HISTORICAL DATA SUMMARY REPORT
FINAL

EMF Site
Seattle, Washington

Prepared for:
THE BOEING COMPANY
SHARED SERVICES GROUP

Prepared by:
CALIBRE Systems, Inc.
Project No. K0502001

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Acronym List

ACOE	US Army Corps of Engineers
AOCs	areas of concern
APN	Asia Pacific Network
AWQC	Ambient Water Quality Criteria
BAF	bioaccumulation factor
BCF	bioconcentration factor
bgs	below ground surface
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
cis-1,2-DCE	cis-1,2-dichloroethene
cm/sec	centimeters per second
COC	chemicals of concern
CWA	Clean Water Act
DNAPL	dense non-aqueous phase liquid
DQO	Data Quality Objective
Ecology	Washington Department of Ecology
EE/CA	Engineering Evaluation and Cost Analysis
EMF	Electronics Manufacturing Facility
EPA	Environmental Protection Agency
ERD	enhanced reductive dechlorination
foc	fraction organic carbon
FS	Feasibility Study
ft	feet
IAEA	International Atomic Energy Agency
IHP/IOC	International Hydrological Program Intergovernmental Oceanographic Commission
ISCO	in-situ chemical oxidation
KCIA	King County International Airport
Kd	soil-water partition coefficient
LDW	Lower Duwamish Waterway
L/kg	liter per kilogram
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
MHHW	mean higher high water
MLLW	mean lower low water
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
NPL	National Priorities List

NSF	National Science Foundation
ppb	parts per billion
PQL	Practical Quantitation Limit
PVC	polyvinyl chloride
RA	Remedial Action
RCRA	Resource Conservation and Recovery Act
RCW	Revised Code of Washington
Rd	retardation coefficient
RFI	RCRA Facility Investigation
RI	Remedial Investigation
RSGD	re-circulated submarine groundwater discharge
SCOR	Scientific Committee on Oceanic Research
SFGD	submarine fresh groundwater discharge
SGD	submarine groundwater discharge
SWMUs	solid waste management units
TCE	trichloroethene
trans-1,2-DCE	trans-1,2-dichloroethene
ug/L	micrograms per liter
UST	underground storage tank
UV	ultra-violet
VOC	volatile organic compound
VCP	MTCA Voluntary Cleanup Program
WA	Washington
WAC	Washington Administrative Code
WPCA	Water Pollution Control Act

HISTORICAL DATA SUMMARY REPORT

EMF Site, Seattle, Washington

1.0 INTRODUCTION

This report summarizes historical environmental data collected during previous investigations of a hazardous materials release at 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 at the identified locations 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 remedial actions have been implemented in the down-gradient areas impacted by the VOC plume from the EMF property.

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). Within the CERCLA process, a number of acronyms are well known and standard terminology, these include Remedial Investigation (RI), Feasibility Study (FS) and Remedial Action (RA) and others. The EMF project was initiated approximately 25 years before the present CERCLA Settlement Agreement under environmental statutes of Washington State (the Water Pollution Control Act, WPCA and the Model Toxics Control Act, MTCA). The MTCA regulations use the same terminology (as CERCLA) for various phases of the required site work including RI, FS, and RA. This historical summary report describes work completed before the CERCLA Settlement Agreement. Since the various environmental statutes use the same terminology, the term “MTCA” RI/FS/RA or “pre-MTCA” RI/FS/RA is used throughout this document to distinguish between CERCLA process steps and work completed previously.

This report is intended (primarily) to summarize the relevant historical data from the site (i.e., the 25-year project history pre-dating the Settlement Agreement) and to develop a conceptual site model. Pursuant to that objective, this historical summary describes the work in the context of the regulatory standards and objectives applicable at the time the work was completed. The summary also notes when the regulatory statutes changed and how those changes subsequently changed the applicable regulatory standards and project objectives.

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 will be a part of the upcoming engineering evaluation/cost analysis (EE/CA).

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.

1.1 Objectives

The objectives of this report are to summarize the chronological history of the project and provide sufficient information (by referencing the pre-existing MTCA RI /FS and MTCA RA reports) to develop the conceptual site model (including hydrogeology, contaminants of concern, contaminant distribution, and exposure pathways) and identify data gaps.

1.2 Organization

Section 2.0 describes the location of the site, presents background information regarding the site, and discusses the general environmental setting. Section 3.0 provides a summary of previous investigation and remedial actions at the EMF site. The conceptual site model is presented in Section 4.0. Section 5.0 summarizes the identification and assessment of discharges to the Lower Duwamish Waterway. Section 6.0 summarizes a Data Quality Objectives (DQO) process used to define anticipated project decisions, evaluation of existing data and definition of data gaps. The bibliography is listed in Section 7.0. Appendix A provides copies of historical aerial photographs and maps; Appendix B presents a review of the bioaccumulation potential for vinyl chloride; Appendix C presents a summary of groundwater monitoring data; Appendix D presents the coordinates and survey elevation of sampling points at the site; Appendix E presents site boring logs and well construction logs (on enclosed compact disk, CD); Appendix F presents a summary of the historical site characterization sampling data (on CD) for the data collected between 1996 and January 2007.

2.0 SITE DESCRIPTION AND BACKGROUND

2.1 Site 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 and Boeing Plant 2 impacted by the EMF VOC plume that is 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 TCE, cis-1,2-dichloroethene (cis-1,2-DCE), trans-1,2-dichloroethene (trans-1,2-DCE), and vinyl chloride.

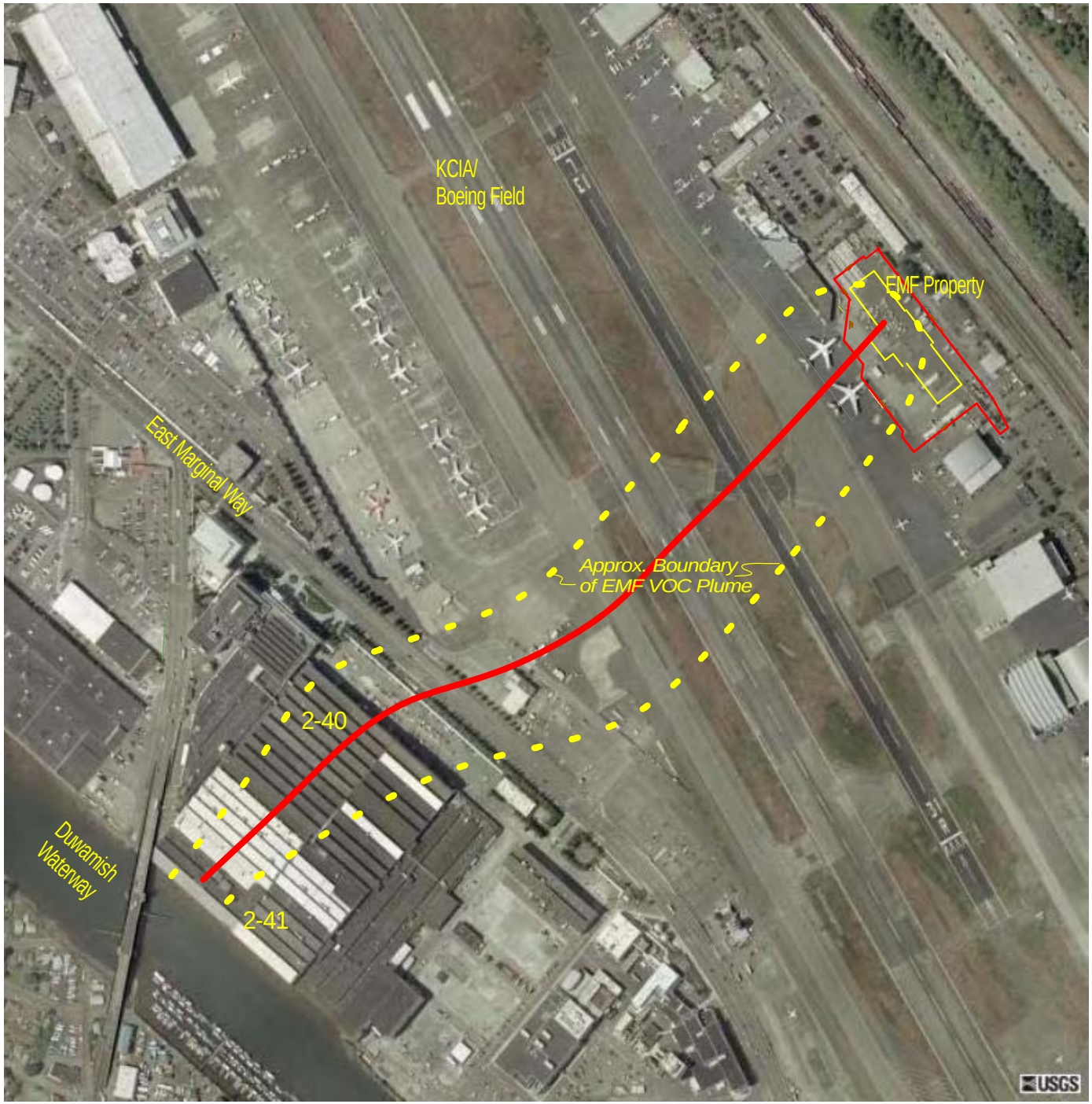
2.2 Background

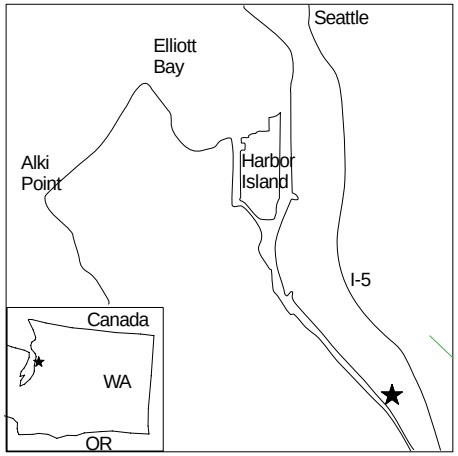
The EMF property is owned by King County and is leased to Boeing under a long-term lease agreement. The facility was originally used for prototype aircraft testing during the 1940s and 1950s, and was converted for use as an electronics manufacturing facility in 1962. A circuit board plating line at the 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 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 1997a). Additional investigation data has been collected and remedial actions implemented between 1997 and 2007 to characterize the site conditions and the down-gradient VOC plume in groundwater (all under the MTCA VCP). Table 2-1 presents a chronology of investigation and remedial activities at the site since 1982. The chronology of site investigation and remedial action activities is shown on a timeline in Figure 2-2.

2.3 Regulatory History and Background

The cleanup criteria described in this historical summary report have not been established by EPA under the current CERCLA Settlement Agreement, but rather by the specific regulatory requirements applicable at the time the historical work was implemented.





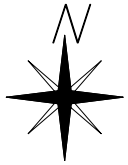


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Figure 2-1 Site Location EMF VOC Plume

DES'D: KBA	CLIENT: Boeing	PROJECT NO.: K502001
CHK'D: TJM	LOCATION: Boeing Fire Station	FIGURE: 1

Table 2-1 RI/FS and RA 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
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:

Date/Year	Scope
	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
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)

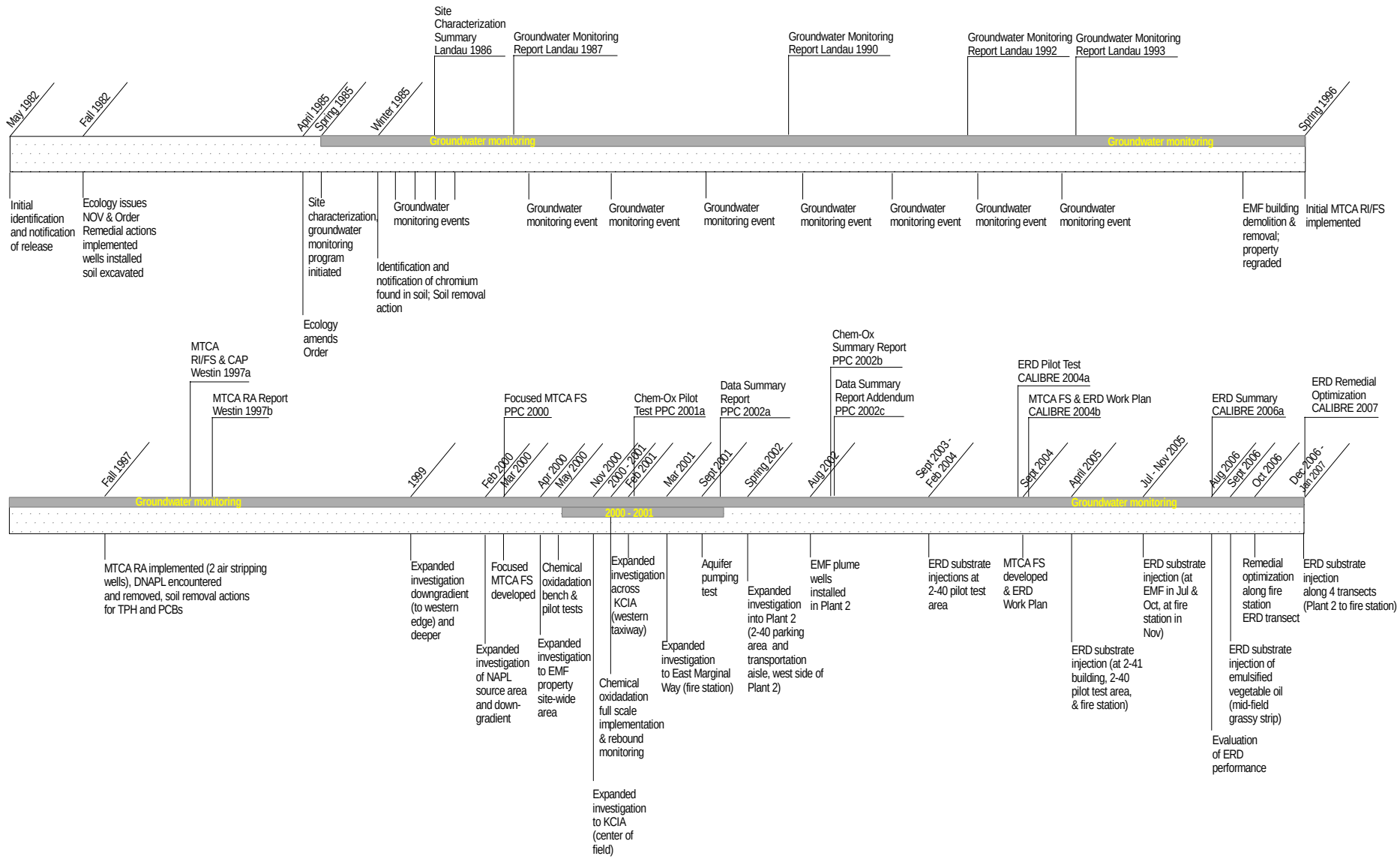

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Figure 2-2. Timeline of pre-MTCA and MTCA RI/FS & RA Activities, Boeing EMF Site 1982-2007

One of the requirements under the Settlement Agreement is an EE/CA. Establishing new/revised cleanup criteria will be a step in the EE/CA.

This section provides a brief summary of the regulatory requirements applicable over the project history. The intent is to provide a context for summarizing the site investigation work and remedial actions implemented over the last 25 years; specifically what specific regulatory criteria were identified by Boeing (and Ecology) and the remedial actions implemented to address those criteria.

The applicable regulations and corresponding regulatory criteria have changed several times over the project history. The intent of the applicable regulations has not changed (substantially) over the intervening years and has always been to protect human health and the environment from exposure to chemicals above specific risk thresholds.

2.3.1 Regulations and Standards in 1982

Removal of the plating lines at the EMF began in May 1982. Visual identification of stained soil/concrete, followed by chemical testing, indicated a release in the vicinity of the plating line. Boeing notified Ecology and the EPA National Response Center regarding the release identified at the EMF property.

After Boeing initiated pre-MTCA remedial actions, Ecology discussed the project with Boeing (Dec 1982) and identified the following concentration criteria for groundwater affected by the release at the EMF property. More details on the pre-MTCA investigation and remedial action work completed at that time (1982) are presented in Section 3.

Compound detected	WA Dangerous Waste Regulations (mg/L)	Ambient Water Quality Criteria (AWQCs) (mg/L)	Drinking water standard (mg/L)
Hexavalent Chromium	5.0	0.5	0.05
TCE	100	45	0.00027

The regulatory authority and responsibility of Ecology at that time is specified in the Water Pollution Control Act (Chapter 90.48 RCW).

2.3.2 Regulations and Standards in 1984

Ecology issued a formal cleanup policy in July 1984 to establish cleanup levels for hazardous material releases (a state-wide policy). The 1984 Ecology Final Cleanup Policy (prepared by the “How Clean is Clean” committee, and approved by Ecology management) addressed initial cleanup levels based on imminent threats, standard/background levels where technically feasible, and protective cleanup levels for cases where the standard/background levels were not technically feasible (based on a technical assessment of the feasibility of achieving the standard/ background levels).

This Ecology policy (1984) was considered in the 1985 pre-MTCA site investigations and did not materially change the cleanup criteria or project objectives.

2.3.3 Regulations and Standards in 1991

The Initiative 97 Model Toxics Control Act was passed in 1988 and became law in March 1989. Ecology adopted rules to implement the MTCA (WAC 173-340) in 1991 with subsequent rule revisions in 1996 and 2001. The MTCA requirements were considered in all subsequent site work and did not materially change the cleanup criteria or project objectives. The 2001 MTCA rule revision changed some details on how soil cleanup standards were established and formalized the ecological risk assessment guidance. These 2001 revisions to the MTCA did not materially change the cleanup criteria or project objectives.

Under the MTCA procedures for establishing cleanup levels (also consistent with the NCP), the first consideration is to identify existing promulgated standards which have been established for protection of public health and ecological receptors (i.e., typical examples for water depend on the applicable exposure scenario and include Maximum Contaminant Levels [MCLs, established under the Safe Drinking Water Act] and Ambient Water Quality Criteria [AWQCs, established under the Clean Water Act]). A number of promulgated standards exist for water, but few exist for soil. The MTCA Method A/B standards are based on residential exposure scenarios and include a goal of no greater than a 10^{-6} risk and Hazard Index (HI) < 1. The MTCA Method C standards are based on industrial exposure scenarios and include a goal of no greater than a 10^{-5} risk and HI<1. Under the MTCA, if the existing promulgated standard exceeds a 10^{-5} risk, then the Method B/C formulae and procedures are used to adjust the standard lower (a reduced cleanup level lower than the existing promulgated standard) to meet a 10^{-5} risk threshold. The NCP is different from the MTCA in this regard, in that a 10^{-4} threshold is set before the criteria established in the promulgated standard should be lowered.

Other modifying factors specified in the MTCA include practical quantitation limits (PQLs), and background distributions of naturally occurring substances. If the cleanup level identified in the MTCA procedures (noted above) are below the PQL, then the MTCA cleanup level is adjusted upwards to the PQL. Recognizing the presence of various metals as naturally occurring substances, the MTCA procedures establish the 90th percentile of the background distribution as the minimum threshold at which a cleanup level should be set (i.e., the MTCA cleanup level may be above the 90th percentile of the background distribution if there is no adverse human or ecological risk). If the promulgated standard or MTCA derived risk-based standard is below the 90th percentile of the naturally occurring distribution, the MTCA cleanup level is adjusted upwards to the 90th percentile of that natural range. Ecology has published 90th percentile values for inorganic compounds in various media based on data collected by Ecology and the USGS (e.g., see Ecology 1994, USGS 1986,1987).

Groundwater at and down gradient of the EMF property is not a source of potable water; therefore, groundwater cleanup standards identified in the ARARs evaluation (pursuant to the MTCA RI/FS requirements) have been based on protection of surface water (non potable) and were set equal to AWQCs for the specific COCs found at the site. The EMF site has always been considered an industrial setting under the MTCA criterion. However, removal actions implemented in the 1997 MTCA RA excavated all soil above MTCA Method A standards (residential or unrestricted use).

Between 1996 and early 2007 the EMF project has been implemented under the Voluntary Cleanup Program (VCP) administered by the Department of Ecology. The VCP includes a range of opportunities for oversight/assistance, ranging from telephone consultation on a completely independent cleanup to full oversight with a signed legal agreement (an agreed order or a consent decree). When the cleanup meets state cleanup requirements, Ecology may issue a written “No Further Action” designation. Under the VCP on the EMF project, Ecology has provided important insight and recommendations (e.g., recommendations for a deeper well down gradient that ultimately identified the larger VOC plume). The subsequent MTCA RI/FS and RAs were implemented with notification of Ecology but Boeing did not request written approval of each phase of the project.

Several pre-MTCA and MTCA RAs have been implemented as source control measures at the EMF property on the east side of KCIA. All of these initial actions are considered MTCA Interim RAs. In conjunction with the source control actions, Boeing implemented phased investigations to identify the spatial position and vertical interval of the VOC plume at multiple locations down gradient of the EMF property. The position of the EMF VOC plume has been positively identified at multiple transect locations from the EMF property boundary to the ultimate discharge location at the LDW. Boeing has implemented MTCA RAs to address the VOC plume in these areas. Historical MTCA investigation and remediation activities are described in more detail in Section 3.

Under the VCP, Ecology has been notified of key actions periodically through the project and has provided advice and review as appropriate. Since the project had not achieved MTCA cleanup requirements prior to issuance of the CERCLA Order, Boeing did not request a closure determination (e.g., a No Further Action letter) from Ecology.

2.3.4 Regulations and Standards in 2000

In 2000, EPA published the Methodology for Deriving Ambient Water Quality Criteria for Protection of Human Health (2000) including guidance on chemical risk assessment, exposure and bioaccumulation. Additional details were published in 2003 as a companion Technical Support Document. The policies and procedures set forth in the guidance were intended to describe EPA methods and guidance for developing or revising AWQCs to protect human health, pursuant to Section 304(a) of the Clean

Water Act (CWA), and to serve as guidance to States and authorized Tribes for developing their own water quality criteria. This revised EPA guidance for deriving AWQCs did not materially change the cleanup criteria or project objectives because the MTCA ARARs evaluation initially focuses on existing standards and the revised guidance and methodology did not change the promulgated standards.

2.3.5 Regulations and Standards in 2003

In December 2003, EPA updated national recommended water quality criteria for the protection of human health for vinyl chloride and 14 other compounds (Federal Register 2003). The revised criteria were based on EPA's 2000 methodology for deriving human health water quality criteria and superseded criteria for those chemicals that EPA had published before the December 2003 notice. The revised AWQC applicable to the EMF project for vinyl chloride was changed to 2.4 ug/L based on exposure through consumption of fish (for nonpotable water). Since the MTCA regulation requires the consideration of promulgated standards (consistent with the NCP), this revised AWQC for vinyl chloride was considered the revised cleanup level. As a result, this regulatory adjustment did change the cleanup criteria (and corresponding actions necessary to meet the project objectives).

2.4 Environmental Setting

2.4.1 General Site Conditions

The EMF property is paved and most of the down-gradient areas are also paved, 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 KCIA property is bounded to the west by East Marginal Way. To the west of East Marginal Way is Boeing Plant 2, which is bounded by the Duwamish Waterway. The EMF VOC plume has been identified under the central areas of two buildings within Plant 2 (Buildings 2-40 and 2-41).

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).

2.4.2 Surface Water and Sediments

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.

2.4.3 Soils

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 hydraulic fill material appears 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 silt and sandy silt layer of variable thickness.

2.4.3.1 Grain-Size Distributions

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. The grain size data indicate a significant transition typically found at a depth of between 45 and 50 feet bgs. Using 100 microns (finer than 0.1 mm sand particles) as an indication of the stratigraphic unit starting at about the 50-foot depth interval, the soil in this lower zone has about 80% silt and very fine sand, where as the upper unit has about 2-3% silt and very fine sand.

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 estimated to be approximately two orders of magnitude higher than that of the underlying stratigraphic unit. Additional discussion of grain-size distributions and hydraulic conductivity are discussed in Section 3.0 with specific details provided in the individual site investigation reports referenced within Section 3.0.

2.4.3.2 Fraction Organic Carbon in Soil

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.

2.4.4 Hydrogeology

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.

2.4.4.1 Regional Conditions

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 from locations distant from the waterway suggest that the deeper water is connate, with the brackish water derived from 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.

2.4.4.2 Local Conditions

Historical investigations in the vicinity of the site have confirmed that the local hydrostratigraphy is similar to the regional characteristics. The lithology generally consists 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 fine to medium fluvial sand layer extending to a depth of approximately 45 to 50 feet bgs. Underlying the sand unit is a relatively fine-grained silt and sandy silt layer of variable thickness. Core samples collected from this silt zone indicated an approximate hydraulic conductivity of 4×10^{-7} cm/sec, indicating that this layer is a low-permeability unit and has provided a significant barrier to vertical plume movement (based on the VOC characterization data from samples collected above and below the unit). Beneath this low permeability unit is a silty sand unit forming another (deeper) water-bearing zone. This deeper water bearing unit (typically at 50+ ft bgs) is brackish and these measurements are consistent with the regional hydrogeologic model which indicates connate water in this deeper water bearing zone (Booth and Herman 1998).

2.4.5 Groundwater Flow

The existing site data (both regional and local) indicate that groundwater flow is towards the Duwamish Waterway, essentially perpendicular to the Waterway. The hydraulic conductivity of the aquifer where the VOC plume is present near the west side of KCIA was measured in an aquifer pumping test conducted at well EMF-EX-35 in September 2001. The aquifer pumping test indicates a hydraulic conductivity in the range of 400 feet/day (1.4×10^{-1} cm/sec, PPC, 2002a). 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 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, 2002a).

2.5 Land Use

Land use at the site is industrial/commercial as the site is part of an active airport facility and Boeing's facilities. The surrounding land use is also industrial/commercial and is not expected to change in the foreseeable future.

2.6 Property Ownership

The location of the EMF property is on the east side of KCIA. The property is owned by KCIA and currently leased to Boeing. Boeing operates a 737/757 flight delivery center on the west side of KCIA in the area of the VOC plume. King County owns all the airport property to the southwest of EMF property on KCIA. Surrounding property is owned by the City of Tukwila, and Boeing. East Marginal Way is owned by the City of Tukwila. The property on the southwest side of East Marginal Way, extending to the Duwamish Waterway, is owned by Boeing and is the location of the Boeing Plant 2.

2.7 Lower Duwamish Waterway

The EMF VOC plume discharges to the LDW on the west side of the 2-41 Building at approximately river mile 3.4. The LDW was added to EPA's National Priorities List (NPL) on September 13, 2001.

2.7.1 General Conditions

The Duwamish River originates at the confluence of the Green and Black Rivers near Tukwila, Washington, then flows northwest for approximately 12 miles discharging into Elliott Bay. A portion of the river is maintained by the US Army Corps of Engineers (ACOE) as a federal navigation channel (i.e., the reach downstream of Turning Basin 3). Navigation depths maintained by the ACOE within the LDW generally range from –4.6 m (–15 ft) mean lower low water (MLLW) from Turning Basin 3 north to Slip 4, and -6 m (–20 ft) MLLW from Slip 4 to the 1st Avenue Bridge.

The shorelines along the majority of the LDW have been developed for industrial and commercial operations. Common shoreline features within the LDW include constructed bulkheads, piers, wharves, buildings extending over the water, and steeply sloped banks armored with riprap or other fill materials (Weston 1999).

The LDW is a well-stratified, salt-wedge type estuary that is influenced by river flow and tidal effects; the relative influence of each is seasonally dependent. Freshwater moving downstream overlies the tidally driven saltwater wedge. Typical of salt-wedge estuaries, the Duwamish has a sharp interface between the freshwater outflow at the surface and saltwater inflow at depth. Santos and Stoner (1972) characterized the primary circulation regime within the salt-wedge portion of the LDW (typically extending from Harbor Island to near the head of navigation). Salinity is the simplest characteristic for distinguishing the upper and lower layers because of their fresh and saline origins. The 25 part-per-thousand (ppt) salinity layer near the river mouth occupies most of the water depth, but tapers toward the upriver portion of the estuary. The EMF VOC plume discharges to the LDW through sediments whose pore water are saline (Lentz 2006).

2.7.2 Outfalls from Storm Drains

The storm drains and outfalls from the areas near the EMF property have been evaluated based on maps provided by KCIA. On the western boundary of the EMF property (near the taxiway) the storm drains flow north through pump stations and ultimately discharge to the LDW at River Mile 2.8 (at Slip 4, designated as Outfall 3 in the KCIA maps). On the east side of the property (near Perimeter Rd) the storm drains flow south through pump stations and ultimately discharge to the LDW at River Mile 3.8 (designated as Outfall 2 in the KCIA maps).

2.7.3 Existing Structures

The existing structures within the LDW in the area of the EMF VOC plume include numerous pilings and rip-rap on the bank. The western edge of the 2-41 Building is constructed on piers over the inter-tidal zone of the LDW. A catwalk exists beneath the overhanging portion of the 2-41 Building and the bank shore is armored with rip-rap.

2.7.4 Future Construction on/in the Lower Duwamish Waterway

Future construction plans on or in the LDW in the area of the EMF VOC plume are uncertain. General expectations are that the 2-41 Building will ultimately be removed and that the building demolition effort will also include some level of habitat restoration/repair within the LDW.

2.8 Aerial Photo Review and History of KCIA/Boeing Field

An 1897 survey map prepared by the Corps of Engineers (under the Rivers and Harbors Act of 1896) shows the position of the prior Duwamish River channel near the present EMF property. The survey includes numerous transects of the channel depth. The maximum channel depths near the EMF property are approximately 8 to 10 feet. A 1911 map of the area was prepared by the Engineers Office, Commercial Waterway

District No 1. The 1911 map shows the realigned Duwamish Waterway channel, the position of the prior Duwamish River channel (presumably filled at that time), and the property owners throughout the area. Copies of the relevant portions of historical maps and more recent aerial photographs are included in Appendix A.

In 1928, King County approved a plan for construction of the region's first municipal airport. The terminal and administration buildings were completed in 1930. A 1938 aerial photo shows the KCIA terminal building and two large aircraft hangers that were the original structures on the EMF property. The KCIA runway is dirt and most of the area of Boeing Plant 2 appears to be farmland. Some construction at Plant 2 is apparent based on a saw-toothed roof structure on the western edge of the photo. In 1941 KCIA opened a paved 5,825-foot-long runway. In December 1941, the airport was closed to the public and taken over by the federal government because of its strategic location. During World War II, the airport was devoted to the production of thousands of B-17 and B-29 bombers.

A 1947 aerial photo shows the two large hangers on the EMF property. Multi-engine aircraft (likely B-17 or B-29 bombers) are visible around the hangars. The area of the EMF property appears paved. The Plant 2 property is fully developed.

A 1968 aerial photo shows that the two large hangers have been combined as one building on the EMF property (a central building section is added to connect the two pre-existing hangars). The entire property is paved (parking stripes are visible). Process tanks are visible in the front center of the building (facing to the east). Additional white tanks, which may be above-ground fuel tanks, are visible in the southwest corner of the EMF property. The south end of the property includes a small fenced storage area with approximately ten 55-gallon drums visible.

A 1978 aerial photo shows the EMF structure the same as the 1968 photo. The entire property is paved and numerous cars (~ 100) are parked around the EMF building. The same process tanks and fuel tanks (as the 1968 photo) are visible. The KCIA Terminal building appears to be under construction to expand to the present 2006/2007 configuration (expanding the Terminal building to the south near the western side of the EMF property).

A 1993 aerial photo shows the EMF structure the same as earlier photos. The property is paved but appears unused (no cars are in the parking areas). Some use of the property by United Parcel Service (UPS) is apparent based on a UPS plane and cargo loading equipment.

2.9 Interviews with Former EMF Employees

In March 2007, CALIBRE interviewed Boeing employees Kirk Thomson, Eric Blackwehl, Steven Tochko and Carl Bach. These employees have worked at the EMF facility or have otherwise supported EMF facility operations at various times between 1978 and 1995. These employees have knowledge of the former EMF facility and of recent historical operations.

Two employees provided the description of the manufacturing process for fabricating electronic circuit boards. The primary process involved chromic acid etching of the circuit boards and included plating baths (<30 gallons) of copper, lead, selenium, nickel, gold, and zinc. One employee described the process as standard plating line without any research and development activities or other exotic processes. The manufacturing process included use of a TCE cleaner for degreasing circuit boards.

The spent chromic acid solution (contaminated from the etching process) was transferred through an above-floor sluiceway/chase way to a sump that was pumped to an above-ground storage tank near the front center of the building (east side). One employee recalled that it was an underground storage tank (UST). When the tank was filled, a tanker removed the solution for off-site treatment/neutralization. On one occasion, one of the employees recalled that inspection of the chase way indicated that the chromic acid had eaten through the concrete base and maintenance personnel repaired the structure. All other process chemicals (plating bath solutions) were pumped to 55-gallon drums for off-site treatment/neutralization.

One employee stated that there may have been occasions (this was uncertain) where TCE was transferred via the same chase way noted above.

At the south end of the EMF building was the shipping and receiving area (also the employee entrance). According to one employee, a small hazardous materials storage area was located south of this entrance (visible in 1968 aerial photo, see Section 2.7). The front of the building (east central area) included a boiler area, (with Bunker C tanks), a spent acid tank, and a solvent tank. According to the same employee, the white structures visible in 1968 aerial near the southeast corner of property (which may be 2 horizontal aboveground storage tanks [ASTs] for fuel storage) were not known to be owned or operated by Boeing.

One employee supervised the removal of USTs and other minor equipment (compressors) from the EMF building circa 1985 to 1986. The removed USTs were used for fuel storage for the boiler (using Bunker C). Minor fuel releases were noted and work was completed under the oversight of Ecology. The front of the EMF building (to the east) was also investigated for USTs associated with the plating process lines. Outside of the building, the former plating line UST location was identified (based on the chase way) and excavated. The concrete pad (saddle) and hold-down straps for the prior tanks were found at a depth of approximately 10 feet. The tanks were not present and had been removed previously. The soil was visibly stained/contaminated with green material. A soil excavation covered an area approximately 20 feet by 30 feet to a depth of 10 to 12 feet. Excavated soil was transported off site for disposal.

Another employee described the building demolition and re-grading project. The initial planning and asbestos abatement was started in 1995. The building was removed in early 1996. Demolition included breaking out the concrete slab and any subsurface structures/footings found. A boiler fuel UST was removed which had no visible signs of a release. Sampling indicated low levels of TPH above MTCA standards so the area was over excavated. A new storm drain line was installed on the east side of the former building. At the completion of the demolition work the ground was re-graded and paved.

2.10 Review of Ecology Files on the EMF Site

The files present in the Ecology Library regarding the EMF site were reviewed (Northwest Regional Office in Bellevue). The information is presented in Table 2-2. The files are consistent with the Boeing records and the Boeing files are more complete.

Table 2-2 List of Items/Records in Ecology Files Regarding EMF Site

Date	Type of Record	To/From	Description
Aug 1982	Letter	Boeing/Ecology	Notice of Violation (NOV)
Aug 1982	Letter	Ecology/Boeing	Report of Action in response to NOV
Sept 1982	Letter	Boeing/Ecology	Comments on proposed actions
Oct 1982	Letter	Ecology/Boeing	Results of actions conducted
Nov 1982	Letter	Ecology/Boeing	Request for relief from requirement to meet Federal Drinking Water Standards
Nov 1982	Letter	Boeing/Ecology	Request accepted and cleanup level must be acceptable to Ecology
Jan 1983	Letter	Ecology/Boeing	Summary of status of cleanup actions
Mar 1983	Letter	Ecology/Boeing	Request to fill in trench excavation
Nov 1984	Letter	Ecology/Boeing	Groundwater monitoring results
Jan 1985	Letter	Boeing/Ecology	TCE cleanup levels presented
Mar 1985	Letter	Boeing/Ecology	Request for relief from stipulations of Order
May 1985	Letter	Boeing/Ecology	Review of groundwater assessment program
May 1985	Letter	Boeing/Ecology	Comments on Work Plan
June 1985	Letter	Ecology/Boeing	Status of cleanup actions
June 1985	Letter	Ecology/Boeing	Soil and Groundwater Assessment Plan
July 1985	Letter	Boeing/Ecology	Comments on Assessment Plan
July 1985	Letter	Boeing/Ecology	Additional comments on assessment plan
Sept 1985	Letter	Boeing/Ecology	Approval of Assessment Plan
Sept 1985	Letter	Ecology/Boeing	Schedule of well installation
Nov 1985	Letter	Ecology/Boeing	Plan for cleanup of additional sources of hexavalent chromium
Jan 1986	Letter	Ecology/Boeing	Details of well installations
July 1986	Letter	Ecology/Boeing	Status of Monitoring and Assessment Plan
Sept 1986	Letter	Boeing/Ecology	Summary of communications and actions to be conducted by Boeing
Oct 1986	Letter	Ecology/Boeing	Summary of actions completed to date
Dec 1992	Letter	Boeing/Ecology	Issues regarding 1992 hazardous waste reporting requirements
1993	Report	Landau 1993	Groundwater monitoring report
April 1997	Letter	Ecology/EG&G	Details on NoVOCs technology and need for underground injection permit
Jun 1997	Report	Weston 1997a	EMF MTCA RI/FS
Jun 1997	Report	Weston 1997b	EMF MTCA Cleanup Action Plan
Aug 1997	Report	Weston 1997c	EMF MTCA Remedial Action report
Oct 1998	Report	Boeing/Ecology	Dangerous Waste Compliance Checklist inspection report of extraction and treatment of soil vapors
May 2000	Letter	Ecology/Boeing	Request for Contained-In Policy for soils
May 2000	Letter	Ecology/Boeing	Additional information on characterization of soils for contained-in policy
June 2000	Letter	Boeing/Ecology	Contained-In Policy Determination
Oct 2000	Letter	Ecology/Boeing	Request for Contained-In Policy for soils
Oct 2000	Letter	Boeing/Ecology	Contained-In Policy Determination
Jan 2002	Report	PPC 2002c	EMF MTCA RI report across Boeing Field/KCIA
Jan 2002	Letter	Boeing/ Ecology	Work Plan for EMF Investigation into Plant 2 under VCP
Feb 2002	Letter	Ecology/ Boeing	Approval of Work Plan for EMF Investigation into Plant 2 under VCP

3.0 PREVIOUS INVESTIGATIONS AND REMEDIAL ACTIONS

This Section provides a brief summary of pre-MTCA and MTCA investigations and remedial actions that have been conducted at the site. The summary is generally organized in chronological order. Details regarding each of the actions at the site can be found in the individual reports referenced. Figure 3-1 presents a general plan-view diagram of the site showing the different areas investigated (specifically the plume mapping transects implemented to identify the horizontal and vertical position of the down-gradient VOC plume).

3.1 Initial Identification of EMF Release and Regulatory Notification

Boeing operated a plating facility at the EMF site from approximately 1962 until the early 1980's. The plating process line, used for electronic circuit board manufacturing, included the use of TCE for cleaning of circuit boards and chromic acid for plating. Removal of the line began in May 1982. Visual identification of stained soil/concrete, followed by chemical testing, indicated a release in the vicinity of the plating line. Chromic acid had leaked into a concrete lined maintenance chase way beneath the electroplating line and infiltrated through the base of the concrete chase way into underlying soil.

Ecology and the EPA National Response Center were notified on May 20, 1982 regarding the release at the EMF property.

3.1.1 Objectives

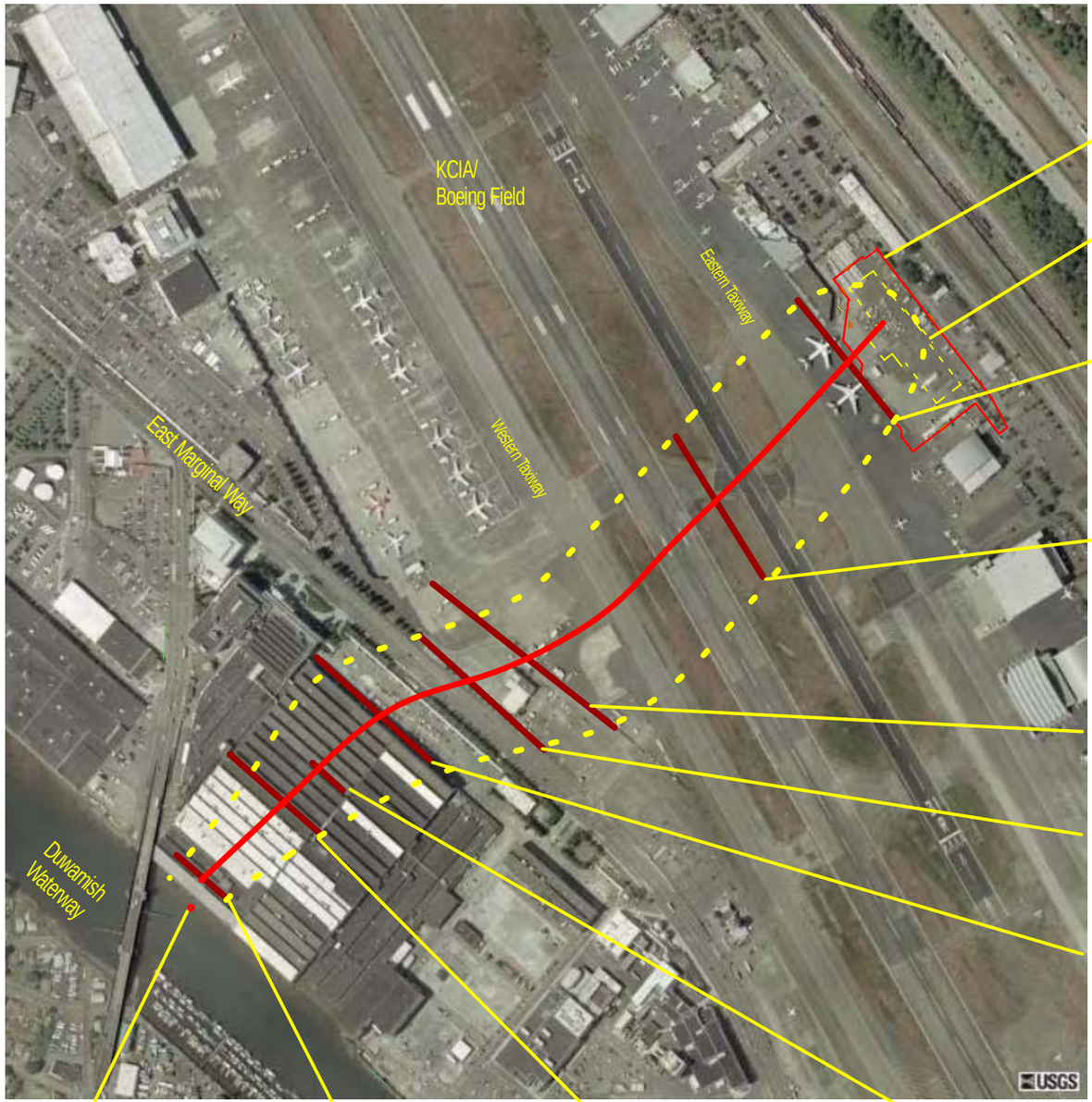
As part of the notification, Boeing indicated that cleanup operations would be initiated.

3.1.2 Approach

Boeing installed nine test holes through the floor of the chase way to sample soil and groundwater. Chromium was detected in soil and groundwater samples. Boeing met with Ecology in July 1982 to develop a removal plan which consisted of:

1) Removing the concrete floor at base of the chase way, excavating and disposing of soil in accordance with Washington Dangerous Waste regulations.
2) Installing two new well points in groundwater, pumping from one of them and monitoring from the other.
3) Pumping water to a waste holding tank for disposal in accordance with applicable discharge standards and Washington Dangerous Waste regulations.

Ecology issued a Notice of Violation (NOV) 82-149 in August 1982 and issued an Order (DE 82-469) to excavate soil and treat groundwater in October 1982.



EMF lease property boundary

Footprint of former EMF building

Down gradient plume mapping transect No. 1: 1999, see Figure 3-2

Down gradient plume mapping transect No. 2: 2000, see Figures 3-3, 3-4

Down gradient plume mapping transect No. 3: 2001, see Figures 3-5, 3-6

Down gradient plume mapping transect No.4: 2001, see Figures 3-7, 3-8

Down gradient plume mapping transectNo. 5: 2002, see Figures 3-9, 3-10

Pore water sampling location by EPA : 2005

Down gradient plume mapping transect No. 7: 2002, see Figure 3-13

Down gradient plume mapping transect No.6: 2002, see Figures 3-11, 3-12

ERD pilot test plume mapping transect 2003, see Figure 3-14

Down gradient plume mapping transect with date and corresponding cross-section figure

Approximate center of EMF VOC plume based on transect data

Approximate boundary of EMF VOC plume based on transect data

SCALE IN FEET

0 500 1,000

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FIGURE 3-1. Location of Down Gradient Investigation Areas for EMF VOC plume

3.1.3 Remedial Actions

The removal action was initiated in October 1982 and consisted of excavation of chromium contaminated soil. The removal action included excavation of 36 cubic yards of soil, installation of two well points, and pumping groundwater from one well point. Contamination of soil with TCE was identified during this excavation.

In December 1982, Ecology discussed the project with Boeing and identified the following concentration criteria (Table 3-1) for groundwater affected by the release at the EMF property.

Table 3-1 Range of Concentration Criteria Identified in 1982 Remedial Actions

Compound detected	WA Dangerous Waste Regulations (mg/L)	Ambient Water Quality Criteria (AWQCs) (mg/L)	Drinking water standard (mg/L)
Hexavalent Chromium	5.0	0.5	0.05
TCE	100	45	0.00027

Boeing met with Ecology during February 1983 to summarize the removal action and determine a suitable remedial action and future monitoring plan. The groundwater extraction had removed approximately 250,000 gallons of groundwater near the spill area and groundwater sampling indicated that concentrations of hexavalent chromium and TCE were below the AWQCs, except for one location where TCE was present in groundwater at 120 mg/L. In March 1983, Ecology gave permission to Boeing to backfill the excavated area, repave the area, reduce groundwater pumping, add one additional well point for monitoring, maintain existing well points, and continue groundwater monitoring on a quarterly basis.

In April 1985, Ecology amended the original Order which required Boeing to define the nature, extent, and sources of contamination. Boeing initiated an investigation to comply with the amended Order (see Section 3.2).

In November 1985 Boeing initiated construction of a new pedestrian entryway on the east side of the EMF Building. During construction, an abandoned 10-inch pipe chase associated with the chromic acid plating line was uncovered. When a section of the pipe chase was broken out, the soil was visibly stained, and sampling indicated the presence of 1,100 mg/kg of hexavalent chromium and 1,500 mg/kg of total chromium.

Ecology was notified of the observations and sampling in November 1985. Boeing met with Ecology on 25 November 1985 to discuss an appropriate remedial action (pre-MTCA). Based on these discussions, the following actions were undertaken:

1) Soil in the vicinity of the pipes to a depth of approximately four feet (approximate depth of physical evidence) was removed and disposed of as hazardous waste. A section of the pipe chase was also removed.
2) After excavation, soil samples were collected around the perimeter of the excavation to determine the need for further excavation.
3) The excavation was backfilled and lined according to specifications agreed upon by Ecology.

In review of the available project files (both Boeing and Ecology files), analytical results related to confirmation samples collected with the two removal actions noted above were not identified. As a result, these areas were considered a priority for sampling in the subsequent 1996 MTCA RI. The soil characterization results (from 1996) collected in and around these prior removal action areas are presented in Section 3.3.

In December 1985, Ecology rescinded the Consent Order related to site contamination (Stipulation and Order of Dismissal, Pollution Control Hearing Board 85-71, December 12, 1985). The Order was rescinded without prejudice (i.e., Ecology could issue a new Order for the same site/issues, if desired). Boeing continued with all site characterization activities requested in the prior Order (no longer in effect) including submitting work plans for review, comment and revision to Ecology.

3.2 Characterization of Soil and Groundwater at EMF Property

The characterization of soil and groundwater at the EMF property was continued by Landau and Associates starting in 1985 to comply with the amended (and subsequently rescinded) Order. The pre-MTCA soil and groundwater investigation report is presented in Landau 1986. The subsequent groundwater monitoring data is presented in Landau 1987, 1990, 1992 and 1993.

3.2.1 Objectives

The objectives of the initial investigation conducted at the EMF site were to characterize subsurface soil and groundwater (geology, hydrology and contaminant concentrations, volumes and sources), determine effective clean-up remedies, and to describe on-site and off-site groundwater uses in accordance with Consent Order DE-82-469. The areas targeted for investigation included the EMF building and surrounding area.

3.2.2 Approach

The subsurface soil and groundwater investigations conducted between 1985 and May 1993 included:

- Installing 8 new monitoring wells at six locations at the EMF property.
- Collecting soils samples for geological characterization and chemical analysis (4 soil samples from EMFMW01 and 4 soil samples from EMFMW03).
- Collecting groundwater samples from new monitoring wells and pre-existing wells for chemical analysis.

- Collecting water level measurements to determine groundwater gradient.
- Conducting permeability tests (slug tests) to estimate the hydraulic conductivity.
- Conducting regular groundwater monitoring at 9 wells for one year and then annually thereafter. Beginning in 1991, only filtered metals data were collected under the effort described in this section.

3.2.3 Results

The results from the Landau investigations indicated the following:

1) There are no registered groundwater production wells within a 3-mile radius of EMF; therefore, the Duwamish Waterway was established as the primary receptor of concern.

2) The location of the former Duwamish River channel near the EMF property could not be determined with certainty.

3) Except for concentrations of TCE in well points inside the EMF building, all levels of organics in the groundwater were below Ambient Water Quality Criteria.

4) Several unfiltered samples collected from WPl0 had detectable concentrations of hexavalent chromium but the last two rounds were non-detect. Concentrations of hexavalent chromium were at or below detection limits in all monitoring wells. This was attributed to the reduction of hexavalent chromium to trivalent chromium within the natural soils and groundwater environment.

5) Boring EMF 1 included soil sampling at 5, 10, 15 and 20 ft bgs, boring EMF 3 included soil sampling at 3.5, 8.5, 13.5, and 18.5 bgs. Total chromium ranged from 9 to 86 mg/kg; hexavalent chromium was nondetect (< 0.5 mg/kg) in all samples; copper ranged from 7 to 11 mg/kg; lead ranged from 0.5 to 3 mg/kg; nickel ranged from 6 to 18 mg/kg; zinc ranged from 19 to 32 mg/kg; iron ranged from 7,400 to 12,000 mg/kg; manganese ranged from 65 to 130 mg/kg; and cyanide was reported below detection limits (< 0.5 mg/kg) in all samples. The same soil samples were also analyzed for selected volatile organic compounds (trans 1,2 DCE, TCE and 1,1,1- trichloroethane). Sample B1-14 (from boring EMF 1 at 20 ft bgs) is reported at 215 ug/kg for trans 1,2 DCE (the water table is encountered at approximately 8 to 10 ft bgs; the text of the report has a typographical error as 214 mg/kg, actual units are ug/kg). The other soil samples (for the VOCs noted above) are reported as nondetect (<4 ug/kg).

6) Elevated concentrations of trivalent chromium, copper, lead, and zinc were found in well points within the EMF building. The metal exceeding criteria by the highest ratio was copper, with a maximum concentration of 10,000 ppb.

7) The extent of the VOC plume had not been fully characterized.

8) Metals in groundwater included chromium, copper, lead, nickel, and zinc. The authors stated that metals detected outside of the EMF building area appear to be in the expected background range (the authors opinion) for an urban area. Elevated concentrations of zinc for one well were likely caused by the galvanized steel used for the well casing. The metals listed above comprise the primary list of metals that have been analyzed for at the site in the referenced reports prepared by Landau Associates. This 1986 report did not provide sufficient information to formally determine the background range of naturally occurring metals in groundwater.

3.3 MTCA RI/FS and Remedial Action

This MTCA RI/FS was initiated in 1996 by Weston and completed in 1997 (Weston 1997a). The subsequent MTCA Remedial Action report is summarized in Weston 1997c.

3.3.1 Objectives

The objectives of the MTCA RI/FS were to characterize soil and groundwater conditions at the EMF property and select appropriate remedial actions following a MTCA RI/FS process. The areas targeted for investigation included five former UST locations, one existing UST location, three transformer pads, one former chrome tank (UST) and associated piping, and one degreasing piping system.

3.3.2 Approach

The soil and groundwater investigations conducted between May and August 1996 included:

- Advancing 25 direct-push probes at various target areas including five former USTs, one existing heating oil UST, three transformer pads, one former chromium tank with associated piping, and one degreasing (TCE) piping system.
- Advancing 28 direct-push probes for water samples (with multiple water samples collected over the depth).
- Advancing 7 direct-push probes for soil samples.
- Sampling 9 existing wells.
- Collecting soil and groundwater samples for chemical analysis.
- Collecting soil samples for physical testing (grain size testing and permeability testing of selected samples).
- Installing 2 treatment wells (EMFNV-01 and EMFNV-02) and 3 new groundwater monitoring wells (EMFMW-8, EMFMW-9 and EMFMW-10).

3.3.3 Results

Areas around all former transformer pads were investigated. PCBs detected 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.

The total metal concentrations that were detected in soils were within natural background concentrations for Washington State (Ecology 1994) or below MTCA cleanup levels for soil. Concentrations of metals in groundwater were below MTCA Method B cleanup levels with the exception of manganese which is typically elevated

under reducing conditions (reducing conditions are also a necessary for chlorinated solvents to degrade by reductive dechlorination).

The soil investigation included 8 borings with multiple samples in and around the locations where a chromic acid release was identified and remediated previously (in 1982 and 1985). The laboratory results for hexavalent and total chromium analysis are presented below (Table 3-2, all are soil samples):

Table 3-2 1996 Laboratory Results for Hexavalent and Total Chromium Analysis of Soil Samples in Area of Historic Chromic Acid Release (Weston 1997a)

Sample ID	Date	Depth ft bgs	Cr^{+6}	Qualifier	Total Chromium	Qualifier	Units
SB-EMF01-0025	5/8/96	2.5	0.24	U	14		mg/kg
SB-EMF01-0040	5/8/96	4.0	0.26	U	12.1		mg/kg
SB-EMF01-0060	5/8/96	6.0	0.27	U	18.3		mg/kg
SB-EMF02-0025	5/8/96	2.5	0.22	U	12.4		mg/kg
SB-EMF02-0040	5/8/96	4.0	0.26	U	14.5		mg/kg
SB-EMF02-0060	5/8/96	6.0	0.27	U	21.2		mg/kg
SB-EMF03-0025	5/8/96	2.5	0.23	U	22.8		mg/kg
SB-EMF03-0040	5/8/96	4.0	0.24	U	20.3		mg/kg
SB-EMF03-0060	5/8/96	6.0	0.25	U	15.7		mg/kg
SB-EMF04-0025	5/8/96	2.5	0.24	U	14.9		mg/kg
SB-EMF04-0040	5/8/96	4.0	0.27	U	17.7		mg/kg
SB-EMF04-0060	5/8/96	6.0	0.27	U	15.4		mg/kg
SB-EMF05-0025	5/8/96	2.5	0.25	U	11.2		mg/kg
SB-EMF05-0040	5/8/96	4.0	0.26	U	16.7		mg/kg
SB-EMF05-0060	5/8/96	6.0	0.25	U	12.2		mg/kg
SB-EMF06-0025	5/8/96	2.5	0.24	U	16.7		mg/kg
SB-EMF06-0040	5/8/96	4.0	0.26	U	14.7		mg/kg
SB-EMF06-0060	5/8/96	6.0	0.25	U	12		mg/kg
SB-EMF07-0025	5/8/96	2.5	0.26	U	15.5		mg/kg
SB-EMF07-0040	5/8/96	4.0	0.28	U	19.5		mg/kg
SB-EMF07-0060	5/8/96	6.0	0.27	U	18.8		mg/kg
SB-EMF08-0025	5/8/96	2.5	0.26	U	15		mg/kg
SB-EMF08-0040	5/8/96	4.0	0.27	U	19.8		mg/kg
SB-EMF08-0060	5/8/96	6.0	0.27	U	21.3		mg/kg

The sample ID is the boring location (SB-EMF01), followed by a depth indication (0025 for 2.5 ft bgs)
A sample location map is presented in Weston 1997a.

The additional soil sampling results (for VOCs, PCBs, TPH, and Metals,) reported in the 1997 RI (collected in 1996) are presented in Tables 3-3, 3-4 and 3-5.

Table 3-3 Summary of 1996 Vadose Zone Soil Samples for VOCs, PCBs, and TPH Analysis (Weston 1997a)

		Minimum	Maximum	Median
VOCs				
Methylene Chloride	ug/kg	2.1	2.3 (SB-EMF25-0050)	1.45 (1.61)
cis-1,2-Dichloroethene	ug/kg	9.6	18 (GS-EMF07-0060)	0.6 (3.21)
Chloroform	ug/kg	2	2 (GS-EMF07-0060)	0.6 (0.71)
1,1,1-Trichloroethane	ug/kg	11	11 (GS-EMF07-0060)	0.6 (1.61)
Trichloroethene	ug/kg	1.4	230 (GS-EMF07-0060)	4.15 (33.4)
Tetrachloroethene	ug/kg	1.5	2.3 (GS-EMF02-0060)	0.63 (1.03)
PCBs				
Aroclor 1242	ug/kg	21	78 (SB-EMF21-0005)	19.75 (22.83)
Aroclor 1254	ug/kg	20	240 (SB-EMF21-0005)	20.7 (43.9)
Aroclor 1260	ug/kg	26	290 (SB-EMF18-0005)	20.7 (67.2)
TPH				
TPH 8015 Diesel	mg/kg	290	290 (SB-EMF15-0060)	290 (290)
TPH HCID Diesel Range	mg/kg	140	140 (SB-EMF15-0060)	12.5 (28.4)
TPH HCID Oil Range	mg/kg	340	340 (SB-EMF15-0060)	25 (64.4)
Motor Oil Range	mg/kg	600	600 (SB-EMF15-0060)	600 (600)
TPH-418.1	mg/kg	13	3300 (SB-EMF22-0005)	51.5 (490.2)

Table 3-4 Summary of 1996 Saturated Zone Soil Samples for VOCs (Weston 1997a)

Constituent	Units	Minimum	Maximum (Sample with max)	Median (Arithmetic Mean)
VOCs				
Toluene	ug/kg	2.2	2.2 (GS-EMF07-0360-C)	0.7 (2.4)
Ethylbenzene	ug/kg	9.4	25 (GS-EMF07-0230)	0.7 (4.3)
Methylene Chloride	ug/kg	51	62 (GS-EMF07-0230)	1.85 (13.0)
Acetone	ug/kg	18	220 (GS-EMF05-0230)	21.5 (60.2)
Carbon Disulfide	ug/kg	1.4	20 (GS-EMF05-0230)	4.1 (6.6)
Trans-1,2-Dichloroethene	ug/kg	4.8	130 (GS-EMF04-0340)	0.75 (15.7)
cis-1,2-Dichloroethene	ug/kg	1.7	170 (GS-EMF07-0360-C)	9.4 (40.8)
2-Butanone	ug/kg	28	33 (GS-EMF02-0230)	3.45 (14.8)
Trichloroethene	ug/kg	1.6	20,000 (GS-EMF02-0230)	170 (2,919.2)
Tetrachloroethene	ug/kg	3	660 (GS-EMF03-0230)	0.7 (56.8)
1,1,2,2-Tetrachloroethane	ug/kg	2.8	55 (GS-EMF03-0230)	0.7 (5.3)
MP-Xylene	ug/kg	3.1	30 (GS-EMF03-0230)	0.7 (3.9)

Table 3-5 Summary of 1996 Total Metals Soil Samples from Area of Former Chrome waste Tank (Weston 1997a)

Constituent	Units	Minimum	Maximum (Sample with max[1])	Median (Arithmetic Mean)
Arsenic	mg/kg	7	13 (SB-EMF03-0040)	3 (3.6)
Beryllium	mg/kg	0.1	0.2 (SB-EMF01-0025)	0.1 (0.11)
Cadmium	mg/kg	0.3	0.5 (SB-EMF03-0040)	0.1 (0.16)
Chromium	mg/kg	11.2	22.8 (SB-EMF03-0025)	15.6 (16.4)
Copper	mg/kg	8.1	29 (SB-EMF08-0040)	16.45 (16.9)
Lead	mg/kg	3	38 (SB-EMF03-0040)	6 (8.5)
Mercury	mg/kg	0.09	0.45 (SB-EMF03-0040)	0.03 (0.06)
Nickel	mg/kg	3	30 (SB-EMF03-0025)	6 (7.3)
Selenium	mg/kg	7	7 (SB-EMF01-0060)	3 (3.2)
Zinc	mg/kg	11.1	82 (SB-EMF06-0025)	19.8 (23.7)

[1] the samples described above represent the maximum concentrations detected in the 1996 RI (Weston 1997a), additional soil samples for waste disposal characterization in 1997 Cleanup Action included 2 samples with Cadmium at 1.4 mg/kg (Weston 1997b).

TCE was detected in saturated zone soil samples at maximum concentrations of approximately 20,000 ug/kg. The maximum concentrations in groundwater of TCE (190,000 ug/L) and its breakdown products vinyl chloride (390 ug/L) and cis-1,2-DCE (2,900 ug/L) were detected at relatively shallow depths (8 to 25 feet bgs). These results indicated some retention of free-phase solvent. Solvents were not detected in groundwater in the silty sand beneath the fine-grained zone at approximately 50 feet bgs. Laboratory results of soil permeability tests from the underlying low permeability unit indicated a hydraulic conductivity of 4 $x10^{-7}$ cm/sec. Sample locations GP-29 and GP-30 included water samples at a depth of 54 and 58 ft bgs, respectively. Analytical results for the COCs were non-detect (vinyl chloride <0.01, cis12,DCE <1, TCE <1) in both locations. The total dissolved solids (TDS) from these two samples was also much higher than in the water bearing zone above the aquitard (where the EMF plume is located).

The solvent plume was suspected of originating from supply and return lines for a TCE storage tank and sump from operations in the 1960s to late 1970s time frame. The 1997 MTCA RI/FS initially estimated total mass of solvent in the aquifer at approximately 600 pounds (subsequent additional site characterization data indicated this estimate to be low).

The groundwater remediation technologies evaluated in the MTCA FS included UV/Oxidation, aboveground air stripping, subsurface air stripping, enhanced bioremediation, in-situ oxidation and carbon adsorption. Containment technologies (slurry wall, sheet pile wall) were not considered in this evaluation due to the desire to

remove the chemicals of concern (COCs) from groundwater. In-situ air stripping, a technology that consists of air stripper wells being placed in the area of contamination was recommended as the most favorable technology because it removed the VOCs from the groundwater which would prevent migration to the Duwamish Waterway.

3.3.4 Remedial Actions

Thirty five cubic yards of soil in three areas with TPH in excess of MTCA Method A criteria were excavated. Prior to backfilling with clean soil, these areas were sampled to confirm clean up levels were met. The confirmation sample results are presented in Weston 1997c (the units reported in the Weston 1997c report for TPH are incorrect [they are listed as ug/kg, the correct units are mg/kg], the report does not include the lab data sheets which have been provided to the administrative record under separate letter). The results from the 1997 confirmation sampling of excavations (from the original laboratory data sheets) are presented in Table 3-6.

Table 3-6 Summary of TPH Analysis from 1997 Remedial Action (Weston 1997c and CALIBRE 2008 addendum letter)

MTCA Remedial Action Area	Sample ID	WTPH-O1 (mg/kg)	Sample ID	WTPH-O1 (mg/kg)	
Excavation Area 1 Former transformer pads (375 ft^2 area , 20 yds^3 removed)	SBEI-GR01-0035	<10.0	SBEI-GR10-0015	<10.0	
	SBEI-GR02-0035	<10.0	SBEI-GR11-0015	<10.0	
	SBEI-GR03-0035	120	SBEI-GR12-0015	1175.7**	
	SBEI-GR04-0035	195.7	SBEI-GR13-0015	532.4**	
	SBEI-GR05-0035	<10.0	SBEI-GR14-0015	230.0**	
	SBEI-GR06-0035	<10.0	SBEI-GR15-0035	<0.25	
	SBEI-GR07-0035	<10.0	SBEI-GR16-0035	<0.25	
	SBEI-GR08-0035	<10.0	SBEI-GR17-0035	<0.25	
	SBEI-GR09-0015	<10.0			
		WTPH-D1 (mg/kg)		WTPH-D1 (mg/kg)	WTPH-O1 (mg/kg)
	SBTR-GR21-0015	<0.25	SBTR-GR27-0015	<0.25	
	SBTR-GR22-0015	<0.25	SBTR-GR28-0015	<0.25	710.0**
	SBTR-GR23-0015	<0.25	SBTR-SP01-0065	NA	151.7
	SBTR-GR24-0015	3.13	SBTR-GR29-0015	<0.25	
	SBTR-GR25-0015	<0.25	SBTR-GR30-0015	<0.25	188.4
	SBTR-GR26-0015	<0.25	SBTR-GR31-0015		
			SBTR-GR32-0015		195.6
Excavation Area 2 Former Fuel Oil UST (120 ft^2 area , 10 yds^3 removed)			SBTR-GR18-0070	<0.25	
Excavation Area 3 Former Fuel Oil UST (120 ft^2 area , 5 yds^3 removed)			SBTR-SP02-0060	<10.0	

** denotes initial confirmation samples which exceeded MTCA standards, the removal areas exceeding MTCA standard (200 mg/kg TPH) were then excavated deeper and resampled (3.5 ft depth) with all samples meeting MTCA standards.

Additional soil sampling was completed with the installation of the two treatment wells: EMFNV-01 was sampled at depths of 9, 24 and 33 ft bgs, EMFNV-02 was sampled at depths of 14.5, 25 and 32 ft bgs. The results for the VOCs detected in the analysis are presented Table 3-7, all of the samples were collected below the water table.

Table 3-7 Soil Samples Collected in May 1997 with Installation of Two Treatment Wells at EMF

Sample ID	Date	depth ft	units	Analyte	value	flags
SBR1-NV01-0090	5/12/97	9.0	ug/kg	cis-1,2-Dichloroethene	75.16	
SBR1-NV01-0090	5/12/97	9.0	ug/kg	Trichloroethene	4,585.9	E
SBR1-NV01-0240	5/12/97	24.0	ug/kg	Trichloroethene	50,493	E
SBR1-NV01-0330	5/12/97	33.0	ug/kg	cis-1,2-Dichloroethene	97.22	
SBR1-NV01-0330	5/12/97	33.0	ug/kg	Trichloroethene	15,152	E
SBR1-NV02-0145	5/13/97	14.5	ug/kg	cis-1,2-Dichloroethene	183.73	E
SBR1-NV02-0145	5/13/97	14.5	ug/kg	Trichloroethene	1,023.6	E
SBR1-NV02-0250	5/13/97	25.0	ug/kg	cis-1,2-Dichloroethene	69.69	
SBR1-NV02-0250	5/13/97	25.0	ug/kg	Trichloroethene	360.45	E
SBR1-NV02-0320	5/13/97	32.0	ug/kg	trans-1,2-Dichloroethene	61.63	
SBR1-NV02-0320	5/13/97	32.0	ug/kg	cis-1,2-Dichloroethene	860.30	E
SBR1-NV02-0320	5/13/97	32.0	ug/kg	Trichloroethene	436.57	E

All other VOCs (Method 8260B) were less than detection limits which vary by sample and analyte (typically in the range of 0.6 to 1.2 U ug/kg). Actual detection limit by sample and analyte are reported in Appendix F.

In-situ air stripping (NoVOCs recirculating wells) was the chosen remedial action technology for treating TCE in groundwater. The groundwater remedial action included the installation of two treatment wells (EMFNV-01 and EMFNV-02) and three additional monitoring wells (EMFMW-8, EMFMW-9, EMFMW-10) between May and July 1996. One of the treatment wells (EMFNV-01) recovered a limited amount of TCE as free-phase solvent [dense non-aqueous phase liquid (DNAPL)]. Each of the two treatment wells include two adjacent piezometers for sampling. The deeper piezometer (for sampling) is in the same borehole and filter-pack as the extraction screen interval. The shallow piezometer is in the infiltration gallery near the recharge screen. All subsequent data described in this report (for EMFNV-01 and EMFNV-02) are from the piezometer installed with the filter pack of deeper screen interval representing the influent concentration to the treatment well (the piezometer is the sampling port for the well).

Subsequent groundwater monitoring (after 10 years of MTCA remedial actions) has demonstrated a 99.9% decrease in total VOCs (primarily TCE) from a piezometer constructed adjacent to treatment well EMFNV-01. This observed concentration reduction is the cumulative result of the remedial actions taken and pre-existing natural attenuation processes. Additional soil and groundwater sampling (conducted in 1999 to define a DNAPL source and described in Section 3.5) did not find evidence suggesting DNAPL remains in this area.

3.4 Additional Site Characterization at EMF Property Boundary

Additional site characterization was conducted near the EMF property boundary during 1999 (PPC 2002a).

3.4.1 Objectives

The objective of this investigation was to characterize the horizontal and vertical extent of the VOC plume down gradient (west) of the location of the former EMF building. The area targeted for investigation was the western edge of the EMF lease boundary that was down gradient of the prior investigation (near the front of the aircraft parking area).

3.4.2 Approach

The investigation conducted between May and July 1999 included:

- Advancing direct-push probes and collecting groundwater samples at the expected central plume target areas.
- Installing five new groundwater wells.
- Sampling new and existing monitoring wells for chemical analysis.

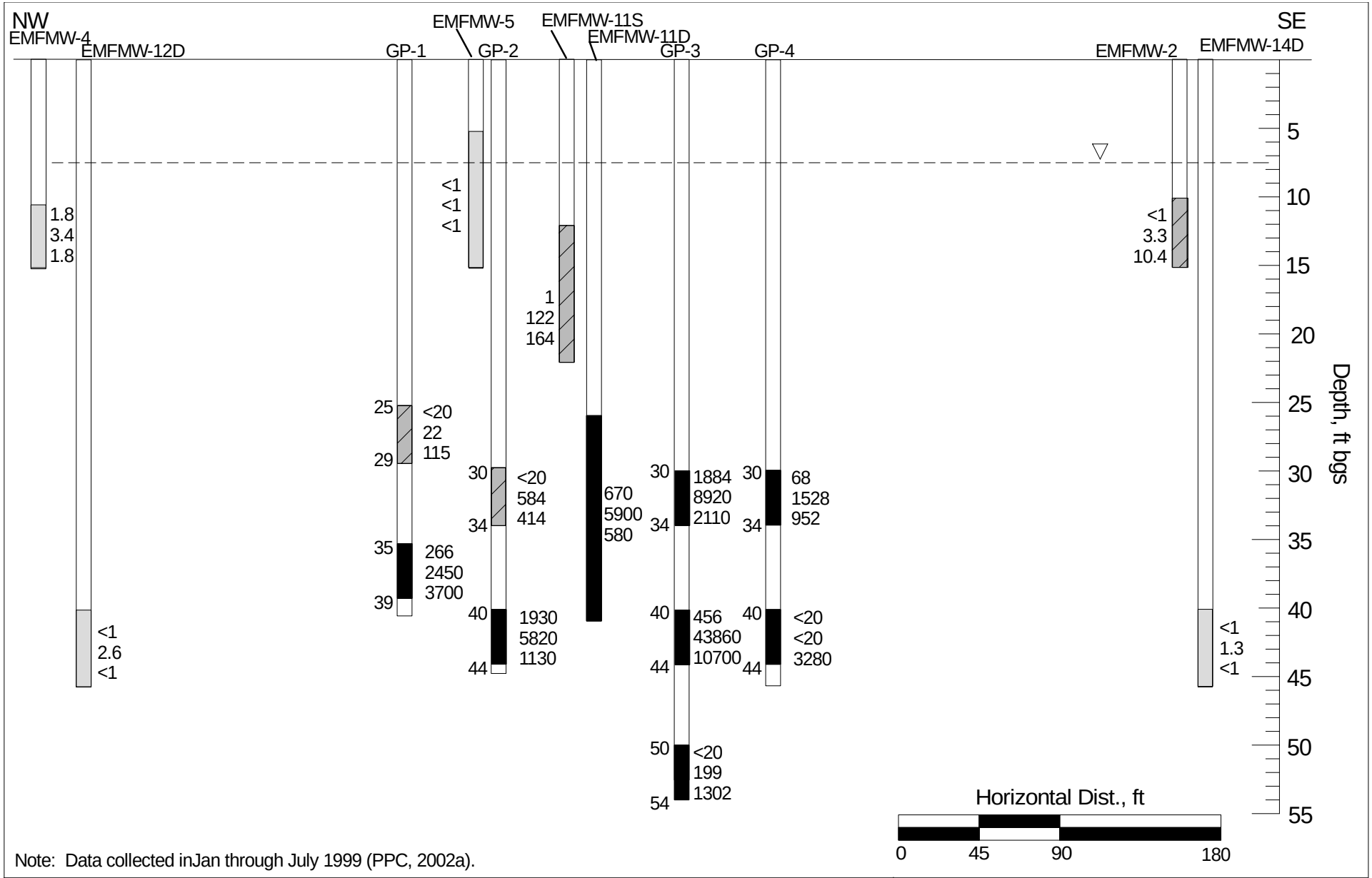
3.4.3 Results

A summary of the results from the data collected in this plume mapping transect is shown in Figure 3-2 (these data represent conditions from the 1999 time frame and remedial actions have been implemented since that time).

As noted in the introduction and objectives of this historical summary report, all data interpretations, plume boundaries, and other considerations have been presented within the context of the applicable regulatory standards in effect at the time the work was completed (the data interpretations presented herein are extracted from the historical reports). Within the CERCLA process, EPA will re-evaluate the cleanup criteria and all historical data interpretations of the plume position relative to applicable criteria.

The results from the groundwater sampling from this down gradient characterization indicated the following:

1) The VOC plume from the EMF property was larger than anticipated from the 1997 MTCA RI/FS and extended beyond the lease property boundary.
2) Down-gradient data indicated that the VOC plume appeared to have converted from the initial TCE compound into the subsequent degradation by products cis-1,2-DCE and vinyl chloride.



Note: Data collected inJan through July 1999 (PPC, 2002a).

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LEGEND

Sample interval

ft bgs TCE (ug/L)

12DCE (ug/L)

ft bgs Vinyl chloride (ug/L)

Top of water table (approx)

Indicates VOC above old AWQCs

Indicates VOC above revised (2003)AWQCs

Indicates no VOCs above AWQCs

FIGURE 3-2. Results of Geoprobe and Well Sampling at Boundary of EMF Facility, May and July 1999

3) The analytical results identified a stratified VOC plume located primarily within a depth interval of about 35 to 45 feet bgs. The VOC concentrations in this zone were detected at 60,000 ug/L for the degradation byproducts (cis-1,2-DCE and vinyl chloride). Monitoring wells in the intermediate zone indicate comparatively lower levels of VOCs in the range of 200 ug/L at a depth of 12 to 22 feet bgs. Monitoring wells in the shallow zone indicate lower levels of VOCs in the range of 1-3 ug/L at a depth of 8-15 feet bgs. Based solely on the Figure 3-2 data where the vinyl chloride concentration is detected in a sample collected between 50-55 feet bgs, it is possible that vinyl chloride is present at levels of concern at deeper depths (however other historical data, see Section 3.3.3 and Section 3.5.3 demonstrated that it was not at deeper depths). The Geoprobe sampling method is prone to carry-down problems associated with pushing a sampling probe through the plume to collect a sample beneath it (including multiple sequences of the rods pushed through and extracted from the push-probe hole to characterize contaminants at multiple depths).

3.5 Expanded Source Area Characterization within EMF Property and In-Situ Chemical Oxidation Remedial Action

This investigation occurred in multiple phases between January and April 2000 (PPC 2002a). Subsequent remedial actions were implemented from Spring of 2000 through Fall of 2001 (PPC 2002b).

3.5.1 Objectives

The objectives of the investigation were to further characterize the VOC plume and geology on the EMF lease property, define the areas where source control would subsequently be implemented, evaluate appropriate cleanup remedies following a MTCA FS process, and collect data for design of source treatment remedial actions.

3.5.2 Approach

The first phase of the soil and groundwater investigations conducted in January and February 2000 included:

- Advancing 10 direct-push probes within a 50-foot radius of treatment well EMFNV-01.
- Advancing direct-push probes for water and soil samples between the down gradient treatment well (EMFNV-02) and the lease property boundary where elevated VOC concentrations were detected during the 1999 sampling.
- Collecting groundwater samples for chemical analysis.

The second phase of sampling activities involved collection of soil and groundwater samples at additional locations on the EMF lease property to define the extent of the VOC plume. Water samples were collected to define the areas where source control would subsequently be implemented. The general area of the investigation extended to

the west to the eastern taxiway along KCIA and the southernmost locations were near the southern plume boundary. The sampling was focused primarily on water samples from a depth of about 25 to 45 feet bgs, but also included some soil/water samples at shallower depths (7-10 feet bgs) and deeper depths (50 - 66 feet bgs). The second phase of soil and groundwater sampling was conducted in April 2000 and included:

- Advancing 27 direct-push probes on the former EMF lease property west of the former EMF building up to the eastern taxiway on KCIA.
- Collecting soil and groundwater samples for chemical analysis.

3.5.3 Results

The results from this phase of the site characterization indicated the following:

1) The area of the known TCE release (the location where TCE DNAPL was initially recovered) no longer contained the highest TCE concentrations.
2) In the immediate vicinity of the known TCE release location, the concentrations were reduced to levels that were no longer indicative of a continuing DNAPL presence. Maximum concentrations in groundwater were at concentrations less than 0.5% of the TCE solubility limit.
3) The highest VOC concentrations (~400,000 ug/L total VOCs) were detected down gradient of the existing treatment system area of influence.
4) Down-gradient data indicated that the TCE was being rapidly degraded to the expected daughter products of cis-1,2-DCE and vinyl chloride. At the source area, TCE comprised essentially 100% of the total VOCs detected, while TCE in the down gradient samples was in the range of 0.1% to 0.5% of the total VOCs detected for the samples with high VOC concentrations.
5) The conceptual model of the site geology and plume distribution was revised to reflect the observations of a semi-confining layer (~30 feet bgs) and a thin stratified VOC plume found primarily in the interval of approximately 35 to 45 feet bgs.
6) The existing down-gradient treatment well (EMFNV-02) was completed in the upper aquifer zone and would not control the plume migration below the semi-confining layer present at 30 to 32 feet bgs. The majority of the VOCs were present in a permeable zone located about 35 to 45 feet bgs. Based on this re-evaluation of site geology and stratigraphy, the existing EMFNV-02 well was closed and replaced with a deeper treatment well completed to a depth of 43 feet bgs in April 2000. The screen interval on this new (replacement) EMFNV-02 treatment well was from 38-43 feet bgs.
7) The westernmost sampling locations indicated that the plume migration pattern appeared to maintain the same direction after passing over the location of the former Duwamish river channel. The VOC data from these locations indicated that the plume width in this area was at least 500 feet wide.

8) The southernmost sampling locations defined the southern plume boundary with all VOCs near or below detection limits.

9) Soil and water samples collected from the deeper aquifer zone below the central area of the plume indicated that the VOC plume had not migrated above levels of concern through the underlying aquitard. These results are consistent with prior samples collected in the 1997 EMF MTCA RI. Sample location GP-38 included soil samples through the underlying aquitard which indicated non-detect levels for all VOCs below a depth 50 feet (3 samples with detection limits of ranging from <3.5 to <4.9 ug/kg at depths of 50, 54 and 66 feet bgs). A water sample was collected at a depth of 64 ft bgs from GP-38; the analytical results indicated all VOCs below applicable criteria (vinyl chloride <2, cis-1,2-DCE at 8.1J, and TCE at 4.4J).

10) The soil sampling results from the Jan-Febr 2000 investigations included the following (Table 3- 8, all samples are below the water table):

Table 3- 8 Soil Sampling Results from the Jan-Febr 2000 Investigations

LOCATION NEAR EMFNV-1 Sample ID	Depth (ft bgs)	TCE ug/kg	cis12DCE ug/kg	Trans 12 DCE ug/kg	Vinyl chloride ug/kg
OXP01S-24	24-25	25,196	484	<37.04	<37.04
OXP01S-41	41-42	<2.41	<2.41	<2.41	<2.41
OXP02S-24	24-25	4,698	72	<32.26	<32.26
OXP02S-30	30-31	2,031	<10.64	970	<10.64
OXP03S-30	30-31	663	32	<12.05	<12.05
OXP03S-38	38-39	<10.02	372	<10.02	<10.02
OXP04S-23	23-24	<27.93	159	<27.93	<27.93
OXP06S-23	23-24	5,461	55.4	<12.85	<12.85
OXP010S-22	22-23	1,543	112	<15.11	<15.11
DOWN GRADIENT LOCATIONS (near EMFMW13d)					
GP38SS44	44-46	<4.93	28.1 J	12.3 J	2,071 E
GP38SS46	46-48	<3.69	88.6	<4.12	22.9 J
GP38SS50	50-52	<4.12	<4.12	<3.45	<4.12
GP38SS54	54-56	<3.45	<3.45	<4.92	<3.45
GP38SS66	64-66	<4.92	<4.92	<4.12	<4.92

3.5.4 Remedial Action Implemented for Source Control (In-Situ Chemical Oxidation)

Four remedial alternatives were developed in a focused MTCA FS identifying remedial options to address the high levels of VOCs, primarily TCE, cis-1,2-DCE, and vinyl chloride, found at the site. These included: 1) monitored natural attenuation; 2) treatment of the entire plume; 3) passive treatment at the site boundary; and 4) active

treatment at the site boundary. Based on the focused MTCA FS evaluation, the remedy selected was in-situ chemical oxidation (ISCO) to treat the plume area with the highest VOC concentrations.

The field implementation of ISCO at the EMF property was conducted in several phases including lab/bench scale tests, pilot testing, expanded site investigations to refine the area for implementation, and full-scale application within three ISCO treatment areas (beyond the pilot test area). The three ISCO treatment areas are all on the EMF property around the centerline of the plume (over a distance of approximately 170 feet) between treatment well EMFNV-02 and down gradient monitoring well EMFMW-13D.

The general conclusions derived from the lab and pilot testing included:

- The lab results indicated that the oxidants tested can fully destroy the target VOCs;
- Field sampling results indicated effective in-situ VOC destruction throughout the area treated. In-situ VOC destruction rates of approximate 95+% removal were estimated based on pre-oxidation and post-oxidation testing. This estimated removal efficiency relied on pre and post pilot testing results from Geoprobe samples which do not allow for direct pre and post remediation comparisons.

Implementation of the full-scale ISCO at the EMF property began after the pilot test had proved successful at reducing VOC concentrations. The ISCO work for the pilot test and ISCO Area 1 (May 2000 through October 2000) used potassium permanganate as the oxidation agent. The work for the ISCO Areas 2 and 3 (May 2001 through October 2001) used sodium persulfate as the oxidation agent. In-situ oxidation of the central area of the EMF plume required treatment of an aquifer zone initially estimated to be roughly 170 feet (parallel to the flow direction) by 100 feet (perpendicular to the flow direction). Some limited additional sampling data were required to refine the dimensions of the targeted treatment zone. The planned approach for treating this large area was to use three five-spot injection/flushing patterns (a larger version of the pilot test) to sweep the oxidant throughout the targeted area. The radial position of the four corner points (injection wells) defined each area to be treated and a central well was used to extract water.

Subsequent groundwater monitoring has demonstrated a 98.8% decrease in total VOCs (primarily DCE and vinyl chloride) from well EMFMW-13D, located immediately down gradient of the ISCO treatment area. This observed concentration reduction is the cumulative result of all up-gradient remedial actions taken and pre-existing natural attenuation processes. This well (EMFMW -13D) was installed at the center of the VOC plume in the interval with highest VOC concentrations detected in the Geoprobe samples from the plume mapping transect at the EMF property boundary.

3.6 Investigations across KCIA to East Marginal Way

The investigations across KCIA to East Marginal Way were conducted in several phases between November 2000 and September 2001 and investigation phases moved

in a westerly direction as the location of the VOC plume was identified (PPC 2001b, 2002a).

3.6.1 Objectives

The objectives of these investigations were to:

1) Define the VOC plume limits across KCIA and up to the area of East Marginal Way;
2) Evaluate the rate of VOC plume attenuation/degradation processes (dechlorination);
3) Provide down gradient monitoring points to evaluate the rate of degradation processes; and
4) Determine hydraulic conductivity, transmissivity and groundwater velocity.

3.6.2 Approach

Subsurface soil and groundwater investigations were conducted in multiple phases from November 2000 through September 2001 and included:

- Advancing 6 push-probe borings within the grassy strip between the two runways at the airport, approximately 900 feet down gradient of the EMF source area.
- Advancing 7 direct-push probes along the western side of KCIA approximately 1,900 feet down gradient of the EMF source area.
- Advancing 8 direct-push-probes on the west side of the airfield along the east side of East Marginal Way, approximately 2,200 feet down gradient of the EMF source area.
- Collecting and submitting groundwater samples for chemical analysis.
- Geologic logging of borings throughout the areas investigated for interpretation of geological conditions/structure within the plume area.
- Collecting multiple samples (within and below the VOC plume interval) for grain size analysis.
- Installing six new groundwater wells, five along the western boundary of KCIA along East Marginal Way and one approximately 300 feet up gradient of this area.
- Conducting aquifer pumping test in the specific stratigraphic interval of the aquifer where the VOC plume is present in order to determine hydraulic conductivity.

3.6.3 Results

The results from this phase of the site characterization indicated the following:

1) VOCs remained in a thin, stratified plume present primarily within a depth of 40 to 60 feet bgs (approximately). Given the vinyl chloride concentration detected in a sample collected between 60-64 feet bgs, it is possible that vinyl chloride is present at levels of concern at deeper depths; however, as noted previously the Geoprobe sampling method is prone to carry-down problems associated with

pushing a sampling probe through the plume to collect a sample beneath it. Also, other historical data exists (see Sections 3.3.3, 3.5.3 and 3.9.3) indicating that VOCs have not migrated (at levels of concern) into the deeper zone over a 2,000 ft travel distance from the EMF property.

2) VOC data indicated that the plume width in the area between the two KCIA runways was approximately 500 feet wide (at concentrations above the AWQCs).

3) The centerline of the VOC plume is consistent with the regional groundwater gradient, flow directions appear approximately perpendicular to the Duwamish Waterway.

4) Maximum detected concentrations of VOCs decreased in a westerly direction (i.e. down gradient in the VOC plume). From mid-field at KCIA to the east side of East Marginal Way, peak cis-1,2-DCE concentrations decreased from 30,000 ug/L to 11,000 ug/L; peak vinyl chloride concentrations decreased from 8,600 ug/L to 2,200 ug/L; and peak TCE concentrations decreased from 11,000 ug/L to 230 ug/L.

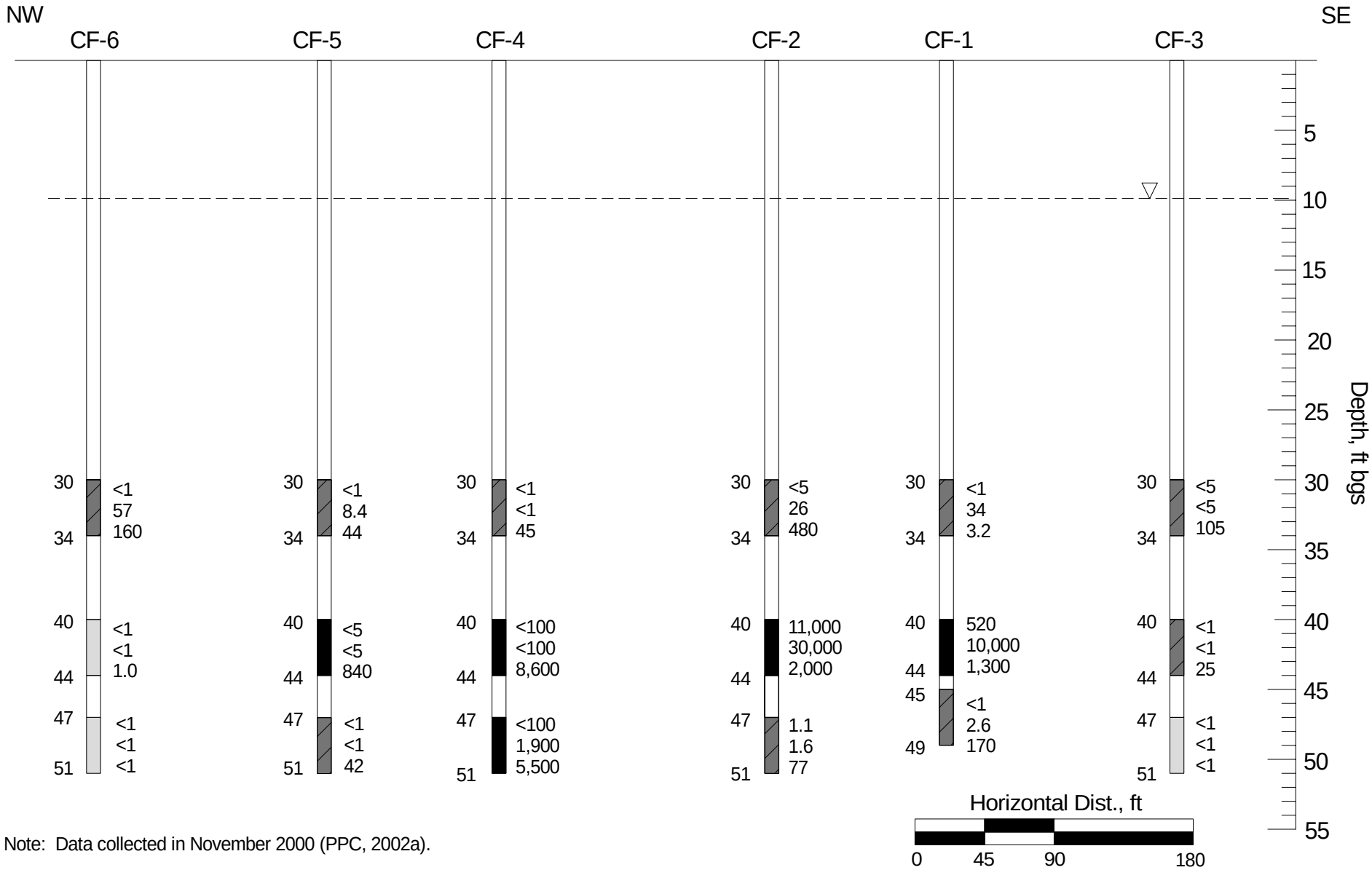
5) Detected concentrations of TCE indicated it was not entirely degraded (as prior up-gradient sampling locations had indicated).

6) Maximum concentrations of VOCs detected in monitoring wells in the area were 5,600 ug/L, 1,300 ug/L and 44 ug/L for cis-1,2-DCE, vinyl chloride and TCE, respectively. The maximum concentrations detected in monitoring wells were about one-half the maximum values detected in direct-push probe samples.

7) The grain-size analysis indicated soil samples in the plume area are a well-sorted fine to medium sand with very minor silt/fine materials (< 1%). When compared to the grain size curves for soil samples collected at the EMF property, the soil in this specific area is coarser (the D_{10} of the grain size curves is about 2 times larger), it is more uniform in size (well sorted –poorly graded), and contains less fine materials (< 1% fines versus 5 to 10% fines for soil samples from the EMF property).

8) The aquifer pumping test indicated a hydraulic conductivity of 400 ft/day (1.4 x 10^{-1} cm/sec). Based on this conductivity, the measured gradient of 0.001 ft/ft and an estimated porosity of 0.33, the predicted groundwater velocity in this area is estimated at 450 ft/year.

A summary of the results from the data collected in the three plume mapping transects are shown in Figures 3-3 through 3-8 (these data represent conditions from the 2000-2001 time frame and MTCA remedial actions have been implemented since that time).



Note: Data collected in November 2000 (PPC, 2002a).

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LEGEND

Sample interval

ft bgs TCE (ug/L)

12DCE (ug/L)

ft bgs Vinyl chloride (ug/L)

▽ Top of water table (approx)

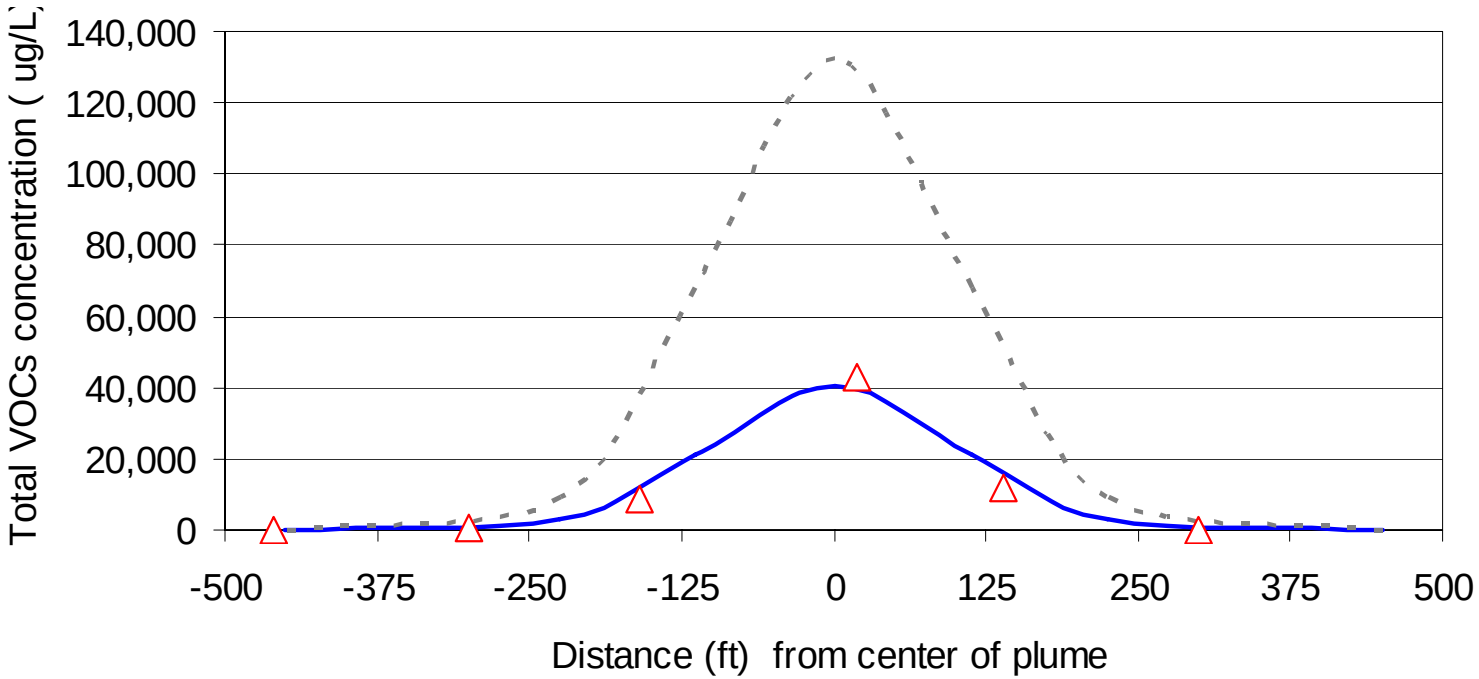
Indicates VOC above old AWQC

Indicates VOC above revised AWQC

Indicates no VOCs above AWQC

FIGURE 3-3. Results of Geoprobe Sampling in Center of Boeing Field, November 2000

NW SE



Modeled VOC plume X-section at 900 ft with 1st order degradation (half-life = 19 months)

Field measured VOC plume X-section at 900 ft

Modeled VOC plume X-section at 900 ft with No Degradation, this model does not fit the field data

Note: Data collected in November 2000 (PPC, 2002a).

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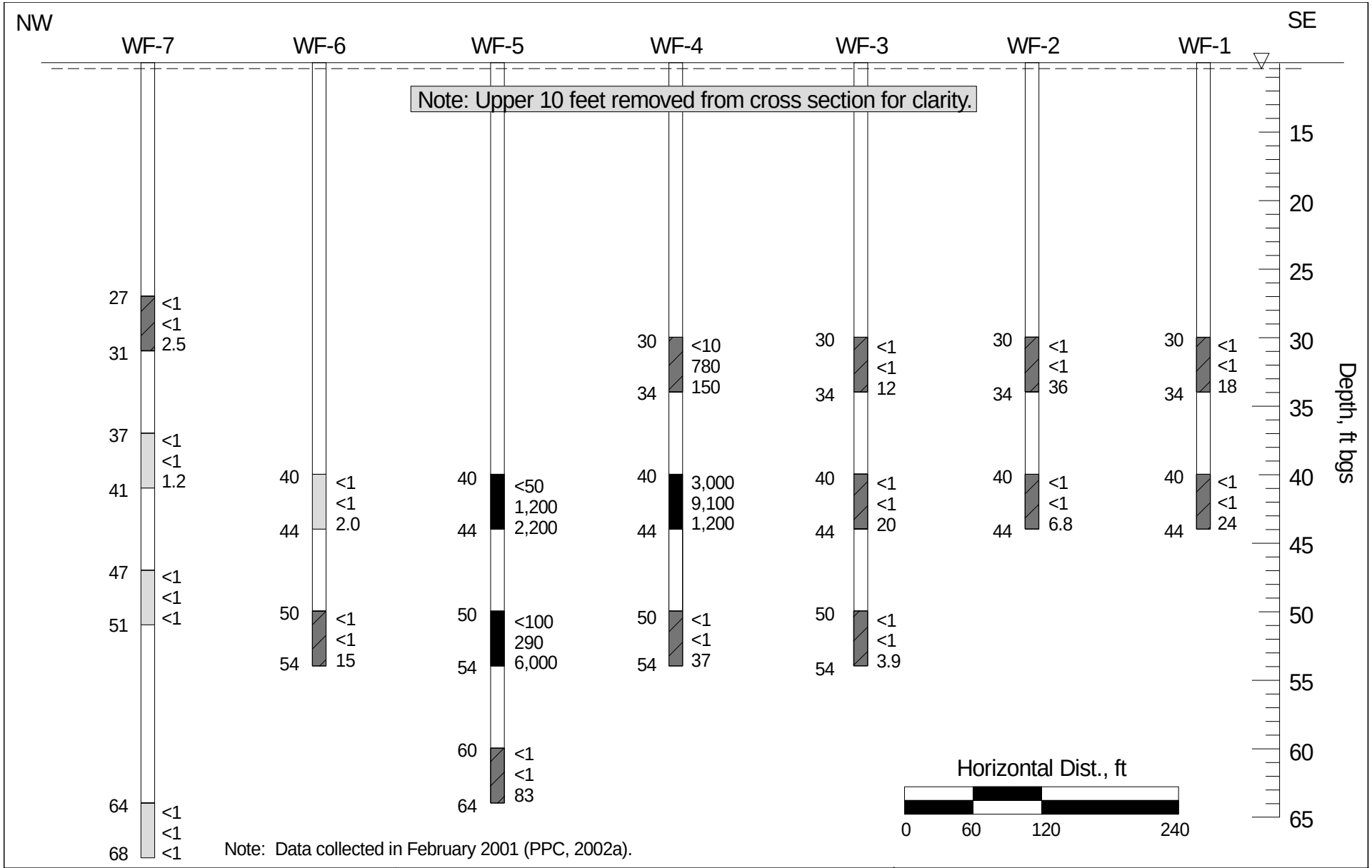
All concentrations noted represent total VOCs. The maximum concentration detected at any depth in vertical profile is presented.

FIGURE 3-4. Results of Modeling and Geoprobe Sampling for EMF VOC Plume in Center of Boeing Field, November 2000



Note: Data collected in February 2001 (PPC, 2002a).

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LEGEND

Sample interval

ft bgs TCE (ug/L)

12DCE (ug/L)

ft bgs Vinyl chloride (ug/L)

Top of water table (approx)

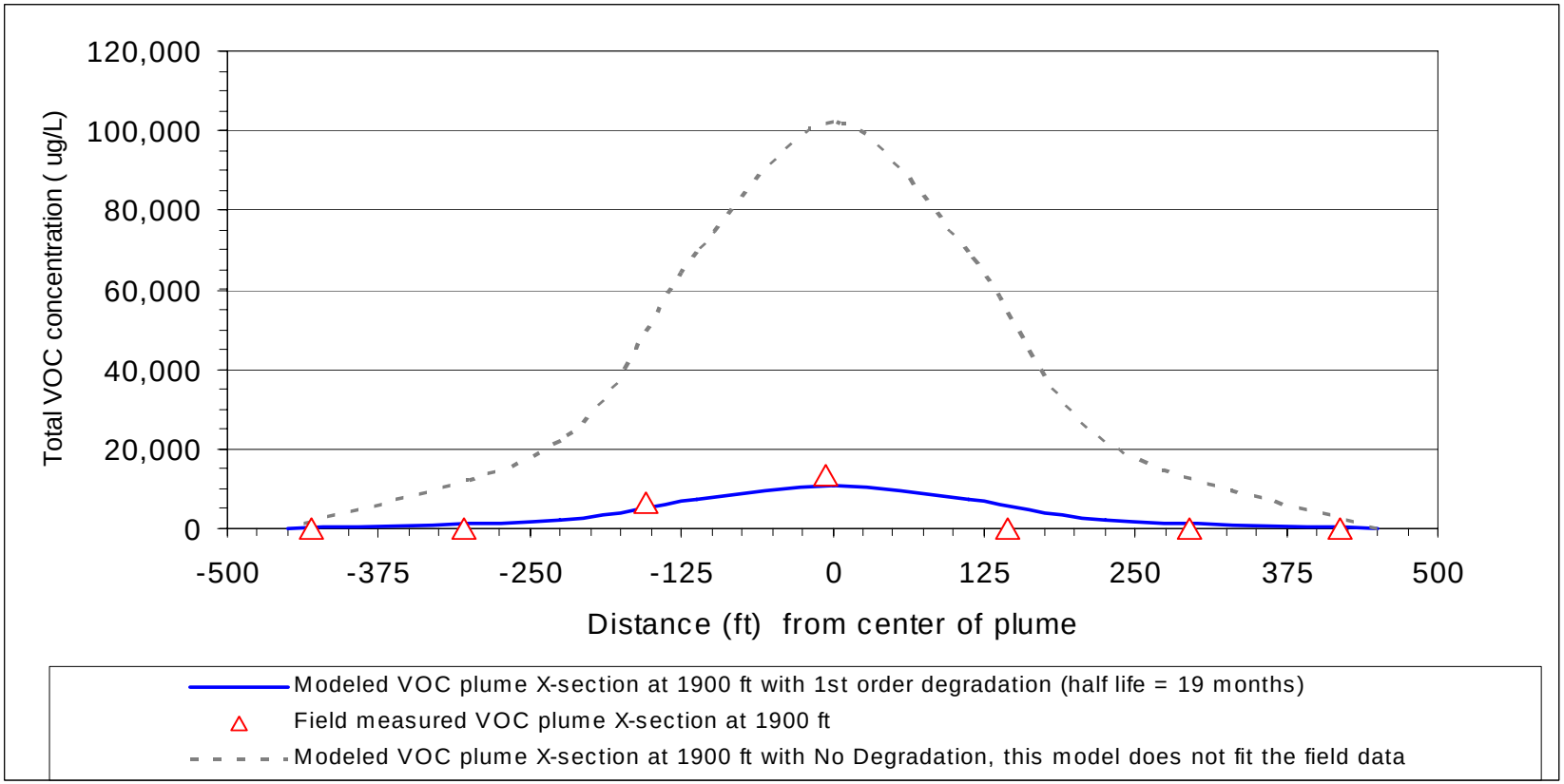
Indicates VOC above old AWQC

Indicates VOC above revised AWQC

Indicates no VOCs above AWQC

FIGURE 3-5. Results of Geoprobe Sampling on Western Taxiway, February 2001

NW SE



Note: Data collected in February 2001 (PPC, 2002a).

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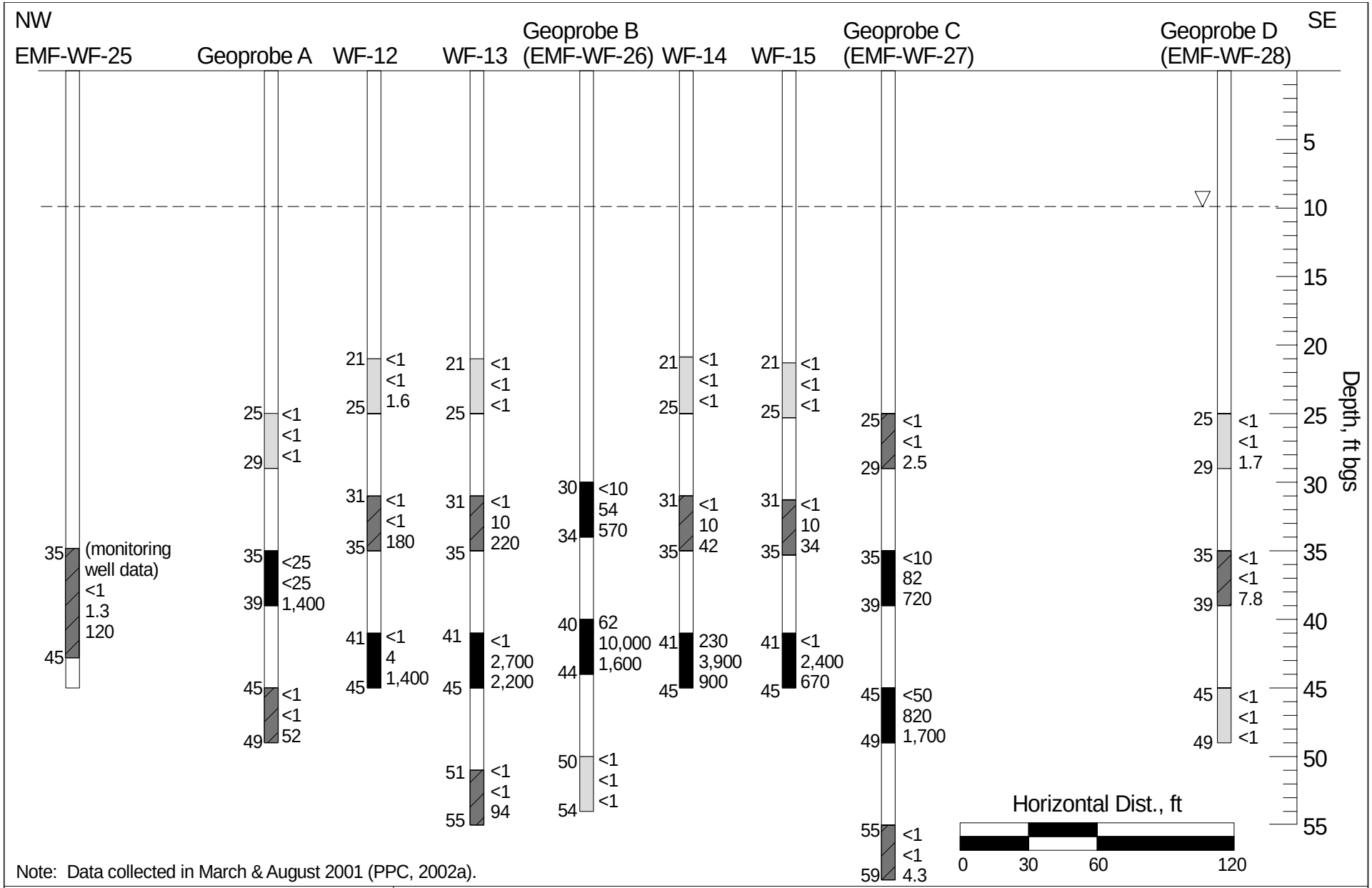
All concentrations noted represent total VOCs. The maximum concentration detected at any depth in vertical profile is presented.

FIGURE 3-6. Results of Modeling and Geoprobe Sampling for EMF VOC Plume on Western Taxiway, February 2001



Note: Data collected in March & August 2001 (PPC, 2002a).

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CALIBRE Systems Inc.

LEGEND

Sample interval

ft bgs TCE (ug/L)
12DCE (ug/L)
ft bgs Vinyl chloride (ug/L)

Top of water table (approx)

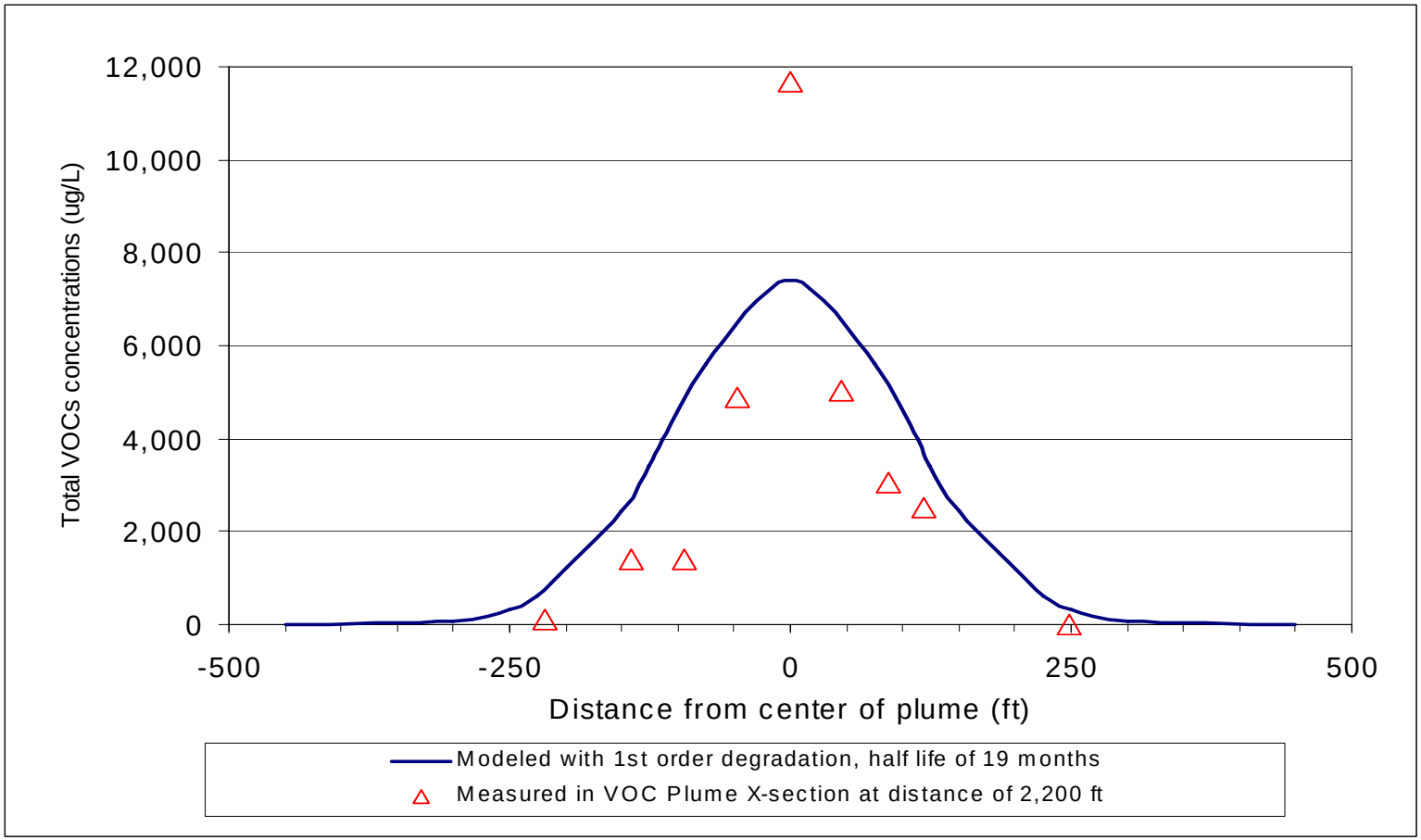
Indicates VOC above old AWQC

Indicates VOC above revised AWQC

Indicates no VOCs above AWQC

FIGURE 3-7. Results of Geoprobe Sampling Adjacent to East Marginal Way, March & August 2001

NW SE



Note: Data collected in March & August 2001 (PPC, 2002a).

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All concentrations noted represent total VOCs. The maximum concentration detected at any depth in vertical profile is presented.

FIGURE 3-8. Results of Modeling and Geoprobe Sampling for EMF VOC Plume Adjacent to East Marginal Way, March & August 2001

3.7 Investigations to Characterize the EMF Plume Under Plant 2

Investigations to identify the EMF plume in the Boeing Plant 2 area were conducted between March and August 2002 (PPC 2002c).

3.7.1 Objectives

The objectives of the March 2002 though August 2002 investigations were to:

1) Define the VOC plume limits within the Plant 2 area on the west side of East Marginal Way;
2) Provide down gradient monitoring points to evaluate the rate of VOC degradation processes; and
3) Further characterize geology within the area of the VOC plume.

3.7.2 Approach

The soil and groundwater investigations were conducted in several phases: two during March 2002, one during May 2002 and one during August 2002. These included:

- Advancing 6 direct-push probes in the parking area approximately 20 feet from the east side of Building 2-40, approximately 2,250 feet down gradient of the EMF source area.
- Advancing 7 direct-push probes in the 2-40 Building along the west side of the building (in the transportation aisle). This transect is approximately 2,700 feet down gradient of the EMF source area.
- Advancing 6 direct-push probes in the 2-41 Building approximately 75 ft east of the western building boundary, approximately 3,500 feet down gradient of the EMF source area.
- Advancing 2 direct-push probes in the 2-41 Building between the transportation aisle transect and the 2-41 Building transect near what was estimated to be the center of the plume. These were spaced at 1/3 intervals between the two transects.
- Installing three new groundwater monitoring wells (EMFWF-30, EMFWF-31, and EMFWF-32), one along each of the plume characterization transects at the center of the VOC plume (as identified in the prior plume transect data).
- Collecting groundwater samples for chemical analysis.
- Collecting multiple soil samples for grain size analysis.

3.7.3 Results

The results from the March to August 2002 investigations indicated the following:

1) The VOCs remained in a thin stratified plume with the primary plume interval encountered at a depth of about 35 to 50 feet bgs. Vinyl chloride was detected

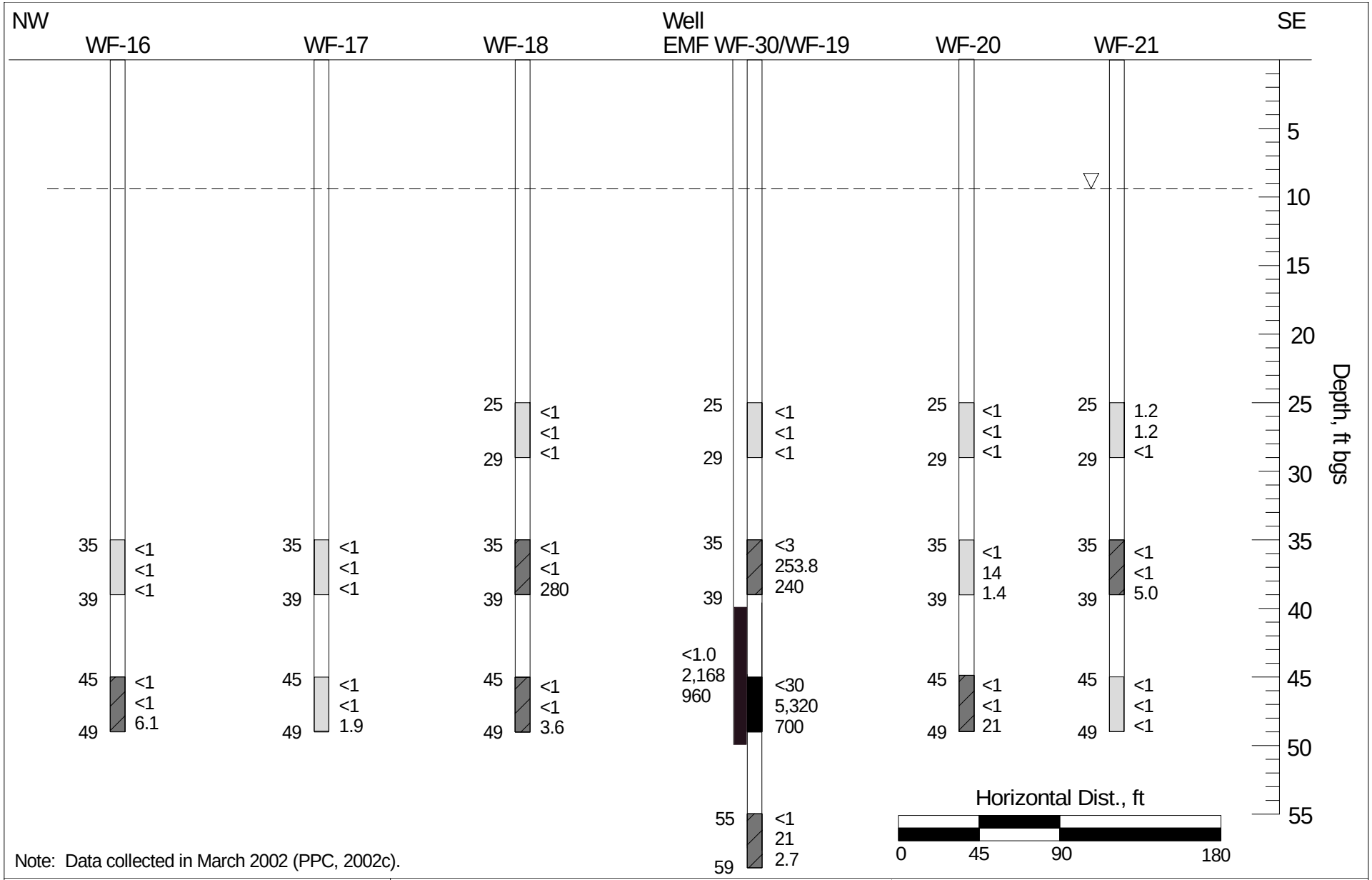
in two of the deepest samples collected between 55-59 feet bgs, and it is possible that vinyl chloride is present at levels of concern at deeper depths. However, as noted previously the Geoprobe sampling method is prone to carry-down problems associated with pushing a sampling probe through the plume to collect a sample beneath it.

2) VOC data indicated that the plume width narrows from approximately 500 feet wide along the west side of East Marginal Way to approximately 200 feet wide once it reaches the Duwamish Waterway.

3) Maximum concentrations in direct-push probe samples were cis-1,2-DCE at 5,320 ug/L in probe WF-19 and vinyl chloride at 1,600 ug/L in probe WF-25. Maximum concentrations in monitoring well samples were cis-1,2-DCE at 2,330 ug/L in well EMFWF-31 and vinyl chloride at 2,800 ug/L in well EMFWF-32. (The maximum vinyl chloride detection was 5,800 ug/l in well EMFWF-32 during October 2002.) TCE was not detected in any of the samples.

4) Vinyl chloride in excess of the AWQC (525 ug/L at the time the data were collected) was reaching the Duwamish Waterway. The plume size was estimated at approximately 200 feet across and 15 feet thick. The VOC flux was estimated at approximately 0.1 lbs (or less) of VOCs per day.

A summary of the results from the data collected in the three plume mapping transects are shown in Figures 3-9 through 3-13 (these data represent conditions from the March to August 2002 time frame and MTCA remedial actions have been implemented since that time).



Note: Data collected in March 2002 (PPC, 2002c).

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LEGEND

Sample interval

ft bgs — TCE (ug/L)

ft bgs — 12DCE (ug/L)

Vinyl chloride (ug/L)

▽ Top of water table (approx)

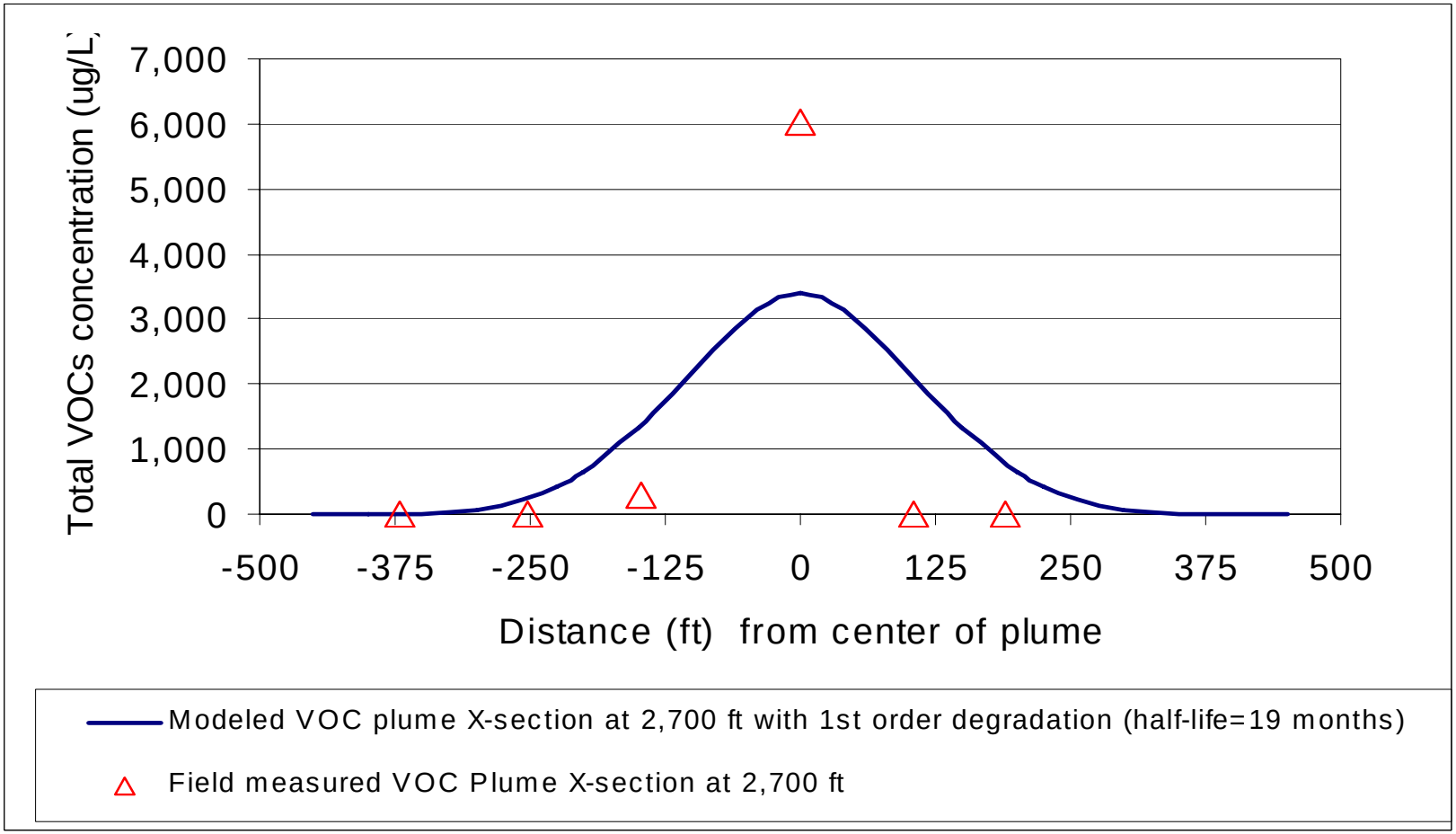
Indicates VOC above old AWQC

Indicates VOC above revised AWQC

Indicates no VOCs above AWQC

FIGURE 3-9. Results of Geoprobe Sampling in 2-40 Parking Lot, March 2002

NW SE



Note: Data collected in March 2002 (PPC, 2002c).

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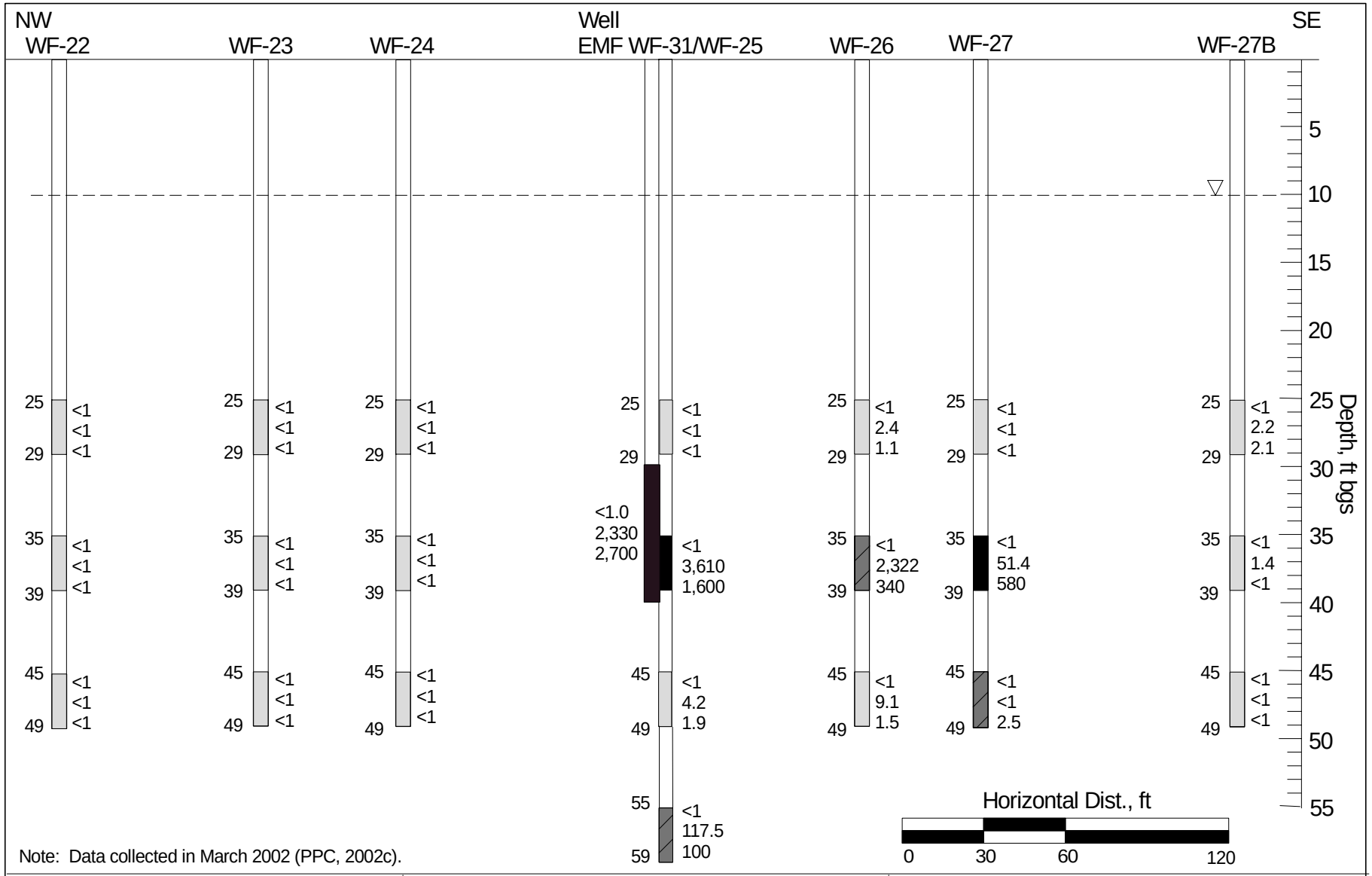
All concentrations noted represent total VOCs. The maximum concentration detected at any depth in vertical profile is presented.

FIGURE 3-10. Results of Modeling and Geoprobe Sampling for EMF VOC Plume in 2-40 Parking Lot, March 2002



Note: Data collected in March 2002 (PPC, 2002c).

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LEGEND

Sample interval

ft bgs TCE (ug/L)

ft bgs 12DCE (ug/L)

Vinyl chloride (ug/L)

Top of water table (approx)

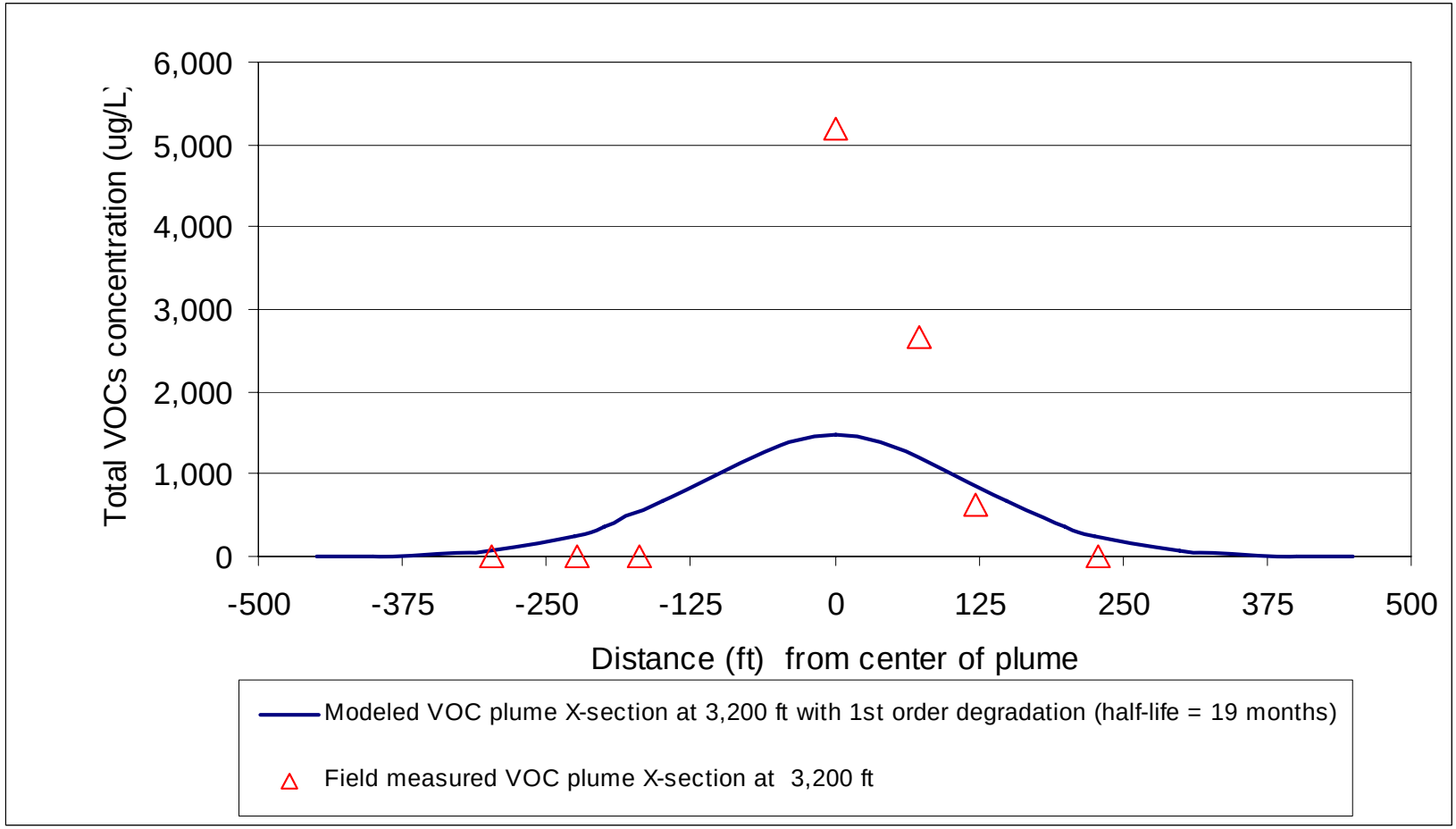
Indicates VOC above old AWQC

Indicates VOC above revised AWQC

Indicates no VOCs above AWQC

FIGURE 3-11. Results of Geoprobe Sampling in Transportation Aisle SW Side of 2-40 Building, March 2002

NW SE



Note: Data collected in March 2002 (PPC, 2002c).

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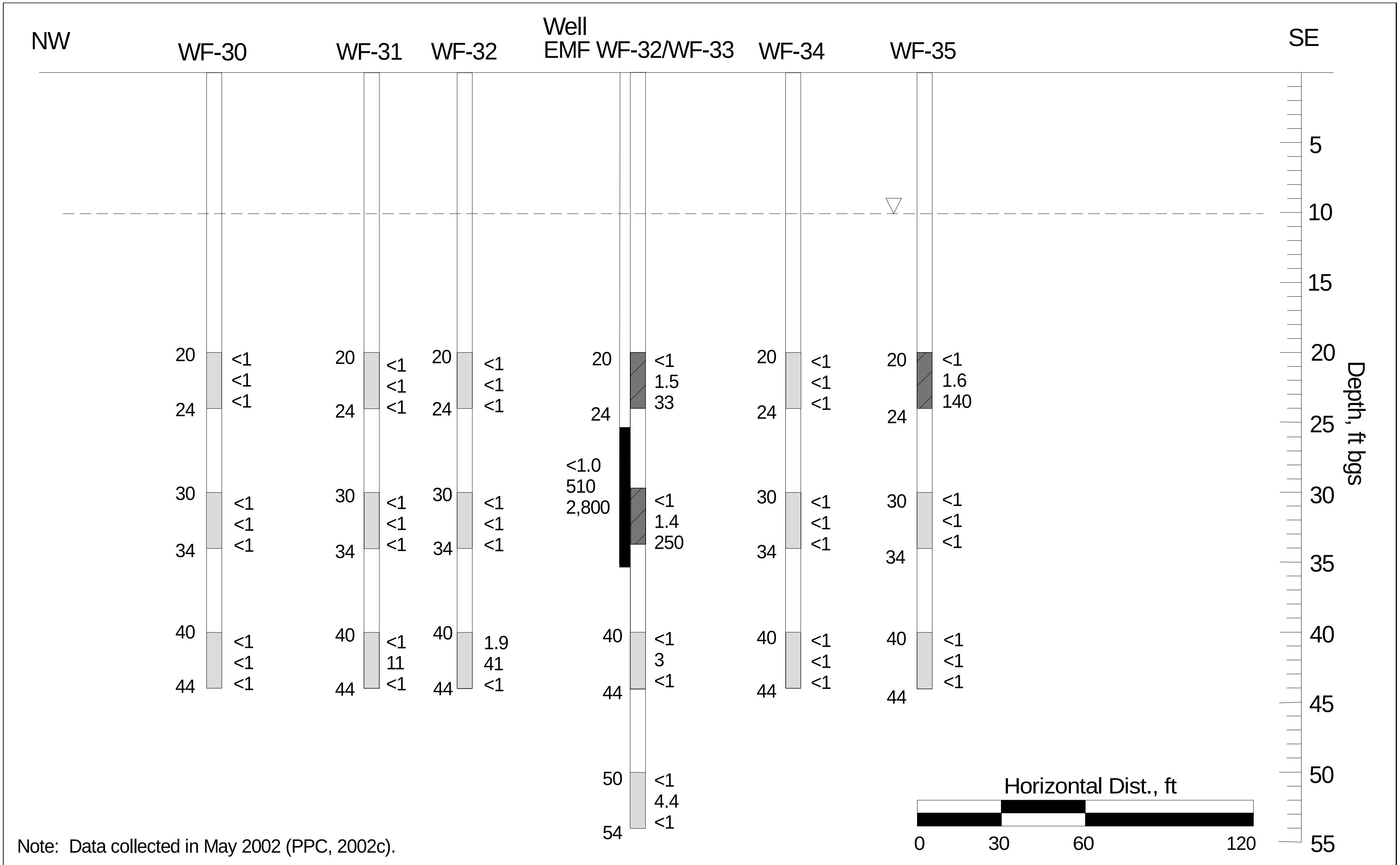
All concentrations noted represent total VOCs. The maximum concentration detected at any depth in vertical profile is presented.

FIGURE 3-12. Results of Modeling and Geoprobe Sampling for EMF VOC Plume in Transportation Aisle SW Side of 2-40 Building, March 2002



Note: Data collected in May 2002 (PPC, 2002c).

CALIBRE Systems Inc.

LEGEND

Sample interval

ft bgs — TCE (ug/L)

12DCE (ug/L)

ft bgs — Vinyl chloride (ug/L)

▽ Top of water table (approx)

■ Indicates VOC above old AWQC

▨ Indicates VOC above revised AWQC

□ Indicates no VOCs above AWQC

FIGURE 3-13. Results of Geoprobe Sampling in 2-41 Building Near Edge of Duwamish Waterway, May 2002

3.8 Enhanced Reductive Dechlorination Pilot Test

The ERD pilot test was initiated in July 2003. A work plan for the ERD pilot was submitted to Ecology and EPA. Review comments received were addressed in a revised work plan.

3.8.1 Objectives

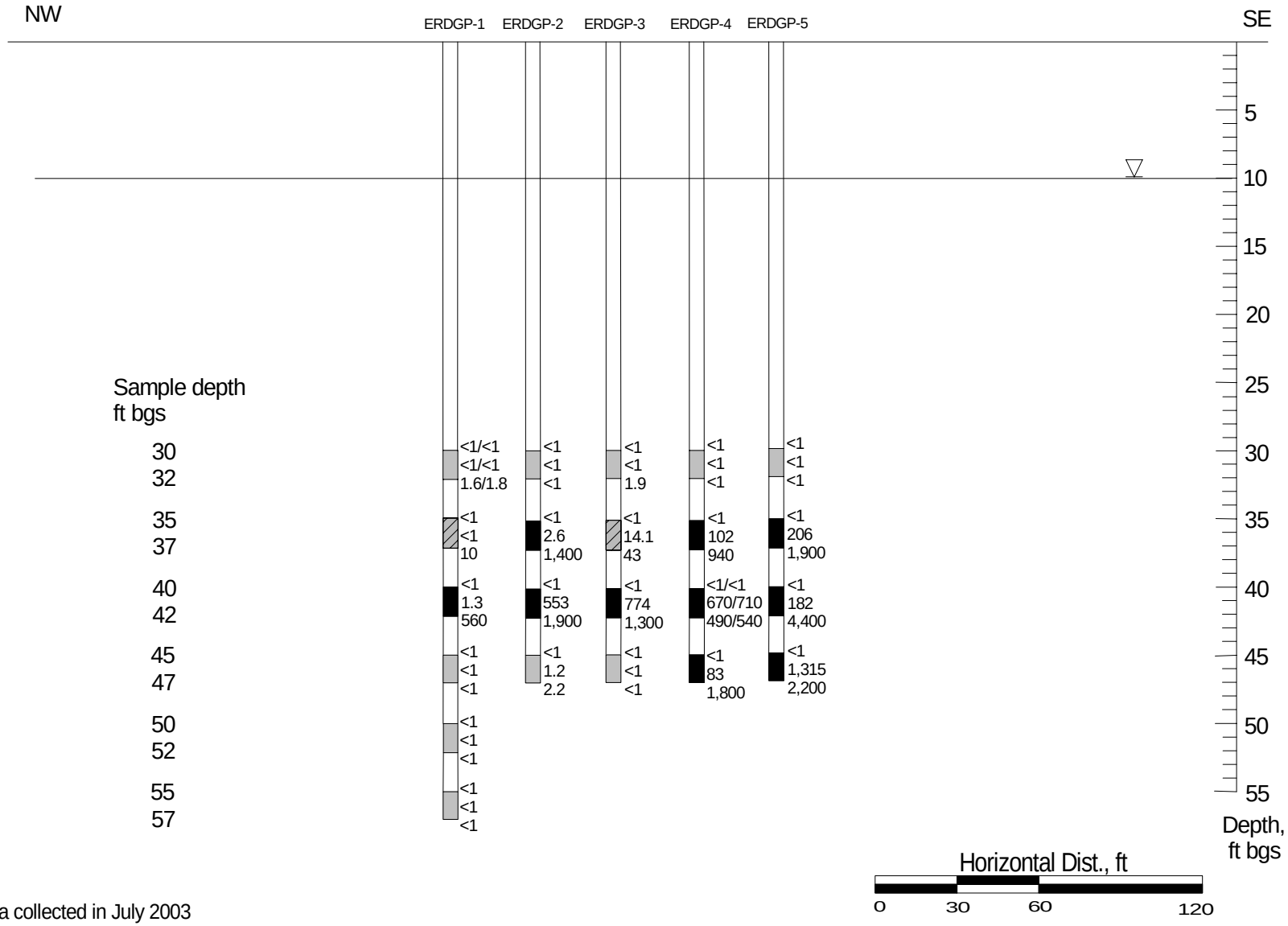
The objectives of the ERD Pilot Test, implemented between July 2003 and August 2004, were to provide performance and implementability data to support evaluation of this remedial approach for a new MTCA FS. Specific elements considered in developing the pilot test work plan included:

1) Identify the central area of the EMF VOC plume with the highest concentration of VOCs in order to locate the pilot test injection wells.
2) Determine if the substrate injection was effective in driving redox conditions to a lower state.
3) Evaluate changes to the VOC degradation rate.
4) Determine if ERD could achieve cleanup levels for cis-1,2-DCE and vinyl chloride in the site-specific conditions.
5) Determine best protocols for implementing ERD.
6) Determine the length of time that biostimulation was effective.

3.8.2 Approach

The field work conducted between July 2003 and August 2004 included:

- Advancing 5 direct-push probes for groundwater sampling in the middle of the 2-40 Building, approximately 2,500 feet down gradient of the EMF source area. The plume mapping data for this transect are shown in Figure 3-14. The data were used to establish the placement of the ERD pilot test injection wells.
- Installing three new injection wells. The wells transect a portion of the VOC plume at a location near the middle of the 2-40 Building.
- Installing three new groundwater monitoring wells down gradient of the pilot test injection wells.
- Collecting groundwater samples for chemical analysis in order to establish baseline VOCs, biological components, metals, anions, dissolved gases and field parameters.
- In September 2003, injecting 5,900 gallons of sodium lactate substrate (1.4 tons of sodium lactate) and 5,900 gallons of chase water mixed with 13.2 pounds of sodium bromide (added as a tracer) into the three new injection wells.
- Collecting groundwater samples throughout the pilot test duration for chemical and biological analyses to monitor efficacy of the ERD treatment.



Note: Data collected in July 2003

CALIBRE Systems Inc.

LEGEND

Sample interval

ft bgs TCE (ug/L)

12DCE (ug/L)

ft bgs Vinyl chloride (ug/L)

Top of water table (approx)

Indicates VOC above old AWQCs

Indicates VOC above revised (2003)AWQCs

Indicates no VOCs above AWQCs

Figure 3-14. Results of ERD Pilot Test Geoprobe Sampling in 2-40 Building Near Column C-7, July 2003

3.8.3 Results

The results from the ERD pilot test indicated the following:

1) Evaluation of performance data indicated that the ERD pilot test was performing effectively. Significant reductions in VOC concentrations (approximately 90 to 99+% reductions from pretest conditions) were observed. Monitoring from the 3 injection wells indicated decreases ranging from about 85% to 92% (for total VOCs). The first down-gradient well impacted by the biostimulation effort indicated a 99+% decrease from prior peak values (the timing of the decrease followed shortly after arrival of the bromide tracer and organic acids associated with the substrate breakdown products). All concentration trends noted include the combined effect of all removal processes (i.e., up-gradient remedial actions implemented prior, and other pre-existing attenuation processes).
2) Additional monitoring data indicated a portion of the observed VOC concentration reduction was a direct result of the pilot test biostimulation effort (tracer/organic acids arrival times, increased microbial census count, increased degradation by-products [ethene and ethane]).
3) Monitoring data indicated that the substrate in the injection wells decreased after about five months. Based on these data, an additional substrate injection was implemented on February 10, 2004. The results indicated that the ERD pilot test was successfully accelerating the rate of VOC removal (via reductive dechlorination) from the EMF VOC plume.
4) The results for the metals analysis were unchanged from the baseline conditions. These data indicate the ERD pilot test did not change geochemical conditions sufficiently to cause a measurable change in metals concentrations or mobility. The metals analysis for the ERD pilot test included analysis for the RCRA 8 metals with the following detection limits:

Arsenic	Barium	Cadmium	Chromium	Lead	Mercury	Selenium	Silver
<0.05 mg/L	<0.003 mg/L	<0.002 mg/L	<0.005 mg/L	<0.02 mg/L	<0.0001 mg/L	<0.05 mg/L	<0.003 mg/L

3.9 Full-Scale Implementation of Enhanced Reductive Dechlorination

The full-scale implementation of ERD was initiated in April 2005 and has continued through the present date (February 2007). This work is summarized in CALIBRE 2004b, 2006a, 2007.

3.9.1 Objectives

The objectives of the MTCA FS and design work (CALIBRE 2004b) were to:

1) Complete a MTCA FS evaluating remedial alternatives for clean-up actions for the EMF VOC plume.
2) Evaluate and test different ERD substrate solutions to determine if alternative substrates (different than the lactate used in the pilot test) would be effective.
3) Design, construct, and plan operation/monitoring of an ERD system for in-situ treatment of the EMF VOC plume.

3.9.2 Approach

The ERD remedial actions have been implemented between July 2004 and early January 2007 in six areas. Area 1 includes the wells in Building 2-41, located approximately 320 feet up gradient from the LDW. Area 2 is at the same location as the ERD pilot test (with expanded injection well) in Building 2-40. Area 3 is in the parking lot of Building 2-40 (west of East Marginal Way), Area 4 is adjacent to the Boeing fire station on KCIA (along the fence line with East Marginal Way), Area 5 is in the mid-field grassy strip, and Area 6 is the location of the EMF property.

The MTCA FS and design report includes:

- Evaluation of five remedial alternatives: no action, monitored natural attenuation, bioremediation through ERD, groundwater extraction, and air stripping. The MTCA FS selected ERD as the preferred remedial alternative pursuant to the MTCA FS evaluation criteria.
- Summary of bench tests for evaluation of alternative substrates for fermentation to generate electron donors as part of ERD.
- Estimates of degradation rate constants under baseline and ERD conditions.
- Design details for the full-scale ERD application.

The VOC plume treatment with ERD has included:

- Injecting 7.3 tons of sucrose into 15 wells in Areas 1, 2, and 4 in April 2005 (substrate injection in Area 3 was not completed at the request of EPA in June 2005). This includes injecting 5,100 gallons of solution (1.3 tons of sucrose) into 3 wells in Area 1; 10,200 gallons of solution (1.7 tons of sucrose) into 4 wells in Area 2; and 16,300 gallons of solution (4.3 tons of sucrose) into 8 wells in Area 4.
- Injecting 17,900 gallons of substrate solution (6.0 tons of sucrose) into 7 wells at the EMF property (Area 6) in late June and early July 2005.
- Injecting 15,400 gallons of substrate solution (6.8 tons of sucrose) into 12 injection wells at the EMF property in October 2005.
- Injecting 22,800 gallons of substrate solution (10.9 tons of sucrose) into 8 wells in Area 4 in November 2005.
- Injecting 1,050 gallons (estimated at 1.8 tons) of emulsified vegetable oil/sodium lactate substrate into 18 direct-push probe locations in mid-field grassy strip (Area 5) corresponding with a short-term airport closure in September 2006.

- Collecting and submitting 3 groundwater samples for priority pollutant metals analysis to characterize the potential for metals mobilization after ERD injection in the plume area.

The remedial optimization implemented as part of the site-wide ERD application has included expansion of the ERD transect at the Boeing fire station (Area 4, completed in November 2006) and substrate re-injection. Remedial optimization and additional remedial actions include:

- Advancing 5 direct-push probes near East Marginal Way in the fire station parking area, approximately 2,200 feet down gradient of the EMF source area
- Collecting groundwater samples for chemical analysis and 2 soil samples for grain size analysis for determining placement of wells.
- Installing two new groundwater monitoring wells; EMFWF-37 and EMFWF-38 in Area 4. EMFWF-37 was placed to bound the southern end of the VOC plume in this transect area. EMFWF-38 is a deeper well beneath the base of the VOC plume in a central area of the plume.
- Installing 6 new injection wells expanding the width of the injection transect adjacent at the Boeing fire station (Area 4). Two injection wells were installed northwest of the previous injection wells, and four were installed southeast of the prior injection wells.
- Injecting 12.8 tons of sucrose into 23 wells in Areas 1 through 4 in December 2006 and early January 2007. This includes injecting 15,900 gallons of substrate solution (7.7 tons of sucrose) into 13 wells in Area 4; 4,700 gallons of substrate solution (0.7 tons of sucrose) into 4 wells in Area 3; 8,200 gallons of substrate solution (1.8 tons of sucrose) into 3 wells in Area 1; and 8,700 gallons of substrate solution (1.8 tons of sucrose) into 4 wells in Area 2.

3.9.3 Results

The initial bench-scale test results indicated that the sucrose in beverage products was an effective biostimulation substrate for the dechlorination process that was capable of matching the performance of sodium lactate as a fermentation substrate/electron donor.

The performance monitoring results have indicated significant reductions in VOC concentrations throughout the areas treated with ERD. All concentration trends noted include the combined effect of all removal processes (i.e., the ERD actions implemented, up-gradient remedial actions implemented prior, and other pre-existing attenuation processes). The performance monitoring data indicate that the treatment process is removing VOCs and that complete dechlorination of all COCs is achieved (chlorinated compounds of vinyl chloride and cis-1,2-DCE). Complete dechlorination results in the production of benign degradation byproducts (ethene/ethane).

Performance monitoring from well EMFWF-32, located adjacent to the LDW, has demonstrated a 99.98% decrease in total VOCs (primarily vinyl chloride) since the start of remedial actions in up-gradient areas. This observed reduction includes the

cumulative effects of all up-gradient source control actions implemented previously and the pre-existing natural attenuation processes (baseline reductive dechlorination before ERD was implemented). This well (EMFWF-32) was installed at the center of the VOC plume in the interval with highest VOC concentrations detected in the Geoprobe samples from the plume mapping transect adjacent to the LDW.

The monitoring associated with the ERD project has included sampling and analysis of groundwater to determine if the reducing conditions also had an adverse impact of increased metals mobilization. A reducing environment is a necessary condition for effective ERD treatment and the concern is specifically related to redox-sensitive elements such as arsenic and selenium. The monitoring data collected indicate no change from baseline conditions (the metals concentration for the RCRA 8 metals tested were non detect for all analytes in both the baseline sampling and sampling completed after ERD conditions were achieved). Added sampling for metals analyses (priority pollutant metals, including copper) was conducted in selected site wells in September 2006. This sampling for priority pollutant metals has not identified any elevated levels of metals as a result of the ERD treatment for the VOC plume. The January 2007 priority pollutant metals analysis from EMFWF-32 (near the LDW) is presented in Table 3-9 (total and dissolved metals along with detection limits);

Table 3-9 EMFWF-32 Sampling Results for Metals, Jan 2007

Analyte	Units	Total	Dissolved		Analyte	Units	Total	Dissolved
Antimony	mg/L	0.05 U	0.05 U		Manganese	mg/L	1.07	1.11
Arsenic	mg/L	0.0007	0.0007		Mercury	mg/L	0.0001 U	0.0001 U
Beryllium	mg/L	0.001 U	0.001 U		Nickel	mg/L	0.003	0.001
Cadmium	mg/L	0.0002 U	0.0002 U		Selenium	mg/L	0.05 U	0.05 U
Chromium	mg/L	0.001 U	0.001 U		Silver	mg/L	0.0002 U	0.0002 U
Copper	mg/L	0.0006	0.0005 U		Thallium	mg/L	0.0002 U	0.0002 U
Iron	mg/L	23.7	23.4		Vanadium	mg/L	0.004	0.003
Lead	mg/L	0.001 U	0.001 U		Zinc	mg/L	0.009	0.004 U

Expansion of the injection transect in Area 4 (near the Fire station) has been completed in 2006. The investigation and design process used for expansion of the transect included grab samples (Geoprobe) to characterize the depth and width of the VOC plume followed by installation of added (new) injection wells to fully treat the VOC plume width (based on the revised AWQC for vinyl chloride). This investigation and ERD optimization work also included installation of a deeper monitoring well in the central area of the EMF VOC plume. The deeper well (EMFWF-37) was installed to a depth of 70 ft bgs beneath the fine grained zone (~ 50+ ft bgs) that serves as the base of the EMF VOC plume. The sampling data from this new well (Jan 2007) indicated non-detect (< 0.1 ug/L) for TCE, 1.1 ug/L for cis-1,2-DCE and 0.7 ug/L for vinyl chloride.

3.10 Regular Sampling of Groundwater Monitoring Network

The network of site monitoring wells has been sampled on a regular basis since installation. Sampling initially started on a quarterly basis and was reduced to a bi-annual basis based on a review of the data and seasonal trends observed.

3.10.1 Objectives

The objectives of the site groundwater monitoring has been to characterize the nature and extent of the VOC plume, evaluate any seasonal changes (if present), evaluate natural attenuation processes, and collect performance monitoring data for evaluation and optimization of MTCA remedial actions.

3.10.2 Approach

Groundwater monitoring has been conducted at the site since the early 1980's. Monitoring of 9 wells on the EMF property that were installed between 1985 and the 1997 MTCA RI/FS has continued. Chemical analyses initially included VOCs, priority pollutant metals, and other conventional parameters. As wells were installed at down gradient locations, they were added to the monitoring program and most wells have been monitored quarterly for the first 1-2 years after installation. Based on the data, chemicals of concern were identified as VOCs. Further evaluation of data from the monitoring wells throughout the plume identified a short list of VOCs that are present in the plume, specifically TCE, cis-1,2-DCE, trans-1,2-DCE and vinyl chloride. Subsequent analysis of VOCs has focused solely on these specific analytes. Additional monitoring for priority pollutant metals has been implemented at selected areas at the request of EPA. Other analytes added for evaluation of the ERD performance included total organic carbon (TOC) and dissolved gasses (ethene, ethane and methane).

3.10.3 Results

The results of the groundwater monitoring have been included in many of the reports discussed in the above Sections. The data has been evaluated and summary tables prepared (CALIBRE 2006a). The site-wide groundwater sampling data have been used throughout the project for characterizing the nature and extent of the VOC plume and for performance monitoring/evaluation and optimization of remedial actions. A summary of the data from the site-wide groundwater monitoring are included in Appendix C.

Table 3-10 presents a summary of recent changes in VOCs detected within the monitoring well network (from Jul 2006 to Jan 2007). Longer term trends regarding VOCs detected in wells throughout the EMF plume are discussed in more detail (including graphs) in Section 4 with the Conceptual Site Model.

Table 3-10 Summary of Recent Changes in VOCs from Site-wide Monitoring Wells

Monitoring well ID	Vinyl Chloride (ug/L)		Direction of change Jul 06-Jan 07	trans 1,2- DCE (ug/L)		Direction of change Jul 06-Jan 07	cis-1,2- DCE (ug/L)		Direction of change Jul 06-Jan 07	TCE (ug/L)		Direction of change Jul 06-Jan 07
	Jul-06	Jan-07		Jul-06	Jan-07		Jul-06	Jan-07		Jul-06	Jan-07	
EMFNV-01	150 U	10 U	--	150 U	10 U	--	210	41	Down	9800	660	Down
EMFNV-02	3800	9.8	Down	1000	11	Down	26000	36	Down	28000	20	Down
EMFMW-1S	4.2	1.7	Down	1.0 U	0.2 U	--	21	8.7	Down	1.0 U	12	*Up*
EMFMW-1D	44	61	*Up*	4.3	3.5	Down	39	90	*Up*	1.0 U	13	*Up*
EMFMW-8	130	15	Down	73	15	Down	3700 D	880	Down	1200	44	Down
EMFMW-10	120	320	*Up*	100	110	*Up*	2000	2600	*Up*	520	600	*Up*
EMFMW-11S	160	160	*Up*	48	21	Down	1200	480	Down	30 U	10 U	--
EMFMW-11D	1000	850	Down	580	790	*Up*	6400	6100	Down	120	58	Down
EMFMW-13D	540	320	Down	150	130	Down	220	210	Down	10 U	20 U	--
EMFMW-16	7.5	2.5	Down	12	4.9	Down	93	9.7	Down	85	1.6	Down
EMFMW-17	130	98	Down	170	110	Down	890	500	Down	780	58	Down
EMFMW-24	300	19	Down	100	21	Down	220	22	Down	37	1.1	Down
EMFMW-34	470	470	--	140	74	Down	3600 D	1900	Down	1300	430	Down
EMFIW-18	960	2200	*Up*	310	350	*Up*	14000	12000	Down	610	100 U	Down
EMFIW-21	51	290	*Up*	110	180	*Up*	100	2900	*Up*	19	320	*Up*
EMFWF-25	1.9	1.4	Down	1.0 U	0.2 U	--	1.0 U	0.2 U	--	1.0 U	0.2 U	--
EMFWF-26	850	520	Down	20 U	30 U	--	180	30 U	Down	20 U	30 U	--
EMFWF-27	610	950	*Up*	35	58	*Up*	120	270	*Up*	15 U	15 U	---
EMFWF-28	98	100	*Up*	1.0 U	1.0 U	--	4	5.5	*Up*	2.3	1.0 U	Down
EMFWF-29	1300	1400	*Up*	25 U	20 U	--	25 U	20 U	Down	25 U	20 U	--
EMFWF-30	500	120	Down	19	10 U	Down	440	18	Down	10 U	10 U	--
EMFWF-31	2300	2400	*Up*	35	27	Down	180	20 U	Down	30 U	20 U	--
EMFWF-32	1.0 U	1	*Up*	1.0 U	0.2 U	--	1.0 U	0.2 U	--	1.0 U	0.2 U	--
EMFWF-36	210	260	*Up*	28	5.6	Down	260	5.0 U	Down	3.0 U	5.0 U	--

Samples with a U flag are below the reporting limited noted.
Samples where both time periods are below the reporting limit (U) are not used to identify a direction of change (up or down) and are depicted as "--".
If a Jan 2007 reporting limit (U flag) is less than a quantified Jul 2006 sample, the direction of change is noted as down.

3.11 Sampling of Discharge to the Lower Duwamish Waterway

A recent study published by EPA (Lentz 2006) evaluated the possible impact on the LDW from groundwater plumes in the vicinity of Boeing Plant 2. The samples reported in this study were collected from pore-water piezometers installed in the sediments to capture groundwater just before the groundwater discharges to the LDW.

3.11.1 Objectives

The stated objectives of this 2005 pore-water sampling include the following:

1) Determine the hydraulic connections between on-shore groundwater and the river bottom.
2) Analyze contaminants in the discharging transition-zone water to evaluate the relative risk to river biota from upland contaminants.
3) Further the understanding of groundwater - surface water interactions.
4) Assess the relationship between bulk sediment chemistry and transition zone water (or pore water) chemistry.
5) Field test the ongoing development of site conceptual models of groundwater-sediment-surface water interaction.

EPA has indicated that this sampling was not intended to evaluate tidally-induced dispersion processes but rather to verify that groundwater (plumes) discharged to the LDW.

3.11.2 Approach

Sampling locations were selected based on known up-gradient plumes (Lentz 2006). The sampling location near the EMF VOC plume (sample BOE1) was placed approximately 100 feet directly down gradient of EMF plume monitoring well EMFWF-32. Pore-water piezometers were installed (by divers) in the sediments to capture groundwater in the transition zone just before the groundwater discharges to the LDW. The samples were collected before the low tide on November 16, 2005. Pore water was pumped from the piezometers (using a surface peristaltic pump in a boat) until the turbidity cleared and field parameters stabilized, after which samples were collected.

3.11.3 Results

The reported results for sample BOE1 included the following:

Vinyl chloride is reported at 5.8 ug/L, cis-1,2-DCE is reported at 0.11 ug/L, and toluene is reported at 0.11 ug/L. Dissolved oxygen (DO) values for pore-water samples were lower than river water measurements and this was interpreted as confirmation that surface water was not being sampled. The temperature of the pore-water sample was also higher than the river water. Common seawater analytes detected in the BOE1 pore-water sample included sodium (at 720,000 ug/L) and potassium (at 411,000 ug/L). Based on the presence of high concentrations of seawater analytes in samples with

VOC detections, the study concluded that seawater (the LDW) is not acting as a significant barrier to contaminants. The recommendations presented in the report included the following:

1) A correlation of pore-water sample results and upland groundwater detects for the VOCs should be completed.
2) High concentrations of seawater analytes in samples with VOCs indicate that seawater does not act as a barrier to contaminant migration and the data illustrate that mixing of contaminated groundwater from the site and the "saltwater wedge" is occurring.
3) A more in-depth analysis of the tidal impact to the sub-surface environment at the site is recommended.

3.12 Modeling Evaluation of Attenuation Processes

Fate and transport modeling has been conducted throughout various stages of the EMF project. The modeling work has been conducted primarily to understand the key attenuation processes rather than to predict impacts in areas beyond the existing data. The overall investigative approach has been to collect necessary plume characterization data at specific areas and use the models as one tool for interpretation of the field data.

3.12.1 Objectives and Key Processes Evaluated

Previous work at the site has including modeling efforts to evaluate the impacts of key attenuation processes on the VOC concentrations in the EMF VOC plume. The key attenuation processes occurring throughout the VOC plume are primarily degradation and dispersion. The primary degradation process is thought to be reductive dechlorination. In addition, tidally-enhanced dispersion affects the plume discharge concentrations prior to discharging to the LDW. The following Sections summarize the methods and results of the modeling efforts, along with existing monitoring data and literature derived values used to develop and calibrate the models (where applicable).

3.12.2 First-Order Degradation Modeling

The degradation processes for TCE via reductive dechlorination are discussed in multiple site investigation reports (e.g., PPC 2002, CALIBRE 2004a, 2004b) and summarized in the conceptual site model described in Section 4. The site geochemical conditions are conducive to reductive dechlorination processes and each of the daughter products (through ethene) have been measured within the EMF VOC plume.

Prior work (summarized in PPC 2002) evaluated the rate of VOC concentration reductions observed in the EMF VOC plume using first-order degradation modeling. The objectives of this analysis were to:

1) Determine if the observed plume constituents and distribution were consistent with first-order degradation processes.
2) Derive rate constants for the degradation processes.
3) Provide a tool for estimating down gradient concentrations beyond the area where existing monitoring points were located (at that time).

The first-order degradation equation was transformed from concentration as a function of time [C ~ (f(t)] to concentration as a function of down gradient position using the groundwater velocity [C ~ f(x/v)]. This modeling approach is derived from the chain-decay of radionuclides (i.e., generation of multiple daughter products based on first-order degradation processes). The BIOCHLOR model was subsequently developed and is functionally equivalent to this modeling analysis.

The site data used for calibrating the degradation modeling were the peak VOC concentrations detected along several transects of the plume from the source area to East Marginal Way. A reasonable maximum concentration of TCE at the source area was set at 250,000 µg/L. The highest concentration of VOCs detected at subsequent down gradient plume mapping transects were used for additional model calibration data.

3.12.3 Results and Comparison with Field Data

The site data and the degradation modeling results revealed that the primary VOC being degraded down gradient from the former EMF property is cis-1,2-DCE (i.e., most of the TCE had been degraded before reaching the EMF property boundary, over 99.9% of up-gradient levels). The peak cis-1,2-DCE concentrations (i.e., the estimated center of the plume) were reduced from ~109,000 µg/L down to ~4,000 µg/L (a factor of 27 reduction) in the transit from the EMF property to the transect at East Marginal Way. The daughter product derived from the cis-1,2-DCE degradation is vinyl chloride.

In this same groundwater transport range, the peak vinyl chloride concentrations were reduced from ~23,000 µg/L down to 1,300 µg/L (a factor of 17 reduction). This measured vinyl chloride reduction occurred over the same interval that the cis-1,2-DCE degradation had generated a larger amount (mass and concentration) of vinyl chloride. That is, each mole of cis-1,2-DCE that is degraded creates one mole of vinyl chloride (i.e., 109,000 µg/L of cis-1,2-DCE would degrade to 70,269 µg/L of vinyl chloride). These data indicate that complete dechlorination to ethene is occurring and that, within the area evaluated (EMF property to East Marginal Way), degradation of cis-1,2-DCE appeared to be a rate limiting step.

As discussed in the site characterization reports (PPC 2002a), the sampling results within the plume mapping transects indicate substantial variability and heterogeneity in the degradation processes. Different portions of each plume mapping transect had varying fractions of TCE, cis-1,2-DCE and vinyl chloride. Some of the measurements closer to the EMF property indicated a more rapid TCE degradation than some of the down gradient data.

A simpler presentation of the degradation processes is as a combined removal process (i.e., total VOCs present). The modeling results for total VOC degradation showed a much clearer fit of the field data (total VOCs) to the model-predicted concentrations. The degradation rate constant was determined by a least-squares fit of the model predictions to the measured field data. The results indicated a good fit between the field data and the model predictions (an R^2 of 0.98). The estimated half life ($T_{½}$) for the

slowest-degrading VOC is 12.5 months. This corresponds to the predicted concentration decreasing by 50% (a factor of 2 reduction) for every 500 feet of travel distance.

3.12.4 Attenuation Modeling

The results of the first-order degradation modeling were used to estimate the maximum VOC concentrations along the plume centerline. After the initial phase of modeling confirmed that the observed VOC plume distribution was consistent with a first-order degradation process (and using a half-life of 19 months), the BIOSCREEN model was used as a screening model that simulates advection, dispersion, adsorption and first-order degradation. Input data for this modeling include hydrogeologic parameters (hydraulic conductivity, gradient and porosity), dispersion, adsorption, biodegradation rate constants, and source data. The BIOSCREEN model is based on the Domenico analytical solution to the solute transport equation with first-order degradation.

Subsequent to completing this EMF modeling work (~ 2001), an error was identified in the mathematical approximation used in the BIOSCREEN model (i.e., the Domenico analytical solution, e.g., Guyonnet and Neville 2004, Srinivasan, et al 2007, West et al 2007). The approximation error becomes significant when larger longitudinal dispersion coefficients are used. Due to the specific characteristics of the EMF plume, small dispersion coefficients were always used to match the very limited spreading/dispersion of the plume as identified in the multiple plume mapping transects.

A subsequent revised version of the model, BIOSCREEN AT, has been developed and distributed by the EPA Kerr lab. The BIOSCREEN AT model was tested with the EMF plume data set and parameters. The results indicated that the BIOSCREEN model (with the known error applicable to certain conditions) estimates peak concentration along the plume centerline that are approximately 8 to 9% lower than the BIOSCREEN AT model. The models have not been used in the EMF project to predict or project conditions, but rather as an aid to assist in the interpretation of the site characterization data. As such, the relatively minor error (known) in the BIOSCREEN results has been considered acceptable for the intended purpose of data interpretation.

3.12.5 Results and Comparison with Field Data

The model-predicted results were compared to field measured concentrations along several plume mapping transects aligned perpendicular (generally) to the flow direction of the EMF VOC plume. The second plume mapping transect is located about 900 feet from the source (between the runways at KCIA). The model-predicted results for this transect showed excellent agreement with the measured concentrations and displayed a Gaussian distribution of total VOCs along the transect. Both the maximum VOC concentration (total VOCs) and the spread of the plume are matched by the model-predicted results. The third plume mapping transect is located about 1,900 feet from the source (on the western taxi-way for KCIA). The model-predicted results for this transect also show good agreement with the measured VOC concentrations. The fourth plume mapping transect is located about 2,200 feet from the source (along the fence

line with East Marginal Way). The model-predicted results for this transect generally show good agreement with the measured VOC concentrations for the spread of the plume but the peak concentration (modeled) is below the measured value. These model-predicted results and the measured concentration of total VOCs are shown with the respective push probe sampling transects in Figures 3-2 through 3-12.

Moving further down gradient, the agreement between the predicted and the measured concentrations becomes less aligned (see Figures 3-10 and 3-12). By the time the plume reaches the 2-40 parking lot in Boeing Plant 2, the highest VOC concentration (measured in the central core of the VOC plume) is much higher than predicted by the model. In the same plume mapping transect, the measured VOC concentrations are lower than the model-predicted concentrations on the fringes of the plume. Thus, the actual plume becomes narrower (frequently with multiple samples at non-detect levels) than predicted by the model but with a higher maximum concentration in the central core of the plume.

Since the VOC plume does not spread significantly (either horizontally or vertically) as it moves down gradient, the observed reduction in concentrations on the fringes of the plume are believed to be the result of degradation by reductive dechlorination where natural background levels of dissolved organic carbon serve as electron donors. In the central core of the plume near Plant 2, there appeared to be an insufficient supply of electron donors to facilitate reductive dechlorination. In this area continued VOC attenuation rates are reduced and concentrations remain higher than predicted with the convection/dispersion/ degradation model (i.e., the degradation process is rate limited to the available supply of electron donors).

3.12.6 Tidally-Enhanced Dispersion Prior to Discharge to Lower Duwamish Waterway

Changing tides affect the groundwater discharge to tidally-influenced surface water. This near-shore groundwater discharge zone is termed the hyporheic zone[1]. Research projects, including field studies and modeling studies, have clearly demonstrated that the rapidly changing water levels in the intertidal zone have a significant impact on the groundwater discharge and the concentration of various contaminants within that discharge. The dispersive nature of the tidally influenced flow regime in groundwater has been recognized and documented for nearly 50 years (e.g., Cooper, 1959; Kohout, 1960). More recently, several quantitative models have been developed to characterize the chemical transport conditions within the intertidal zone (Neville and Thrupp, 2002; Robinson and Gallagher, 1999; Yim and Mohsen, 1992).

One important process in the near-shore, tidally-active region of the aquifer is the rapidly changing groundwater flow velocity. The tidally-active region of an aquifer is the zone where the water table (or piezometric surface) is influenced by the tide. The inland extent of the tidally-active region varies with the hydrogeological properties of the aquifer and the amplitude and frequency of the tidal fluctuation. The tidal influences in a

[1] from the Greek roots – *hypo*, meaning under or beneath, and *rheos*, meaning a stream or to flow

typical unconfined aquifer in the Duwamish area is expected to extend inland approximately 100-200 feet from the shoreline; within confined or semi-confined conditions the tidal influences may be observed as far as 700 feet inland (Booth and Herman, 1998). The tidal conditions in the surface water create fluctuating water table elevations and corresponding changes in the groundwater velocities (the changes are both in magnitude and direction). In the near-shore zone of the aquifer (approximately 50 to 100 feet up gradient from the discharge boundary), the changes in groundwater velocities are dramatic, including reversal in flow direction during every high-tide cycle. The change in flow direction at the discharge boundary imports water from the river to the groundwater zone near the shore.

The significantly higher water flux in this groundwater zone prior to the discharge is comprised of in-flowing water (from the surface water into the aquifer) on the flood tide (high-tide cycle) and discharging water on the ebb tide (low-tide cycle). This mixing of tidally induced groundwater flow with the ambient groundwater discharge has an important impact on the concentration of chemicals present in the discharged water. If one assumes that the chemical concentrations in the surface water are very low (or zero), then the effect of the tidal mixing within this near shore groundwater zone is to significantly attenuate the concentrations of dissolved compounds present in groundwater prior to the point where they are discharged to the waterway.

In a previous report, PPC (2001b) estimated the expected magnitude of the tidally-induced dispersion for the EMF VOC plume using a model of the important transport processes based on the analytical methods described by Yim and Mohsen (1992). The model is based on the standard advection-dispersion equation for evaluating transport in a porous media. The model simulations evaluate groundwater discharge to a typical tidal system using generic and site-specific data. The model was then applied to a typical condition expected for groundwater discharges to the LDW (i.e., tidal amplitude/frequency and hydrogeological conditions). Additional discussion of the relative importance of this tidally-enhanced dispersion, along with relevant research from locations throughout the United States (and internationally) is presented in Section 5.

3.12.7 Results and Comparison with Field Data

Modeling results indicate that the tidal fluctuations induce tidally-enhanced dispersion which has a significant impact on the concentration of dissolved species discharging from the aquifer to the surface water. The modeling results showed that the dispersion in the near-shore zone (within groundwater) induced by tidal mixing appears to be approximately a factor of 50 (e.g., an up gradient groundwater concentration of 50 ug/L would be reduced to 1 ug/L at the point of discharge to the river). It is important to note that this tidally-induced dispersion does not impact the VOC mass flux to the LDW but rather attenuates the discharge concentration because of the increased water flux in the tidal flushing zone.

Vinyl chloride was measured at concentrations of 590 ug/L and 32 ug/L in samples collected from well EMFWF-32 in July 2005 and January 2006, respectively. Sampling for metals within the EMF plume has generally not focused on common seawater analytes. However, one recent sampling event included samples from three EMF wells spread over the airport (see Sept 2006 data in Appendix C). The sodium and potassium levels detected in these wells are in the range of 73,000 ug/L for sodium and 7,300 ug/L for potassium.

The relation between salinity intrusion at a specific point and corresponding attenuation of dissolved chemicals in discharging groundwater is linear. Groundwater monitoring near the edge of the river at various locations along the LDW has demonstrated the tidal influence and the net transport of saline waters into the near-shore groundwater zone (PPC 2002a).

3.13 Other Relevant Investigations Within Plant 2

A number of investigations have been implemented in the areas of the 2-40 and 2-41 Buildings as part of the RCRA Facility Investigations (RFI). General summaries of the multiple investigations are presented in EPI 2004, 2006. Data from the hydrogeologic investigations in the Plant 2 area provide a significant portion of the regional data used to develop the conceptual hydrogeologic model of the Duwamish River valley (Booth and Herman 1998).

3.13.1 Objectives

The objectives of the RFI investigations in the area have been to identify potential releases from waste management units and other suspect areas in the vicinity and to identify the nature and extent where a release has occurred.

3.13.2 Approach

Subsurface investigations performed in the 2-40s Area RFI focused on a number of Solid Waste Management Units (SWMUs), Areas of Concern (AOCs), and Other Areas (OAs) through sampling of groundwater wells, soil borings, and samples of both media from direct-push probe methods. Results from these investigations indicate that there were some impacts to the environment from manufacturing operations in the area.

3.13.3 Results

The soil and groundwater data from the RFI (in the EMF plume area) are characterized as relatively low-level detections of limited aerial and vertical extent. A few samples from the 2-40s area had detections above screening criteria (screening criteria defined in the 2004 Plant 2 Data Gaps Investigation Screening Report prepared by Environmental Partners Inc and approved by EPA). Chlorinated VOCs detected above screening criteria were limited to vinyl chloride detections in the northwest corner of the 2-41 Building and detections in the parking area east of the 2-40 Building. The vinyl chloride detections at the northwest corner the 2-40s area are likely from SWMUs 2-41.32, 2-41.32, and 2-41.34. The vinyl chloride detections above screening criteria east of the 2-40 Building likely originate from RCRA Unit OA18.

The available data indicate that the EMF VOC plume and shallower A-level vinyl chloride detections in the 2-40s area associated with past practices at Plant 2 do not commingle (EPI 2004). Given sample locations and depth intervals with no detections of vinyl chloride, the existing data indicate that the EMF plume is separated from the shallower A-level vinyl chloride occurrences. It is likely that this separation has been maintained, in part, by biodegradation along the margins of the EMF plume, which greatly limits its lateral and vertical spreading.

The Plant 2 RFI has also included groundwater seep samples at the LDW in the area near the EMF VOC plume (Weston 1997d, see Table 5-16 and Maps 51b, 52b and 53b in the RFI for seep locations SE-04101-0000, SE-04102-0000, and SE-04105-0001). Seep sample locations SE-04101-0000 and SE SE-04102-0000 are down gradient from sample location WF-35 from the EMF plume investigation. Seep sample location SE-04105-0001 is down gradient from sample location WF-30 from the EMF plume investigation (see Figures 3-13 and 4-2 in this report). The laboratory results from the seep samples were:

Seep location	TCE	cis-1,2-DCE	vinyl chloride
	ug/L	ug/L	ug/L
SE-04101-0000	1.9	1.2	ND <2
SE-04102-0000	ND <1	ND <1	ND <2
SE-04105-0001	ND <1	ND <1	ND <2

4.0 CONCEPTUAL SITE MODEL

A release of hazardous substances to the environment at the site was identified in 1982. Since that time, a significant amount of work has been completed with site characterization and remedial actions implemented at the source area and throughout the plume over the last several years. A large body of environmental, hydrogeologic, and geochemical data has been collected based on the project history and maturity of the environmental restoration efforts. Prior MTCA remedial investigation and remediation work at the site is summarized in Section 3.0.

4.1 Objective

The overall objective of the Conceptual Site Model (CSM) is to assemble and summarize existing data in a consistent framework and understanding for project stakeholders. The specific objective of the CSM is to assist in subsequent project planning and implementation in the following manner:

1) Use existing site data and CSM in the Data Quality Objective (DQO) process to define likely future site decisions and establish the data requirements necessary to support the expected decisions.
2) Identify and prioritize relevant site exposure pathways.
3) Identify data gaps (in existing site characterization data) that must be satisfied to support decisions.

Key elements of the CSM include:

1) Site setting and boundaries
2) Geologic and hydrogeologic conditions
3) Source(s) of chemical release
4) Chemicals of concern
5) Contaminant transport pathways from site
6) Exposure pathways for human and ecological receptors
7) VOC plume boundaries
8) Remedial actions implemented to date
9) Performance metrics

The CSM forms the basis for organizing all site data, testing the efficacy of proposed data collection efforts going forward, and ultimately, testing performance of proposed and implemented remedies. As such, the CSM must be developed to reflect the best interpretation of all relevant site data at any given time. As new data are collected, they are to be tested for consistency with the CSM and the CSM modified as appropriate. The CSM is intended to evolve with our understanding of the site performance monitoring of remedial measures.

4.2 Summary of Conceptual Site Model for EMF Site and VOC Plume

A CSM has been developed for the site that discusses the key elements listed above based on data collected during site investigations and remedial actions implemented over the last 25 years. A graphical representation of the CSM is shown in Figure 4-1.

4.2.1 Site Setting and Boundaries

The site is located within the Duwamish River valley. As discussed in Section 2.4, the land uses at the site include an active airport facility and areas of industrial manufacturing. These land uses at the site are not expected to change in the foreseeable future. The site consists of that portion of the KCIA and Boeing Plant 2 impacted by the EMF VOC plume that is located west to southwest of the former EMF property. The down-gradient boundary of the site is the Lower Duwamish Waterway (LDW).

Past industrial activities at the EMF property resulted in the release of hazardous substances to the ground and the subsequent development of a groundwater plume beneath and down gradient of the EMF property. Over time, the EMF VOC plume has been transported by natural groundwater movement southwest from the EMF property, across KCIA, passing under Boeing Plant 2 towards the Duwamish River located approximately 3,600 ft southwest of the EMF site.

4.2.2 Geologic and Hydrogeologic Conditions

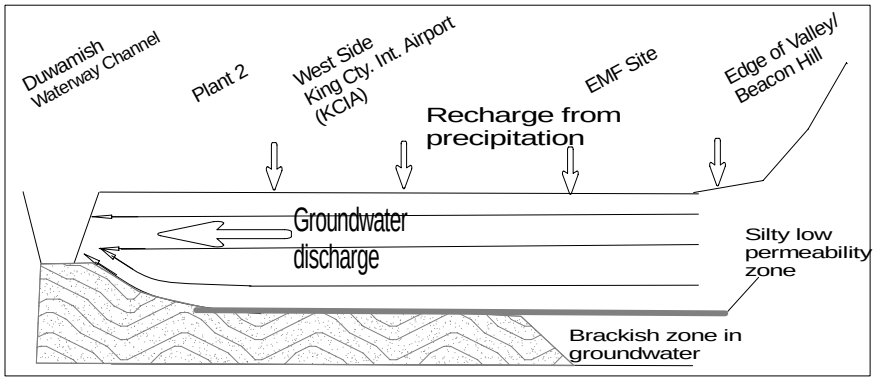
The geologic and hydrogeologic conditions of the Duwamish River valley and the site are discussed in detail in Section 2. The aquifer system within the Duwamish valley is typically considered a single unit, but includes distinction between “upper” and “lower” groundwater zones, which are characteristically differentiated based on locally-continuous silt aquitards and/or the occurrence of saline groundwater. Brackish groundwater conditions are encountered in the lower groundwater zone throughout much of the valley. The brackish water is expected to have a significant impact on groundwater flow (Booth and Herman 1998).

The lithology within the EMF plume generally consists of sandy silt/silty sand, extending to a depth of approximately 45 to 50 feet bgs. Underlying the sand unit is a relatively fine-grained silt and sandy silt layer of variable thickness. This silt layer is a relatively low permeability unit and has provided a partial barrier to vertical plume movement. Beneath this low permeability unit is a silty sand unit forming another (deeper) water-bearing zone. The deeper water is brackish and the density difference (higher density in the lower brackish zone) provides restriction to vertical plume mixing.

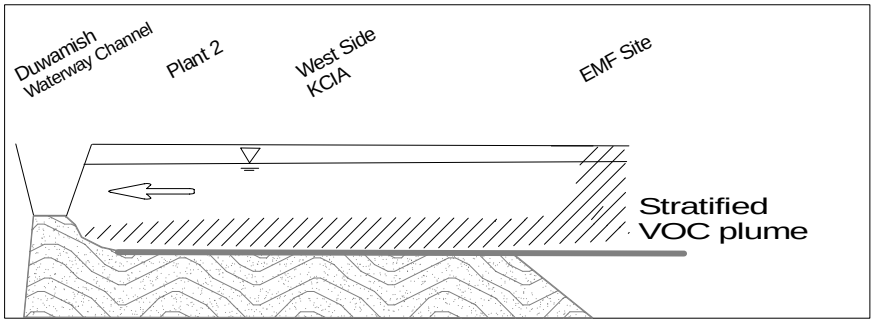
4.2.3 Source(s) of Chemical Release

The VOC plume originated from processes at the EMF facility that was located on the east side of KCIA. Releases are thought to have been from supply and return lines from a trichloroethene (TCE) storage tank and sumps. The release of TCE was identified in 1982.

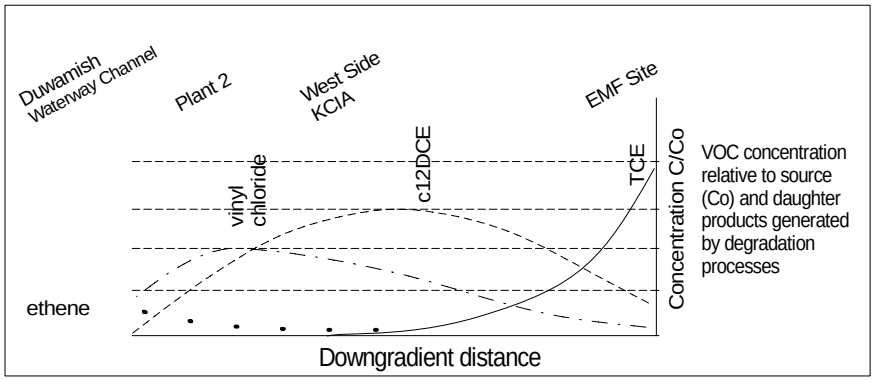
Fluxes for Water Balance of Aquifer in Duwamish Valley



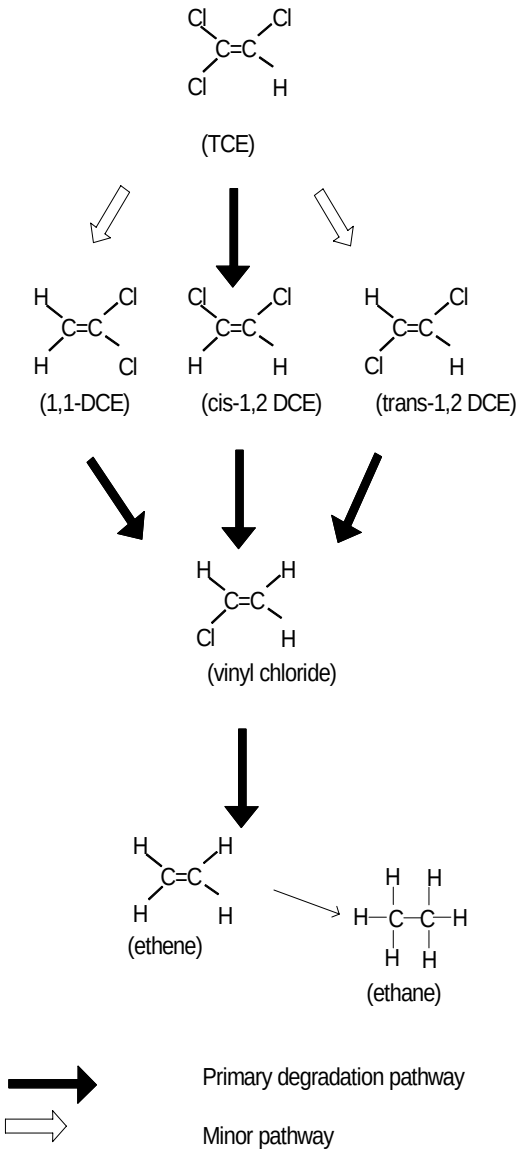
VOC Plume Pathway



Degradation/Daughter Product Processes in VOC Plume



Chlorinated Compound



Enabling Aquifer Condition	Typical Redox Energy Level for Optimum Degradation (see note below)
Anaerobic Denitrification	Redox measures +250 to +100 mV
Anaerobic Iron (III) reduction	Redox measures +100 to 0 mV
Anaerobic Sulfate reduction	Redox measures 0 to -200 mV
Methane fermentation Methanogenesis	Redox measures -200 mV and lower

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Figure 4-1 Conceptual Site Model, EMF VOC Plume

Trichloroethene released at the former EMF migrated downward through the shallow vadose zone and through the aquifer, accumulating as dense non-aqueous phase liquid (DNAPL). The DNAPL served as a source of dissolved phase contamination, creating a stratified plume between depths of approximately 35 and 55 feet bgs that migrated southwest towards the LDW.

As the dissolved TCE plume moved down gradient, it has been subject to degradation through reductive dechlorination processes, producing cis-1,2-DCE, vinyl chloride, and ethene as degradation products. By the time the plume reaches the west side of KCIA, the contaminants present in groundwater consist of a mixture of cis-1,2-DCE, and vinyl chloride. At the LDW almost all VOCs remaining have been degraded to vinyl chloride.

Historically, other releases in the EMF facility have been investigated (chromium; TPH from USTs; PCBs from transformers). All of these compounds were either below MTCA Method A levels (risk based standards based on residential exposure), or were remediated to meet those standards.

4.2.4 Chemicals of Concern

The VOCs detected near the LDW (in monitoring well EMFWF-32 at a depth of approximately 30 feet bgs) were vinyl chloride (peak concentration of 5,800 ug/L in October 2002) and cis-1,2-DCE (peak concentration of 370 ug/L in October 2002). Note that most recent concentrations (January 2007) at this location are 1 ug/L vinyl chloride and non detect (<0.2 ug/L) for cis-1,2-DCE. All concentration trends noted include the combined effect of all removal processes (i.e., the ERD actions implemented, up-gradient remedial actions implemented prior, and other pre-existing attenuation processes). TCE remains in some up-gradient portions of the VOC plume extending across KCIA before it is fully converted to degradation daughter products. Low levels of trans-1,2-DCE have also been detected in many samples, but this specific VOC is considered to be a relatively minor component of the EMF VOC plume that is not expected to influence site assessment and remedial action decisions.

4.2.5 Contaminant Transport Pathways

The primary transport mechanism of the VOC plume is groundwater flow. Numerous 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, R_d = 2.4
cis-1,2-DCE	K_d =0.07 L/kg, R_d = 1.4
vinyl chloride	K_d =0.04 L/kg, R_d = 1.2

Degradation via reductive dechlorination (degradation rates 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 extent of the VOC plume are generally well understood. Based on previous investigations, the lower boundary of the plume is the relatively fine-grained silt layer at a depth of approximately 50 feet bgs. The upper boundary of the plume is within the upper sand layer at a depth of approximately 30 feet bgs based on extensive direct-push sampling data. These data are consistent with all historical sampling data collected to characterize the plume (multiple transects throughout the path of the plume, and additional shallow zone wells less than 30 ft bgs in Plant 2). These plume characterization data indicate that the EMF VOC plume remains as a discrete, highly-stratified plume present between depths of approximately 30 and -55 feet bgs with very little spreading or dispersion in the vertical and horizontal directions as it has moved toward the LDW.

Other transport pathways such as soil vapor, storm water drainage, or subsurface utilities have not been considered significant due to the depth of the stratified VOC plume. In general, these other pathways do not contact the VOC plume. In any areas where a shallow plume exists and an exposure route exists, such as a building, these pathways would be re-considered as complete.

4.2.6 Exposure Pathways for Human and Ecological Receptors

Actual and potential exposure paths have been evaluated using the existing site characterization data. Exposure to contaminated soil has not been considered a significant exposure pathway because the site is paved and the removal of impacted soil in the initial remedial actions (to levels considered for unrestricted future use under the MTCA). Although it is feasible that soil contamination and DNAPL remain in saturated soil within the source area, the transport mechanism of the VOC plume is groundwater flow. The surface is paved and any future development on the EMF property will require appropriate measures to mitigate potential exposure paths (such as a soil vapor barrier).

Similarly, soil vapor has not been considered a complete exposure pathway based on existing buildings and the highly stratified nature of the VOC plume, depth of the plume, the land use and the asphalt/concrete covering the site. Surface water flow (including storm drainage and utility conduits) is also considered an incomplete exposure pathway because of the depth of the plume (primarily between 30 and 55 feet bgs) is below the deepest utility lines. In any areas where a shallow plume exists and an exposure route exists, such as a building or access to subsurface soils , these pathways would be complete.

Groundwater containing VOCs from the release area is the primary transport pathway for potential exposure to COCs from the site. However, since groundwater at the site is not a source of potable water, 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. Under CERCLA and the planned EE/CA, future cleanup levels will be derived that are protective of incidental soil ingestion, vapor intrusion from groundwater and also protective of aquatic organisms as well as the people who consume fish and shellfish harvested from the LDW.

4.2.7 VOC Plume Boundaries

The vertical and lateral extent of the plume have been mapped in multiple (7) 2-dimensional vertical transects (throughout the 3,600 foot length of the plume). Based on the site investigations, the lower boundary of the plume is the fine-grained silt layer at a depth of approximately 50-55 feet bgs. 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 vinyl chloride. 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 reveal very low or non-detect concentrations of 1,2-DCE and vinyl chloride. The width of the plume is estimated to range between 500 and 200 feet (depending on location) west of KCIA and beneath Boeing Plant 2.

4.2.8 Remedial Actions Implemented to Date

Details of previous remedial actions at the site are summarized in Section 3.0. Briefly, the following remedial actions have been performed at the site:

- 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
- 2005-2007: ERD full-scale implementation throughout VOC plume.

4.2.9 Performance Metrics

Performance monitoring data collected during the remedial action phases throughout the site demonstrate significant progress in mitigating site risks and meeting the remedial action goals. The source control actions implemented at the EMF property have resulted in a reduction of VOC concentrations of approximately 99% from prior levels before source control actions were implemented. Additional performance monitoring data throughout the VOC plume, and the point of discharge to the LDW, indicate that the ERD treatment process is performing effectively in all areas that have been treated. Significant reductions in VOC concentrations (99.98% reduction from pre-remedial action conditions) have been achieved in the monitoring well installed just prior to the point of discharge to the LDW. All concentration trends noted include the combined effect of all removal processes (i.e., the ERD actions implemented, up-gradient remedial actions implemented prior, and other pre-existing attenuation processes). Other performance metrics are summarized in Table 4-1. Specific data on performance monitoring within the VOC plume are shown in Table 4-2. Table 4-3 presents a summary of performance monitoring data from wells located within the central area of the VOC plume /source area on the EMF property (see Figure 4-3). Additional details on the existing performance monitoring data are summarized in Appendix C.

Figure 4-2 shows the position of specific monitoring wells throughout the length of the EMF VOC plume. Figures 4-4 through 4-7 show the VOC concentration data collected as part of remedial action performance monitoring over the duration of the recent project history (i.e., since remedial actions for groundwater have been implemented). Each of the wells shown (Table 4-2 and Figures 4-4 through 4-7) were installed in the plume based on the results of the plume transect data (each well was placed at the horizontal position and vertical interval of the highest VOCs detected in the plume mapping transect).

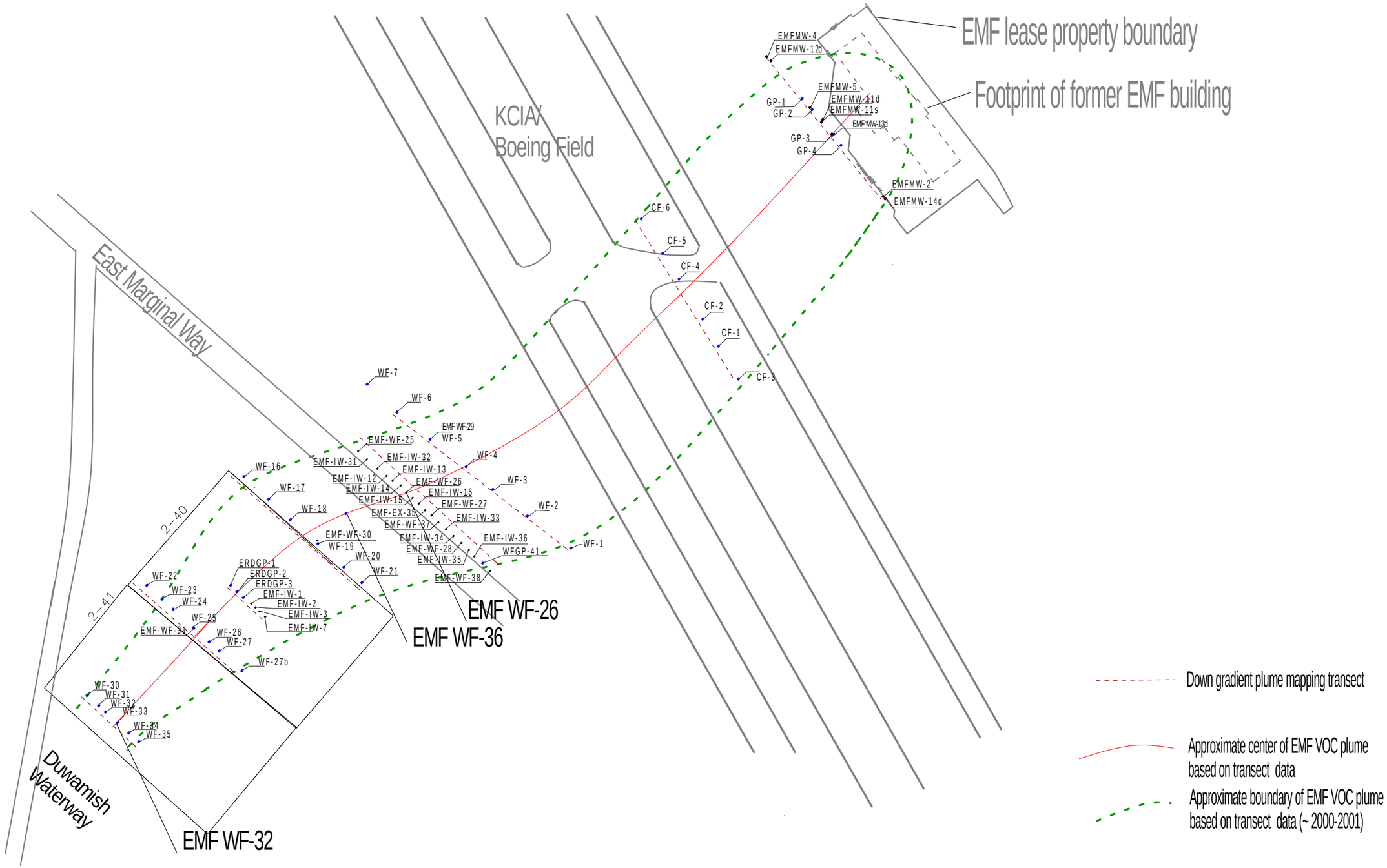

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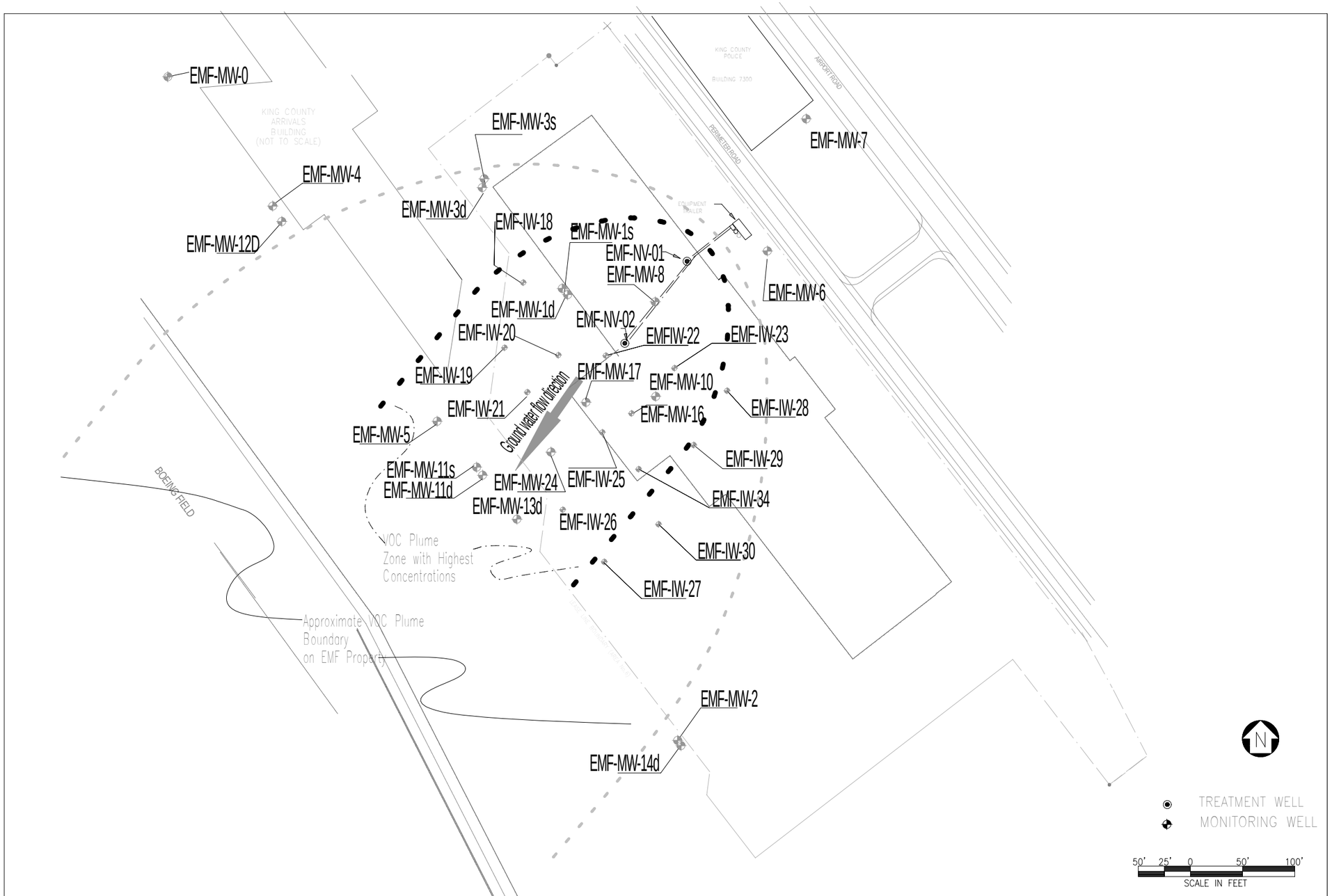
FIGURE 4-2. Location of Down Gradient Investigation Areas for EMF VOC plume



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SURVEYING AND MAPPING BY: DUANE HARTMAN AND ASSOCIATES, INC.
HORIZONTAL DATUM: WASHINGTON STATE PLANE COORDINATES, NORTH ZONE NAD83-91 (US FEET)
VERTICAL DATUM: NATIONAL GEODETIC VERTICAL DATUM 1929 (NGVD29)

DHA JOB No. 06-1081

Figure 4-3 Monitoring Wells on EMF Property and Approximate VOC Plume Boundary

Figure 4-4 VOC Concentration Trends in
EMFMW-13d (Down gradient edge of EMF property)

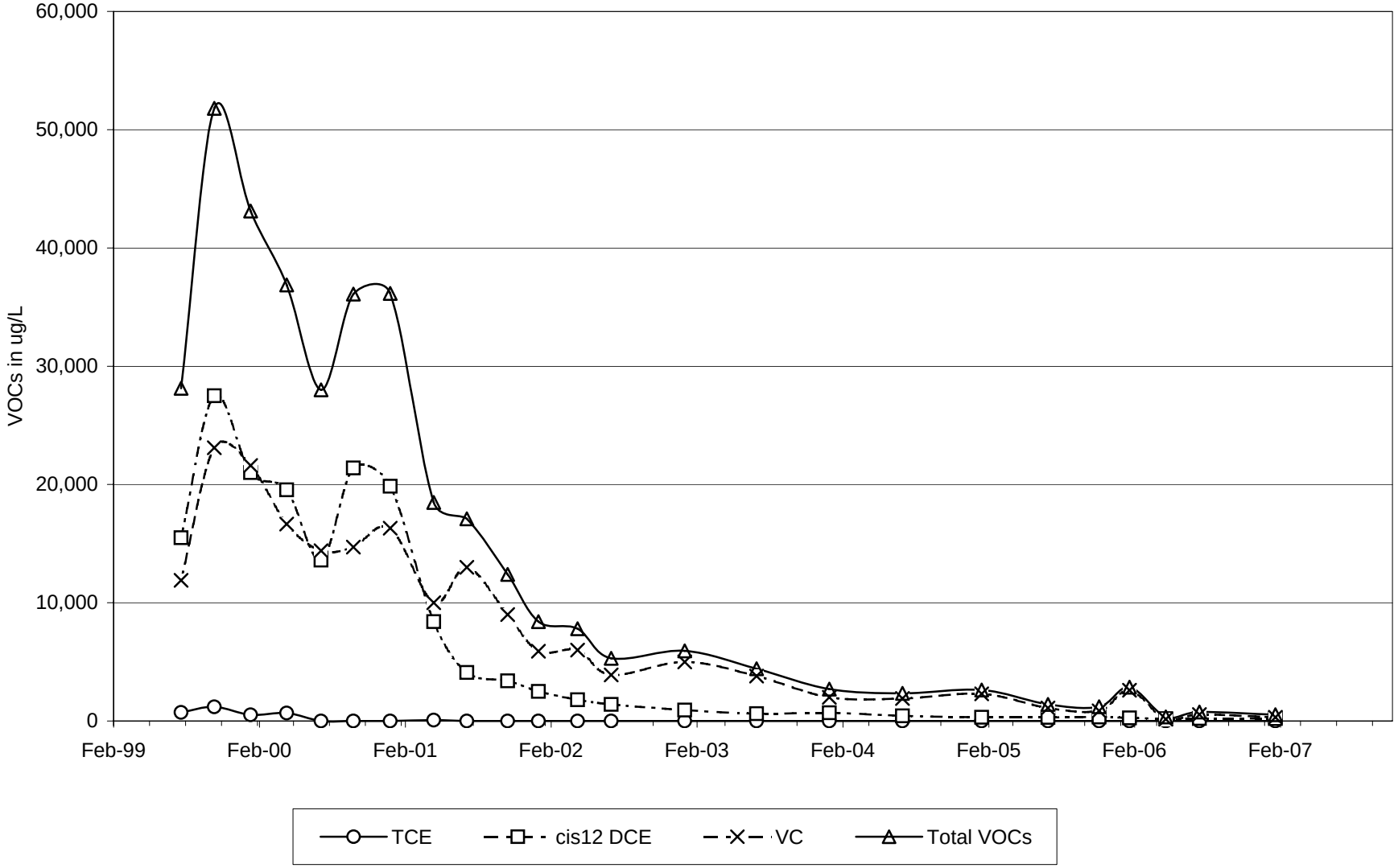
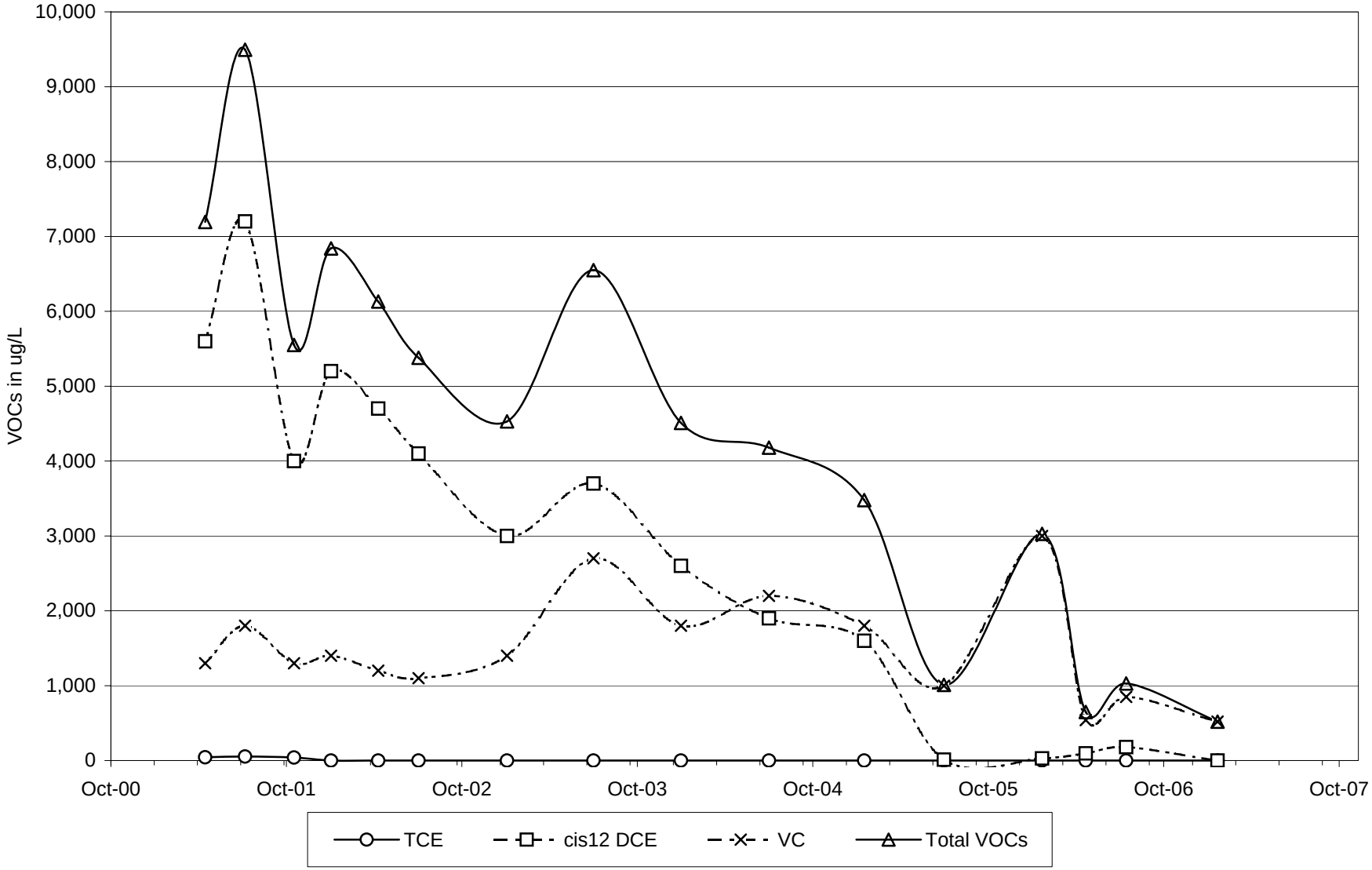


Figure 4-5 VOC Concentration Trends in
EMFWF-26 (West side of KCIA)



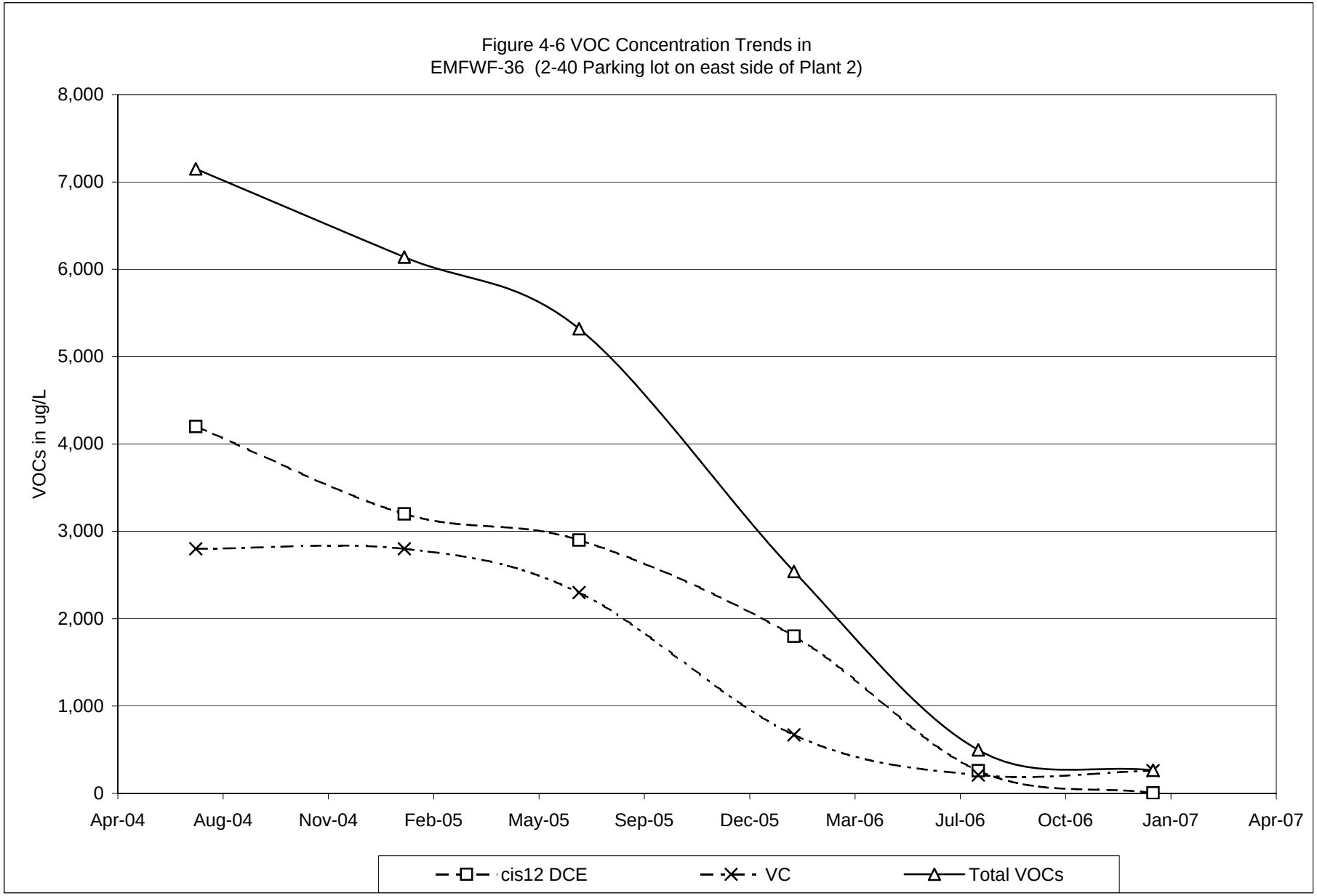


Figure 4-6 VOC Concentration Trends in
EMFWF-36 (2-40 Parking lot on east side of Plant 2)
VOCs in ug/L
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
Apr-04
Aug-04
Nov-04
Feb-05
May-05
Sep-05
Dec-05
Mar-06
Jul-06
Oct-06
Jan-07
Apr-07
cis12 DCE
VC
Total VOCs

Figure 4-7 VOC Concentration Trends in
EMF WF-32 (West side of 2-41 Building near LDW)

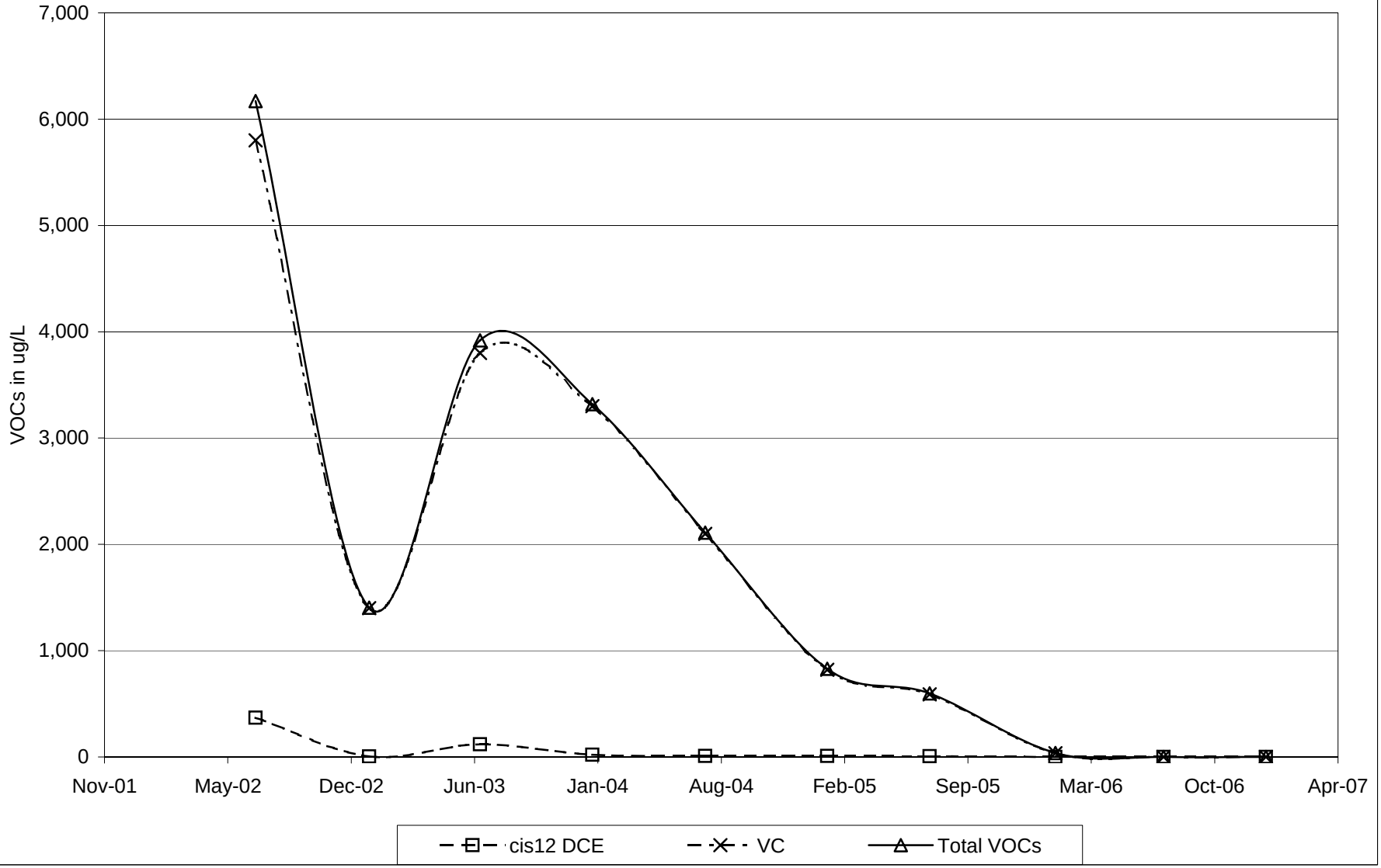


Table 4-1
Summary of Conceptual Site Model
EMF VOC Plume

CSM Elements	Conditions Considered Within CSM	Basis
Setting and Boundaries	• Former Electronics Manufacturing Facility (EMF) located on east side of KCIA. Down gradient boundary is Lower Duwamish Waterway (LDW). • Present land use as an airport (KCIA), air transport facility, aircraft delivery center, and industrial manufacturing; similar projected land use in foreseeable future.	Zoning, present and projected future land uses.
Geology and Hydrogeology	• Alluvium within river valley, interbedded silts and sands. Locally, silty sand/sand to ~45 to 50 feet bgs, underlain by unit with relatively fine-grained silt. Beneath the low permeability unit is a silty/sand-sandy/silt unit forming another (deeper) water-bearing zone. • Groundwater flows towards and discharges to LDW. Deeper brackish groundwater affects flow and vertical mixing. Hydraulic conductivity (K) is 400 ft/day based on aquifer pumping test. In shallow zone, the gradient (i) has been measured at 0.001 ft/ft, with a calculated groundwater pore velocity of 450 ft/year (based on K, i, and porosity of 33%). These velocities/fluxes apply solely to the interval of the EMF VOC plume.	Regional studies, EMF site and plume characterization, hydrogeologic characterization studies within Boeing Plant 2.
Source(s) of Chemical Release	• Release of hazardous substances identified in 1982. TCE and hexavalent chromium released from supply and return lines for storage tanks and sumps in plating process within the building at the EMF property. • Other releases investigated (as reported in 1997 MTCA RI report): TPH (from USTs) and PCBs (from transformers) at relatively low levels. TPH and PCBs addressed during 1997 removal action to MTCA Method A (residential) levels; chromium below applicable standards. • Within Plant 2, several shallow (A-zone) wells and probe samples have detected lower levels of vinyl chloride in areas above and near the EMF plume. These detections may or may not be attributed to the EMF plume, but the actual source (EMF plume or Plant 2 release) is not expected to impact remedial action decisions.	Known materials used in plating processes, spills known/reported, other suspect areas investigated in MTCA RI.

CSM Elements	Conditions Considered Within CSM	Basis
Chemicals of Concern	• TCE and degradation daughter products, 1,2-DCE and vinyl chloride. Concentrations of vinyl chloride detected above AWQCs near LDW. • Others considered: TPH & PCBs in soil removed to below MTCA Method A levels; metals in soil and water were below applicable standards.	MTCA RI data and comparison with MTCA risk-based standards. On-site groundwater monitoring has included analysis for metals in groundwater.
Transport Pathways	• Primary transport from source area is through groundwater. Key processes include: - Groundwater velocity (~450 ft/yr) - Adsorption/retardation (K_d =0.3 L/kg, R_d = 2.4 for TCE; K_d =0.07 L/kg, R_d = 1.4 for cis-1,2-DCE and K_d =0.04 L/kg, R_d = 1.2 for vinyl chloride) - Degradation via reductive dechlorination (degradation life, $T_{½}$= 19 months prior to ERD; 0.7 months after ERD implementation). - Tidally-enhanced dispersion (within groundwater) prior to point of discharge (hyporheic groundwater zone mixing before surface water discharge, presently based on modeling evaluation and measurements at other sites with tidally-influenced discharge). • Other pathways considered include soil vapor, soil contact and migration through storm water conveyance system. These have historically not been considered the primary pathway due to the stratified nature of the VOC plume (i.e., clean water of approximate thickness of 10-20 feet is present above the plume). Within the CERCLA process, applicable regulatory standards (i.e., cleanup criteria) have not yet been established by EPA for this site and will be a part of the upcoming EE/CA. The revised cleanup criteria will require a re-evaluation of these pathways when revised criteria are established.	Shallow groundwater with stratified VOC plume; measured fraction organic carbon in soil; baseline degradation and ERD pilot test results; Modeling of flux at tidal boundary and pore-water sampling in LDW. Stratified plume is bounded by clean water; from water table down to a depth of 20 ft below the ground surface.
Exposure Pathways	• Discharge of groundwater to the Lower Duwamish Waterway is considered to be the primary exposure pathway at the site. Groundwater is not a source of potable water. The LDW is saline and not a potable source of water. Exposure pathway for human health risk is expected to be (primarily) ingestion of fish from the Duwamish Waterway. • Other potential exposure pathways include soil contact, soil vapor, and surface water drainage which, historically, have not been considered the primary exposure pathway (due to the stratified VOC plume). As noted above, the revised cleanup criteria will require a re-evaluation of these pathways when revised criteria are established.	Site setting and land use, hydrogeology, MTCA RI data, stratified VOC plume.

CSM Elements	Conditions Considered Within CSM	Basis
VOC Plume Boundaries	• The lower boundary is the relatively fine-grained silt layer at a depth of ~50 feet bgs. The upper boundary is the upper sand layer at a depth of about 20-30 feet bgs. • The plume width is defined by the locations of wells with VOC concentrations near or below AWQCs. The plume width is estimated to be ~200 to 400 feet wide west of KCIA and beneath Boeing Plant 2. • The plume is a discrete stratum present primarily between depths of approximately 35 and 55 feet bgs (much lower VOCs levels have been detected above and below this primary interval) with very little spreading or dispersion as it moves toward the Duwamish.	Previous investigations, hydrogeology, multiple transects across EMF VOC plume.
Remedial Actions Implemented to Date	• 1982-1985: Removal actions at source area (soil and groundwater) • 1997: Removal actions (TPH and PCBs in soil) and start of in-well stripping at EMF property (including DNAPL recovery) • 2000-2002: Chemical oxidation at source area • 2003-2004: ERD pilot study within down gradient plume • 2005-2007: ERD full-scale implementation throughout VOC plume	1982 and 1985 pre-MTCA RAs implemented as Interim Remedial Measures when release was identified. Actions from 1997 to 2007 have been selected following a MTCA FS.

CSM Elements	Conditions Considered Within CSM	Basis
Performance metrics	• Soil removal actions focused on MTCA Method A levels (residential cleanup standards) – Confirmation monitoring with 1997 removal actions indicated cleanup standards were met. • AWQCs have been used as groundwater cleanup goals based on ARARs, site setting, and exposure pathways. Future goals to be based on exposure pathways specific to the EMF site to be assessed through calculations of cleanup criteria protective of aquatic organisms as well as the people who consume fish and shellfish harvested from the LDW. • Initial sampling in groundwater (just prior to LDW discharge) indicated VOCs above AWQCs. • Significant decrease in VOC concentrations in source area and down-gradient areas (concurrent increase in ethene/ethane concentrations demonstrates destruction through ERD process). • The last 2 rounds of sampling (July 2006 and January 2007) have indicated all VOCs below AWQCs at the last monitoring well located just up gradient of the LDW discharge point. • Estimated ERD degradation rate constant (after ERD treatment) of 0.031 ($days^{-1}$), corresponding to a half life of 0.7 months. • Consideration of other potential impacts (such as potential mobilization of metals through ERD).	

Table 4-2
Performance Monitoring Data Before and After Remedial Actions Implemented
Within EMF VOC Plume

Location within VOC Plume	Well ID and date sampled	TCE	1,2-DCE	Vinyl chloride	Total VOCs Percent Reduction Observed Over		
		ug/L	ug/L	ug/L	Period 1*	Period 2*	Period 3*
Source area where TCE was released	EMFNV -01 Jan-97	1,007,000	NA*	NA*	++	++	
		DNAPL, (separate phase TCE)					
	EMFNV-01 Jan-07	660	41	ND(<10)			99.9%
Down gradient boundary of EMF property, Center of Plume	EMFMW-13D Oct-99	1,200	29,790	23,100			
	EMFMW-13D Nov-05	4.7	500	860	97.5%		
	EMFMW-13D Jan-07	ND(<20)	340	320		51.6%	98.8%
West Side of KCIA at Boeing Fire Station	EMFWF-26 Jul-01	54	7,640	1,800			
	EMFWF-26 Jan-05	ND(<30)	1,678	1,800	63.4%		
	EMFWF-26 Jan-07	ND(<30)	ND(<30)	520		85.0%	94.5%
Up gradient side of Plant 2 (in 2-40 parking lot)	EMFWF-36 Jul-04	ND(<30)	4,350	2,800			
	EMFWF-36 Jan-06	ND(<25)	1870	670	64.5%		
	EMFWF-36 Jan-07	ND (<20)	5.6	260		89.5%	96.3%
Near Boundary with LDW	EMFWF-32 Jul-02	ND(<50)	370	5,800			
	EMFWF-32 Jan-05	ND(<20)	ND(<20)	820	86.7%		
	EMFWF-32 Jan-07	ND(<1)	ND(<1)	1		99.9%	99.98%

ND not detected at the detection limit noted, 1,2 DCE data presented are sum of cis & trans isomers.
++ no ISCO or ERD implemented in this area; remedial actions included In-well stripping, DNAPL recovery (and other pre-existing attenuation processes).
*All concentration reductions noted include the cumulative effect of all prior removal processes;
Period 1 covers ISCO, In-well stripping, DNAPL recovery and other pre-existing attenuation processes.
Period 2 covers the same actions/effects as Period 1 plus ERD after the date noted for Period 1.
Period 3 covers Periods 1 and 2 combined.

Table 4-3
Performance Monitoring Data
Before and After Remedial Actions Implemented
Within Source Area of EMF VOC Plume

Well Name	Location/ Description	Highest Total VOCs Concentration	Total VOCs Concentration Jan 2000	Total VOCs Concentration Jul 2005	Total VOCs Concentration Jan 2007	% Reduction from Jan 2000-Jul 2005	% Reduction from Jul 2005-Jan 2007	% Reduction from Highest Prior Concentration
		ug/L	ug/L	ug/L	ug/L			
EMFNV-01	source area	1,007,000	162,000	14,220	701	91.2%	95.1%	99.9%
EMFMW-8	central plume	52,186	20,400	26	954	99.9%	-3612.1%	98.2%
EMFMW-1s	N of plume center	1,238	139	NS	22	--	--	98.2%
EMFMW-1d	N of plume center	23,160	13,540	NS	168	--	--	99.3%
EMFNV-02	central plume	70,400	34,300	3,520	66	89.7%	98.1%	99.9%
EMFMW-10	S of plume center	43,200	364	NS	3,630	--	--	91.6%
EMFMW-9	central plume	20,250	39	NS	NS	--	--	99.8%
EMFMW-16	central plume	14,190	14,190	465	19	96.7%	96.0%	99.9%
EMFMW-17	central plume	13,600	8,740	1,780	766	79.6%	57.0%	94.4%
EMFMW-24	central plume	42,300	42,300	10,500	63	75.2%	99.4%	99.9%
EMFMW-11s	central plume	14,300	242	1,364	662	-463.2%	51.5%	95.4%
EMFMW-11d	central plume	24,670	13,660	10,870	7,798	20.4%	28.3%	68.4%
EMFMW-13d	central plume	54,090	44,580	1,570	660	96.5%	58.0%	98.8%

Data from EMFMW-08 and EMFMW-09 are from Jan 05 (not sampled in Jul 2005)
Data from EMFMW16 are from Apr 2000 (not sampled in Jan 2000)
Data from EMFMW16 are from Jan 2005 (not sampled in Jul 2005)
Data from EMFMW24 are from Oct 2000 (not sampled in Jan 2000)

(1) % Reduction from Jan 2000-Jul 2005 is presented as concentration change over the period based on cumulative effect of natural attenuation processes, DNAPL recovery (1997), In-well stripping (1997-2005), ISCO (2000-2001).
(2) % Reduction from Jul 2005-Jan 2007 is presented as concentration change over the period based on cumulative effect of natural attenuation processes, DNAPL recovery (1997), In-well stripping (1997-2006), ISCO (2000-2001), and ERD (Nov 2005-present).
(3) % Reduction from highest prior concentration is presented as concentration change based on cumulative effect of natural attenuation processes, DNAPL recovery (1997), In-well stripping (1997-2006), ISCO (2000-2001), and ERD (Nov 2005-present), considering data as early as 1997 when first groundwater remedial actions were initiated.

5.0 IDENTIFICATION AND ASSESSMENT OF DISCHARGES TO LOWER DUWAMISH WATERWAY

Throughout the history of the EMF site investigations and remedial actions, the objectives of the project have been to:

1) Identify the nature and extent of contamination.
2) Evaluate exposure pathways and risks.
3) Identify applicable ARARs (specifically including standards set to protect water quality for beneficial uses).
4) Design and implement remedial measures to mitigate any risks defined in 2) above and/or take steps to meet the ARARs defined in 3) above.

The MTCA RI data necessary to evaluate and meet the objectives, as defined above, have significantly changed the conceptual site model over the 25-year project history. Significant changes have included:

- The COCs changed from the initially identified release;
- The understanding of the nature and extent has changed and the corresponding exposure pathways have been revised;
- The ARARS have changed based on new regulations and revised regulatory standards; and
- The remedial measures implemented have been modified/adapted and expanded based on changes to the conceptual site model, understanding of the key geochemical and hydrogeologic processes affecting the plume, and corresponding exposure risks.

Notwithstanding the multiple changes and evolution throughout the project history, the objectives noted above have been met and have been implemented in accordance with the requirements of the National Contingency Plan (NCP) and subsequently the MTCA.

As described in the conceptual site model (Section 4), the EMF VOC plume discharges to the LDW and this discharge is believed to be the primary exposure pathway by which any unacceptable risk is derived from the EMF site. Other pathways have been considered, but the general assessments performed under the project to date (based on the site characterization data collected) 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.

5.1 Chemicals of Concern

The COCs identified in the EMF groundwater plume just prior to its discharge into the LDW include vinyl chloride and cis-1,2-DCE. Other portions of the EMF plume (not at the LDW discharge area) also contain TCE and lower levels of trans-1,2-DCE. Sampling at other locations within the EMF plume (near the EMF property and at selected down-gradient wells) has included analysis for priority pollutant metals. The work completed to date has not identified metals as COCs within the EMF VOC plume.

A site monitoring well (EMFWF-32) was placed at the center of the plume mapping transect adjacent to the LDW. The highest VOC concentrations detected in this well (EMFWF-32 sampled in October 2002) were 5,800 ug/l vinyl chloride and 370 ug/l cis-1,2-DCE. Analytical results of a sample from this well in January 2007 were 1 ug/L vinyl chloride and < 0.2 ug/L cis-1,2-DCE reflecting the effectiveness of remedial measures implemented in up-gradient areas. All concentration trends noted include the combined effect of all removal processes (i.e., the ERD actions implemented, up-gradient remedial actions implemented prior, and other pre-existing attenuation processes).

5.1.1 Evaluation of Potential Impacts to Aquatic Organisms

The potential ecological impacts (i.e., impacts to aquatic organisms) have been evaluated based on available ecological screening criteria. Results of testing to evaluate the aquatic effects of vinyl chloride are described in the relevant literature. In a recent reference, EPA cites a subchronic LC_{100} value of 388,000 ug/L for vinyl chloride (EPA 1999). These data are then used with a safety factor of 100 to set a toxicity reference value (TRV) of 3,880 ug/L for vinyl chloride in marine/estuarine surface water bodies. The highest levels detected in groundwater (not in the surface water) are in the range of this TRV criteria set for vinyl chloride.

Other references in EPA's ACQUIRE database (EPA 2002) indicate that vinyl chloride toxicity to invertebrates only occurs at high concentration levels. Reported IC_{50} levels (where the IC_{50} is the concentration at which inhibition of a biological process occurs for 50% of the test population) for population growth in *Tetrahymena pyriformis* (a ciliate) range from 405,000 to 806,000 ug/L. The highest levels of vinyl chloride detected in groundwater at this site are less than 1% of the lower IC_{50} values cited in EPA's ACQUIRE database.

Additional fate and transport data (EPA, 1979) indicates that vinyl chloride is too readily volatilized to undergo bioaccumulation, except perhaps in the most extreme exposure conditions. Studies on five bacterial, three fungal, and two single organism cultures from natural aquatic systems did not show bioaccumulation to be an appreciable process. All technical references regarding fate and transport indicate that vinyl chloride will be rapidly attenuated in surface water with half-lives typically in the range of tens of minutes to hours.

The historical assessment of potential ecological impacts has been based on the ecological criteria defined above, the existing site monitoring data, and the modeling evaluation of the tidally-enhanced dispersion (combined with general levels of tidally induced dispersion measured at many other sites, see Section 5.4 and Table 5-1). Based on these factors, historical interpretations in the project have been that potential ecological impacts are minor (if any) because measured vinyl chloride concentrations have been well below ecological screening criteria.

5.1.2 Potential Human Exposure

The basis of the MTCA risk evaluation (used in the project to-date) is to protect human exposure from discharges to the LDW. The MTCA exposure scenario is based on the assumption that exposure to vinyl chloride would occur through bioconcentration in fish and subsequent human ingestion of fish. As noted in the introduction, 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 will be a part of the upcoming EE/CA.

Under the MTCA for nonpotable surface waters which support or have the potential to support fish or shellfish populations, concentrations that are estimated to result in an excess cancer risk less than or equal to one in one million (1×10^{-6}) are determined using the following equation:

$$\text{cleanup level (ug/l)} = \frac{\text{RISK} \times \text{ABW} \times \text{AT} \times \text{UCF1} \times \text{UCF2}}{\text{CPF} \times \text{BCF} \times \text{FCR} \times \text{FDF} \times \text{ED}} \qquad \text{Eq. 730-2 from MTCA}$$

Where:

CPF	= Carcinogenic potency factor as specified in WAC 173-340-708(8) (kg-day/mg)
RISK	= Acceptable cancer risk level (unitless)
ABW	= Average body weight during the exposure duration (kg)
AT	= Averaging time (years)
UCF1	= Unit conversion factor (ug/mg)
UCF2	= Unit conversion factor (grams/liter)
BCF	= Bioconcentration factor as defined in WAC 173 340-708(9) (liters/kilogram)
FCR	= Fish consumption rate (grams/day)
FDF	= Fish diet fraction (unitless)
ED	= Exposure duration (years)

The MTCA exposure scenario additionally notes that the bioconcentration factor used to establish the AWQC under Section 304 of the Clean Water Act (CWA) shall be used unless the department determines that there is adequate scientific data which demonstrates that the use of an alternate value is more appropriate (WAC 173-340-708(9)).

The BCF for vinyl chloride, and other related highly volatile compounds has been the subject of much research and uncertainty over the last 40 years (e.g., EPA 1979 notes that vinyl chloride is too readily volatilized to undergo bioaccumulation). A short summary of the relevant research related to bioconcentration of vinyl chloride that has been considered in the EMF project history is presented in a following Section.

However, none of the BCF approaches have been considered further because MTCA requires meeting the ARARs described below.

5.1.3 ARARs Established to Protect Water Quality

Pursuant to the requirements of the MTCA, the cleanup goals used throughout the project have been based on the AWQCs which are identified as existing state/federal standards (ARARs). As a result, the risk-based calculations defined in Section 5.1.2 have not been used (they are not applicable under MTCA) because other promulgated standards exist (see WAC 173-340-730). This is also consistent with the NCP (40 CFR 300.43), the AWQCs are an ARAR, and acceptable exposure levels are generally concentration levels that represent a 10^{-4} and 10^{-6} cancer risk. The 10^{-6} risk level is intended as the point of departure for determining remediation goals when ARARs are not available or are not sufficiently protective because of the presence of multiple contaminants at a site or multiple pathways of exposure.

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 chemical concentrations in ambient water). At the start of the EMF project, the AWQC established for vinyl chloride was 525 ug/L based on exposure through consumption of fish and recognition that the Duwamish aquifer and the LDW did not represent a potable water source due to high salinity.

In December 2003 EPA announced the availability of updated national recommended water quality criteria for the protection of human health for vinyl chloride and 14 other compounds (Federal Register 2003). The revised criteria were based on EPA's 2000 methodology for deriving human health water quality criteria and superseded criteria for those chemicals that EPA had published before the December 2003 notice. The revised AWQC for vinyl chloride is 2.4 ug/L based on exposure through consumption of fish (for nonpotable water). This revised AWQC is based on an updated cancer potency factor for vinyl chloride, a BCF of 1.17 and a fish intake of 17.5 grams/day. One technical comment submitted to EPA noted that they (the commenter) believed EPA’s BCF of 1.17 was overstated because:

1) This value is based on the assumption of equilibrium conditions between water and an organisms tissue, which is not the case because vinyl chloride is highly metabolized.
2) The high volatility of vinyl chloride would contribute to its depuration [loss] during processing or cooking.
3) The portions of the fish most likely to contain the vinyl chloride, (e.g., skin and fat) are not typically consumed by humans.
4) Cooking would result in further off-gassing or destruction of vinyl chloride the chemical.

In response, EPA noted they had used the BCF derived from the 1980 AWQC National Guidelines (45 FR 79347). EPA noted that, if a contaminant is readily metabolized in fish, the actual BCF might be less than estimated using the KLEDow method….and that EPA will consider it when the Agency comprehensively updates the vinyl chloride criterion document to incorporate the BAF derivation procedures described in the 2000 Human Health Methodology.

5.2 Review of BCFs for Vinyl Chloride

Chemicals that are likely to concentrate in aquatic species to levels higher than those found in the ambient environment (water) are characterized as substances that are prone to bioconcentration or bioaccumulation. Several classes of organic chemicals have the potential to bioconcentrate or bioaccumulate. The basic research regarding bioaccumulation has been underway since the 1970's (at least). Some of the key references include Neely et. al. 1974, Veith et. al. 1979, Gossett et. al. 1983, and Boethling and Mackay 1992. A summary of considerations relevant to the bioaccumulation potential of vinyl chloride are included in Appendix B.

In the context of this historical summary report, the AWQCs considered as the promulgated standard (both in 1980 and in 2003) have been based on a vinyl chloride BCF of 1.17 L/kg (as noted in EPA 1980, this is a calculated value and includes a lipid correction for the specific fish species consumed). Subsequent to the development of the 1980 AWQC criteria, EPA has revised the guidance for calculating AWQCs (EPA 2000) including; 1) revised fish consumption levels (as appropriate based on locally exposed populations), 2) revised formula and methods for calculating the BCF and 3) improved guidance regarding lipid considerations (specifically when differing fish consumption species and levels are used).

5.2.1 Application to the EMF Project

Based on the EMF site conditions, exposure pathways defined in the conceptual site model and field data regarding the potential BCF for vinyl chloride, the project has historically used the AWQCs as the appropriate threshold to evaluate potential human health and ecological exposure risks. The interpretations that have been completed in the project are that the AWQCs are a relevant ARAR and have been established to be sufficiently protective of human health and ecological risks. As noted in the introduction, 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 will be a part of the upcoming EE/CA.

5.3 EMF Plume Discharge to Lower Duwamish Waterway

5.3.1 Historical Conditions

5.3.1.1 COC Concentrations

The maximum COC concentrations detected in the monitoring well adjacent to the LDW has been 5,800 ug/L vinyl chloride and 370 ug/L cis-1,2-DCE. Considering the tidally-

enhanced dispersion between this monitoring point and the LDW (over the last 75 feet), the anticipated discharge concentrations to the LDW would be expected to be lower as a result of seawater (tidally induced) mixing in the hyporheic zone.

5.3.1.2 Loading to Lower Duwamish Waterway

The hydraulic loading to the LDW from the EMF plume was estimated at approximately 6 gpm (based on the plume geometry and hydrogeologic conditions). The mass flux in this loading was estimated under 0.1 lbs VOCs per day, primarily as vinyl chloride (PPC 2002c).

5.3.2 Present Conditions

Remedial actions have been initiated throughout the EMF VOC plume and the site monitoring data indicate a significantly reduced VOC loading to the LDW under current conditions.

5.3.2.1 COC Concentrations

The January 2007 COC concentrations detected in the monitoring well adjacent to the LDW has been 1 ug/L vinyl chloride and <0.2 ug/L cis-1,2-DCE. Considering the tidally-enhanced dispersion between this monitoring point and the LDW (over the last 75 feet), the anticipated discharge concentrations to the LDW would be expected to be lower as a result of seawater mixing in the hyporheic zone.

5.3.2.2 Loading to Lower Duwamish Waterway

The hydraulic loading to the LDW from the EMF plume is estimated at approximately 6 gpm (based on the plume geometry and hydrogeologic conditions). The mass flux in this loading is estimated at approximately 0.0001 lbs VOCs per day, primarily as vinyl chloride.

5.4 Groundwater Discharge to Marine Waters

Submarine groundwater discharge (SGD) is a universal coastal process that is driven by precipitation and near-shore hydrogeologic (landward), and oceanographic (seaward) processes. Until the mid-1990s, studies on SGD did not receive widespread attention because it was generally thought that SGD rates were not large enough to be a direct influence on water budgets and nutrient loading to marine waters. However, it was ultimately recognized that the submarine discharge of groundwater (including fresh, brackish, and marine components) into marine waters can be just as important as river discharge in some areas. Mixing between upland fresh water and sea water produces brackish to saline water in many coastal aquifers. In this near-shore mixing zone, physical and chemical reactions of the salt water modify the composition of the SGD. Significant research into this subject started in the mid 1990's when Willard Morris coined the phase "subterranean estuaries" for this near-shore mixing zone within groundwater. Subsequent to that time, research into the processes and implications of SGD has been implemented around the world with major initiatives funded by the United Nations, International Atomic Energy Agency (IAEA), National Science

Foundation (NSF), Asia Pacific Network (APN), International Hydrological Program/Intergovernmental Oceanographic Commission (IHP/IOC), and the Scientific Committee on Oceanic Research (SCOR).

5.4.1 Re-circulated Sea Water as a Portion of Submarine Groundwater Discharge

Early research into SGD found that the process is tidally influenced in the near-shore hyporheic zone. Some common definitions of the hyporheic zone include the zone in which groundwater and surface water mix. Other research has defined the hyporheic zone as that part of the sub-surface in which both surface and groundwater are present, but surface water exceeds 10 percent of the total volume. Early SGD research also found that the net discharge of groundwater at the surface-water interface (submersed) greatly exceeded the upland groundwater flux (typically more than an order of magnitude higher).

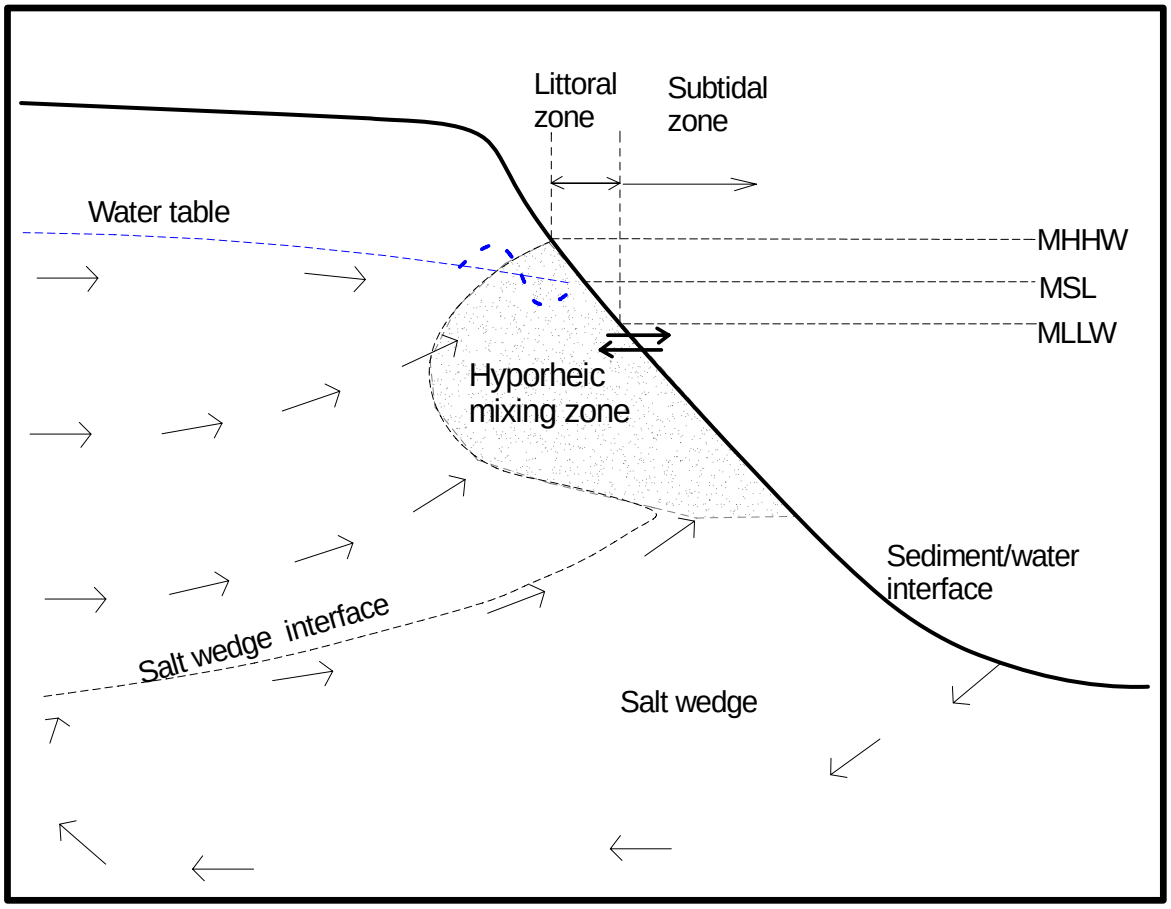
As a result, it is important for any evaluation of water and solute flux from upland groundwater (fresh) to marine water by SGD to separate SGD into submarine fresh groundwater (SFGD) and re-circulated SGD (RSGD). A graphical depiction of the hyporheic zone and relevant process/fluxes is shown in Figure 5-1. Taniguchi et al. (2002) defined RSGD to consist of re-circulated water due to tidally driven oscillation, wave setup, and convection (either density or thermal).

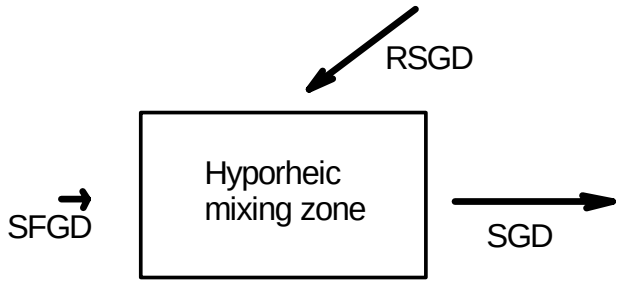
SGD (total) = SFGD + RSGD

Tidally-enhanced dispersion = SGD/SFGD = 1 + RSGD/SFGD

Taniguchi and Iwakawa (2003) compared SGD measured by automated seepage meters with SFGD calculated using Darcy's law, multiplying the observed hydraulic gradients between sea level and groundwater level by the estimated hydraulic conductivity. They found the ratio of SFGD to SGD ranged from 1% to 29% in Osaka Bay, Japan (this corresponds with a concentration reduction due to tidally-enhanced dispersion ranging from of 3.5 to 100). A summary of other recent measurements and estimates of the SGD/SFGD ratio from various locations is shown in Table 5-1.

The primary driving force in the SGD/SFGD ratio for most of these sites is tidal oscillations (near-shore groundwater exchange with the marine water body due to periodic change in the tidal boundary condition/elevation). The tidal range within this portion of the LDW is typically in the range of 10+ feet which is much greater than most of the areas were significant research projects have been conducted.





SFGD submarine fresh groundwater discharge
RSGD re-circulated submarine groundwater discharge
SGD submarine groundwater discharge

SGD >> SFGD due to tidal pumping

Figure 5-1 Subterranean Groundwater Mixing and Discharge to Tidal Water

BOEING
CALIBRE Systems Inc.

Table 5-1 Summary of Submarine Groundwater Discharge Monitoring Projects

SGD/SFGD ratio	Basis of Estimate	Water body	Tidal Range	Reference
11:1	seepage meters, ^{222}Rn tracers, modeling	Saruga Bay, Japan	4 ft	Taniguchi et al 2005
25:1	Modeling	NA	5 ft	Li et al 1999
10:1	^{222}Rn tracer	Chesapeake Bay, MD	2 ft	Hussain, et al 1999
80:1	seepage meters, ^{222}Rn tracers, modeling	Indian River, FL	4 ft	Cable et al 2004
60:1				
60:1				
133:1				
26:1	salinity	West Neck Bay, NY	2 ft	Dulaiova,et al 2006
29:1				
73:1	^{222}Rn tracer	West Neck Bay, NY	2 ft	
18:1				
15:1	Groundwater porewater and seepage meters	Cockburn Sound, Western Australia	2.6 ft	Taniguchi et al 2004
5:1				
135:1	seepage meters, ^{222}Rn tracer, modeling	Manila Bay, Philippines	6.5 ft (lower permeability soils)	Taniguchi et al 2005

6.0 DATA GAPS IDENTIFIED USING DATA QUALITY OBJECTIVES PROCESS

A Data Quality Objectives (DQO) process was used to define project objectives and corresponding data requirements. The DQO process was structured around the following steps:

1) Define the problem statement/ objectives.
2) Define the boundaries of the study.
3) Identify anticipated project decisions that must be made in order to select the best response for the defined problem.
4) Identify the data necessary to make those decisions (including a review of existing data and summary of other data necessary for a decision).
5) Identify data gaps within the existing data that are necessary to make the decisions from 3) above.
6) Identify the preliminary decision criteria/thresholds that can be used to formulate decision rules linking actions to the outcome of efforts to fill data gaps identified in 5.

A review of the existing project data was conducted and used to identify pre-existing data that can be used to support decisions defined in 3) above. The DQO process applied to the EMF site is summarized in Table 6-1.

6.1 Problem Statement

The site characterization data, exposure pathways and ARARs were used to develop a conceptual site model (CSM). As reflected in the CSM, the historical site data indicated that the contamination in the EMF plume at the point of discharge had reached concentrations in excess of ARARs and remedial action was required to meet those ARARs. The site remedial action needs to address contamination in a way that ensures against any unacceptable risks and meet ARARs.

6.2 Boundaries of the Study

The boundaries of the study (necessary to define the DQOs) are that portion of the Duwamish valley watershed that is impacted by releases from the EMF facility from the EMF property to the ultimate discharge at the LDW.

6.3 Key Decisions

Evaluation of the likely considerations/outcomes of the problem statement indicates the following key decisions are needed to resolve the problem:

1) Does the VOC plume represent a potential exposure risk at the discharge point?
2) Are other exposure pathways (indoor air and storm drains) complete pathways?
3) Are there areas in excess of ARARs that have not been or are not being addressed with ongoing remedial actions?

4) Can the existing treatment process selected in the MTCA RI/FS and implemented in the RA be translated to wider areas of the plume not yet addressed?
5) Have the source control actions implemented at the EMF property been sufficient to mitigate the risks from the plume migration from the EMF property?
6) Does the remedial action, as implemented, have unintended adverse impacts (e.g., mobilization of metals)? If adverse impacts are expected, can they be mitigated?

6.3.1 Data Gaps

Data gaps associated with each of the six key decisions are discussed below.

Key Decision 1 (Does the exposure risk exceed acceptable standards defined in the NCP?)

Data required: Concentrations at exposure points, or characterization data demonstrating an incomplete pathway.
Existing data: Site characterization data define the VOC plume path from the source to the LDW.
Data gaps: Additional data are needed to define the exact boundaries and present discharge at the LDW.

Key Decision 2 (Are other specific exposure pathways [potential] complete?)

Data required: Concentrations at exposure points, or characterization data demonstrating an incomplete pathway.
Existing data: Characterization of the VOC plume from the eight transects and subsequent wells show a stratified plume with no exposure potential to COCs in shallow groundwater. Clean water above the plume (the stratified nature of the plume) precludes the potential for exposure through indoor air.
Data gaps: As-built depths of storm drains can help assess the potential for other exposure pathways.

Key Decision 3 (Are there areas in excess of ARARs that have not been or are not being addressed with ongoing remedial actions?)

Data required: Nature and extent of plume from source to LDW.
Existing data: The source of the plume is a TCE release at the EMF property. The plume has migrated southwest towards the Duwamish Waterway. The flow path of the plume has been established (defined by ~40 year flow paths and definitive tracer data). The data indicate a predictable plume; a Gaussian shape with symmetrical spread along each plume mapping transect.
Data gaps: Plume boundaries (to revised AWQCs) where exposure may occur.

Key Decision 4 (Can existing treatment processes treat wider a plume and meet goals?)

Data required: Remedial performance data.

Existing data: The remedial action at the source area has resulted in 98 – 99% reduction in VOCs in the immediate down-gradient well. The ERD remedial action in multiple areas has resulted non-detect levels of VOCs in some down-gradient wells. These performance data suggest that the remedial actions can meet the goals, with continued performance monitoring.
Data gaps: Additional data are needed to characterize the edges of the plume where the revised AWQCs have redefined the extent of contamination. This effort can be combined with the remedial optimization of the ERD approach.

Key Decision 5 (Effectiveness of source control actions at the EMF property)

Data required: Representative monitoring data at and immediately down gradient of the EMF property.
Existing data: Water quality monitoring from the wells throughout the EMF property for VOCs.
Data gaps: Continued performance monitoring.

Key Decision 6 (Are there adverse impacts from remedial actions/mitigation strategies)

Data required: Representative monitoring data to detect changes in metals concentrations as a result of ERD actions taken.
Existing data: Water quality monitoring from the ERD pilot test (RCRA 8 metals) indicated mobilization of metals was not observed. Additional sampling has been recently conducted confirming this for priority pollutant metals.
Data gaps: In order to verify that remedial actions are not causing the mobilization of metals, metals analysis in targeted areas should continue in the site monitoring program.

6.4 Inputs to the Decision

The primary data inputs required to support the anticipated project decisions include the following:

1) The concentration of COCs at the discharge point.
2) The nature and extent of the plume above AWQCs necessary to establish the exposure pathways.
3) Performance monitoring associated with prior and ongoing remedial actions.

6.5 Decision Rules

The decision rules are presented in Table 6-1. They are based on the concentration of VOCs at the Duwamish Waterway, the effectiveness of the remedial action being implemented and consideration of other potential exposure pathways/plume migration paths.

TABLE 6-1 Data Quality Objectives (DQO) Process, Data Summary, and MTCA RI/FS, RA

DQO process step	**Application to EMF VOC Plume**	**Existing Data**	**Additional Data Required to Support MTCA RI/FS and Select Remedial Action (or optimize Remedial Actions presently underway)**
The problem to be resolved at the site	Contamination is present above ARARs in EMF VOC plume. The site remedial action needs to address contamination in a way that ensures against any unacceptable risks and meet ARARs.	Conceptual model, degradation processes, exposure pathways, water quality data throughout plume, point of discharge, RA implemented and ARARs defined.	No other data required to determine if problem exists: ARARs are established and site characterization data (groundwater and porewater data) exceeded standards. The approach to meet ARARs has been developed and implemented, it must be monitored to verify performance.
The boundaries of the study	EMF VOC Plume Horizontal and vertical boundaries Discharge point to Waterway Other potential exposure pathways (storm drains and vapor intrusion)	Water quality data throughout plume, the plume pathway is established (defined by the VOC plume footprint as a definitive tracer). The data indicate a very predictable plume pattern, Gaussian shape with symmetrical spread around highest concentration. Plume is highly stratified (no contamination, or very limited at elevations above 25 ft bgs, exposure via shallow groundwater pathways is unlikely).	Definition of discharge conditions at waterway. Shallow groundwater data at structures. As-built depths of storm drains.
The decisions needed to resolve the problem	1) Does the VOC plume represent a potential exposure risk at point of discharge?	Release occurred to the environment (soil, groundwater, surface water), existing water quality data throughout plume, pore water sampling conducted by EPA, the existing data define the VOC plume path, groundwater concentrations above AWQCs exist.	Discharge to LDW; exactly where and at what concentration. Definition of discharge at waterway (position/location, width, depth, concentration).
	2) Are other exposure pathways (indoor air and, storm drains) complete pathways?	Characterization data from MTCA RI (8 plume transects and subsequent wells) show stratified plume with no exposure potential to COCs in shallow groundwater.	As-built depths of storm drains
	3) Are there other unknown areas of the VOC plume in excess of ARARs ?	The plume has migrated southwest towards the Duwamish Waterway. The flow path of the plume has been established (the VOC data represent an approximate 40 year groundwater flow paths and are definitive tracer data). The data indicate a predictable plume pattern (Gaussian shape with symmetrical spread around the highest concentration).	Plume boundaries (to revised AWQCs) where exposure may occur.
	4) Can the existing treatment processes selected in the MTCA RI/FS & implemented in the MTCA RA be translated to wider areas of plume (i.e., are there any fatal flaws that would suggest that the RAs implemented cannot meet the goals?	1) ISCO IRA at source has resulted in 98% to 99% reduction in VOCs in immediate down gradient well (the prior down gradient hot spot). 2) ERD (pilot and full scale) in multiple areas has reached non-detect levels in down gradient wells.	Characterize those areas (edges of plume near revised AQWC), expand RA, monitor performance.

TABLE 6-1 (Continued)

DQO process step	Application to EMF VOC Plume	Existing Data	Additional Data Required to Support MTCA RI/FS and Select Remedial Action (or optimize Remedial Actions presently underway)
The decisions needed to resolve the problem	5) Have the source control actions implemented at the EMF property been sufficient to mitigate the risks from the plume migration from the EMF property?	Water quality monitoring from the wells throughout the EMF property for VOCs.	Continued performance monitoring.
	6) Does the RA, as implemented, have unintended adverse impacts (e.g., mobilization of metals)? If adverse impacts are expected can they be mitigated?	Monitoring of water quality from ERD pilot test and full scale implementation. Additional recent sampling for priority pollutant metals.	Continue metals analysis in targeted areas, expand analyte list (in selected wells near ERD injection) to all LDW metals.
The inputs to the decision	Nature and extent of plume above AWQC necessary to establish exposure pathways	Existing water quality data throughout plume defining horizontal and vertical extent (EMF site data, KCIA data, Plant 2 data).	Definition of discharge at waterway, attenuation processes from boundary wells to waterway (EPA pore water sampling and tidally-enhanced dispersion)
	Concentration of Contaminants of Concern (COCs) at the discharge.	Existing water quality data at discharge point	
The decision rules	If ../ then… format with quantitative limits: 1) If VOC discharge is > AWQC, then discharge to waterway is occurring and must be addressed; evaluate options for control (completed in prior MTCA RI/FS and to be reconsidered in the EE/CA) and implement actions. 2) If remedy selected (in prior FS and re-evaluated in the EE/CA) can meet the revised VC AWQC, then expand remedy, implement and monitor performance. 3) The EE/CA will evaluate various response actions and if the remedy selected (in prior MTCA FS) cannot meet the revised VC AWQC, alternate RAs will be considered further. 4) If other exposure pathways exist (or seem likely), then characterize potential, evaluate options and implement remedial actions. 5) If vinyl chloride at the discharge boundary to the LDW is above the detection limit then additional characterization may be required to define plume boundary. 6) If VOCs in existing boundary of mapped plume is > AWQC and the shape does not follow an expected Gaussian plume pattern in the mapped plume, then flow path/condition may be different than anticipated and must be addressed through additional characterization to define plume boundary and RA.		

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