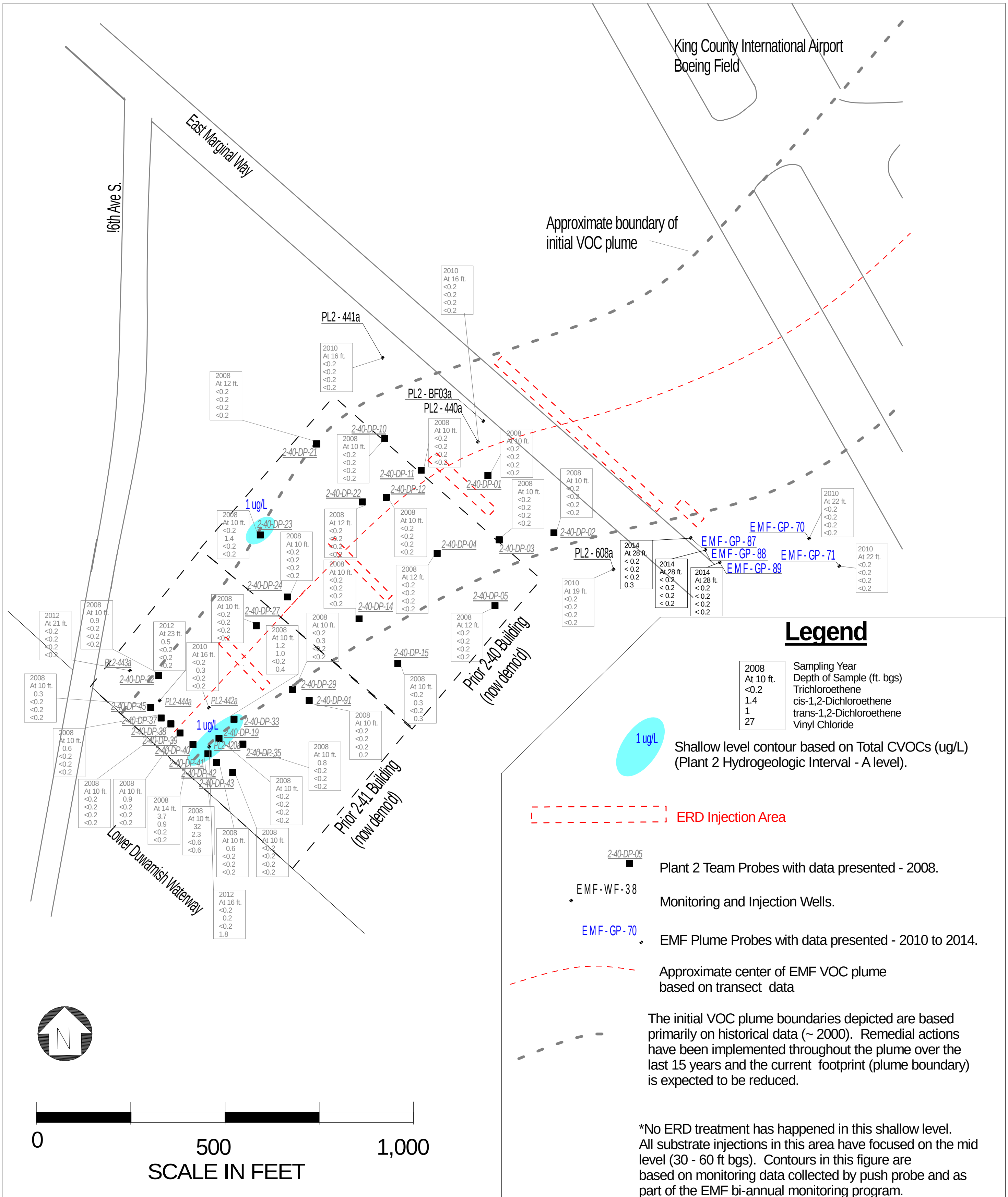
Figure 2-2
EMF Investigation and Remediation Timeline



BOEING CALIBRE Systems Inc.	Location: EMF Site Seattle, WA	Figure 3-1. Current/Recent Groundwater CVOC Concentrations - Shallow Level Total CVOC Contours (<25 ft bgs).



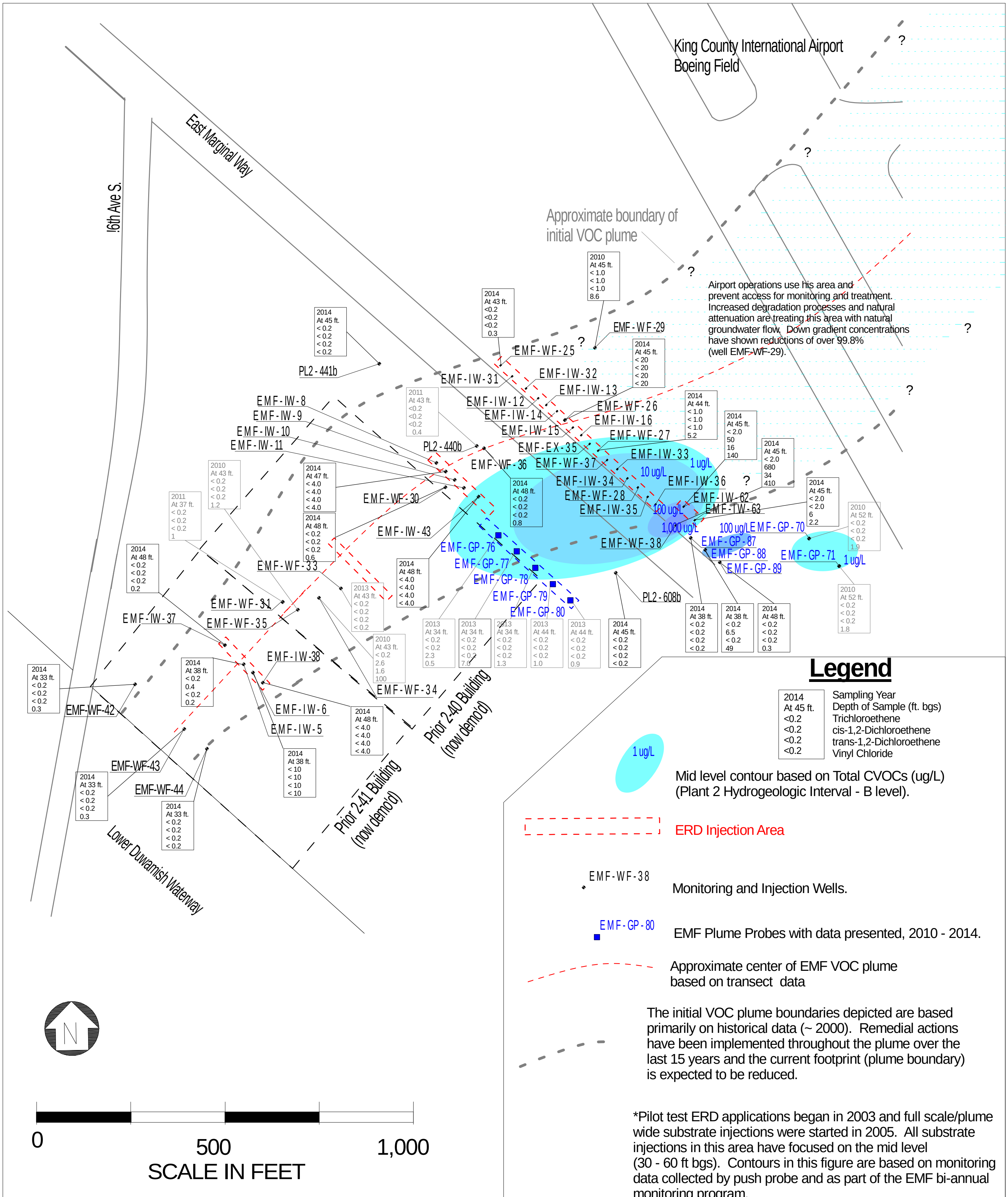
BOEING / CALIBRE Systems Inc.	Location: EMF Site Seattle, WA	Figure 3-2. Current/Recent Groundwater CVOC Concentrations - Mid Level CVOC Contours (25-50 ft bgs)



CALIBRE Systems Inc.

Location:
EMF Site
Seattle, Wa

Figure 3-3
Current/Recent Groundwater CVOC Concentrations - Shallow Level Total CVOC Contours (<30 ft bgs)



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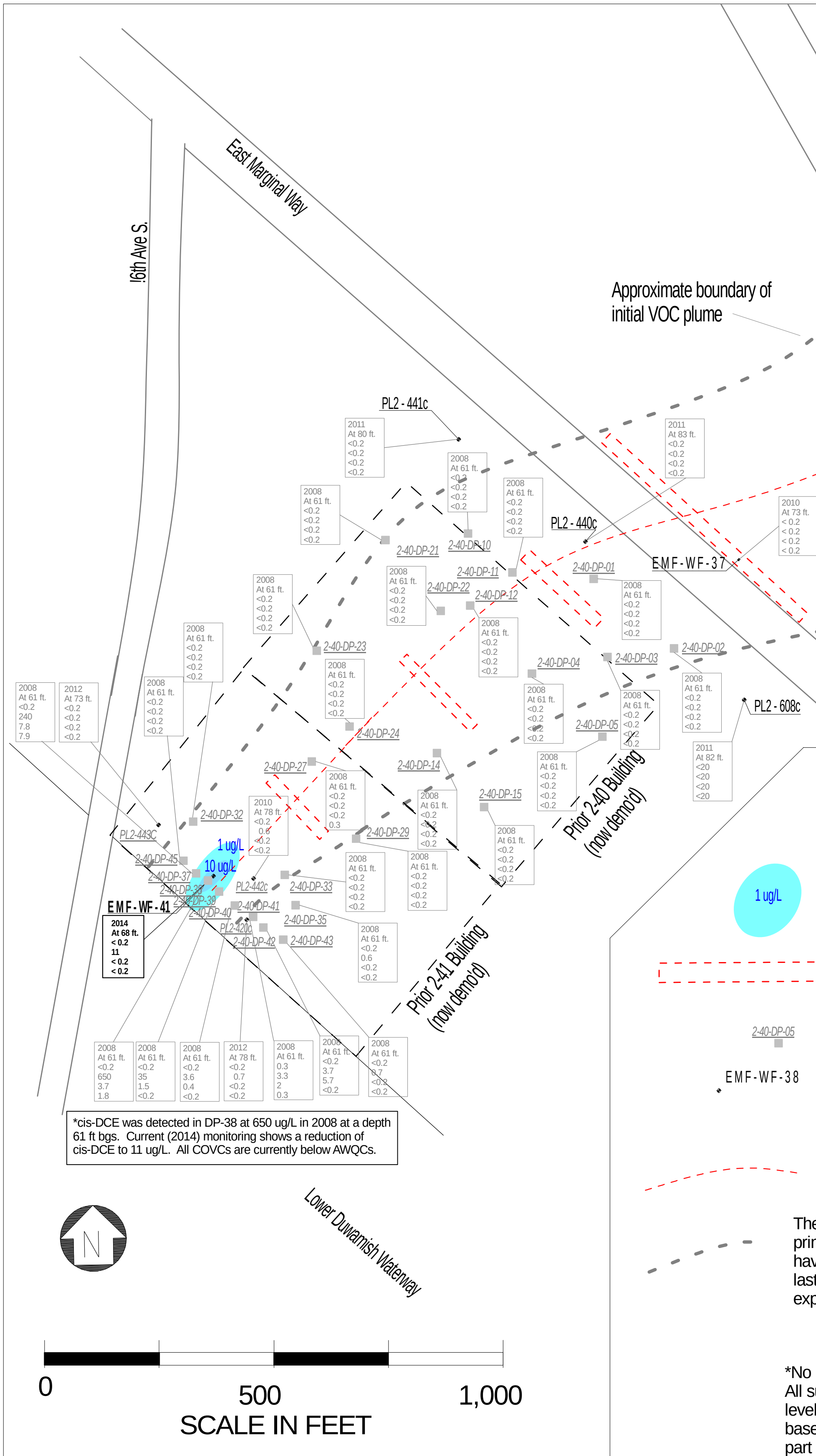
Location:
EMF Site
Seattle, Wa

Figure 3-4
Current/Recent Groundwater CVOC Concentrations - Mid Level Total CVOC Contours (30 - 60 ft bgs)



Legend

2014 — Sampling Year
At 68 ft. — Depth of Sample (ft. bgs)
<0.2 — Trichloroethene
11 — cis-1,2-Dichloroethene
<0.2 — trans-1,2-Dichloroethene
<0.2 — Vinyl Chloride

1 ug/L — Deep level contour based on Total CVOCs (ug/L) (Plant 2 Hydrogeologic Interval - C level).

ERD Injection Area

2-40-DP-05 — Plant 2 Team Probes with data presented - 2008.

EMF-WF-38 — Monitoring and Injection Wells.

Approximate center of EMF VOC plume based on transect data

The initial VOC plume boundaries depicted are based primarily on historical data (~ 2000). Remedial actions have been implemented throughout the plume over the last 15 years and the current footprint (plume boundary) is expected to be reduced.

*No ERD treatment has happened in this deep level. All substrate injections in this area have focused on the mid level interval (30 - 60 ft bgs). Contours in this figure are based on monitoring data collected by push probe and as part of the EMF bi-annual monitoring program.

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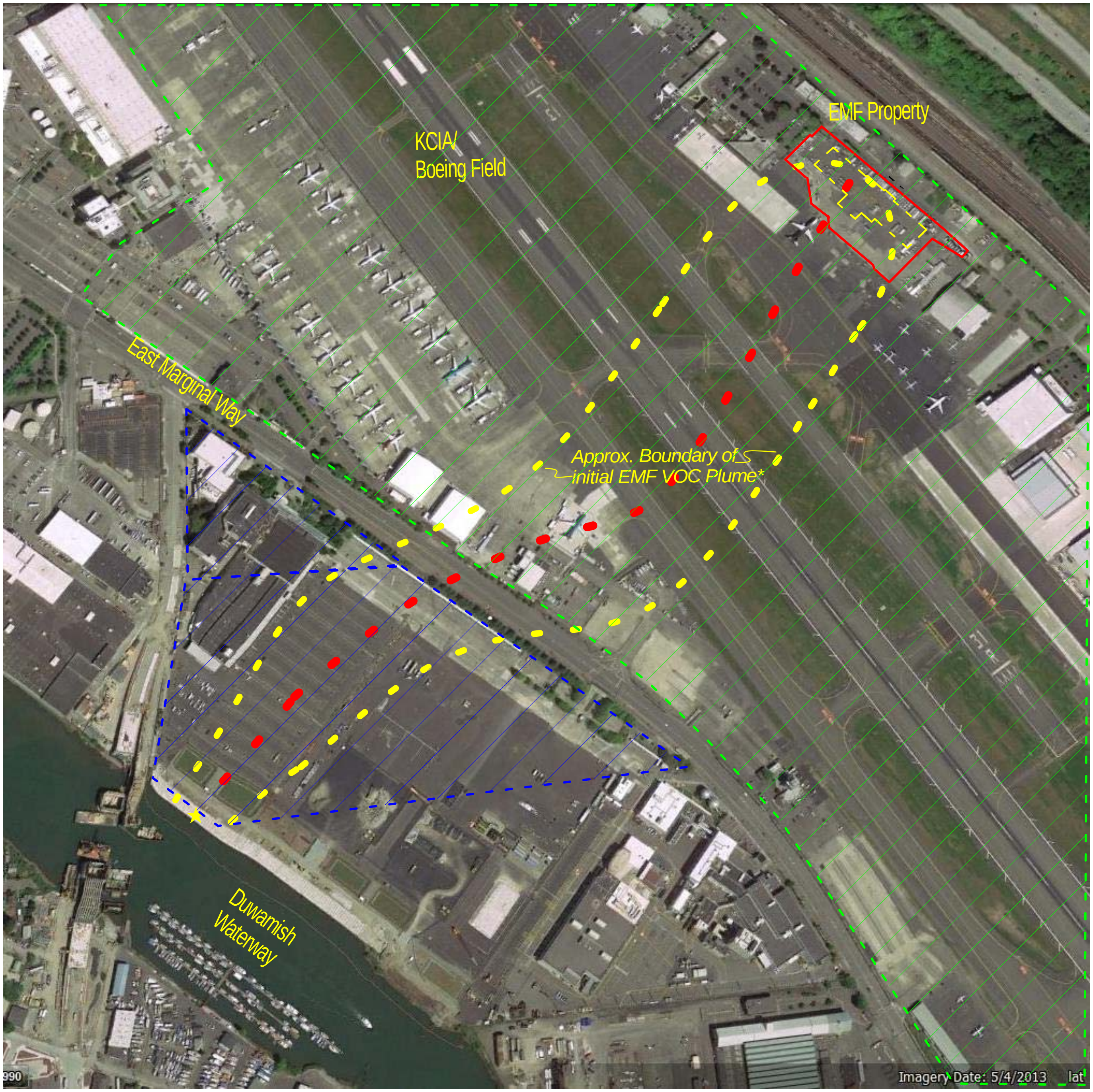
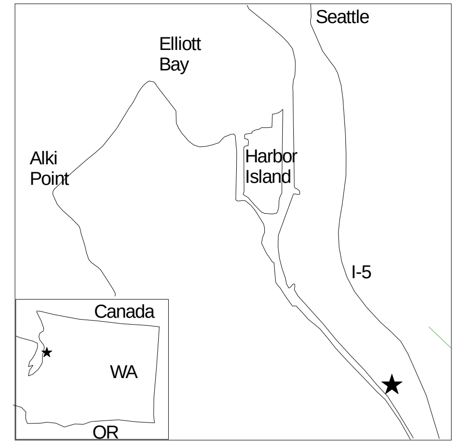
Location:
EMF Site
Seattle, Wa

Figure 3-5
Current/Recent Groundwater Total CVOC Concentrations - Deep Level Contours (>60 ft bgs).





*The initial VOC plume boundaries depicted are based primarily on historical data (~ 2000). Remedial actions have been implemented throughout the plume over the last 15 years and the current footprint (plume boundary) is expected to be reduced.

Boeing Property Parcels

King Coutny Property Parcel

N

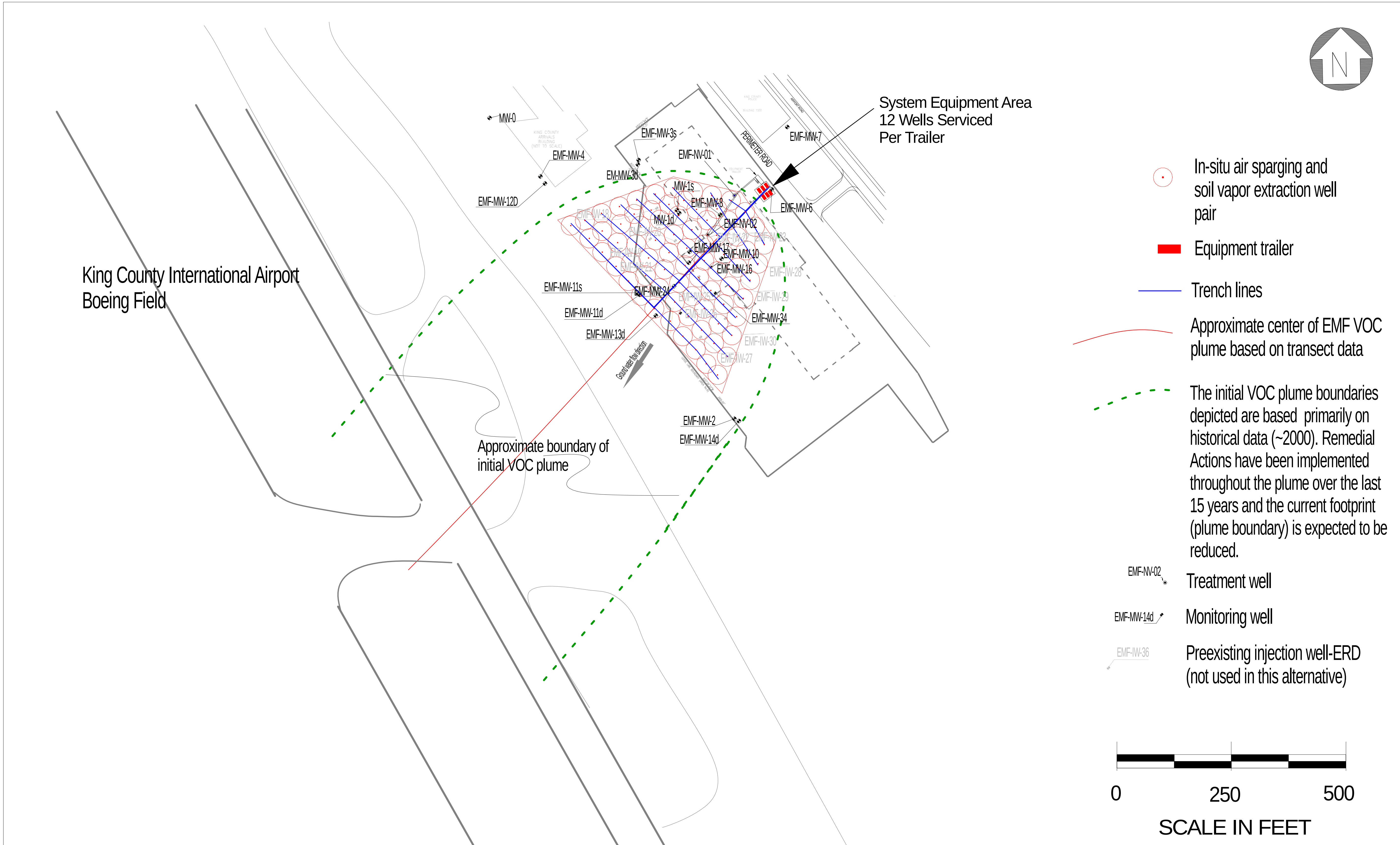
APPROXIMATE SCALE IN FEET

0 250 500 1000

BOEING® CALIBRE Systems

REVISION NO.: 0	DATE: 1/31/2014	FILE: Fig 3-6 Plume and Property

Figure 3-6 EMF VOC Plume and Property Parcels



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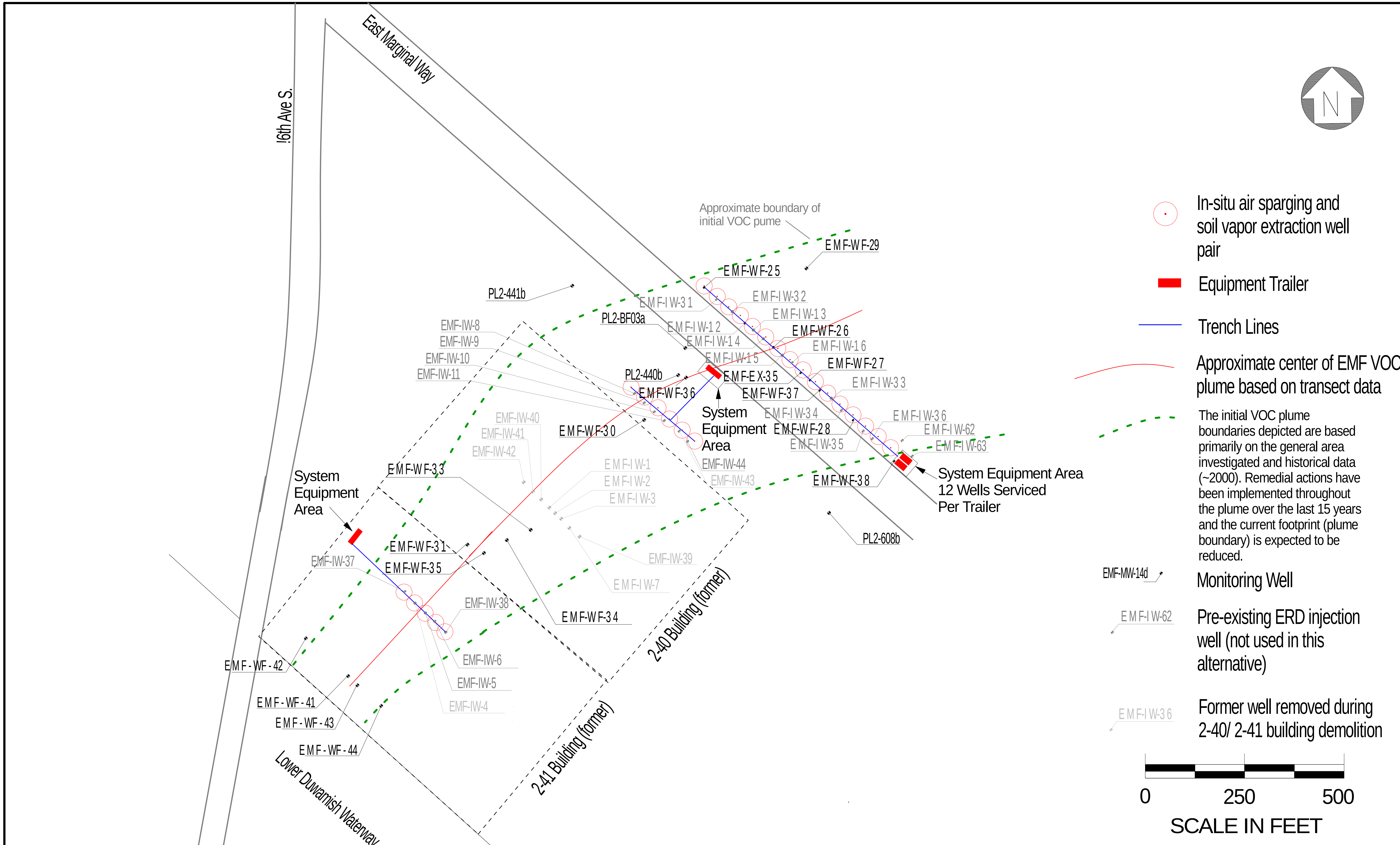
CALIBRE Systems Inc.

LOCATION:

EMF Site
Seattle, WA

Figure 5-1
IAS/SVE Wells and Equipment Locations at Source End of Plume (Alternative 3)



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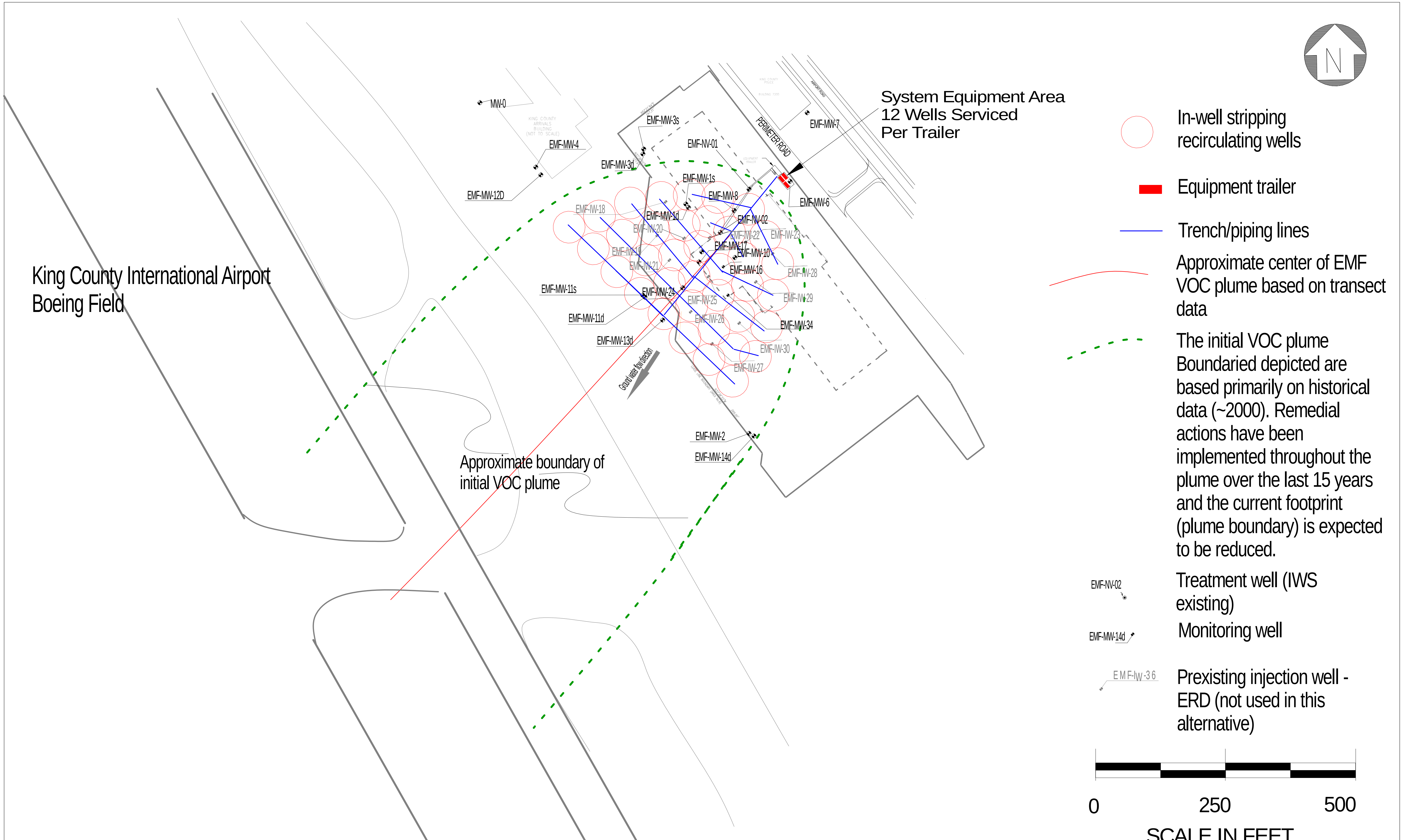
CALIBRE Systems Inc.

LOCATION:

EMF Site
Seattle, WA

Figure 5-2
IAS/SVE Wells and Equipment Locations at Distal End of Plume (Alternative 3)



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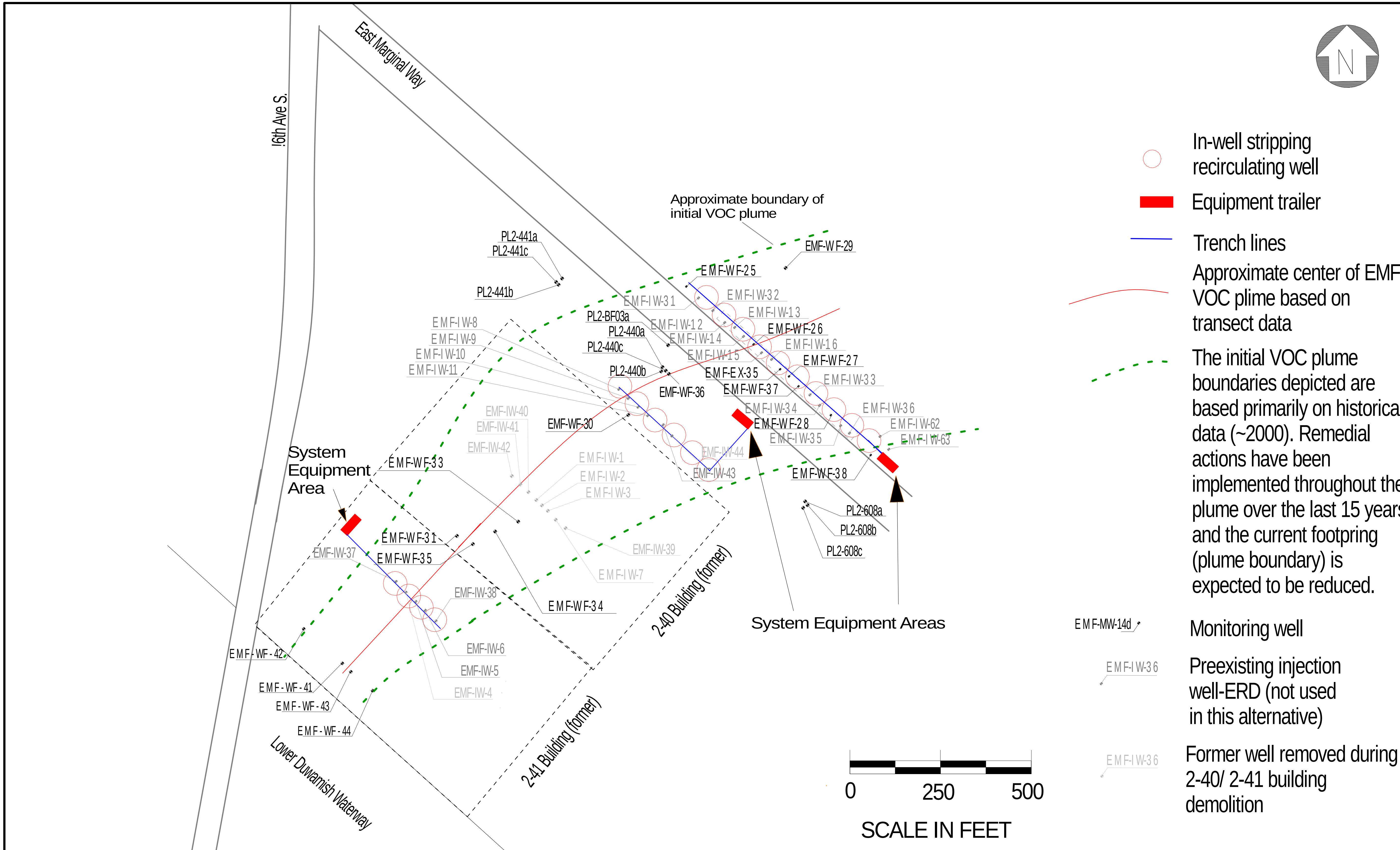
CALIBRE Systems Inc.

LOCATION:

EMF Site
Seattle, WA

Figure 5-3
IWS Wells and Equipment Locations at Source End of Plume (Alternative 4)



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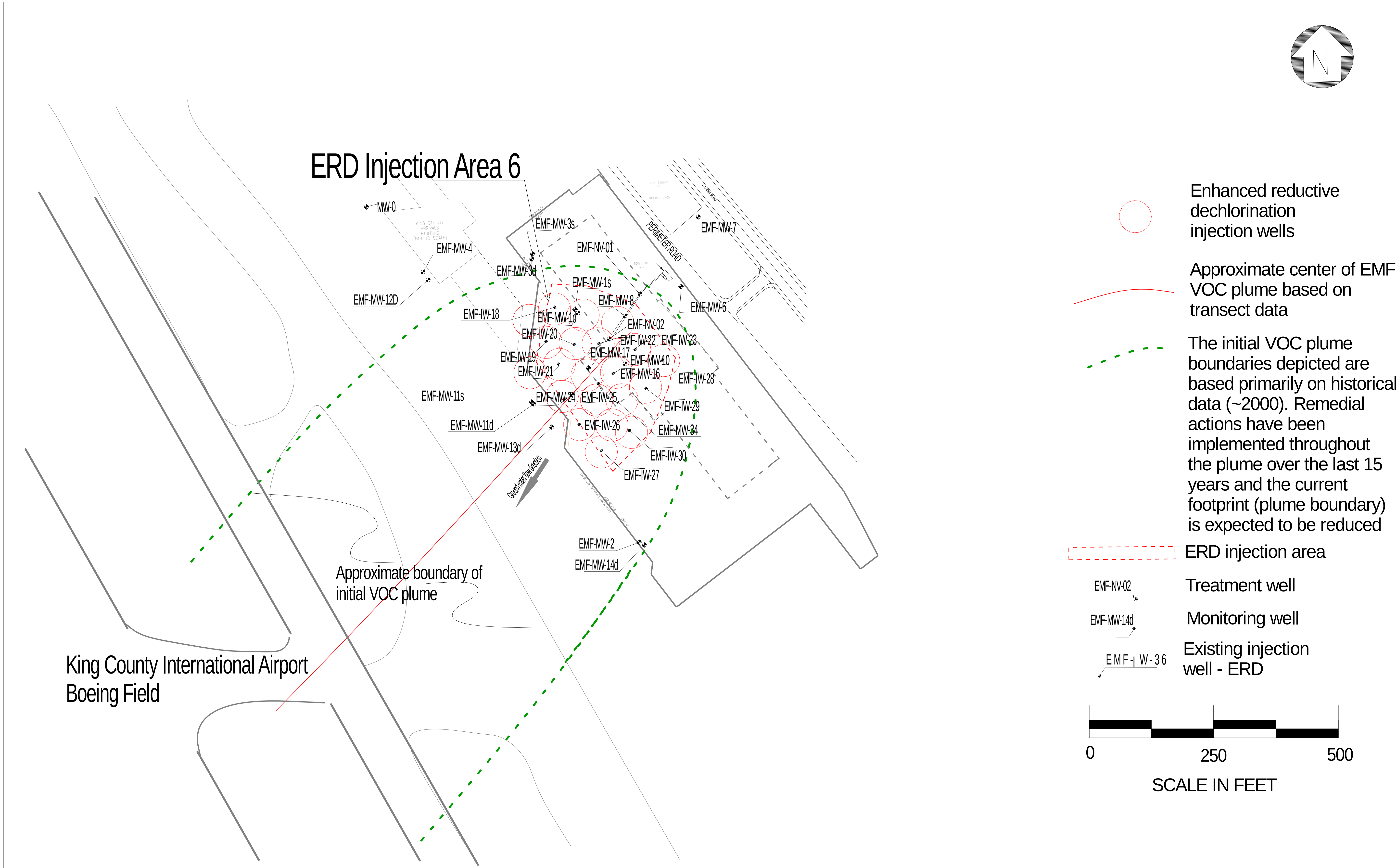
CALIBRE Systems Inc.

LOCATION:

EMF Site
Seattle, WA

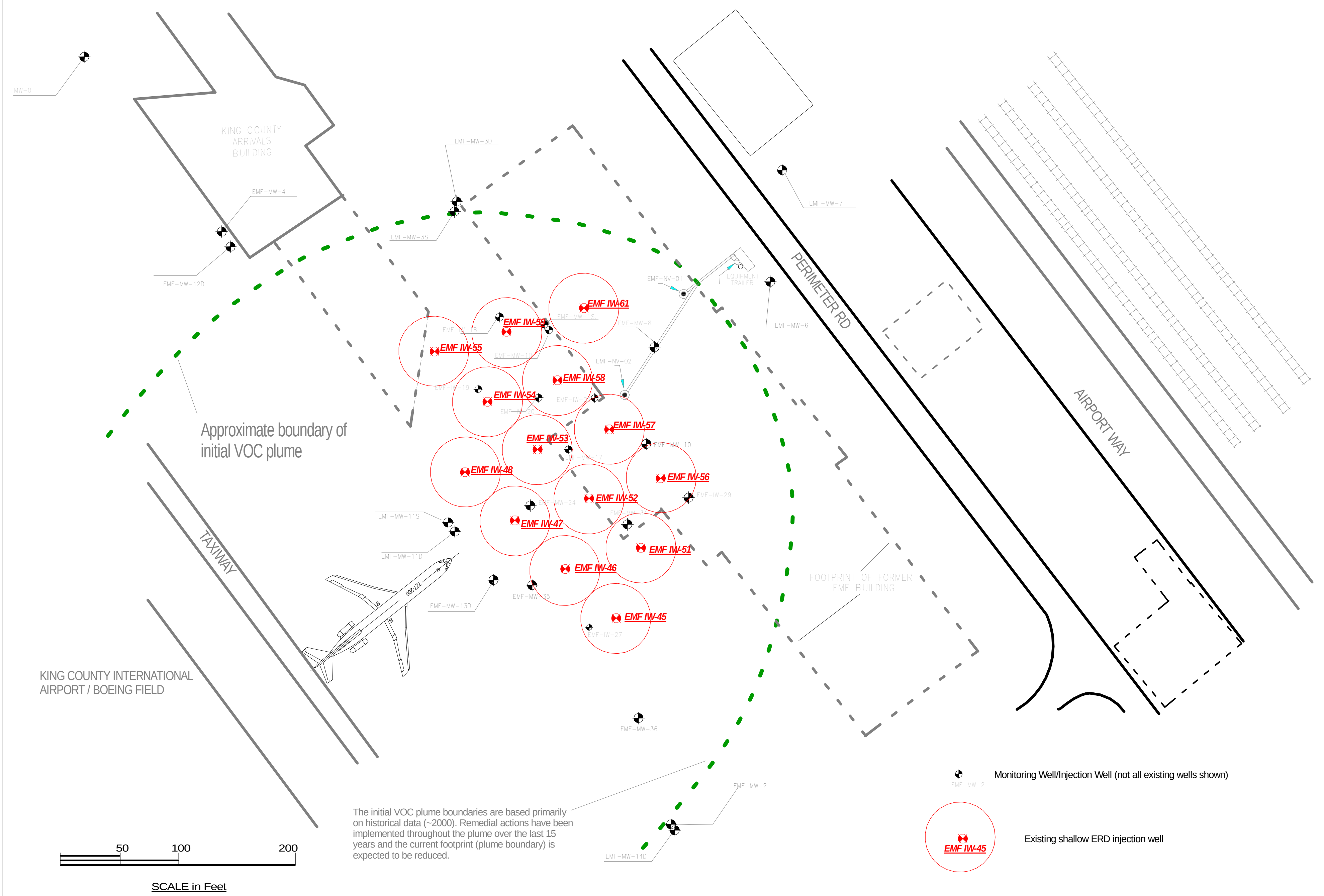
Figure 5-4
IWS Wells and Equipment Locations at Distal End of Plume (Alternative 4)



CALIBRE Systems Inc.

LOCATION:
EMF Site
Seattle, WA

Figure 5-5
ERD Source Area Deep Injection Well Locations (Alternative 5)



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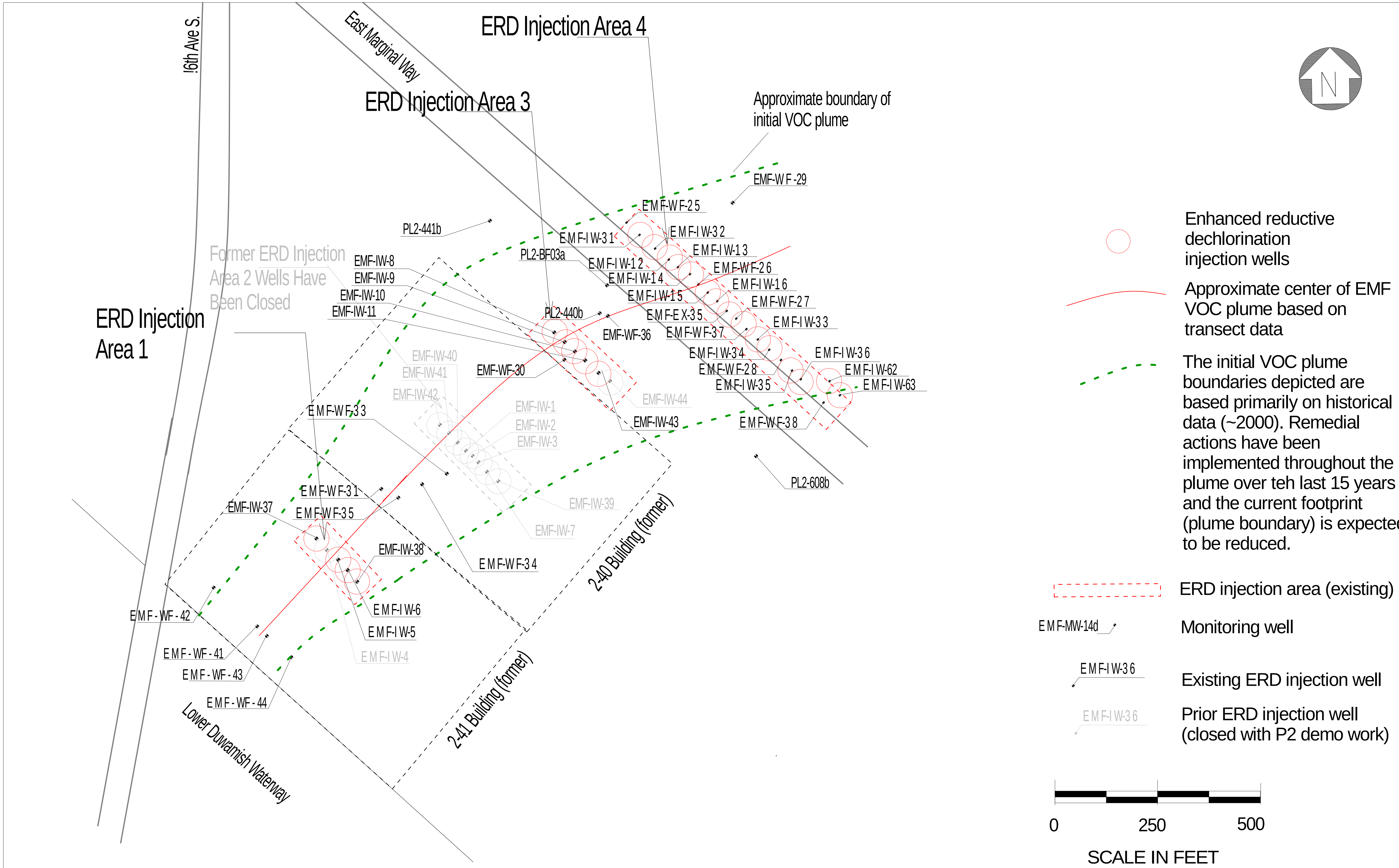
Location:

EMF Site
Seattle, WA

Figure 5-6 ERD Source Area Shallow Injection Well Locations (Alternative 5)



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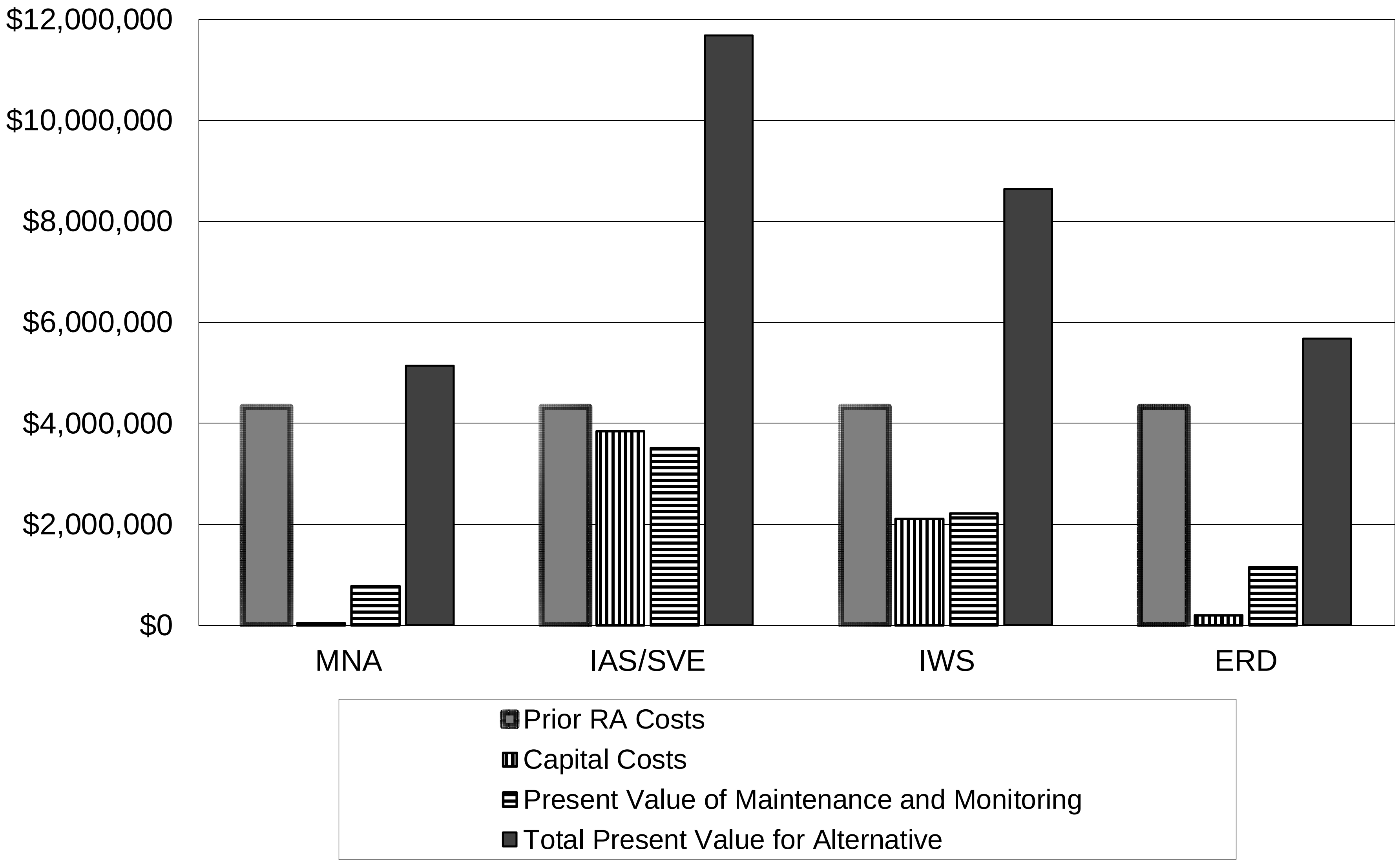
LOCATION:
EMF Site
Seattle, WA

Figure 5-7
ERD Injection Well Locations at Distal End of Plume (Alternative 5)

Figure 5-8 Comparison of Costs for Alternatives
(Excluding No Action)



Attachment A
Summary of Current Monitoring/Injection Wells

Table A-1. Complete List of Current Wells (EMF Site)

EMF Wells

Well ID	SCREENED INTERVAL (ft bgs)	TOTAL DEPTH (FT)	WELL DESCRIPTION
EMF-MW-04	5-15	15	Monitoring Well
EMF-MW-10	20-25	25	Monitoring Well
EMF-MW-11DR*	30-40	40	Monitoring Well
EMF-MW-11SR*	10-20	20.25	Monitoring Well
EMF-MW-12DR*	35-45	45.25	Monitoring Well
EMF-MW-13DR*	35-45	45	Monitoring Well
EMF-MW-14D	40-45	45	Monitoring Well
EMF-MW-16	34.5-44.5	44.5	Monitoring Well
EMF-MW-17	35-45	45	Monitoring Well
EMF-MW-1D	20-30	30	Monitoring Well
EMF-MW-1S	5-15	15	Monitoring Well
EMF-MW-02	5-15	15	Monitoring Well
EMF-MW-24	32-42	42	Monitoring Well
EMF-MW-34	22-37	37	Monitoring Well
EMF-MW-35	10-20	20	Monitoring Well
EMF-MW-36	10-20	20	Monitoring Well
EMF-MW-3D	20-30	34.5	Monitoring Well
EMF-MW-3S	5-15	15	Monitoring Well
EMF-MW-6	5-14	14	Monitoring Well
EMF-MW-7	5-15	15	Monitoring Well
EMF-MW-8	20-25	25	Monitoring Well
EMF-NV-01	26.5-31.5	34	Prior IWS Well
EMF-NV-02	33-43	43	Prior IWS Well
EMF-IW-18	31-41	41.5	Injection Well
EMF-IW-19	30-40	40.5	Injection Well
EMF-IW-20	32-42	42.5	Injection Well
EMF-IW-21	31.5-41.5	41.5	Injection Well
EMF-IW-22	31-41	41.5	Injection Well
EMF-IW-23	31.5-41.5	41.5	Injection Well
EMF-IW-25	32-42	42.5	Injection Well
EMF-IW-26	31-41	41.5	Injection Well
EMF-IW-27	32-42	42.5	Injection Well
EMF-IW-28	32-42	42.5	Injection Well
EMF-IW-29	32-42	42.5	Injection Well
EMF-IW-30	31.5-41.5	41.5	Injection Well
EMF-IW-45	10-20	20	Injection Well
EMF-IW-46	10-20	20	Injection Well
EMF-IW-47	10-20	20	Injection Well
EMF-IW-48	10-20	20	Injection Well
EMF-IW-51	10-20	20	Injection Well
EMF-IW-52	10-20	20	Injection Well
EMF-IW-53	10-20	20	Injection Well
EMF-IW-54	10-20	20	Injection Well

EMF-IW-55	10-20	20	Injection Well
EMF-IW-56	10-20	20	Injection Well
EMF-IW-57	10-20	20	Injection Well
EMF-IW-58	10-20	20	Injection Well
EMF-IW-59	10-20	20	Injection Well
EMF-IW-61	10-20	20	Injection Well

* Indicates a replacement well, previous well had been damaged.

NBF/ Fire station Wells

Well ID	SCREENED INTERVAL (ft bgs)	TOTAL DEPTH (FT)	WELL DESCRIPTION
EMF-WF-25	35-45	45	Monitoring Well
EMF-WF-26	37-47	47	Monitoring/Injection Well
EMF-WF-27	36-46	46	Monitoring/Injection Well
EMF-WF-28	35-45	46	Monitoring/Injection Well
EMF-WF-29	35-45	46	Monitoring Well
EMF-WF-37	64.8-74.6	74.6	Monitoring Well
EMF-WF-38	37.5-46.9	47.5	Monitoring Well
EMF-EX-35	35-45	47	Extraction Well
EMF-IW-12	35-45	45	Injection Well
EMF-IW-13	35-45	45	Injection Well
EMF-IW-14	34-44	45	Injection Well
EMF-IW-15	35-45	45	Injection Well
EMF-IW-16	35-45	45	Injection Well
EMF-IW-31	25.7-40.3	40.6	Injection Well
EMF-IW-32	29.5-44	44.8	Injection Well
EMF-IW-33	29.9-44.4	44.8	Injection Well
EMF-IW-34	28.6-43.2	43.2	Injection Well
EMF-IW-35	29.4-44	44	Injection Well
EMF-IW-36	30.1-44.6	44.6	Injection Well
EMF-IW-62	27-47	47	Injection Well
EMF-IW-63	27-47	47	Injection Well

Attachment A

Table A-1

Plant 2 Wells

Well ID	SCREENED INTERVAL (ft bgs)	TOTAL DEPTH (FT)	WELL DESCRIPTION
EMF-WF-30	40-50	50	Monitoring Well
EMF-WF-31	29-39	39	Monitoring Well
EMF-WF-33	35-45	45	Monitoring Well
EMF-WF-34	35-45	45	Monitoring Well
EMF-WF-35	35-45	45	Monitoring Well
EMF-WF-36	40-50	50	Monitoring Well
EMF-WF-41	60-70	70	Monitoring Well
EMF-WF-42	25-35	35	Monitoring Well
EMF-WF-43	25-35	35	Monitoring Well
EMF-WF-44	25-35	35	Monitoring Well
PL2-440A	8-18	18	Monitoring Well
PL2-440B	40-45	45.5	Monitoring Well
PL2-440C	79.5-84.5	85	Monitoring Well
PL2-441A	8-18	18	Monitoring Well
PL2-441B	35-45	45	Monitoring Well
PL2-441C	76.5-81.5	82	Monitoring Well
PL2-608A	6-26	26	Monitoring Well
PL2-608B	40-45	45	Monitoring Well
PL2-608C	78.5-83.5	83.5	Monitoring Well
PL2-BF03A	8-18	18	Monitoring Well
EMF-IW-5	30-40	40	Injection Well
EMF-IW-6	30-40	40	Injection Well
EMF-IW-8	39-49	50	Injection Well
EMF-IW-9	39-49	49	Injection Well
EMF-IW-10	40-50	50	Injection Well
EMF-IW-11	40-50	50	Injection Well
EMF-IW-37	35-50	50	Injection Well
EMF-IW-38	35-50	50	Injection Well
EMF-IW-43	40-50	50	Injection Well

Table A-2. Frequently Monitored Wells
EMF Wells

Well ID	SCREENED INTERVAL (ft bgs)	TOTAL DEPTH (FT)	RATIONALE FOR SAMPLING
EMF-IW-18	31-41	41.5	Update VOC sampling data EMF source area injection network
EMF-NV-01	26.5-31.5	34	Monitor VOC reduction in source area well and TOC levels for ERD optimization
EMF-NV-02	33-43	43	Monitor VOC reduction in source area well and TOC levels for ERD optimization
EMF-MW-24	32-42	42	Monitor VOC reduction in ERD treatment area and TOC levels for ERD Optimization
EMF-MW-10	20-25	25	Monitor VOC reduction in ERD treatment area and TOC levels for ERD Optimization
EMF-MW-34	22-37	37	Monitor VOC reduction in ERD treatment area and TOC levels for ERD Optimization
EMF-IW-29	32-42	42.5	Help define VOC plume central monitoring area and TOC levels for ERD optimization
EMF-IW-30	31.5-41.5	41.5	Monitor VOCs in southern portion of plume
EMF-MW-04	5-15	15	Help define northern VOC plume boundary, shallow
EMF-MW-12DR*	35-45	45.25	Help define northern VOC plume boundary, deep
EMF-MW-11SR*	10-20	20.25	Monitor VOC reduction down gradient of ERD treatment area (in this well use 2 PDBs, placed at base and top of screen interval)
EMF-MW-11DR*	30-40	40	Monitor VOC reduction down gradient of ERD treatment area and generation of ethane
EMF-MW-13DR*	35-45	45	Monitor VOC reduction down gradient of ERD treatment area and generation of ethane
EMF-MW-35	10-20	20	Help define VOC plume boundary along the southern edge
EMF-IW-27	32-42	42.5	Monitor VOC reduction in ERD treatment area and TOC levels for ERD Optimization
EMF-MW-36	10-20	20	Bounding shallow well along the southern edge of the plume
EMF-MW-02	5-15	15	Help define southern VOC plume boundary
EMF-MW-14D	40-45	45	Help define southern VOC plume boundary

* Indicates a replacement well, previous well had been damaged.

Attachment A

Table A-2

NBF/ Fire station Wells

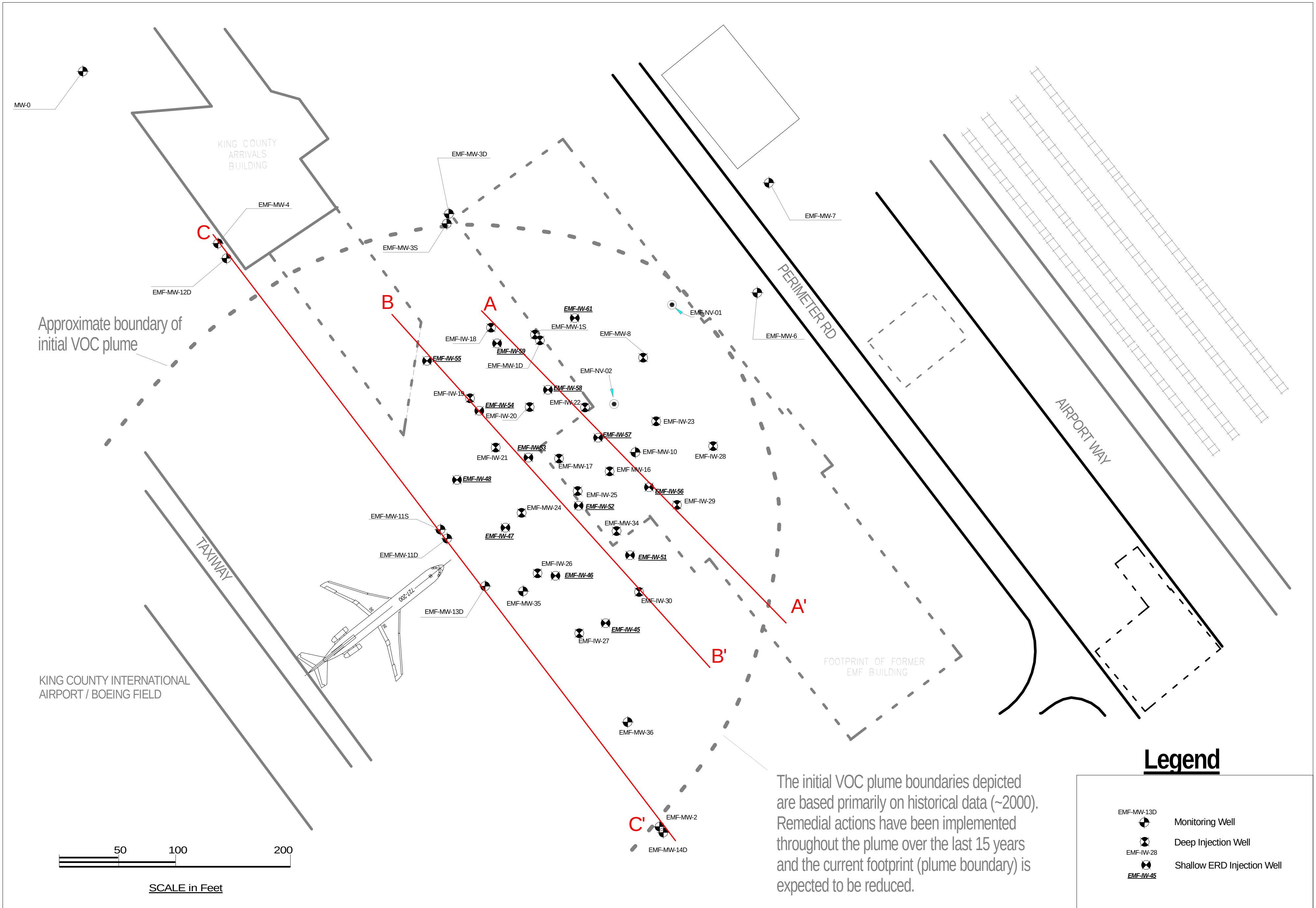
Well ID	SCREENED INTERVAL (ft bgs)	TOTAL DEPTH (FT)	RATIONALE FOR SAMPLING
EMF-WF-25	35-45	45	Monitor VOCs at northern boundary well defining plume
EMF-WF-29**	35-45	46	Upgradient of Firestation transect, bounding northern edge well
EMF-WF-26	37-47	47	Monitor VOC reduction in ERD treatment area and TOC levels for ERD Optimization
EMF-WF-27	36-46	46	Monitor VOC reduction in ERD treatment area
EMF-IW-62	27-47	47	Monitor VOCs at southern boundary well defining VOC plume and TOC for ERD optimization
EMF-WF-38	37-47	47.5	Monitor VOCs at southern boundary well defining VOC plume
EMF-IW-63	27-47	47	Monitor VOCs at southern boundary well defining VOC plume and TOC for ERD optimization

**Well is sampled less frequently than remainder of the list.

Plant 2 Wells

Well ID	SCREENED INTERVAL (ft bgs)	TOTAL DEPTH (FT)	RATIONALE FOR SAMPLING
PL2-441B	35-45	45	P2 boundary transect at E Marginal way (in DGSWP) south edge of plume
EMF-IW-9	39-49	49	Monitor VOCs along plume centerline
EMF-WF-36	40-50	50	Monitor VOC reduction down gradient of ERD treatment area and generation of ethene
EMF-WF-30	40-50	50	Monitor VOC reduction in ERD treatment area
EMF-IW-43	40-50	50	Monitor VOCs along plume centerline
PL2-608B	40-45	45	P2 boundary transect at E Marginal way (in DGSWP) north edge of plume
EMF-IW-37	35-50	50	Monitor VOC reduction in ERD treatment area and TOC levels for ERD Optimization
EMF-IW-5	30-40	40	Monitor VOC reduction in ERD treatment area and TOC levels for ERD Optimization
EMF-IW-6	30-40	40	Monitor VOC reduction in ERD treatment area and TOC levels for ERD Optimization
EMF-IW-38	35-50	50	levels for ERD Optimization
EMF-WF-42	25-35	35	Monitor VOC levels northern edge/near to the LDW
EMF-WF-41	60-70	70	Monitor VOC levels central area/near to the LDW
EMF-WF-43	25-35	35	Monitor VOC levels central area/near to the LDW
EMF-WF-44	25-35	35	Monitor VOC levels southern edge/near to the LDW

Note: Wells are presented in order from North to South as depicted on accompanying cross section figures.



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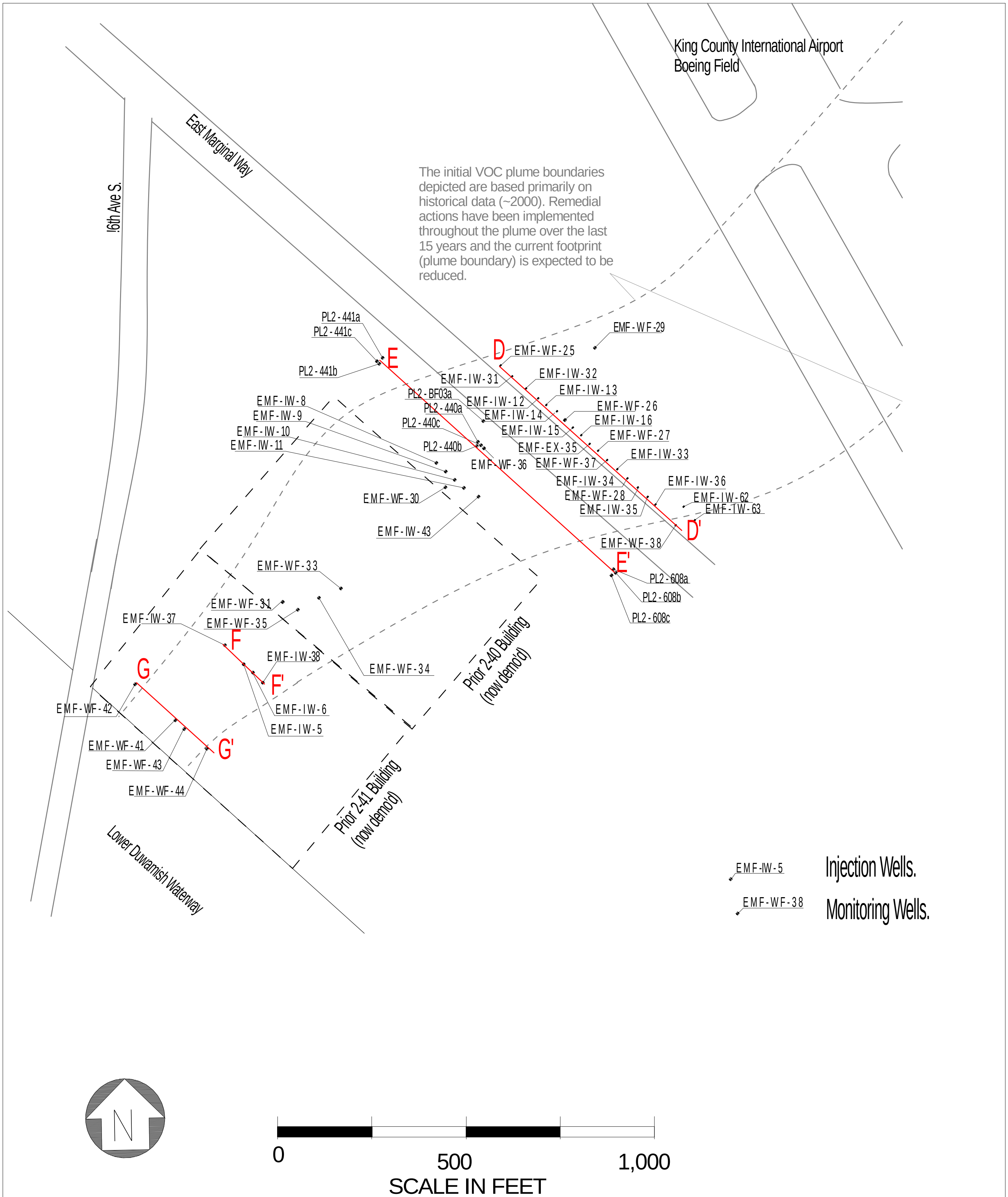
Location:
EMF Site
Seattle, WA

Figure A-1 Plan View of Well Transects in the Former EMF Source Area



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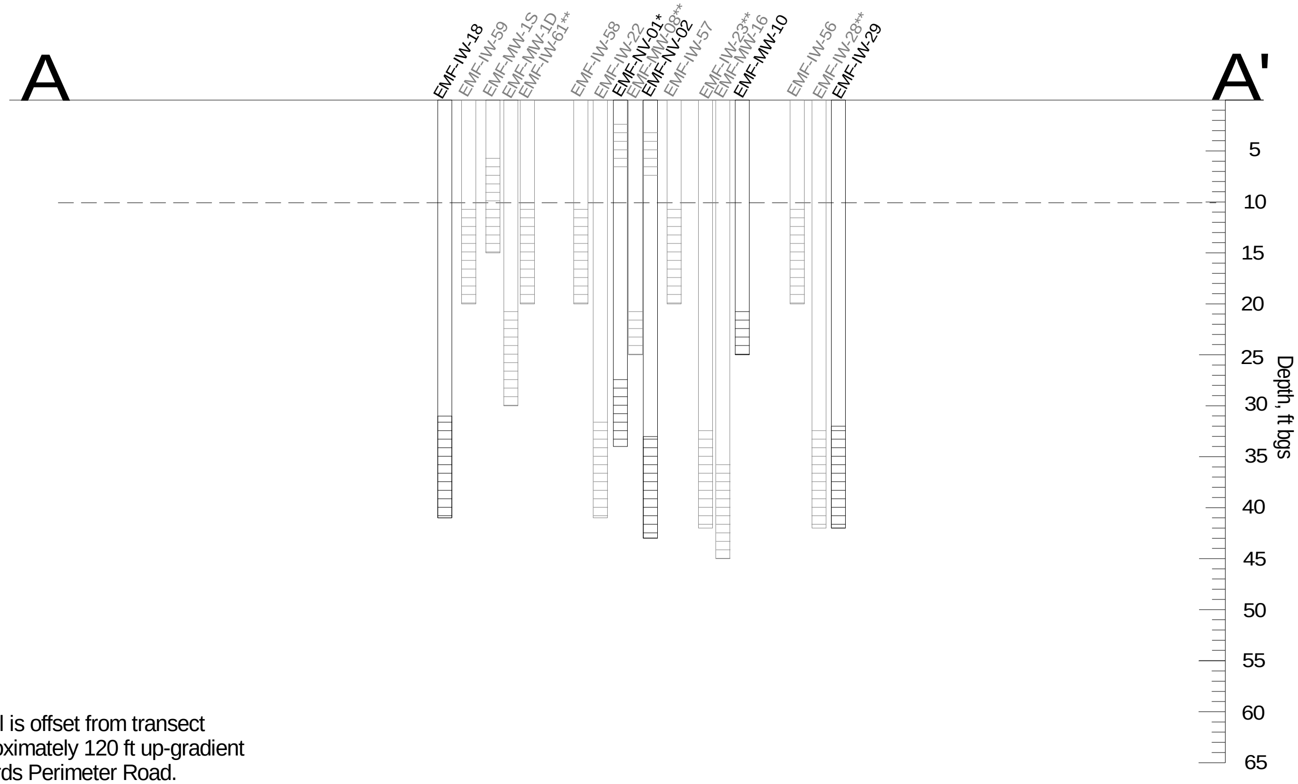
Location:
EMF Site
Seattle, Wa

Figure A-2 Plan View of Well Transects at the Fire Station and Plant 2 Areas



* Well is offset from transect
approximately 120 ft up-gradient
towards Perimeter Road.

** Well is offset from transect
approximately 60 ft up-gradient
towards Perimeter Road.

Wells in black are regularly monitored.
Wells in dark gray are not regularly monitored.

Horizontal Dist., ft

0 45 90 180

Vertical Scale 1:6 Horizontal Scale

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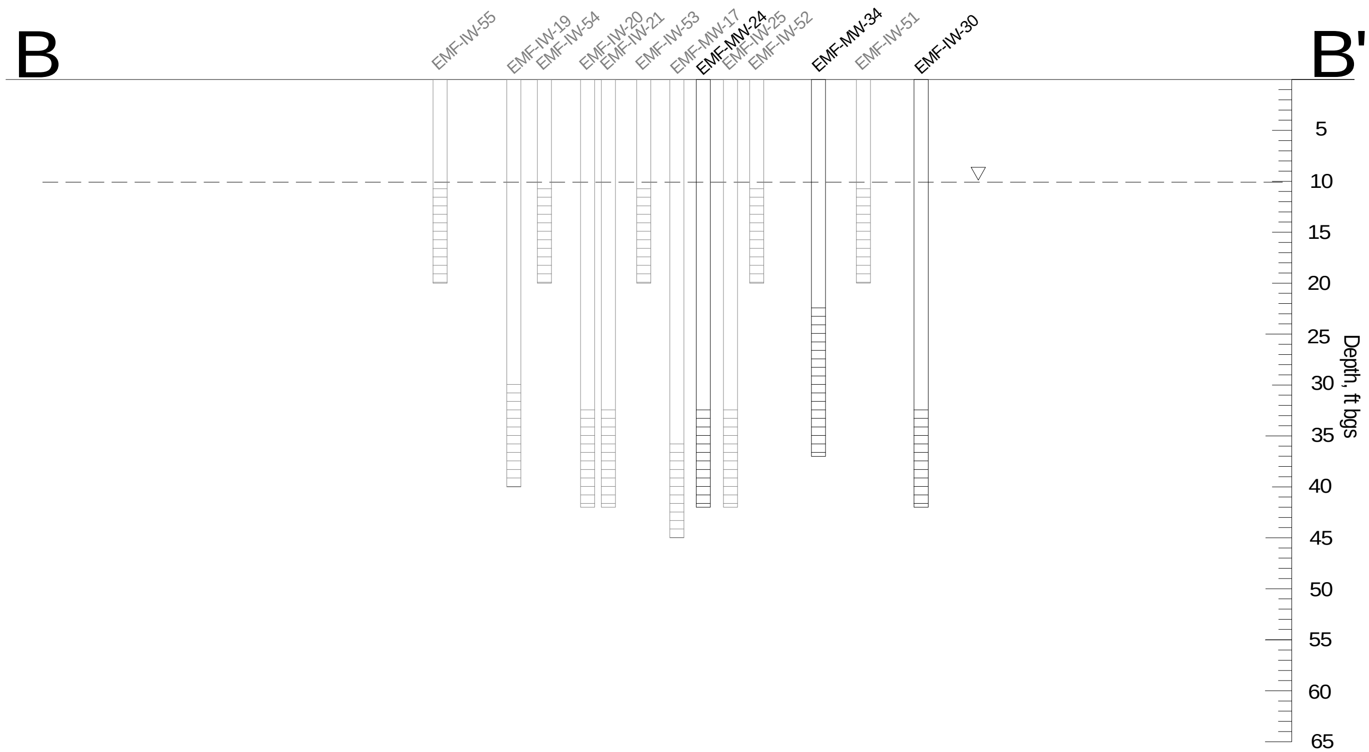
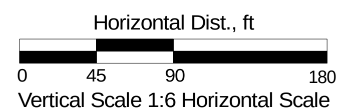
LEGEND

▽ Top of water table (approx)

Well screen

FIGURE A-3 Well Depths and and Screen Intervals - EMF Source Area-East





Wells in black are regularly monitored.
Wells in dark gray are not regularly monitored.

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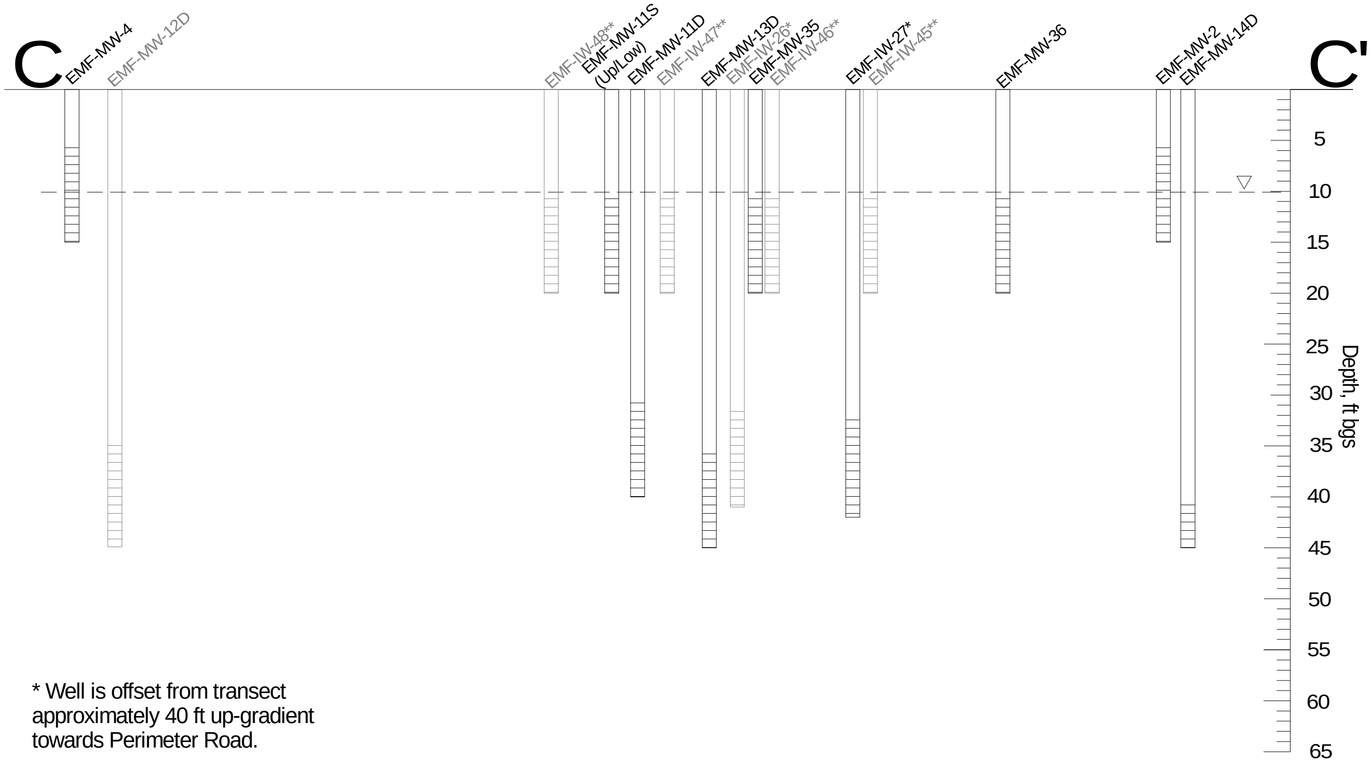
LEGEND

▽ Top of water table (approx)

Well screen

FIGURE A-4 Well Depths and and Screen Intervals - EMF Source Area (Central)



* Well is offset from transect approximately 40 ft up-gradient towards Perimeter Road.

** Well is offset from transect approximately 65 ft up-gradient towards Perimeter Road.

Wells in black are regularly monitored.
Wells in dark gray are not regularly monitored.

Horizontal Dist., ft

0 45 90 180

Vertical Scale 1:6 Horizontal Scale

BOEING®

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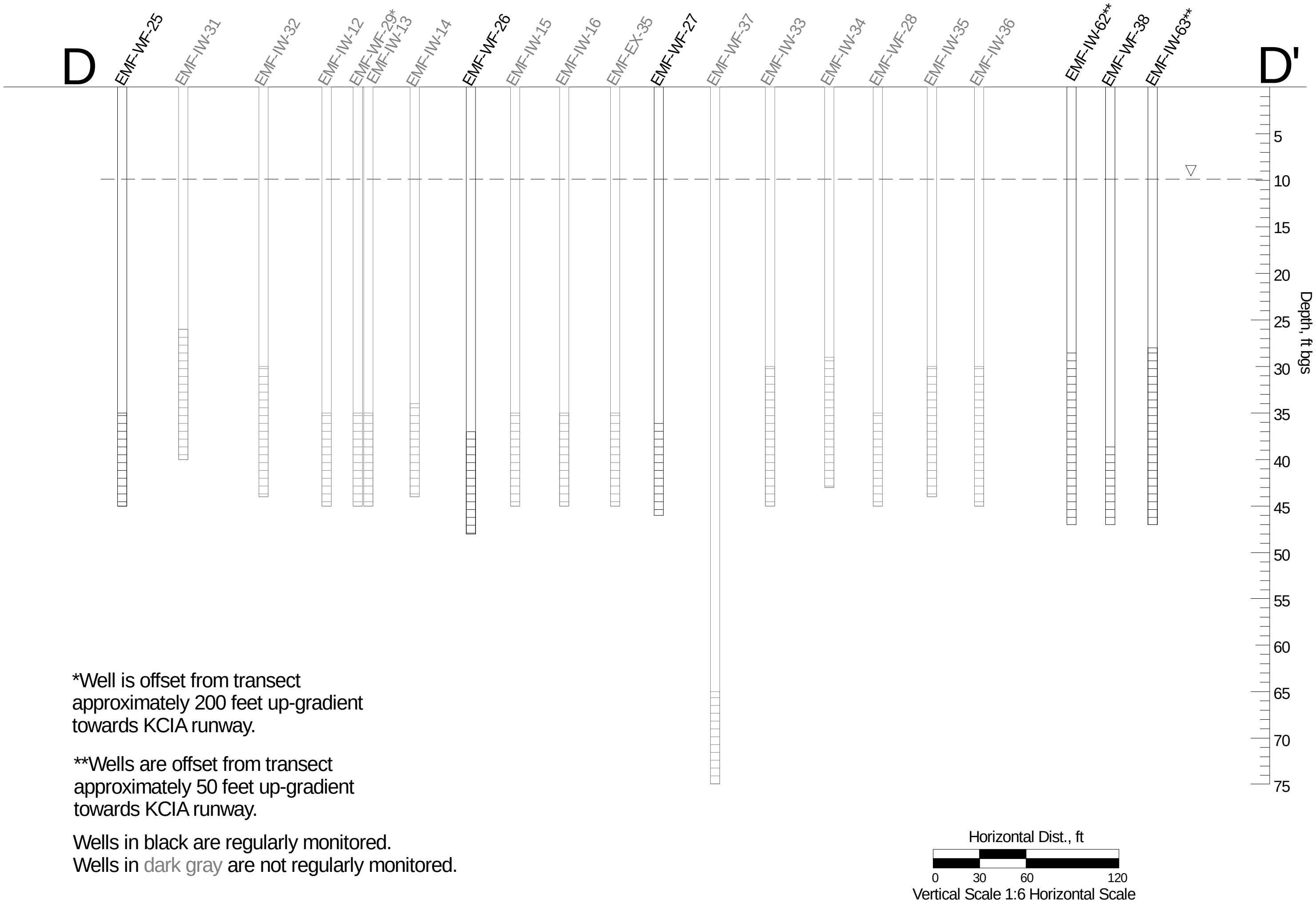
LEGEND

▽ Top of water table (approx)

Well screen

FIGURE A-5 Well Depths and and Screen Intervals - Transect at EMF Source West Side



*Well is offset from transect approximately 200 feet up-gradient towards KCIA runway.

**Wells are offset from transect approximately 50 feet up-gradient towards KCIA runway.

Wells in black are regularly monitored.
Wells in dark gray are not regularly monitored.

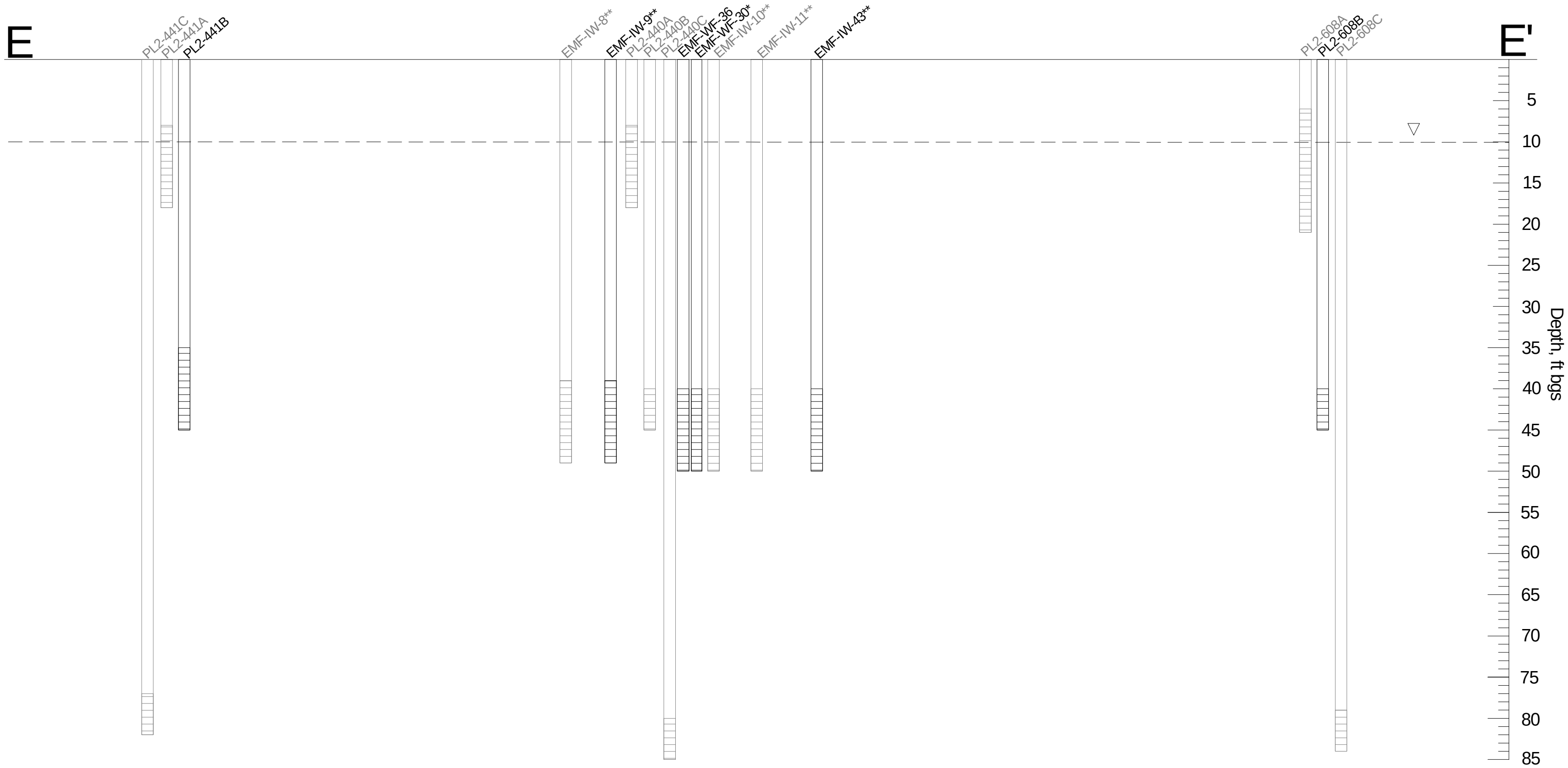
BOEING
CALIBRE Systems Inc.

LEGEND

▽ Top of water table (approx)

Well screen

FIGURE A-6 Well Depths and and Screen Intervals - Fire Station Area



* Well offset from transect
approximately 140 ft down-gradient.

** Wells offset from transect
approximately 100 ft down-gradient.

Wells in black are regularly monitored.
Wells in dark gray are not regularly monitored.

Horizontal Dist., ft

0 45 90 180

Vertical Scale 1:6 Horizontal Scale

BOEING®

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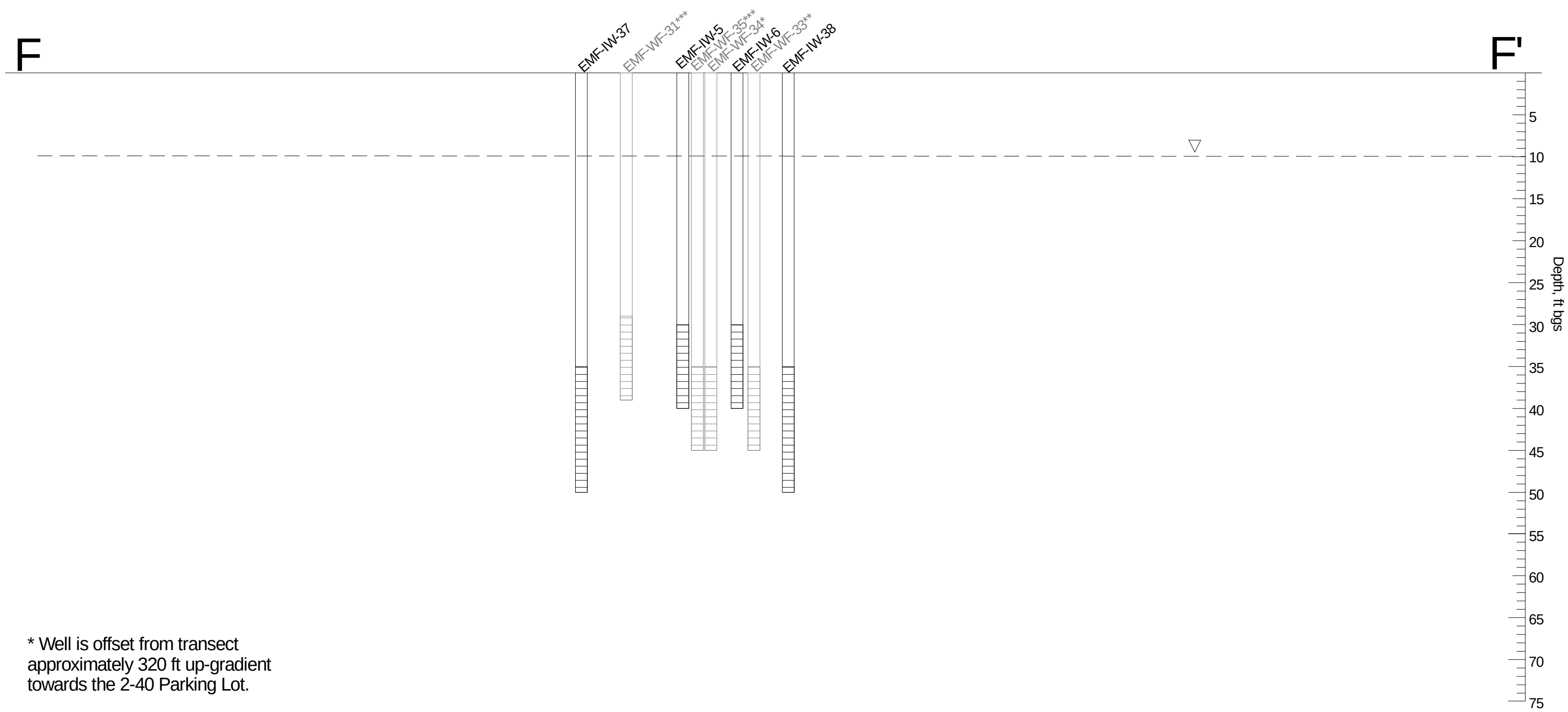
LEGEND

▽ Top of water table (approx)

Well screen

FIGURE A-7 Well Depths and and Screen Intervals -Former 2-41 Parking Lot



* Well is offset from transect approximately 320 ft up-gradient towards the 2-40 Parking Lot.

** Well is offset from transect approximately 265 ft up-gradient towards the 2-40 Parking Lot.

*** Well is offset from transect approximately 200 ft up-gradient towards the 2-40 Parking Lot.

Wells in black are regularly monitored.
Wells in dark gray are not regularly monitored.

Horizontal Dist., ft

0 45 90 180

Vertical Scale 1:6 Horizontal Scale

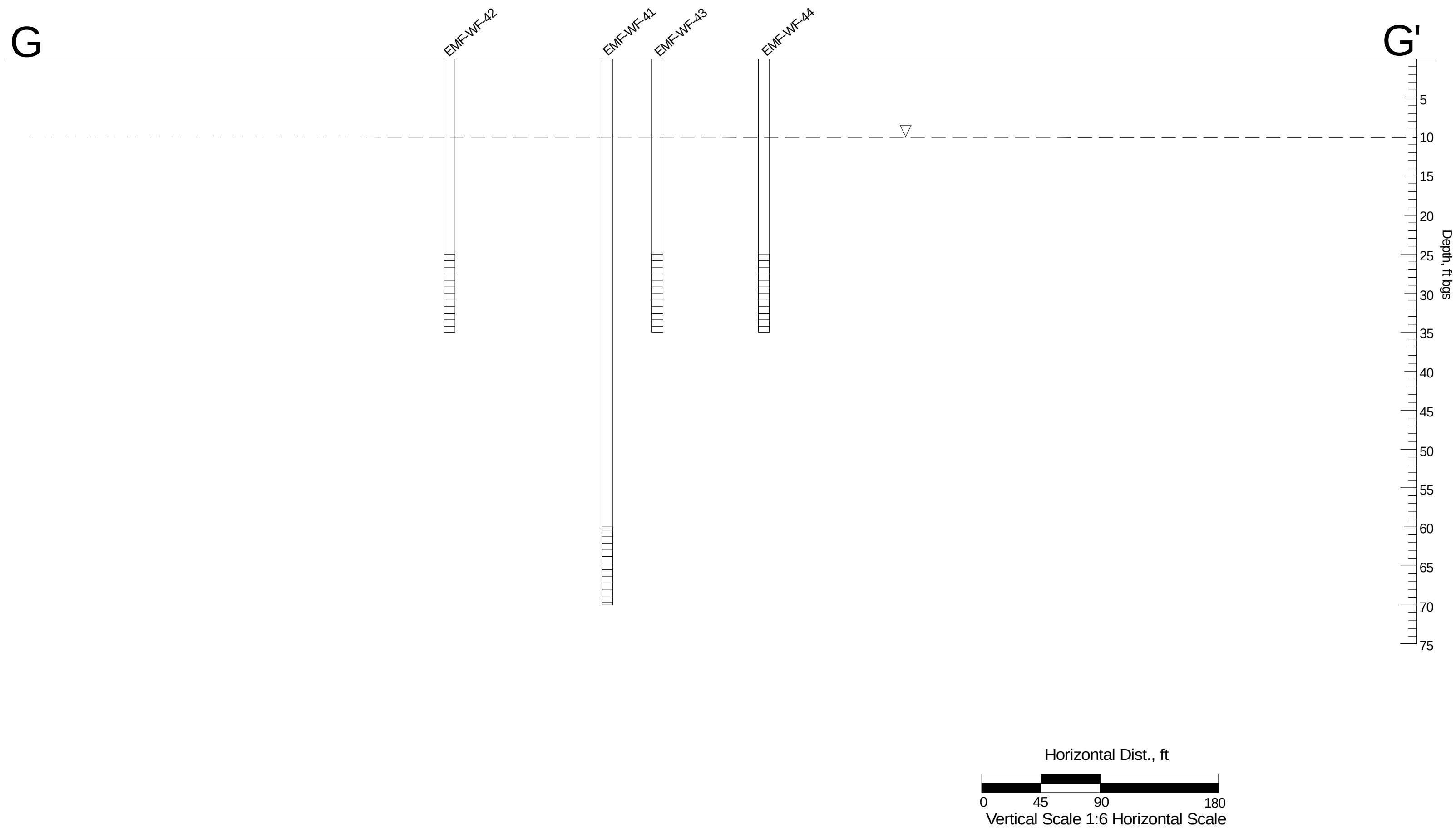
BOEING®
CALIBRE Systems Inc.

LEGEND

▽ Top of water table (approx)

Well screen

FIGURE A-8 Well Depths and and Screen Intervals -Former 2-41 Building



BOEING

CALIBRE Systems Inc.

LEGEND

▽ Top of water table (approx)

Well screen

FIGURE A-9 Well Depths and and Screen Intervals - Lower Duwamish Waterway

Attachment B
Detailed Cost Estimates for Alternatives

Attachment B
Table B-1

	Alt 2	Alt 3	Alt 4	Alt 5
Historic Costs				
In-Well Stripping (1997-2000)	$1,050,019	$1,050,019	$1,050,019	$1,050,019
In-Situ Chemical Oxidation (2000-2002)	$1,025,151	$1,025,151	$1,025,151	$1,025,151
Enhanced Reductive Dechlorination (2003-2013)	$2,249,389	$2,249,389	$2,249,389	$2,249,389
Total Historic Costs to Remedial Actions	$4,324,559	$4,324,559	$4,324,559	$4,324,559
Other EMF Non-RA Costs (MTCA FS, Expanded Characterization, Reporting, Planning of EE/CA, etc.) **Not Included in Total Costs Below**	$ 630,400	$ 630,400	$ 630,400	$ 630,400
Capital Costs				
Engineering and Planning	$0	$36,300	$37,620	$24,420
Well Drilling	$38,280	$751,080	$258,192	$68,904
Site Work	$0	$608,705	$390,852	$0
Installation and Startup	$0	$306,240	$227,040	$43,692
Equipment and Materials	$0	$1,635,551	$912,135	$35,640
Waste Management	$0	$4,732	$2,558	$1,156
Subtotal	$38,280	$3,342,608	$1,828,397	$173,812
Permitting (PSCAA/construction/other)	$0	$3,000	$3,000	$0
Project Contigency	$5,742	$501,841	$274,710	$26,072
Total Capital Costs	$44,022	$3,847,450	$2,106,106	$199,884
Institutional Controls				
Implementation of Deed Restrictions	$23,496	$23,496	$23,496	$23,496
Court Filing of Deed Restrictions	$16,104	$16,104	$16,104	$16,104
Present Value of Five Year Reviews	$51,953	$51,953	$51,953	$51,953
Subtotal ICs	$91,553	$91,553	$91,553	$91,553
Annual O&M				
Inspections and maintenance	$0	$149,919	$73,689	$40,079
Utilities	$0	$232,786	$126,425	$0
Materials	$0	$87,665	$48,875	$31,618
Subtotal (O&M)	$0	$470,370	$248,989	$71,697
Monitoring				
Compliance monitoring	$71,610	$67,568	$67,568	$67,568
Present Value Future O&M Costs				
Present value of 7 yr O&M @ 5% *	$0	$2,721,735	$1,440,741	$414,863
Present value of 13 yrs monitoring @ 5% **	$672,674	$634,700	$634,700	$634,700
Present value of replacement costs	$10,893	$63,886	$44,298	$12,536
Total Costs				
(Prior + Capital costs + NPV of Future costs)	**$5,143,700**	**$11,683,882**	**$8,641,957**	**$5,678,096**

**The O&M cost estimate (as net present value) is based on 7 years operation (for consistency between alternatives). Actual operations (to be determined based on performance monitoring data) may be different, particulary for the ERD alternative where this voluntary remedial action has been underway at the site for several years.*

***The monitoring cost (as net present value) is based on 13 years of monitoring (for consistency between alternatives). The actual monitoring period (to be determined based on performance monitoring data) may be different.*

Attachment B
Table B-2

Removal Action Alternative	Specific Wells	SVE Wells	Total Number of New Wells	Trenching ft	Pipe ft Totals	Notes
Monitored Natural Attenuation	0	0	0	0	0	
In-situ Air Sparging with SVE	103	103	206	4,338	61,018	one pipe to each well
In-well Stripping with SVE	58	0	58	3,670	38,337	two pipes to each well
Enhanced Reductive Dechlorination	8	0	8	0	0	

Attachment B
Table B-3

SUMMARY OF ALTERNATIVE 2: MONITORED NATURAL ATTENUATION

CAPITAL COSTS

	Units	Qty	Unit Cost	Total Cost
Well Drilling				
Compliance monitoring wells (45ft bgs)	ea	10	$2,900	$29,000
Subtotal				$29,000
Contingency	20%			$5,800
Profit	10%			$3,480
Total				$38,280
Project Subtotal				$38,280
Project Contingency	15%			$5,742
Project Total				**$44,022**

ANNUAL O&M COSTS

	Units	Qty	Unit Cost	Total Cost
Inspections and Maintenance				
Subtotal				$0
Contingency	5%			$0
Profit	10%			$0
Total				$0
Compliance monitoring				
Sample collection	hrs	120	$75	$9,000
Sample analysis	samples	35	$200	$7,000
Reporting	ea	1	$15,000	$15,000
Subtotal				$31,000
Contingency	5%			$1,550
Profit	10%			$3,255
Events per Year				2
Total				$71,610
Materials				
Subtotal				$0
Contingency	5%			$0
Profit	10%			$0
Total				$0
Total Annual O&M				$71,610

PERIODIC REPLACEMENT COSTS

		Replacement Year		
Discount rate	5.00%			
	baseline cost cost	5	10	PV
Well rehab	$4,500	$3,526		$3,526
Well replacement	$12,000		$7,367	$7,367
Total Present Value				$10,893

SUMMARY OF ALTERNATIVE 3: IN-SITU AIR SPARGING WITH SOIL VAPOR EXTRACTION CAPITAL COSTS

Engineering and Planning	Units	Qty	Unit Cost	Total Cost
Design labor	hr	240	$100	$24,000
ODCs	ls	1	$3,500	$3,500
Subtotal				$27,500
Contingency	20%			$5,500
Profit	10%			$3,300
Total				$36,300
Well Drilling				
Shallow wells (40ft bgs)	ea	81	$2,800	$226,800
Deep wells (50ft bgs)	ea	22	$3,000	$66,000
Soil vapor extraction wells (10 ft bgs)	ea	103	$900	$92,700
Vaults	ea	103	$1,500	$154,500
Compliance monitoring wells (45ft bgs)	ea	10	$2,900	$29,000
Subtotal				$569,000
Contingency	20%			$113,800
Profit	10%			$68,280
Total				$751,080
Site Work				
Airport rated well vault	ea	103	$1,000	$103,000
Backfill	ea	103	$1,000	$103,000
Replace concrete	cy	100	$40	$4,000
Utility reroute	ls	11	$5,000	$55,000
Trenching	ft	4338	$30	$130,140
Pad/Building/Civil/Utilities	ea	11	$6,000	$66,000
Subtotal				$461,140
Contingency	20%			$92,228
Profit	10%			$55,337
Total				$608,705
Installation and Startup				
Installation labor	hr	880	$80	$70,400
Mobilization/demobilization	ls	2	$50,000	$100,000
Startup labor	hr	176	$100	$17,600
Electrical work	ls	11	$4,000	$44,000
Subtotal				$232,000
Contingency	20%			$46,400
Profit	10%			$27,840
Total				$306,240

Attachment B
Table B-4

Equipment and Materials	Units	Qty	Unit Cost	Total Cost
Piping	ft	61018	$3	$183,054
IAS/SVE Equipment Package*	ea	11	$80,000	$880,000
1,800-pound capacity GAC adsorber	ea	22	$5,000	$110,000
700-pound capacity permanganate media vessel	ea	22	$3,000	$66,000
Subtotal				$1,239,054
Contingency	20%			$247,811
Profit	10%			$148,686
Total				$1,635,551

*IAS/SVE Equipment Package includes pressure blowers, PLC controls, moisture seperators, control valves, flow meters, etc.

Waste Management				
Drilling cuttings and soil	ton	34	$60	$2,040
Development water	gallons	15450	$0.10	$1,545
Subtotal				$3,585
Contingency	20%			$717
Profit	10%			$430
Total				$4,732
Project Subtotal				$3,342,608
PSCAA permitting				$3,000
Project Contingency	15%			$501,841
Project Total				**$3,847,450**

ANNUAL O&M COSTS

Inspections and Maintenance				
Inspections, routine maintenance	hrs	1000	$100	$100,000
Miscellaneous equipment repair	ls	1	$10,000	$10,000
Process monitoring sample analysis	samples	132	$150	$19,800
Subtotal				$129,800
Contingency	5%			$6,490
Profit	10%			$13,629
Total				$149,919

Compliance monitoring				
Sample collection	hrs	120	$75	$9,000
Sample analysis	samples	35	$150	$5,250
Reporting	ea	1	$15,000	$15,000
Subtotal				$29,250
Contingency	5%			$1,463
Profit	10%			$3,071
Events per Year				2
Total				$67,568

Attachment B
Table B-4

Utilities	Units	Qty	Unit Cost	Total Cost
Electrical power	kwh	2,519,332	$0.08	$201,547
Subtotal				$201,547
Contingency	5%			$10,077
Profit	10%			$21,162
Total				$232,786

Materials				
Vapor-phase GAC media	lb	19800	$1.50	$29,700
Permanganate media	lb	15400	$3	$46,200
Subtotal				$75,900
Contingency	5%			$3,795
Profit	10%			$7,970
Total				$87,665

Total Annual O&M **$537,937**

PERIODIC REPLACEMENT COSTS

Discount rate 5.00%

		Replacement Year		
	cost	5	10	PV
Blower replacement (5K per system)	$55,000	$43,094		$43,094
Other misc. equipment replacement	$6,000	$4,701		$4,701
Well rehab/development (once/5years)	$8,000	$6,268		$6,268
Well replacement (every 10 years)	$16,000		$9,823	$9,823
Total Present Value		$54,063	$9,823	$63,886

Attachment B
Table B-5

SUMMARY OF ALTERNATIVE 4: IN-WELL STRIPPING
CAPITAL COSTS

Engineering and Planning	Units	Qty	Unit Cost	Total Cost
Design labor	hr	240	$100	$24,000
Bench-scale tests	ls	1	$2,000	$2,000
ODCs	ls	1	$2,500	$2,500
Subtotal				$28,500
Contingency	20%			$5,700
Profit	10%			$3,420
Total				$37,620
Well Drilling				
Shallow wells (40ft bgs)	ea	37	$2,800	$103,600
Deep wells (50ft bgs)	ea	21	$3,000	$63,000
Compliance monitoring wells (45ft bgs)	ea	10	$2,900	$29,000
Subtotal				$195,600
Contingency	20%			$39,120
Profit	10%			$23,472
Total				$258,192
Site Work				
Gallery excavation	ea	58	$1,000	$58,000
Backfill	ea	58	$1,000	$58,000
Trenching	ft	3670	$30	$110,100
Replace concrete	cy	100	$40	$4,000
Utility reroute	ls	6	$5,000	$30,000
Pad/Building/Civil/Utilities	ea	6	$6,000	$36,000
Subtotal				$296,100
Contingency	20%			$59,220
Profit	10%			$35,532
Total				$390,852
Installation and Startup				
Installation labor	hr	480	$80	$38,400
Mobilization/demobilization	ls	2	$50,000	$100,000
Startup labor	hr	96	$100	$9,600
Electrical work	ls	6	$4,000	$24,000
Subtotal				$172,000
Contingency	20%			$34,400
Profit	10%			$20,640
Total				$227,040

Equipment and Materials	Units	Qty	Unit Cost	Total Cost
Piping	ft	38337	$3	$115,011
IWS Equipment Package*	ea	6	$80,000	$480,000
1,800-pound capacity GAC adsorber	ea	12	$5,000	$60,000
vessel	ea	12	$3,000	$36,000
Subtotal				$691,011
Contingency	20%			$138,202
Profit	10%			$82,921
Total				$912,135

*IWS Equipment Package includes pressure blowers, PLC controls, moisture separators, control valves, flow meters, etc.

Waste Management				
Excavation spoils, soil	ton	32.3	$60	$1,938
Development water	gal	8700	$0.10	$870
Subtotal				$1,938
Contingency	20%			$388
Profit	10%			$233
Total				$2,558
Project Subtotal				$1,828,397
permits				$3,000
Project Contingency	15%			$274,710
Project Total				**$2,106,106**

ANNUAL O&M COSTS

Inspections and Maintenance				
Inspections, routine maintenance	hrs	480	$100	$48,000
Miscellaneous equipment repair	ls	1	$5,000	$5,000
Process monitoring sample analysis	samples	72	$150	$10,800
Subtotal				$63,800
Contingency	5%			$3,190
Profit	10%			$6,699
Total				$73,689

Compliance monitoring				
Sample collection	hrs	120	$75	$9,000
Sample analysis	samples	35	$150	$5,250
Reporting	ea	1	$15,000	$15,000
Subtotal				$29,250
Contingency	5%			$1,463
Profit	10%			$3,071
Events per Year				2
Total				$67,568

Attachment B
Table B-5

Utilities	Units	Qty	Unit Cost	Total Cost
Electrical power	kwh	1374181.2	$0.08	$109,934
Subtotal				$109,934
Contingency	5%			$5,497
Profit	10%			$10,993
Total				$126,425
Materials				
GAC media	lb	9,000	$2	$13,500
Permanganate media	lb	7,000	$3	$21,000
Iron control chemicals	lb	4,000	$2	$8,000
Subtotal				$42,500
Contingency	5%			$2,125
Profit	10%			$4,250
Total				$48,875
Total Annual O&M				$316,556

PERIODIC REPLACEMENT COSTS

Discount rate	5.00%			
		Replacement Year		
	cost	5	10	PV
Blower replacement (5K per system)	$30,000	$23,506		$23,506
Other misc. equipment replacement	$6,000	$4,701		$4,701
Well rehab/development (once/5years)	$8,000	$6,268		$6,268
Well replacement (every 10 years)	$16,000		$9,823	$9,823
Total Present Value		$34,475	$9,823	$44,298

SUMMARY OF ALTERNATIVE 5: ENHANCED REDUCTIVE DECHLORINATION

CAPITAL COSTS

Engineering and Planning	Units	Qty	Unit Cost	Total Cost
Design labor	hr	160	$100	$16,000
ODCs	ls	1	$2,500	$2,500
Subtotal				$18,500
Contingency	20%			$3,700
Profit	10%			$2,220
Total				$24,420
Well Drilling (*)				
Shallow injection wells (40ft bgs)	ea	4	$2,800	$11,200
Deep injections wells (50ft bgs)	ea	4	$3,000	$12,000
Compliance monitoring wells (45ft bgs)	ea	10	$2,900	$29,000
Subtotal				$52,200
Contingency	20%			$10,440
Profit	10%			$6,264
Total				$68,904
Installation and Startup				
Installation labor	hr	320	$80	$25,600
Mobilization/demobilization	ls	1	$7,500	$7,500
Startup labor	hr	0	$100	$0
Subtotal				$33,100
Contingency	20%			$6,620
Profit	10%			$3,972
Total				$43,692
Equipment and Materials				
Sugar substrate (Dilute solution, includes transport, scheduling, etc.)	tons	300	$90	$27,000
Subtotal				$27,000
Contingency	20%			$5,400
Profit	10%			$3,240
Total				$35,640
Waste Management				
Excavation spoils, soil	ton	12.6	$60	$756
Development water	gal	1200	$0.10	$120
Subtotal				$876
Contingency	20%			$175
Profit	10%			$105
Total				$1,156
Project Subtotal				$173,812
Project Contingency	15%			$26,072
Project Total				**$199,884**

Attachment B
Table B-6

ANNUAL O&M COSTS

Annual Injections	Units	Qty	Unit Cost	Total Cost
Injection Labor	hrs	320	$85	$27,200
Truck, Tank, Equipment	ls	1	$7,500	$7,500
Subtotal				$34,700
Contingency	5%			$1,735
Profit	10%			$3,644
Total				$40,079
Compliance monitoring				
Sample collection	hrs	120	$75	$9,000
Sample analysis	samples	35	$150	$5,250
Reporting	ea	1	$15,000	$15,000
Subtotal				$29,250
Contingency	5%			$1,463
Profit	10%			$3,071
Events per Year				2
Total				$67,568
Materials				
Sugar substrate (Dilute solution, includes transport, scheduling, etc.)	tons	300	$90	$27,000
Sodium bicarbonate	lb	500	$0.75	$375
Subtotal				$27,375
Contingency	5%			$1,369
Profit	10%			$2,874
Total				$31,618
Total Annual O&M				$139,264

PERIODIC REPLACEMENT COSTS

Discount rate	5.00%			
		Replacement Year		
	cost	5	10	PV
Well replacement	$16,000	$12,536		$12,536
Total Present Value				$12,536

(*) Prior expenditures for the site-wide ERD injection well network (existing)are not included in this cost estimate

SUMMARY OF INSTITUTIONAL CONTROL COSTS (APPLIED TO ALL ALTERNATIVES)

CAPITAL COSTS

Developing/preparing Deed Restrictions	Units	Qty	Unit Cost	Total Cost	
Professional Labor	hr	120	$140	$16,800	
ODCs	ls	1	$1,000	$1,000	
Subtotal				$17,800	
Contingency	20%			$3,560	
Profit	10%			$2,136	
Total				$23,496	
Filing/recording of Deed Restrictions					
Professional Labor	hr	80	$140	$11,200	
ODCs	ls	1	$1,000	$1,000	
Subtotal				$12,200	
Contingency	20%			$2,440	
Profit	10%			$1,464	
Total				$16,104	
Five Year Review					
Professional Labor	hr	150	$140	$21,000	
ODCs	ls	1	$1,000	$1,000	
Subtotal				$22,000	
Contingency	20%			$4,400	
Profit	10%			$2,640	
Total (as 2014 costs for 5-year review)				$29,040	
Discount Rate	5%				
	NPV		2020 Event	$21,670	
	NPV		2025 Event	$16,979	
	NPV		2030 Event	$13,304	
			5-Year Review Total*	$51,953	as NPV
Institutional Control Total				**$91,553**	

Note: Developing Deed Restrictions and the Filing Tasks are one-time captial costs; the five-year review costs are summarized as net present values. Assume 5-year reviews will be completed 3 times total (Beginning in 2020). Events will occur 2020, 2025, 2030, costs are presented in a Net Present Values.

SUMMARY OF HISTORIC COSTS: ENHANCED REDUCTIVE DECHLORINATION (ERD)

CAPITAL COSTS

Engineering and Planning	Units	Qty	Unit Cost	Total Cost
Design labor	hr	100	$100	$10,000
ODCs	ls	1	$4,599	$4,599
Total				$14,599
Well Drilling				
Shallow injection wells (2"-Probe Installed)*	ea	14	$1,000	$14,000
Deep injections wells (4"-HSA Installed)	ea	44	$3,750	$165,000
Total				$179,000
Substrate Injections (2003-2006)				
Labor	hr	200	$85	$17,000
Mobilization/demobilization	ls	1	$1,000	$1,000
Substrate loads	ea	5	$400	$2,000
ODCs	ls	1	$3,500	$3,500
Subtotal				$23,500
Events				6
Total				$141,000
Substrate Injections (2007-2012)				
Labor	hr	400	$85	$34,000
Mobilization/demobilization	ls	1	$1,000	$1,000
Substrate loads	ea	10	$400	$4,000
ODCs	ls	1	$3,500	$3,500
Subtotal				$42,500
Events				17
Total				$722,500
Compliance Monitoring				
Sample collection	hrs	120	$75	$9,000
Sample analysis	samples	44	$150	$6,600
Reporting	ea	1	$15,000	$15,000
Subtotal				$30,600
Events per Year				2
Years (2003-2013)				11
Total				$673,200
Project Subtotal				$1,730,299
Miscellaneous Project Costs			10%	$173,030
Boeing PM, Labor, Oversight, and Management			20%	$346,060
Project Total				**$2,249,389**
Other EMF Non-RA Costs (MTCA FS, Expanded Characterization, Reporting, Planning of EE/CA, etc.)				$275,800

(*) Shallow injection wells were installed using a probe vehicle, shallow wells are 2" diameter.
Note: Costs depicted in the Historical Costs for ERD have already been incurred, these costs also affect the other alternatives (current groundwater conditions have been beneficially impacted by past ERD treatment).

SUMMARY OF HISTORIC COSTS: IN-SITU CHEMICAL OXIDATION (ISCO)

CAPITAL COSTS

Engineering and Planning	Units	Qty	Unit Cost	Total Cost
Design labor	hr	200	$100	$20,000
ODCs	ls	1	$2,628	$2,628
Total				$22,628
Well Drilling				
Chemical Oxidation Injection Wells	ea	15	$3,250	$48,750
Total				$48,750
In-Situ Chemical Oxidation (ISCO)				
Labor	hr	2000	$85	$170,000
Materials ($KMNO_4$)	ton	50	$2,000	$100,000
Equipment Package	ea	1	$40,000	$40,000
Support Equipment (Generator, Baker Tank, etc)	ls	1	$30,000	$30,000
ODCs (Hardware, Fuel, etc.)	ls	2	$5,000	$10,000
Total				$350,000
Compliance Monitoring				
Sample collection	hrs	120	$75	$9,000
Sample analysis	samples	44	$150	$6,600
Reporting	ea	1	$15,000	$15,000
Subtotal				$30,600
Events per Year				4
Years (2000-2002)				3
Total				$367,200
Project Subtotal				$788,578
Miscellaneous Project Costs			10%	$78,858
Boeing PM, Labor, Oversight, and Management			20%	$157,716
Project Total				**$1,025,151**
Other EMF Non-RA Costs (MTCA FS, Expanded Characterization, Reporting, Planning of EE/CA, etc.)				$118,200

Note: ISCO was performed from 2000-2002. Costs depicted in the Historical Costs for ISCO have already been incurred, these costs also affect the other alternatives (current groundwater conditions have been beneficially impacted by past ISCO treatment).

Attachment B
Table B-10

SUMMARY OF HISTORIC COSTS: IN-WELL STRIPPING (IWS)

CAPITAL COSTS

Engineering and Planning	Units	Qty	Unit Cost	Total Cost
Design labor	hr	200	$100	$20,000
ODCs	ls	1	$2,500	$2,500
Total				$22,500
Well Drilling				
IWS Specialty Wells	ea	2	$7,500	$15,000
Vaults	ea	2	$2,000	$4,000
Trenching	ft	210	$25	$5,250
Total				$24,250
In Well Stripping Operation				
Labor	hr	4,500	$85	$382,500
Materials (carbon, acid, etc)	ls	1	$10,000	$10,000
Equipment Package	ea	1	$65,000	$65,000
Power Drop Fee	ls	1	$5,000	$5,000
Power	kwh	338000	$0.08	$27,057
ODCs (Hardware, Fuel, etc.)	ls	1	$5,000	$5,000
Total				$494,557
Compliance Monitoring				
Sample collection	hrs	40	$75	$3,000
Sample analysis	samples	28	$150	$4,200
Reporting	ea	1	$15,000	$15,000
Subtotal				$22,200
Events per Year				4
Years (1997-2000)				3
Total				$266,400
Project Subtotal				$807,707
Miscellaneous Project Costs			10%	$80,771
Boeing PM, Labor, Oversight, and Management			20%	$161,541
Project Total				**$1,050,019**
Other EMF Non-RA Costs (MTCA FS, Expanded Characterization, Reporting, Planning of EE/CA, etc.)				$236,400

Note: IWS was performed from Fall 1997 to April 2006. Costs depicted in the Historical Costs for IWS have already been incurred, these costs also affect the other alternatives (current groundwater conditions have been beneficially impacted by past IWS treatment).