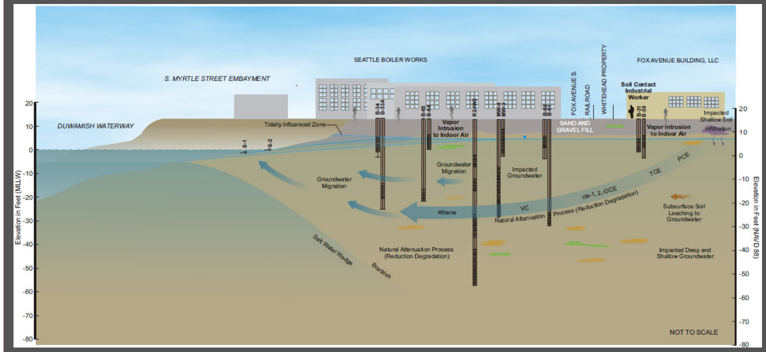
Fox Avenue Site
Seattle, Washington



Remedial Investigation/ Feasibility Study

Prepared for

Fox Avenue Building LLC
6900 Fox Avenue S.
Seattle, Washington 98108

FINAL

June 10, 2011

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Fox Avenue Site
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Remedial Investigation/ Feasibility Study

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List of Abbreviations and Acronyms

Abbreviation/ Acronym	Definition
1,1,1-TCA	1,1,1-Trichloroethane
1^{st} SH	First Silt Horizon
ARAR	Applicable or Relevant and Appropriate Requirement
AST	Aboveground storage tank
bgs	Below ground surface
BTEX	Benzene, toluene, ethylbenzene, xylene
CAA	Cleanup Action Area
CALIBRE	CALIBRE Systems, Inc.
CAP	Cleanup Action Plan
Cascade Columbia	Cascade Columbia Distribution
CEA	Chlorinated ethene and ethane
CFR	Code of Federal Regulations
cis-1,2-DCE	cis-1,2-Dichloroethene
COC	Chemical of concern
CPOC	Conditional point of compliance
CUL	Cleanup level
CVOC	Chlorinated volatile organic compound
DCA	Disproportionate Cost Analysis
DCE	Dichloroethene
DGI	Data Gaps Investigation
DNAPL	Dense non-aqueous phase liquid
DPE	Dual-phase extraction
DVE	Dual vapor extraction
Ecology	Washington State Department of Ecology
EOS	Edible oil substrate
ERD	Enhanced reductive dechlorination
ERM	Environmental Resources Management
Fox LLC	Fox Avenue Building LLC
FS	Feasibility Study
FSI	Floyd & Snider Inc.
GWCC	Great Western International Chemical Company
Hart Crowser	Hart Crowser, Inc.
IRM	Interim Remedial Measure
ISCO	In-situ chemical oxidation
LDR	Land disposal restrictions
LDWG	Lower Duwamish Waterway Group
LGZ	Lower Groundwater Zone
LNAPL	Light non-aqueous phase liquid
MIP	Membrane interface probe
MLLW	Mean Lower Low Water
MNA	Monitored natural attenuation

Abbreviation/ Acronym	Definition
MSL	Mean Sea Level
MTCA	Model Toxics Control Act
NAVD88	North American Vertical Datum
NGVD29	National Geodetic Vertical Datum
ORP	Oxidation-reduction potential
PAH	Polycyclic aromatic hydrocarbon
PCB	Polychlorinated biphenyl
PCE	Tetrachloroethene
Penta	Pentachlorophenol
PID	Photoionization detector
POC	Point of compliance
ppm	Parts per million
PRB	Permeable Reactive Barrier
Qoal	Older alluvium
Qyal	Younger alluvium
RA	Remedial Action
RAO	Remedial Action Objective
RI	Remedial Investigation
RI/FS	Remedial Investigation/Feasibility Study
ROW	Right-of-way
SBW	Seattle Boiler Works
Seattle Chain	Seattle Chain and Manufacturing Company
SH	Silt Horizon
Site	Fox Avenue Site
SMS	Sediment Management Standards
SRI/FS	Supplemental Remedial Investigation/Feasibility Study
SVE	Soil vapor extraction
SVOC	Semivolatile organic compound
TCA	Trichloroethane
TCDD	2,3,7,8-tetrachlorodibenzo-p-dioxin
TCE	Trichloroethene
TEF	Toxic equivalency factor
TEQ	Toxic equivalency quotient
TPH	Total petroleum hydrocarbons
trans-1,2-DCE	trans-1,2-Dichloroethene
UCL	Upper confidence limit
UGZ	Upper Groundwater Zone
UIC	Underground Injection Control Program
URS	URS Corporation
USEPA	U. S. Environmental Protection Agency
UST	Underground storage tank
VC	Vinyl chloride
VFA	Volatile fatty acids

Abbreviation/ Acronym	**Definition**
VOC	Volatile organic compound
WAC	Washington Administrative Code
WBZ	Water Bearing Zone
WRIA	Water Resource Inventory Area
ZVI	Zero-valent iron

Geologist Certification

The geological and hydrogeological facts and conclusions within this document were prepared by or under my responsible charge and that to my knowledge and belief this document was prepared in accordance with the requirements of Chapter 18.220 RCW.

Name: Thomas Colligan, LHG **Date:** June 10, 2011

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Author Recognition

The following individuals were the primary authors of this Remedial Investigation/Feasibility Study:

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1.0 Introduction

The purpose of this Remedial Investigation and Feasibility Study (RI/FS) is to collect and compile the information necessary to adequately characterize the site (the RI) and develop and evaluate appropriate cleanup alternatives (the FS), consistent with the requirements of the Model Toxics Control Act (MTCA). This RI/FS forms the technical basis to allow the Washington State Department of Ecology (Ecology) to select the final cleanup action for the Fox Avenue Site (the Site) located at 6900 Fox Avenue S. in Seattle, Washington (Figure 1.1).

This RI/FS is being performed as a requirement of Agreed Order No. DE 6486 between Fox Avenue Building LLC (Fox LLC) and Ecology, which was entered into on May 6, 2009. The current Agreed Order requires Fox LLC to perform the following activities at the Site:

- Implement an interim action for groundwater
- Conduct a data gap investigation
- Conduct a vapor intrusion evaluation
- Evaluate the continued operation of a soil vapor extraction (SVE) system
- Conduct a supplemental evaluation of remediation alternatives
- Prepare and submit a feasibility study
- Prepare and submit a draft Cleanup Action Plan (CAP)

Since 1991, the Site has been under investigation and cleanup due to past releases of solvents and other chemicals during the former Great Western International Chemical Company (GWCC) operations. GWCC conducted an initial RI/FS, which was completed in 1993 by Hart Crowser, Inc. (Hart Crowser, Inc. 1993). Following the 1993 RI/FS, Hart Crowser designed and implemented an interim action for shallow groundwater and soil. In 1997, the interim action was determined to be ineffective and was shut down. As a result, GWCC completed additional investigations to better understand site conditions and to re-evaluate remedial alternatives. The post-1997 work cumulated in the preparation of a Supplemental RI/FS (SRI/FS) prepared by Terra Vac and Floyd & Snider Inc. (FSI) in 2000 (Terra Vac and FSI 2000). In the 2000 RI, remediation of shallow source area soil and groundwater by dual phase extraction was the recommended remedy combined with monitored natural attenuation (MNA) and biosparging of downgradient groundwater. The recommended remedy was never implemented because of GWCC's financial difficulties. GWCC filed for bankruptcy in 2001.

In 2003, Fox LLC bought the GWCC property and facility, made facility improvements and assumed responsibility for an existing 1991 Agreed Order pursuant to a 2003 amendment. Cascade Columbia Distribution (Cascade Columbia) leases the property from Fox LLC and currently uses the facility warehouse as a chemical distribution facility, as did GWCC.

In November 2009, Fox LLC submitted the draft FS required under the 2009 order (Floyd|Snider 2009c). In June 2010, Ecology requested that Fox LLC prepare an updated RI as a companion document to the FS required under their order. The goal of the updated RI was to consolidate all of the new information gathered since the 2000 SRI/FS.

Additionally, Ecology also requested that the updated RI include a conceptual site model related to current site conditions in consideration of the Site's proximity to the Lower Duwamish Waterway. Groundwater at the Site discharges to the Lower Duwamish Waterway (LDW), a large urban sediment Superfund Site that is currently undergoing source control evaluations and actions in anticipation of a major sediment cleanup later this decade. Therefore, one of the primary elements of the cleanup actions being evaluated in this document is their effectiveness as permanent source control actions to protect water quality in the LDW Superfund Site. This objective is consistent with Ecology's goals for this section of the LDW, as detailed in their Source Control Action Plan for the River Mile 2.0-2.3 East (Slip 3 to Seattle Boiler Works; Ecology 2009a).

1.1 REMEDIAL INVESTIGATION ORGANIZATION

The RI sections of this document are organized as follows:

- Section 1.0 summarizes the regulatory guidelines for the Site and the interim actions that have been performed to date.
- Section 2.0 describes the site history and use, adjacent properties, regional and site geology, and the ecological setting.
- Section 3.0 summarizes previous investigations, pilot studies, and interim actions.
- Section 4.0 provides a summary of preliminary chemicals of concern and cleanup levels for soil, groundwater, and indoor air at the Site.
- Section 5.0 provides a detailed description of current nature and extent of contamination at the Site.
- Section 6.0 summarizes the site conceptual model that will be used in FS to assist in evaluating cleanup alternatives.

1.2 FEASIBILITY STUDY ORGANIZATION

The FS sections of this document are organized as follows:

- Section 7.0 provides discussion of the expectations for solvent cleanup sites, and describes the Remedial Action Objectives, points of compliance, and Cleanup Action Areas developed for the Site.
- Section 8.0 provides a preliminary description and screening of all available technologies to clean up the Site.
- Section 9.0 describes the selection of technologies for each Cleanup Action Area based on site-specific considerations.
- Section 10.0 includes evaluation of alternatives for each Cleanup Action Area according to MTCA threshold requirements, and disproportionate cost analysis.
- Section 11.0 provides a detailed description of the proposed preferred remedial alternatives selected for each Cleanup Action Area.
- Section 12.0 describes proposed performance monitoring, compliance monitoring, and contingency actions to be implemented following remedial actions.
- Section 13.0 provides a list of references cited in this document.

2.0 Site Setting

This chapter describes the overall site setting, including current facility use, ownership and history, surrounding properties, and regional and local geology and hydrogeology.

2.1 SITE DESCRIPTION

The Site includes the Cascade Columbia Facility located at 6900 Fox Avenue S. and certain downgradient properties under which a groundwater contaminant plume travels that eventually discharges to the LDW. The Site is located in the Duwamish industrial corridor of Seattle (Figure 1.1).

The Cascade Columbia Facility occupies approximately 2.5 acres of flat land located approximately 400 feet from the S. Myrtle Street Embayment of the LDW. The elevation of the ground surface surrounding the Cascade Columbia warehouse is approximately 16 to 17 feet North American Vertical Datum (NAVD88), which is equivalent to 18.5 to 19.5 feet Mean Sea Level (MSL). The floor of the warehouse is elevated approximately 5 feet above surrounding grade. The following table provides conversion factors between datum planes at the Site:

Datum Plan	MLLW	NGVD29	NAVD88
Mean Higher High Water	11.10	5.1	8.68
National Geodetic Vertical Datum (NGVD29)	6.00	0.00	3.58
Mean Lower Low Water (MLLW)	0.00	-6.00	-2.42

The property is bordered to the north by South Willow Street, to the south by the Whitehead property (the historical Tyee Lumber Company), to the east by East Marginal Way South, and to the west by Fox Avenue (Figure 2.1). Active rail lines also cross the site area. The area is zoned for heavy industry and a large number of commercial and industrial operations are located nearby, including: Seattle Iron and Metals Corporation, a metals recycler; Seattle Boiler Works, a fabricator of steel pressure vessels; Schultz Fuel Distributing, a distributor of petroleum products; and Dawn Foods Distribution, a warehouse distributor of food products.

2.1.1 Current Facility Use

Cascade Columbia warehouses, packages, and distributes mainly liquid and solid bulk inorganic chemicals for the aerospace, electronics, food manufacturing, personal care, water treatment, and metal plating industries. Product is received either by rail tanker via a rail spur on the south side of the facility or truck via a main loading dock on the northeast side of the warehouse and a smaller loading dock along Fox Avenue. Product is offloaded and stored in bermed aboveground storage tanks (ASTs) or in a variety of sacks, bags, drums, and containers. Products are stored according to hazard class, type of product, and chemical compatibility. The Cascade Columbia Facility has an overhead fire protection system.

To the east of the warehouse is a general storage yard and truck turnaround area. The warehouse itself is divided into outside and inside areas. The outside area that is partially under cover lies approximately 5 feet above surrounding grade and includes a lined and covered "Production Area" where chemicals are custom mixed and blended. Immediately south of the

Production Area is the "Flammables Shed" where drums of flammable liquids are stored under cover, and to the southwest is an "Alkaline Shed" where bulk alkaline products are stored under cover. Dry chemicals are typically stored inside the warehouse structure west of the outside areas. A two-story office is located in the warehouse with the main floor occupied by distribution and production personnel and the upper story by marketing and accounting personnel. In 2004, following acquisition of the facility, Cascade Columbia made significant improvements and reconfigurations to the outside Production Area to better handle their operations, comprising relocating older ASTs, upgrading utilities, new concrete surfacing, and improvements to the facility drainage. Currently there are no active underground storage tanks (USTs) at the facility and Cascade Columbia does not distribute or repackage chlorinated solvents[1]. Approximately 20 personnel work full time at the Cascade Columbia Facility. Figure 2.2 shows the primary operational areas of the Cascade Columbia Facility.

2.1.2 Facility Stormwater

Stormwater falling upon the outside operational areas of the Cascade Columbia warehouse is diverted via downspouts and floor drains to the sanitary sewer system. The combined sanitary and stormwater discharge is neutralized and piped, under permit, to the municipal sewer line that runs west along South Willow Street. This line discharges into a larger sanitary line along Fox Avenue, which in turn, discharges to the main line along East Marginal Way. The main line runs northwest and sewage is eventually routed to the West Point Treatment Plant. Stormwater from the operational areas of the Cascade Columbia Facility is therefore not discharged to the LDW. Runoff from the employee parking lot and other limited paved roadway areas along Fox Avenue flows to catch basins along Fox Avenue that discharge to a storm line running south to S. Myrtle Street, which finally discharges to the LDW via an outfall in the S. Myrtle Street Embayment. A utility map showing the stormwater and sanitary lines is shown on Figure 2.3. The primary stormwater line and the sanitary sewer line are also shown on Figure 2.2.

2.2 HISTORICAL OWNERSHIP

The Fox LLC property was first developed in the early 20th century by the Seattle Chain and Manufacturing Company (Seattle Chain), which leased a 4-lot (city block) of property from King County from 1918 until 1937 when it purchased it outright. Seattle Chain and successor companies operated coke- and oil-fired furnaces and built warehouses on the property. For the next 20 years, ownership of the property changed hands several times until 1956 when Marian Properties LLC Enterprises bought the property and leased a portion of it to GWCC. GWCC, also known as Great Western International, started its operations in the former Seattle Chain warehouse building, a wooden structure that is still in use today by Cascade Columbia as a warehouse and loading dock.

Other lessees of the Site during the 1950s and 1960s included Campbell Chain Company, which leased the warehouse in the northern part of the property, and the Tyee Lumber Company, which leased parts of the warehouse building for storage and product assembly until 1969 when the Tyee Lumber Company shut down. From the 1960s through the 1980s, GWCC replaced and upgraded much of the earlier structures and built the current warehouse and exterior operational areas. Figure 2.4 is an undated historical aerial photograph thought to have been taken in the 1960s.

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[1] Occasionally, a drum of tetrachloroethene or trichloroethene solvent is stored on-site for select customers but according to Cascade Columbia the drum is never opened or repackaged.

GWCC operated a chemical and petroleum repackaging and distribution facility on the property. GWCC received bulk chemical products and repackaged, transferred, and distributed both liquid and dry chemical products, including solvents (e.g., mineral spirits, toluene, tetrachloroethene [PCE[2]], etc.). Until the late 1980s, GWCC supplied chemicals and supplies to the laundry and dry cleaning industry. This aspect of GWCC business, as well as most of its petroleum product handling, was phased out by 1990. GWCC pumped bulk product received via tanker truck or rail through buried pipes at the rail siding area along the southern edge of the warehouse or hoses that ran along the ground surface.

GWCC handled the following chemical classes and product types:

Class	**Product Type**
Ketones	Methyl ethyl ketone (MEK), methyl *iso*-butyl ketone (MIBK), and acetone
Monocyclic Aromatic Solvents	Toluene and xylenes
Alcohols and Glycols	Isopropyl alcohol, ethyl alcohol, methyl alcohol, ethylene glycol, and propylene glycol
Mineral Spirits/Petroleum Solvents	Chevron solvents 325, 350-B, 410 and 450, and kerosene.
Chlorinated Compounds	Methylene chloride, PCE, Penta, trichloroethene (TCE), 1,1,1-TCA
Acids	Nitric, sulfuric and muriatic (hydrochloric) acids
Dry Products	Phosphates, soda ash, titanium dioxide, borax, boric acid
Miscellaneous	Ferric and ammonium chloride etchants, phenols, hydrogen peroxide, and linseed oil

Additionally, GWCC began handling pentachlorophenol (Penta) on the property sometime in 1966. Penta was stored in one of the 12,000-gallon tank compartments and, for a period of 1 to 2 years only, Penta was blended with Stoddard solvents or mineral spirits in a small AST north and west of the drum shed. From 1969 until the late 1970s or early 1980s, GWCC purchased mixed Penta in drums from outside vendors. Product was delivered to customers in vendor-packaged drums or transferred to a tanker truck and delivered in bulk.

The GWCC facility had a number of underground and aboveground storage tanks that stored chemical and petroleum products, including solvents, acids, Penta, and lube oils. A series of six USTs were originally installed in the 1956 under the current Flammables Shed and a set of 10 double-compartment USTs were later installed in 1976 under the current Production Area. Both sets of tanks were decommissioned in 1989 by GWCC. The newer set of 10 USTs was physically removed along with a limited amount of associated contaminated soil; however, the older set of 6 USTs was abandoned in place by cleaning the contents and then filling the USTs with pea gravel. These tanks were not able to be safely removed due to their location under warehouse structural elements. Portable, vertical ASTs called “tote bins,” used for product storage, were stored on pallets in the vicinity of the older UST tank farm.

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[2] The abbreviation “PCE” is derived from perchloroethene, a synonym to the IUPAC name of tetrachloroethene. Other synonyms for tetrachloroethene include Perc, tetrachloroethylene, and perchloroethylene.

A 1000-gallon UST located near the Loading Dock Area historically was used for storage of gasoline. It was decommissioned in place in 1989. Two smaller, 1000-gallon, aboveground “wing tanks” were also used historically on the loading dock. One of the wing tanks contained PCE and the other tank stored methanol.

2.3 ADJACENT AND NEARBY PROPERTIES

The Site is located in an industrial section of the Georgetown neighborhood of South Seattle near the LDW. This area has been intensively used for manufacturing, maintenance, and warehousing operations since the early 20th century. Much of this activity has been associated with metal fabrication and finishing operations. The following discussion is limited to those adjacent properties shown on Figure 2.1.

2.3.1 Whitehead Property (former Tyee Lumber)

The Whitehead Property is unpaved property and lies immediately south of the Cascade Columbia Facility. The property is currently leased to Seattle Iron and Metals for storage of various materials. Formerly, it was the site of a Tyee Lumber’s sawmill and finishing operations from the 1920s to the late 1960s.

At the former sawmill, lumber was treated with preservatives, including Penta, in a top-loading dip tank. The dip tank shed was situated adjacent to S. Myrtle Street, in the approximate location depicted on Figure 2.2. The dip tank was approximately 10 to 15 feet long, 5 feet wide and 5 to 6 feet deep, and partially below grade. Dipped lumber was processed and kiln-dried or, in some cases, air-dried and stored outside or in wooden sheds near the drying kilns. Penta dipping operations continued until 1982. A 300-gallon Penta UST, located adjacent to the dip tank shed, was removed by Northwest Enviroservices in 1986.

Tyee Lumber’s operations terminated in 1969, and the building was demolished. After demolition and degrading, the site was leased in the 1970s and early 1980s by Western Salvage Co., a truck and heavy equipment recycler. This parcel was subsequently leased to Nelson Trucking for container storage, and then leased to Seattle Iron and Metals.

As discussed in Section 5.0, the solvent plume from the Site crosses the western third of the Whitehead Property.

2.3.2 Emerson/Schultz Distributing Block

The Emerson/Schultz Distributing block is located immediately north of the Cascade Columbia Facility. It is currently leased by Schultz Distributing Co., from D.M. Emerson, Jr. This property was developed in the 1920s for the Gypsum Products Corporation. From the late 1930s until the 1960s, Federal Pipe manufactured wood pipes and tanks on the property. Its operations included a dip tank, drying kilns, and warehouse space. In 1964, a group of individuals, including members of the Emerson family, purchased the property. Emerson GM Diesel leased the property in the 1960s, and performed maintenance and repair of diesel motors and trucks on the property. Pacific Detroit Diesel occupied the property between 1989 and 1996. In 1996, the property was leased to Schultz Distributing, Inc. Schultz has used the property as a distribution center for petroleum products. A number of ASTs were installed on the site as part of the Schultz operation.

Past environmental investigations identified solvent use in the central part of the yard and in the shop area. In the west part of the yard, a 2,000- to 6,000-gallon UST collected paint material and solvents from a former paint room/carpenter shop (Geraghty & Miller, Inc. 1989). This property is not part of the Site.

2.3.3 Dawn Foods Distribution

This property is located to the west/northwest of the Cascade Columbia Facility and has been developed since 1978 with a large warehouse used for the storage and shipment of food products. The building was originally occupied by Richardson & Holland and the Sam Wilde Flour Company and most recently, Dawn Foods Distribution. Prior to construction of the warehouse in 1978, this block was occupied by a number of small manufacturing operations. No previous environmental investigations have been identified for this parcel.

As discussed below in Section 5.0, a solvent plume crosses a portion of the Dawn Foods Distribution parcel.

2.3.4 Seattle Boiler Works

The commercial block immediately west of the Cascade Columbia Facility was historically occupied by the National Steel Construction Company, which used the property for construction and storage from approximately 1908 until 1966. National Steel reportedly conducted shipbuilding activities both on this block and on property immediately to the south (south of S. Myrtle Street). The property contained, at various times during National Steel’s tenancy, an iron foundry, woodworking and blacksmith shops, a marine railway, galvanizing and aluminum dipping facilities, a boiler works, and waste metal and slag piles. In 1966, the property was purchased by Seattle Boiler Works, which primarily manufactures pressure vessels (boilers). No previous environmental investigations have been identified for this parcel.

As discussed below in Section 5.0, a solvent plume from the Site crosses the Seattle Boiler Works property.

2.3.5 Seattle Iron and Metals

Seattle Iron and Metals conducts metal scrapping operations on a large parcel located to the southwest of the Cascade Columbia Facility, immediately south of Seattle Boiler Works. Beginning in 1917, this site was used for metalworking, foundry work, painting activities, steel can manufacturing equipment construction, and fuel storage. Both USTs and ASTs were installed at, and removed from, various locations on the property. The property was used primarily for warehousing and terminal operations during the 1980s and 1990s.

This parcel has been the subject of several environmental assessments and investigations during the 1980s and 1990s. In 1998, Othello Warehouse Street Corporation, owner of the property at the time, submitted a Voluntary Cleanup Action Report to Ecology (Hart Crowser, Inc. 1998). Othello intended to sell the property and was seeking an “Interim No Further Action” letter from Ecology to facilitate the sale. The report, which includes a summary of investigative data and remedial actions performed at the property, documents the presence of total petroleum hydrocarbons (TPHs), metals, volatile organic compounds (VOCs), and Penta contamination, and attributes the contamination to both on-site and off-site sources.

Currently, the property is used by Seattle Iron and Metals, a company that receives and purchases scrap metals from various sources, then sorts and shreds the metal in a large metal shredder and sells the scrap metal. At times, scrap metal is loaded onto barges or ships from their wharf along the LDW.

As discussed in Section 5.0, a solvent plume from the Site crosses the northern section of the Seattle Iron and Metals property.

2.3.6 City of Seattle Street Right-of-Ways

The Site includes several public street right-of-ways (ROWs). These include Fox Avenue, S. Willow Street, and S. Myrtle Street. Union Pacific rail lines exist within these ROWs and are actively used, especially along Fox Avenue and S. Willow Street. A rail spur leading to the south side of the Cascade Columbia Facility also exists.

2.4 REGIONAL AND SITE GEOLOGY

2.4.1 Regional Geology

The Site is located in the Lower Duwamish River Valley within the Puget Sound Basin. The Puget Sound Basin topography and geology bear the record of repeated glacial incursions that occurred during the Pleistocene epoch. The Duwamish Valley was carved by overriding ice sheets of the Vashon Stade that advanced into the area about 15,000 years ago. Vashon glacial deposits, termed “drift,” mantle older upland Pleistocene and Tertiary deposits. Following glacial retreat, marine waters of Puget Sound invaded the Duwamish Valley and it became an arm of Puget Sound. Approximately 5,700 years ago, the Osceola Mudflow, descended from the flanks of Mount Rainer along the valley of the White River, building a voluminous fan of sediment into the marine waters at Auburn and progressing down-valley as a submarine flow as far north as Kent (Dragovich et al. 1994). Over subsequent centuries, the deposits of the Osceola were eroded and redeposited downstream, rapidly filling in the Duwamish arm of the Puget Sound. This redeposition, coupled with the post-glacial rising of the land surface (isostatic rebound), resulted in a complex deposition pattern of deltaic and estuarine deposits within the Duwamish Valley. Within the last 100 years, the delta/estuary was extensively modified by hydraulic dredging to form the straightened waterway, by fill that raised the elevation of adjacent lowlands, and by large-scale industrial development in the area.

In general, the Lower Duwamish Valley deposits consist of 50 to 100 feet of older alluvium (Qoal), representing sand and silt estuarine deposits. Locally, these older sediments contain discontinuous gravel lenses, shells, and some wood. The younger alluvial deposits atop the older alluvium have a relatively uniform thickness and depth, with a base that almost everywhere is within 5 to 10 feet of the modern sea level. These deposits, which consist of silt, sand, and sandy silt with abundant wood and organics, represent channel and floodplain deposits laid down by the modern Duwamish River. Overlying the younger alluvium are varying amounts of fill that range in thickness from 3 to 10 feet. The fill material is composed of a mixture of sand, gravel, silt, and miscellaneous construction debris. These deposits are shown conceptually on Figure 2.5, a regional geologic map, and Figure 2.6 a generalized geologic cross section of the Duwamish Valley.

2.4.2 Site Geology

Site geologic conditions are best illustrated by the site geologic cross sections figures (Figures 2.7a to 2.7c). The locations of site geologic cross sections are shown in Figure 2.8. The cross section locations were chosen as a representative schematic of the geologic units encountered by site explorations. The units encountered beginning at the surface and progressing deeper are discussed in the following subsections.

2.4.2.1 Fill Material

Near-surface soil at the Site predominately consists of fill material. Fill ranges in depth from 5 to 10 feet below ground surface (bgs). Typically, the fill is thickest near the center of the Site and thinner near the edges. Some of the thickest fill deposits occur beneath the raised outdoor storage and Production Area.

Fill material is predominately composed of poorly graded silty fine sand to gravelly sand or sandy silt to gravelly sandy silt. Locally, fill includes some organic matter, wood, and debris, including pieces of masonry, cinders, and slag.

2.4.2.2 Recent Alluvial Deposits

The first native soils encountered beneath the fill are interpreted to represent recent (i.e., pre-development) alluvial deposits of the Lower Duwamish Valley. These deposits range in composition from fine to medium sand to slightly silty to very silty fine to medium sand. Locally, within these deposits, fine sandy silt lenses are intercepted. Where fill is lacking, these deposits range in depth from near-surface to approximately 10 to 15 feet bgs. These deposits have been interpreted to represent channel and floodplain deposits laid down by the modern Duwamish River (Booth and Herman 1998). These younger alluvial deposits host the first occurrence of groundwater at the Site, as described in more detail below.

2.4.2.3 First Silt Horizon

One primary low permeability horizon of significance to site conditions has been identified. This unit is termed the First Silt Horizon (1st SH) and occurs at the base of the recent alluvial deposits. The 1st SH is interpreted to represent backwater flood plain deposits. The 1st SH is too discontinuous to act as an aquitard, but it can influence chemical migration. When it is present and relatively clean, it acts to limit diffusion and dispersion of groundwater contaminants with depth; however, when it is contaminated, it acts as a substantial reservoir of contamination.

The 1st SH is located beneath most of the Cascade Columbia Facility, except for a small area northwest of the former main UST farm. The approximate thickness of the 1st SH ranges from less than 0.5 to 2.5 feet and is thickest under the Production Area and Flammables Shed, near the center of the Cascade Columbia Facility. As discussed in Section 5.0, releases have contaminated the 1st SH in several locations at the Site.

The 1st SH is absent south of the Cascade Columbia Facility along Fox Avenue, but tends to exist, with discontinuities, further downgradient. By Seattle Boiler Works, the 1st SH is no longer contaminated, and, where present acts to limit chemical dispersal with depth. Figure 2.9 identifies the extent of the 1st SH across the Site.

2.4.2.4 Older Alluvial Deposits

Estuarine/deltaic sediments are interpreted to be present beneath recent Duwamish River alluvium or the 1st SH (where present). These deposits are typically composed of an upper unit of fine to medium sand that grades into a lower unit of silty fine sands with stringers and lenses of silty to sandy silt. These deposits are typical of a cycle generated by gradual progradation of a delta into a shallow marine environment. In the site area, these estuarine/deltaic sediments are interpreted to occur to depths of at least 80 feet bgs, the depth of the deepest soil exploration at the Site. Geotechnical borings from Seattle Iron and Metals suggest that the older alluvial deposits extend to at least 120 feet bgs (AGRA 1988).

2.5 GROUNDWATER OCCURENCE

Groundwater occurs throughout the Lower Duwamish Valley in both the older and younger alluvial deposits. Shallow groundwater can also occur locally within fill material. In general, the valley alluvium is believed to comprise a single, large aquifer system (Booth and Herman 1998). Locally, where this aquifer is thickest, upper and lower groundwater zones are often differentiated on a site-specific basis, based on the occurrence of locally-continuous silt layers, upward gradients at depth, and/or saline groundwater pockets (Booth and Herman 1998). Although some of the deeper saline pockets are a reflection of the current intrusion of marine waters, most reflect connate or “trapped” seawater from previous depositional events. Groundwater recharge to the valley occurs via both infiltration and from upland aquifers that discharge into the alluvial valley both along subsurface pathways and through visible seeps along valley walls. Groundwater discharge is primarily to the channel of the Duwamish Waterway.

2.5.1 Valley Aquifer System

As noted above, the Duwamish Valley alluvium generally comprises a single large aquifer system. Locally, the valley aquifer is differentiated based on continuous silt aquitards that separate the major water bearing zones and the occurrence of upward gradients and/or the occurrence of saline groundwater pockets.

Of most importance to site conditions is the Upper Groundwater Zone (UGZ). The UGZ is hosted by both younger and older alluvial deposits (i.e., Qyal and Qoal, respectively) and typically occurs down to depths of 60 to 80 feet bgs. This unit contains moderately well sorted silty, sand, and sandy silt, locally containing abundant wood and organics (Figure 2.6). The net groundwater flow within the UGZ is generally toward the LDW; however, locally, daily tidal effects have been shown to cause apparent groundwater flow reversal near the waterway. In general, temporal groundwater flow reversal occurs within 500 feet of the waterway (Booth and Herman 1998). In some areas of the valley, tidal response has been measured as far as 1,000 feet from the river.

Upward gradients are common between the UGZ and Lower Groundwater Zone (LGZ). On the east side of the Duwamish Waterway, gradients are reported to be an order of magnitude lower than on the west side. This difference is likely due to the more limited inflow from bedrock-dominated deposits (i.e., Tertiary deposits) on the east side of the waterway as compared to inflow from glacial deposits on the west. Upward gradients in the alluvium on the west side of the waterway have been reported to range from 0.02 to 0.3, while on the east side of the waterway they range from 0.002 to 0.07. The higher gradients on the west could be attributed to discharge from glacial sands and gravel deposited in the uplands (Booth and Herman 1998).

Of lesser importance to site conditions is the LGZ, which is hosted in deeper estuarine/deltaic deposits (i.e., Qoal). The LGZ is typically differentiated from the UGZ by a higher percentage of fines, an abundance of shell fragments, and brackish groundwater conditions caused by contact with seawater. In the central part of the Duwamish Valley, where the Site is located, the LGZ is estimated to occur at depths greater than 80 feet bgs (Booth and Herman 1998). On the edges of the valley the LGZ occurs at shallower depths. In general, the upper two-thirds of the LGZ is typically described as sand to silty sand, and the lower third is commonly described as sandy silt. Vertical gradients in the LGZ are generally upward (Booth and Herman 1998).

2.5.2 First Water Bearing Zone

Two groundwater bearing zones (i.e., 1st Water Bearing Zone [WBZ] and 2nd WBZ) have been distinguished within the UGZ at the Site. This distinction is based on water chemistry, tidal effects, and the presence or absence of a low permeability deposit (the 1st SH) separating the zones.

The 1st WBZ is the uppermost groundwater bearing unit. This zone is primarily composed of native alluvial deposits of fine to medium sand to slightly silty to very silty, fine to medium sand. The 1st WBZ is unconfined, with depth to the water table ranging from approximately 7 to 13 feet bgs. Where present, the 1st SH serves as the base for the 1st WBZ throughout most of the Site. Where absent, the 1st WBZ grades into the underlying 2nd WBZ with no identifiable marker. The 1st WBZ is 3 to 8 feet thick in sections where the 1st SH is present.

2.5.2.1 Tides, Groundwater Elevations, and Flow Direction

Potentiometric maps for the 1st WBZ show the general direction of groundwater flow at the Site to be to the southwest, towards the LDW, regardless of the tidal cycle (Figures 2.10 and 2.11). At both high and low tides, a depression occurs in the potentiometric surface in the vicinity of Wells B-8, B-42, B-44, and B-49. This depression is close in proximity where the 1st SH is absent and illustrates the direct hydraulic connection between the 1st and 2nd WBZs. A second depression in the potentiometric surface, which is only present at high tide, is located in the vicinity of Wells B-36 and B-64. This depression does not reflect a hole in the 1st SH, but rather the impact of a tidal groundwater pressure wave on the 1st WBZ. The depression is not present at low tide because the impact of the pressure wave on the 1st WBZ is diminished at low tide. At low tide, west of Fox Avenue, groundwater flows toward the S. Myrtle Street Embayment; however, at high tide, groundwater flows northeast towards the Site. This reversal in groundwater flow direction during the tidal cycle is typical of aquifers in contact with marine water bodies. The magnitude and direction of hydraulic gradients are a function of distance from the shoreline (Serfes 1991). The impact of the tidal cycle on groundwater elevations at the Site is discussed in more detail later in this section.

2.5.2.2 Horizontal Hydraulic Conductivity

The hydraulic conductivity of the 1st WBZ varies across the Site. Hydraulic conductivity was measured using slug tests in Wells B10 (abandoned), B10-A, B-28, and B-31 in 1990 and 1992 (Hart Crowser, Inc. 1993). The hydraulic conductivity of the 1st WBZ is estimated to range from 3×10^{-3} to 2×10^{-2} cm/s. The geometric mean of the hydraulic conductivity of the 1st WBZ is 7.5×10^{-3} cm/s.

2.5.2.3 Horizontal Gradients

Horizontal gradients in the Site area are generally flat, reflecting the topography; however, they are locally affected by tides, variations in hydraulic conductivity, and the presence or absence of the 1st SH. In general, gradients become steeper moving from east to west. In the vicinity of Wells B-14, B-25, and B-32, (installed on the east side and upgradient from the Flammables Shed) gradients measured from low and high tide potentiometric contours are both 0.001 feet/foot (ft/ft). In the vicinity of Wells B-31, B-42, and B-47, screened near the hole in the 1st SH, low and high tide gradients are calculated as approximately 0.006 and 0.009 ft/ft, respectively. The similar magnitude of horizontal gradients on the east and central parts of the Site suggests that the hydrologic properties of the 1st WBZ are comparable in these two areas. West of Fox Avenue, near the S. Myrtle Street Embayment, low and high tide horizontal gradients in the vicinity of Wells B-34 and B-64 are calculated as approximately 0.015 and 0.011 ft/ft, respectively. In this area of the 1st WBZ, groundwater flows east during high tide and west during low tide. The reversal of the groundwater flow direction results from the eastward advance of the tidal pressure wave during the flood tide. The gradients in this area are approximately an order of magnitude higher than gradients measured east of Fox Avenue. These higher gradients reflect the strong impact of the tidal cycle on the 1st WBZ west of Fox Avenue, as compared to the east side of Fox Avenue.

2.5.2.4 Groundwater Flow Velocity

Like hydraulic conductivity and gradient, groundwater flow velocity in the area of the Site varies from east to west. Using an average hydraulic conductivity of 21.3 ft/day (7.5 x 10^{-3} cm/s) and an assumed conservative effective porosity of 0.25 (Freeze and Cherry 1979), 1st WBZ groundwater velocities were calculated using Darcy's equation:

$V = \frac{KI}{n}$V = KI/n

Where:
V = Groundwater Velocity
K = Hydraulic Conductivity
I = Hydraulic Gradient
n = Effective Porosity

On the east side of the Site, in the vicinity of Wells B-14, B-25, and B-32 the average groundwater velocity (average of high and low tide) for the 1st WBZ is approximately 0.10 ft/day (36 ft/year). The average groundwater velocity was used for the east portion of the Site because the impact of the tidal cycle on gradient and hydraulic heads is considered to be minimal. In the vicinity of Wells B-31, B-42, and B-49, (screened near the hole in the 1st SH) the low tide groundwater velocity is 0.47 ft/day (172 ft/year), while the high tide velocity is 0.80 ft/day (291 ft/year). West of Fox Avenue, near the S. Myrtle Street Embayment, in the vicinity of Wells B-34 and B-64, the velocity at low tide is 1.25 ft/day (456 ft/year) toward the Duwamish River, while velocity at high tide is 0.93 ft/day (339 ft/year) in the opposite direction. The "back and forth" movement of groundwater in tidal influence regions can increase the dispersion of contaminants.

Due to variability in aquifer properties and difficulty in determining gradients at a complex and tidally-influenced site, these gradients and related velocities should be considered estimates of the actual conditions.

2.5.2.5 *Infiltration and Recharge*

Most of the Site is paved or roofed. Infiltration occurs primarily on the north and east sides of the Cascade Columbia Facility in limited unpaved areas that are not used for chemical storage.

The volume of surface water infiltrating to the 1st WBZ from the Site and the surrounding area is unknown; however, based on an analysis of stormwater runoff conducted at the Site in 1992 (Hart Crowser, Inc. 1992), this volume is believed to be minimal relative to the volume of surface water captured by municipal storm sewers and on-site catch basins. As discussed in Section 2.1.2, the majority of surface water from the Site, especially in the operational areas, is captured and discharged to the sanitary sewer that collects to the City of Seattle's main line along E. Marginal Way.

In early 1990, groundwater data from the Site were evaluated to assess whether buried utilities or surface water infiltration impacted groundwater levels and flow. Results from this qualitative analysis did not find measurable water level changes that could be clearly related to the proximity of buried utilities or other sources (Hart Crowser, Inc. 1992).

2.5.3 Second Water Bearing Zone

The 2nd WBZ is contained within a semi-confined (i.e., locally unconfined) estuarine/deltaic aquifer that consists of fine to medium, silty sands with interbeds, stringers, and lenses of dense to very dense, very silty, fine sand to soft to medium stiff, sandy silt. In general, estuarine/deltaic deposits become fine-grained with depth, but often show repeated sequences of silt to silty sand to sand. The 2nd WBZ ranges in depth from approximately 15 to at least 80 feet bgs.

2.5.3.1 *Groundwater Elevations and Flow Direction*

Potentiometric maps for the 2nd WBZ show the general direction of groundwater flow at the Site to be to the southwest, during both low and high tides (Figures 2.12 and 2.13). At high tide, a depression occurs in the potentiometric surface in the vicinity of Wells B-45, B-59, and B-61. This depression is similar to the depression observed in the potentiometric surface of the 1st WBZ, but shifted to the southwest. At low tide, the depression is not present. This suggests that the phenomenon is a condition of the tidal cycle and possibly represents a local heterogeneity in or beneath the 2nd WBZ. However, due to the complex interaction between groundwater flow tidal reversals, it is not possible to determine whether this depression is a reflection of tidal flux, downward vertical gradients, or lag time, or whether it is an artifact of the measurement process.

At low tide, west of Fox Avenue in the vicinity of Wells B-33A and B-65, groundwater in the 2nd WBZ flows toward the S. Myrtle Street Embayment; however, at high tide, groundwater flows northeast toward the Site. This reversal was also observed in the 1st WBZ. The impact of the tidal cycle on groundwater elevations is demonstrated by Figure 2.14, which shows the response of transducers installed in two wells in the 1st WBZ and two wells in the 2nd WBZ during a 24-hour period. The effect of tides upon groundwater levels is pronounced in the 1st and 2nd WBZ wells located close to the waterway and becomes less pronounced, but still observable, in 1st and 2nd WBZ wells near Fox Avenue.

2.5.3.2 Horizontal Hydraulic Conductivity

The hydraulic conductivity of the 2nd WBZ varies across the Site. Hydraulic conductivity was measured to range from 3 x 10^{-3} to 1 x 10^{-2} cm/s, using slug tests in 1990 and 1992 (Hart Crowser, Inc. 1993). The average hydraulic conductivity of the 2nd WBZ is 5.3 x 10^{-3} cm/s.

2.5.3.3 Horizontal Hydraulic Gradient and Flow Velocity

As measured from low and high tide potentiometric contours, horizontal gradients at the Site, with the exception of the gradient in the vicinity of Wells B-45, B-58, and B-61, are of similar magnitude. From the east side of the Site to the S. Myrtle Street Embayment, low and high tide horizontal gradients range from 0.001 to 0.005 ft/ft, respectively. At Wells B-45, B-58, and B-61, a depression occurs in the potentiometric contours plotted at high tide. Based on those contours, the horizontal gradient at this location is calculated at approximately 0.013 ft/ft.

The groundwater flow velocity in the 2nd WBZ was estimated using an average hydraulic conductivity of 15.0 ft/day (5.3 x 10^{-3} cm/s) and an assumed effective porosity of 0.25, and hydraulic gradients as discussed above. On the south and east side of the Site, in the vicinity of Wells B-8, B-17, and B-25, the average groundwater velocity (average of high and low tides) for the 2nd WBZ is approximately 0.17 ft/day (62 ft/year). In the vicinity of Wells B-45, B-59, and B-61, at the depression in the potentiometric surface at Fox Avenue, the groundwater velocity is calculated at 0.75 ft/day (275 ft/year). West of Fox Avenue, near the S. Myrtle Street Embayment, in the vicinity of Wells B-33A and B-65, the low and high tide velocities are 0.32 ft/day (117 ft/year) and 0.25 ft/day (91 ft/year), respectively.

2.5.3.4 Infiltration and Recharge

In the area of the Site, recharge to the 2nd WBZ occurs from the 1st WBZ, particularly where the 1st SH is absent as well as recharge from upgradient water bearing glacial sediment deposits found in the east uplands. Upward gradients in the alluvium on the east side of the river range from 0.0002 to 0.07 (Booth and Herman 1998).

2.5.4 Groundwater Seeps

Groundwater flow in both the 1st WBZ and 2nd WBZ discharges to the Duwamish Waterway. Groundwater from both zones has been observed to discharge from a series of prominent seeps located along the intertidal zone of the S. Myrtle Street Embayment. Chemicals attributed to the Site have been detected only in certain seeps at the S. Myrtle Street Embayment (i.e., S-1, S-2, S-13, S-16). The locations of the seeps are presented in Figure 2.15.

In 1999, a detailed mapping of the seeps was conducted throughout the S. Myrtle Street Embayment and down into the navigation channel using Gore-sorbers installed on a 50-foot grid. The Gore-sorbers were very sensitive to the collection of PCE, TCE, dichloroethene (DCE), vinyl chloride, and related chemicals. This study indicated that seeps from both the 1st and 2nd WBZs discharged in a distinct seep face between approximately -5 and +5 feet Mean Lower Low Water (MLLW). Near the S. Myrtle Street Embayment, groundwater in the 1st WBZ flows through an area of higher-permeability fill material, likely a zone of concrete rubble placed in this area (AGRA 1988). This very porous fill material channels groundwater so that it discharges as distinct seeps at the S. Myrtle Street Embayment. Several of the seeps are easily sampled with grab sampling equipment and have sufficient flow to have channeled the sediments in the embayment. These seeps, based on differences in chemistry, reflect primarily discharge from the 1st WBZ; however one seep, S-13, reflects the 2nd WBZ. This conclusion is based on a comparison to the type and concentrations of chemicals found in Wells B-34 and B-33A, screened very close to the seeps and in the 1st WBZ and 2nd WBZ, respectively. In addition to the "flowing" seep at S-13, the Gore-sorber study identified a broad seep face at the same elevation that discharges 2nd WBZ groundwater. No other distinct seep or subsurface discharges of the 2nd WBZ chemicals have been identified.

Additional studies for the LDW Superfund site were conducted in the S. Myrtle Street Embayment and confirmed the existence of the seeps, the connectivity of the seeps to the groundwater zone, the presence of a permanent salt water wedge coming from the waterway, and the absence of groundwater discharge at depth (discharge was occurring at their stations located at approximately -5 feet MLLW, and was not occurring at the deeper stations located at approximately -10 feet MLLW).

2.5.5 Vertical Gradients and the Saline Groundwater Wedge

The results from past tidal studies at specific well pairs were used to estimate vertical hydraulic gradients at the Site; however, the continual overprinting of tidal influence upon water levels made it very difficult to interpret the vertical gradient data. In general, downward vertical gradients are observed near the Cascade Columbia Facility and upward gradients are observed closer to the waterway. This is consistent with the hydrogeologic model of the Duwamish Valley where the Duwamish Waterway is the regional discharge for groundwater. It is likely that the Site occupies the transition area between overall downward vertical gradients found away from the waterway to overall upward gradients that occur close to the waterway.

The net upward gradient near the waterway results from two factors: the presence of the waterway as the regional discharge feature as mentioned above, and the presence of dense, saline water in the aquifer beneath the waterway. The salinity in the aquifer under the waterway results from seawater intrusion from the base of the Duwamish Waterway. The saline groundwater forms a widening wedge with depth. This saline wedge acts as a hydraulic barrier/dispersion zone, preventing the underflow of fresher water beneath the waterway. As a result prior to discharge, the groundwater is driven upward, instead of mixing, due to the density contrast.

2.6 AQUIFER NON-POTABILITY DETERMINATION

The alluvial aquifer at the Site is considered non-potable based on site-specific conditions that are consistent with the MTCA definitions (Washington Administrative Code [WAC] 173-340-720) related to evaluation of highest beneficial use (i.e., groundwater potability) and corresponding groundwater cleanup requirements. These conditions are summarized below followed by a summary of past regulatory decisions on potability for the wider Duwamish Valley and finally, a listing of applicable or relevant and appropriate requirements (ARARs) that restrict potable groundwater use in the area. Additional information supporting the non-potability determination is presented in Appendix A.

2.6.1 Site-specific Conditions

The key conditions to consider when determining the potability of groundwater at the Site are presented below:

- **The Regional Aquifer is saline at depth.** Groundwater at the Site is part of the Lower Duwamish Valley aquifer which is saline at depth throughout the area.

- **The Site is adjacent to and discharges to marine waters.** The LDW is within 500 feet of the Site. The LDW is a stratified system with saline waters underlying fresh water and so cannot be used for drinking water purposes (WAC 173-201A-602).
- **There are known or projected points of entry of the groundwater into the surface water.** As discussed in detail in Section 2.5 above, groundwater at the Site discharges into surface water via a series of discrete seeps along the S. Myrtle Street Embayment.
- **The site groundwater is sufficiently connected hydraulically to the surface water so that it is not practicable to use as a drinking water source.** Section 2.5 discusses the influence of tides upon groundwater elevations. Groundwater at the Site is hydraulically connected to the LDW.
- **The surface water is not classified as a suitable domestic water supply source.** Per WAC 173-201A, the LDW is part of Water Resource Inventory Area (WRIA) 9, from the mouth of the Duwamish River south to River Mile 11. This section is not listed as a domestic water supply.
- **The groundwater at the Site does not serve as a current source of drinking water.** Section 2.6.3 discusses the absence of drinking water wells in the vicinity of the Site and the regulations prohibiting installation of new wells.

2.6.2 Area-wide Considerations

The Duwamish Industrial Area Hydrogeologic Pathways Project was jointly funded in 1998–2000 by the City of Seattle and King County. The University of Washington's Center for Urban Water Resources Management, Ecology, and the U. S. Environmental Protection Agency (USEPA) were active participants in the scoping and execution of the project.

The goal of the project was to facilitate the redevelopment of brownfields in the Duwamish Industrial Corridor by improving the quality and pace of cleanup-related decision-making for the area. "Duwamish Basin Groundwater Pathways Guidance Documents" were produced and accepted by Ecology as suitable for use by consultants, property owners, and site managers who will make site-specific cleanup decisions under MTCA for sites within the Duwamish Industrial Valley. The guidance documents provide necessary information for making site-specific arguments that within the studied area, groundwater is non-potable per MTCA criteria, and the highest beneficial use of shallow groundwater is the protection of beneficial uses of adjacent surface waters.

The Ecology-approved "User's Guide" for the guidance documents states that

> "The guidance documents provide the regional setting for evaluating hydrogeologic information for individual properties within the study area. The material is meant to streamline the process for determining, on a site-specific basis, the highest beneficial use of groundwater in the shallow aquifer within the study area and setting the appropriate cleanup standards…Provision of this material should streamline the evaluation and regulatory process for individual sites by reducing the expenditures of individual property owners to replicate this information, and by eliminating redundant and sometimes conflicting interpretation of regional information by multiple consultants and site managers" (Floyd & Snider Team 1999).

Formal acceptance of the guidance by Ecology was documented in a May 1, 2000 letter from Jim Pendowski to King County and City of Seattle officials. The letter states the following:

> "The…products of this project…*Duwamish Industrial Area Technical Memorandum – Shallow Groundwater Use Designation*…have been reviewed by Ecology and found to be suitable for use by site managers and others in making site-specific cleanup decisions under the Model Toxics Control Act (MTCA) for sites within the Duwamish Industrial area." (Pendowski 2000).

The Shallow Groundwater Use Designation technical memorandum summarizes why shallow groundwater in the Duwamish Valley will never be used as a source of potable water, and proposes that the highest beneficial use of shallow groundwater should be classified as discharge to surface water. The memo lays out the rationale relative to the designation criteria in WAC 173-340-720 (Herman and Snider 1998).

The Shallow Groundwater Use Designation Memorandum addresses all of the potable groundwater definition provisions: 720 (a), (b), (c), and (d). Importantly, Ecology confirmed in this process that the criteria defined for designation are not required to be met inclusively. Not all of the criteria need to be met to support designation. The primary criteria for non-potable designation that are met in the Duwamish Industrial area are discussed below.

- The groundwater does not serve as a current source of drinking water. There are no known uses of shallow groundwater for drinking water purposes within the Duwamish Valley north of the turning basin (173-340-720(2)(a)).
- The groundwater is not a reasonable potential future source of drinking water given the industrial nature of the site and surrounding land use. In addition, Ecology has historically considered groundwater in the LDW and Duwamish Valley as non-potable. The site is hydraulically connected to the LDW, which is a saline surface water body that is not suitable as a domestic water supply (tidally influenced by salt water (173-340-720(2)(b)).
- The groundwater at the Site contains natural background concentrations of organic or inorganic constituents that make use of the groundwater as a drinking water source not practicable.
- Distinct hydrogeologic boundary conditions exist that hydraulically separate the shallow aquifer systems from adjacent or underlying water bearing units. Additionally, it is unlikely that hazardous substances will be transported from the contaminated groundwater to groundwater that is a current or potential future source of drinking water because there are no drinking water wells located in the vicinity of the Site or that are hydraulically connected to the Site (173-340-720(2)(c)).
- The Site has an extremely low probability that the groundwater could ever be used as a source of potable water. In these cases Ecology has allowed groundwater to be classified as non-potable if the conditions of Section (2)(a) and (2)(c) are met. The conditions of (2)(a) are met because site groundwater is not currently used as a source of drinking water and the conditions in (2)(c) are met because of the existing hydrogeologic boundary that separates the shallow aquifer system from any adjacent water bearing units (173-340-720(2)(d)(i)).

2.6.3 Drinking Water Regulatory Considerations

Ecology's website currently indicates that there are no drinking water supply wells within 1 mile of the Site. The nearest public water supply wells are located approximately 4 miles southwest of the Site and are operated by the City of Seattle only during the summer. These wells are too far away to have any conceivable influence upon site conditions and draw from a completely different geologic formation known as the Highline Intermediate and Deep Aquifers. These wells tap pre-Vashon glacial units and not Duwamish Valley alluvial aquifers (Booth and Herman 1998). The uppermost aquifer in the well field is the Vashon Advanced Outwash (Qva), which occurs at an elevation of approximately 250 to 400 feet above MSL.

A number of additional rules and regulations are in place that prohibit use of groundwater as a potable supply in the area that includes the Site. These include:

- King County Board of Health Title 12, Section 12.32
- WAC 246-290 & 246-291 Public Water Systems
- Ecology Seawater Intrusion Policy
- WAC 173-160 Well Construction Standards
- King County Coordinated Water Supply Plan

These regulations prohibit the installation and operation of new drinking water wells in the vicinity of the Site. The specifics of these regulations are discussed in Appendix A.

2.7 ECOLOGICAL SETTING

2.7.1 Terrestrial Environment

The Site is located in an industrial area with no undisturbed natural habitat for terrestrial wildlife. All of the Site is paved or contains roofed structures and is surrounded by an 8-foot-high chain-link fence.

The highly industrial nature of the Site and its isolation of the buildings from the surrounding lands make it unlikely that ecological receptors will encounter contaminated soil at the Site. However, it is possible that vermin (rats, raccoons, etc.) use the area, especially near the Duwamish Waterway. According to the Washington State Department of Natural Resources' Natural Heritage Program, there is currently no rare plant or high quality ecosystem in the vicinity of the Site (WADNR 1999).

2.7.2 Aquatic Environment

The Site is located approximately 600 feet east of the Duwamish Waterway; but the S. Myrtle Street Embayment brings the waterway to within about 400 feet of the Cascade Columbia Facility. The waterway is maintained for vessel traffic in the vicinity of the Site. At the S. Myrtle Street Embayment, the shoreline is composed of a steep, debris-rich cut-bank slope joining a low profile, sloping intertidal mud shoreline. Pilings of a former dock are found in both the intertidal and subtidal zones.

The Duwamish Waterway is an estuarine waterway that flows into Elliott Bay. In general, the estuary provides nursery habit for numerous marine fish species and juvenile salmonids. Studies conducted in the LDW have identified 20 marine and anadromous fish species (King County 1996). The lower 6 to 8 miles of the estuary are an important transition zone for juvenile salmon to acclimate to saltwater (Parametrix 1980). The Green River (located well upstream of the Site) and the lower reaches of its tributaries provide important spawning habitat (King County 1996).

The Duwamish Waterway is part of the Duwamish River salt-wedge estuary, a stratified aquatic system in which a bottom layer of saline water intrudes upriver (forming a “saltwater wedge”). The saline water moves inland up to 10 miles from the mouth of the waterway at Elliott Bay during periods of low river flow and high tide (Stoner 1967). The S. Myrtle Street Embayment is located at approximately River Mile 2.35, well within the saline sections of the estuary. The water column in this section consists of marine waters (more than 50 percent of the water column) overlain by a brackish mixing zone, overlain by a relatively thin freshwater layer. Saltwater conditions have been consistently found at least as far up channel as the 16th Avenue South Bridge (River Mile 3.4) and extend past the E. Marginal Way Bridge (River Mile 5) during low river discharges in the summer.

Aquatic mammals observed in the Duwamish River estuary include harbor seal, California sea lion, river otter, and muskrat (Dexter et al. 1981, Walker 1999, Cordell 2001). Seventy-five bird species have been documented in the Duwamish River estuary (Cordell et al. 1999). Some avian species observed in the estuary include osprey, red-tailed hawks, great blue heron, spotted sandpiper, killdeer, mallard, gadwall, Canada geese, pelagic cormorant, and western grebe (Canning et al. 1979, Cordell et al. 1999).

3.0 Site Characterization Activities and Interim Remedial Actions

Soil contamination was first discovered in 1990 at the Site in the main tank farm area following removal of the main tank farm USTs. Subsequent to that discovery, GWCC entered into an Agreed Order (No. DE-TC91-N203) with Ecology in September 1991. The Agreed Order required that GWCC perform an RI to address the nature and extent of contamination discovered during the UST removal, an environmental and health risk assessment (RA) and an FS to study and evaluate remedial options at the Site. Results of the RI were presented in a Remedial Investigation/Preliminary Risk Assessment (RI/PRA), which was submitted to Ecology in December 1993 (Hart Crowser, Inc. 1993).

Since that time, the Site has been the subject of numerous additional investigative activities and interim remedial actions. The chapter briefly summarizes the scope of activities performed by the various environmental consultants and discusses the results of past and ongoing pilot tests and interim actions. Figure 3.1 presents the current map of existing wells. Appendix B presents a list of all current monitoring wells.

3.1 SUMMARY OF PAST ENVIRONMENTAL INVESTIGATIONS AND INTERIM ACTIONS

3.1.1 Hart Crowser, Inc. (1990–1996)

GWCC retained Hart Crowser to oversee UST removals, perform the initial site assessment and fulfill the scope of work for the Ecology Agreed Order. They completed the following activities.

- **1990:** Investigated soil contamination that was discovered in the tank farm area after removal of some of the Site’s chemical storage USTs.
- **1992:** Conducted the initial remedial investigation at the former GWCC Facility and surrounding properties in order to establish the nature and extent of contamination. Wells were installed and groundwater, surface water, soil vapor, and soil sampling was conducted.
- **1994:** Collected samples of Duwamish River surface water seeps and mussel tissue. Sample collection was conducted both in the Duwamish River and at the S. Myrtle Street Embayment located directly downgradient from the former GWCC Facility. Mussel tissue, surface water, and seep sampling continued at these locations on an annual basis through 1996.
- **1995 to 1996:** Installed a soil vapor and groundwater extraction system as an Interim Remedial Measure (IRM) to begin source control of solvent releases along the Rail Spur Area of the Site. However, the soil vapor extraction and groundwater treatment system that was used was unable to meet long-term air quality discharge standards and the system was unable to operate on a routine basis.
- **1993 to 1996:** Performed investigations to obtain additional information on the extent of contamination in the vicinity of Monitoring Well B-12, where dense non-aqueous phase liquid (DNAPL) was observed in the 1st SH. Continued the annual investigations of potential impacts on surface water and mussel tissue in the Duwamish Waterway from site contaminants. Annual soil vapor and groundwater sampling was also performed.

3.1.2 Terra Vac (1997–2000)

GWCC retained Terra Vac in 1997 to perform interim remedial measurements, conduct pilot tests, and to evaluate remedial alternatives for site cleanup. Terra Vac also continued the annual groundwater, surface water, and mussel tissue monitoring program initiated by Hart Crowser, and also initiated a number of additional, discreet investigations to collect additional data to fill critical data gaps concerning the nature and extent of contamination and evaluate remedial alternatives. GWCC retained Floyd & Snider Inc. in 1998 to assist Terra Vac with preparing a Supplemental RI/FS (SRI/FS) that was submitted to Ecology in 2000 documenting the activities described below (Appendix C). The preferred alternative identified in the feasibility study was dual vapor extraction (DVE) and in-situ chemical oxidation (ISCO) in the 1st WBZ source area followed by monitored natural attenuation and potentially biosparging to reach cleanup standards in groundwater at the S. Myrtle Street Embayment. The bankruptcy of GWCC in 2001 prevented the implementation of the preferred remedial action identified in the SRI/FS. The following major activities were conducted by Terra Vac:

- **1997:** Continued the annual groundwater, surface water, and mussel tissue monitoring program initiated by Hart Crowser, and also initiated a number of additional, discreet investigations to collect additional data to fill data gaps concerning the nature and extent of contamination and better evaluate remedial alternatives. The monitoring program continued thru 1999. Results of monitoring indicated that the volatile chemicals in groundwater discharging to the LDW were not bioaccumulating in mussels. Consumption of seafood, such as mussels, is considered one of the primary exposure pathways for humans to become exposed to site contaminants.
- **1998:** Conducted a DVE pilot test at the Site in order to evaluate the effectiveness of DVE to remediate soil and groundwater impacted by VOCs and semivolatile organic compounds (SVOCs). Tested the efficacy of injecting hydrogen peroxide to reduce VOC and SVOC concentrations in groundwater at the Site.
- **1998:** Conducted an investigation to determine whether groundwater is discharging to the S. Myrtle Street Embayment through seeps or through broad areas of groundwater upwelling through sediments. Performed three separate sampling events between October and December 1998 to measure and map the distribution of chlorinated ethenes in sediment porewater. This work lead to the clear delineation of the groundwater discharge zone in the S. Myrtle Street Embayment.
- **1998 to 1999:** Performed an investigation in the Northwest Corner of the Site to evaluate the source of elevated PCE concentrations in Monitoring Wells B-13 and B-22, which are cross-gradient to the primary contamination sources found near the chemical storage tanks and along the rail spur.
- **1999:** Performed a Tidal Influence Study to assess and document the impact of Duwamish River tidal fluctuations on groundwater flow direction and hydraulic gradients at the S. Myrtle Street Embayment.
- **2000:** Performed a supplemental investigation to further assess and document the nature and extent of VOCs in soil and groundwater within the S. Willow Street ROW, north (upgradient) of the Site. Soil samples were collected, temporary wells were installed, and groundwater samples were collected from those wells.
- **2000:** Performed a supplemental investigation to determine the extent of VOC and Penta contamination on the Whitehead Property. Soil samples were collected from 11 auger borings and groundwater samples were collected from 9 temporary wells.

3.1.3 Environmental Resources Management (2003 to 2007)

Following the sale of the former GWCC assets to Fox LLC in 2003, Fox LLC retained Environmental Resources Management (ERM) to implement an expanded pilot study to assess the effectiveness of in-situ chemical oxidation using potassium permanganate and soil vapor extraction as a site-wide remedy.

- **2003 to 2004:** Performed an initial permanganate pilot study to evaluate the effectiveness of potassium permanganate and sodium permanganate chemical injections as a remedy for groundwater at the Site. Pre-injection assessment included collecting soil samples from a series of shallow Geoprobe borings along the Rail Spur Area and the outside Production Area to determine if DNAPL was still present at the Site. Additional monitoring well pairs were installed on downgradient properties as well. A SVE pilot study was conducted to show that it is a technically feasible approach for remediation of the chlorinated VOCs (CVOCs) in vadose zone soil.
- **2005 to 2007:** Operated and expanded the SVE system and continued the in-situ chemical oxidation pilot study to address soil site-wide. In total, the SVE system removed approximately 12,000 lbs of VOCs prior to being shut off after asymptotic levels were reached. Performed three rounds of potassium permanganate injections site-wide in the 1st WBZ soils and one round of injections into the 2nd WBZ on the Whitehead Property. Sampled groundwater up to eight times to assess performance of injections on reducing chemical concentrations.
- **2003–2007:** Conducted multiple rounds of groundwater sampling of various site wells to assess effectiveness of the ISCO pilot test.

3.1.4 Floyd|Snider (2008–2010)

In 2008, Fox LLC retained Floyd|Snider to conduct an interim action for groundwater and evaluate other site-wide remedial alternatives. Floyd|Snider's work was conducted under the terms of the current Agreed Order with Ecology and consisted of the following investigative or interim action elements:

- **December 2008 to Present:** Implemented an interim action for groundwater downgradient from Fox Avenue using enhanced reductive dechlorination (ERD). ERD involves injecting a soluble sugar substrate groundwater to stimulate the bacteria at the Site and naturally degrade the CVOCs in groundwater. Using CALIBRE Systems, Inc. (CALIBRE) as a subconsultant for design and field implementation, groundwater was sampled along Fox Avenue at multiple depths to define plume geometry and 11 initial injection wells (named Phase 1 wells) for ERD were installed in two downgradient transects. Following installation of the ERD wells, groundwater was sampled site-wide to establish baseline conditions. Four rounds of substrate injections were performed to date along with various groundwater sampling events to assess the effectiveness of ERD. Quarterly status reports of the ERD Interim Action were prepared for Ecology.
- **December 2008 to January 2009:** Performed a Data Gaps Investigation (DGI) to better define the location and extent of CVOC source area contamination using a Membrane interface probe (MIP) followed by focused soil and groundwater sampling using a Geoprobe (Figure 3.2).

- **March 2009:** Performed a vapor intrusion evaluation to assess this pathway of exposure at the warehouse. Samples of vapor were collected at various locations at the Cascade Columbia warehouse including inside the office, break room, interior of warehouse, and upwind and downwind of the warehouse (Floyd|Snider 2009a).
- **May 2009:** Evaluated the existing SVE system to determine if restarting the system would be effective in controlling vapor intrusion into the office area of the warehouse. Additionally, an assessment of rebound in chemical concentrations being extracted was conducted. Results indicated that restarting the SVE system would be ineffective to control vapor intrusion or extract contaminant mass.
- **June 2009:** Performed a Supplemental Source Area Geoprobe Sampling to further define the extent and depth of soil contamination in CVOC source areas, specifically in the Loading Dock Area and outside the Production Area. Three ¾-inch diameter microwells were installed and 21 soil borings were advanced using a Geoprobe. Samples of groundwater were also collected via Geoprobe (Floyd|Snider 2009b).
- **October 2010:** Performed additional Geoprobe sampling of groundwater along Fox Avenue to define the area of Phase 2 expansion of the ERD interim measure. The results of this work are reported in Appendix D.
- **November 2010:** Installed three SVE extraction wells in the Northwest Corner area of the Site. The wells were pilot tested with a blower to assess the ability of SVE to remediate CVOC contamination in the unsaturated zone in this area. The results of this work are reported in Appendix D.
- **November 2010**: Performed additional deep Geoprobe source area sampling in the warehouse area to further refine the area for deep thermal treatment. The results of this work are reported in Appendix D.

3.1.5 URS Corporation (2010)

URS Corporation (URS), on behalf of the Seattle Boiler Works property owner, conducted a vapor intrusion investigation at the Seattle Boiler Works facility in 2010. Soil vapor investigation activities included the following:

- **October 2010**: Collection of four sub-slab soil vapor samples from inside the Pipe Shop and Fabrication Shop buildings at Seattle Boiler Works. Results indicate the presence of PCE and TCE in soil gas at concentrations greater than Ecology’s screening level concentrations for unrestricted land use.
- **December 2010**: Collection of three indoor air samples over an 8-hour period from inside the Pipe Shop building, and one from an upwind outdoor ambient location. Results indicate the presence of PCE and TCE in indoor air at concentrations greater than MTCA Method B (unrestricted land use) cleanup levels but less than MTCA Method C (industrial use) cleanup levels when corrected for ambient concentrations. The ambient air sample also contained PCE and TCE at concentrations greater than the Method B concentrations.

3.2 SUMMARY OF PRIOR PILOT TESTS AND INTERIM MEASURES

This section of the report summarizes the past and current pilot tests and interim measures performed at the Site and briefly evaluates their effectiveness. The effectiveness of these past efforts are important considerations for evaluation of cleanup alternatives as they are direct evidence of which technologies can or cannot be successfully implemented at the Site.

3.2.1 Source Control Interim Remedial Measure—Hart Crowser, Inc.

In 1995, a soil vapor and groundwater extraction and treatment system was installed as an interim source control measure while final cleanup plans were being evaluated for the remainder of the Site. The system consisted of several components, including SVE piping installed in the main tank farm excavation pit following tank removal. Additionally, slots were cut into the sides of the closed-in-place tanks at the old tank farm so that these tanks could act as large vapor extraction wells. Additionally, two long horizontal groundwater extraction wells and three horizontal SVE wells installed in the Rail Spur Area of the Site where DNAPL was occasionally observed. Additionally, a monitoring well (B-12) was modified for use in the soil vapor and groundwater extraction system. Refer to Figure 3.3 for the locations of these soil vapor and groundwater extraction features.

The SVE system was designed to use a regenerative blower to extract contaminated soil vapor from the system components described above. Groundwater was to be extracted using dual diaphragm pumps from the two horizontal extraction wells and the converted Monitoring Well B-12. These components of the system were designed to lower the groundwater elevation near Monitoring Well B-12 and expose the DNAPL present in the 1st SH to vacuum influence.

Soil vapor from the extraction points was to be piped to an on-site treatment facility. Treated water was to be discharged to the sanitary sewer under permit. However, following the initial start-up of the system in the spring of 1996, a number of problems developed related to vapor destruction efficiency. The soil vapor extraction and groundwater treatment system was unable to meet long-term air quality discharge standards. Consequently, the system was unable to operate on a routine basis. Efforts to correct the problems ended in April 1997.

3.2.2 DVE/ISCO Pilot Study—Terra Vac

In the spring of 1998, Terra Vac conducted a DVE/ISCO pilot test at the Site. The purpose of the pilot test was to evaluate the effectiveness of DVE and hydrogen peroxide (OxyVac) in remediating soil and groundwater impacted by VOCs and SVOCs. Hydrogen peroxide was injected into three monitoring wells (B-12, B-31 and B-39). Groundwater analytical results indicated a large decrease in both VOC and SVOC concentrations. The results and conclusions from the pilot study were used to justify the preferred remedial action identified in the 2000 SRI/FS.

3.2.3 Expanded Pilot Study—ERM

In 2005, ERM began an expanded pilot study of the Site that consisted of expanding the existing SVE system and performing in-situ chemical oxidation to evaluate whether these two technologies, in combination with natural attenuation, would be sufficient to produce sustained reductions in chemical concentrations. Additionally, the data generated would be used to support an FS in which the final remedy for the Site would be developed. This work was conducted in three phases through 2007 (ERM 2007).

3.2.3.1 Soil Vapor Extraction Expansion

The goal of the SVE expansion was to reduce the mass of CVOCs in the vadose zone thereby reducing the potential for groundwater recontamination. ERM began by upgrading the existing SVE system by adding in a fourth component to the existing three components described above. The fourth component consisted of four new horizontal extraction wells installed in trenches within the alkaline shed and former pump house area (Figure 3.3). The blower and extraction system piping installed by Hart Crowser was upgraded to handle this new configuration. Vapors were treated by activated carbon prior to discharge under permit. The expanded system was turned on in 2005 and ran through January 2007. At the time of shut-off, the influent concentrations had decreased by 97 percent (startup concentrations of 4,155 µg/L decreased to 48 µg/L).

In total, the expanded SVE system extracted approximately 12,000 lbs of CVOCs, consisting primarily of PCE (approximately 85 percent), TCE (approximately 10 percent) and DCE (approximately 3 percent). The average mass removal rate was 9 lbs/day. Most of the contamination was removed from the area where the new horizontal wells were located. The lack of significant contaminant mass extracted from the other system components was attributed to poor system design and/or relatively less contaminant mass in those component areas.

3.2.3.2 In-situ Chemical Oxidation

The objective of the ISCO program was to evaluate the technical and economic effectiveness of a large-scale oxidant injection in the 1st WBZ on chemical concentrations in the 2nd WBZ. Furthermore, the program tested ISCO effectiveness in producing sustained reductions in CVOC mass in the 2nd WBZ. Permanganate was injected via Geoprobe in tightly-spaced locations across wide areas of the Site but primarily in the 1st WBZ groundwater. The ISCO program included two injection events in the Northwest Corner and three in the Drum Shed Area and Rail Spur Area. One limited injection event in the 2nd WBZ on the Whitehead Property was also conducted (Figure 3.4).

ERM concluded that while the ISCO injections had been successful in significantly reducing groundwater CVOC concentrations in the 1st WBZ, it took a very large mass of permanganate to achieve the results and that it was not practicable to continue the injections. There was no effect upon chemical concentrations in the 2nd WBZ and this was attributed to higher than expected levels of soil oxidant demand.

In summary, ERM concluded that the ISCO process had achieved maximum effect at the Site and another technology should be considered for to complete the remediation of site groundwater. ERM also stated that many of the remedial technologies considered by Terra Vac and Hart Crowser also did not include more recent technologies commonly used to address the type of contaminants found at the Site (e.g., enhanced bioremediation, permeable reactive barriers, and thermal treatment) and recommended conducting a revised FS.

3.2.4 ERD Interim Action—CALIBRE

The ERD Interim Action was implemented at the Site in early 2009 by CALIBRE, under subcontract to Floyd|Snider. ERD is an in-situ treatment technology that promotes accelerated anaerobic biodegradation of chlorinated ethenes in groundwater. This technology is applicable to this Site for the following reasons:

- ERD has been implemented at nearby sites in the Duwamish Valley under conditions similar to those at the Site and has demonstrated success.
- A site-specific microcosm study of ERD (a bench-scale test with site soil and groundwater) produced test results indicating that the appropriate bacteria are already present in the aquifer (ERM 2007).

- Reducing conditions are already present in the aquifer as evidenced by significant ongoing reductive dechlorination of chlorinated ethenes, as documented in the 2000 SRI/FS (Terra Vac and FSI 2000).

The objectives of the interim action were twofold:

1. Reduce the risk currently presented by chlorinated ethenes and ethanes (CEAs—PCE, TCE, and their degradation products) in site groundwater.
2. Collect technology performance data to support the FS.

The interim action was conducted in December 2008, installing 11 injection wells to treat the central area of the main plume (i.e., groundwater with CEAs greater than 1,000 µg/L). Figure 3.1 shows the locations of the current injection wells.

The screen for each injection well intersects the thickness of the entire plume (the zone targeted for treatment), typically from the water table to a depth of 65 to 70 feet bgs. The well screen intervals are segmented into sections typically 10- to 15-feet-long that are separated by 5 feet of blank casing. This design allows for targeted (and controlled) substrate injection over specific depth intervals.

The first round of substrate injection occurred in early February 2009 and subsequent injections occurred in July and December 2009 and March and December 2010/January 2011. The substrate that was injected was a solution of sucrose and other carbohydrates derived from off-specification food grade sugars. Injection was carried out under an Underground Injection Control permit/registration from Ecology. Selected injection wells and downgradient monitoring wells were sampled before substrate injections to obtain baseline conditions. Figure 3.5 shows selected graphs that demonstrate important trends in ERD results including the fluctuation and reduction of PCE over time. A full description and discussion of the performance monitoring is provided in the ERD quarterly reports sent to Ecology. A summary of performance monitoring results to date indicates the following general trends:

- Monitoring data indicate that site groundwater demonstrates a continued trend to lower redox levels (more reducing conditions); a necessary step to accelerate enhanced dechlorination. The injection wells indicate the most rapid ORP decline (from a more positive to a more negative reduction potential or stronger reducing conditions) followed by 2nd WBZ downgradient monitoring wells, and then 1st WBZ downgradient monitoring wells. The 1st WBZ downgradient monitoring wells have been much slower to react to ERD. In the spring of 2009, the substrate concentrations dropped to levels that likely slowed dechlorination, as evidenced by an increase in parent compounds in selected wells (Figure 3.5; Injection Wells R1-IW4A and Monitoring Wells B-61 and B-65). This indicates that the time frame between injections should be reduced from approximately once every 6–9 months to approximately once every 4 months in order to ensure high rates of degradation (supplying excess substrate for fermentation to generate dissolved hydrogen). The relative slowness of the 1st WBZ to change towards more reducing conditions is likely attributable to more oxidizing initial conditions due to the continued influx of oxygenated meteoric water from infiltration of stormwater.
- Some of the injection wells provide clear indication of the sequential dechlorination steps (i.e., depletion of parent products PCE and TCE and increase in daughter products cis-1,2-dichloroethene [cis-1,2-DCE], trans-1,2-dichloroethene [trans-1,2-DCE], and vinyl chloride [VC]) as shown in Figure 3.5 (R1-IW4A, R2-IW1, B-61, and B-65).

- A clear indication of the initial steps of accelerated dechlorination is demonstrated by the analytical results from Monitoring Well B-61 at 83 days post-injection—99 percent reductions in both PCE and TCE, 95 percent *increase* in cis-1,2-DCE and trans-1,2-DCE, and VC *increasing* from non-detect up to 1,200 µg/L (Figure 3.5).
- All wells tested show increased concentrations of volatile fatty acids. The presence of volatile fatty acids indicates that the injected substrate has fermented making dissolved hydrogen available for bacterial respiration.
- Dissolved gas concentrations indicative of complete dechlorination (ethane, ethene) have shown significant increases in some of the wells. Ethene is a non-toxic chemical that is mineralized very rapidly to carbon dioxide and water and is not found naturally in aquifers. Dissolved ethene was detected in a majority of the samples whereas pre-injection testing indicated non-detect levels (less than 5 µg/L), as shown in Table 3.1. The ethene data are a positive result that indicates significant VC destruction is occurring. Increased ethene concentrations imply that the ERD process has accelerated the naturally-occurring dechlorination process.
- The majority of 2nd WBZ performance data indicate a material reduction in total CEA concentrations, including the two injection wells installed on Seattle Boiler Works (R2-IW1 and R2-IW2; Figure 3.5). However, a limited number of wells are counter to this trend and show occasional increases in total CEAs, indicating a lack of sufficient substrate and/or eventual exhaustion of substrate by bacteria. The most downgradient monitoring wells at S. Myrtle Street have not yet shown significant decreases in CEAs. An increase in CEA concentrations actually occurred, which is common during the preliminary phases of an ERD treatment process because ERD (by nature and design) generates the lesser chlorinated daughter products.

In summary, performance monitoring data demonstrate that the interim action is changing the reductive nature of the aquifer to be more amenable to the accelerated degradation of solvents. However, as described above, there are a limited number of wells where total CEA concentrations increased, which is most likely due to continued input of CEAs from the upgradient source area, stressing the need for aggressive source control at this Site.

3.2.5 Northwest Corner ERD and SVE Pilot Study

In late 2010, an ERD and SVE pilot study was conducted in the Northwest Corner by CALIBRE. The purpose of the SVE pilot test was to evaluate if SVE was an appropriate technology to remediate unsaturated zone soil in this area. SVE was considered for pilot testing as past data did not indicate the presence of a well-defined soil source that could be directly addressed by other methods (e.g., excavation, thermal treatment). It has been difficult to identify the source of the plume in this area and it has been assumed that, in the absence of a major contributing source, the source(s) is likely from various minor spills that occurred along S. Willow Street during historical operations—possibly related to the rail spur that runs along S. Willow Street. SVE is a low cost and very effective technology to remediate solvents from sandy, unsaturated soils and has a wide radius of influence. The purpose of the ERD pilot study was to verify if the 1st WBZ soils in this location would accept injection of adequate volumes of substrate.

To perform the pilot test, three 4-inch diameter wells (designed for long-term ERD injections) were installed in the Northwest Corner parking lot. Each of these wells was connected to a temporary blower that extracted subsurface vapors from each well for a 4- to 8-hour period. Vacuum influence in the remaining wells was measured. Vapor samples of the blower effluent were collected during the mid-point of each test from each well and analyzed for VOCs. The results indicate that the blower had a radius of influence of around 30 to 50 feet from each well. It was estimated that 1 to 2 lbs/day of PCE can be extracted from a system using 4 new vapor extraction wells hooked up to a central blower. It was also discovered that the concentration of PCE in the soil vapor was in equilibrium with the concentration of PCE found in the underlying groundwater, suggesting that the source of the Northwest Corner Plume is possibly, in part, driven by downward migration of vapors to the water table. Therefore, if the vapors could be controlled and removed by a SVE system, the groundwater may show a significant improvement in quality. CALIBRE made a recommendation to recover the vapors by installing a 4-well SVE system, as discussed in the FS (Section 11.0). A report summarizing the 2010 ERD and SVE pilot study is included in Appendix D.

4.0 Identification of Chemicals of Concern and Cleanup Levels

4.1 INTRODUCTION AND SECTION ORGANIZATION (BY MEDIA)

A large number of environmental samples have been collected at the Site over the previous 2 decades as part of the activities described in Section 3.0. A variety of environmental media have been sampled at the Site, including soil, groundwater, indoor air, seeps, surface water, sediments, and mussel tissue. The table below shows the media and the analyte groups that were tested.

Site Samples	VOCs	SVOCs	Metals	TPH	Others
Soil	X	X	X	X	Glycols and Alcohols, Dioxins
Groundwater	X	X	X	X	Alcohols, Dioxin
Air	X				
Lower Duwamish Waterway (S. Myrtle Street Embayment) Samples					
Seeps	X	X			
Surface Water	X	X			
Mussel Tissue	X	X			
Sediment	(porewater)	X	X		Dioxins, PCBs, Pesticides/Herbicides

Abbreviations:

PCB	Polychlorinated biphenyls
SVOC	Semivolatile organic compound
TPH	Total petroleum hydrocarbons
VOC	Volatile organic compound

Appendix F contains summary tables of all sampling results. These tables are sorted first by media, then by location. Appendix G contains frequency of detection summaries for all COCs, which are sorted by media, then by analyte group.

Samples from soil, groundwater, and air throughout the Site were evaluated in the following steps to identify chemicals of concern (COCs) for the Site. Soil and groundwater data were collected from both the historical GWCC property and from adjacent and downgradient properties. Air samples were collected from both indoors and outdoors at the historical GWCC Facility in 2000 and again at the Cascade Columbia Facility in 2009 (Floyd|Snider 2009a). Indoor air samples were also collected at the downgradient Seattle Boiler Works facility by the owner's consultant in 2010 (Appendix E). The steps for identifying the COCs were as follows:

- Step 1—Identify Detected Chemicals by Media
- Step 2—Develop Preliminary Cleanup Levels for Detected Chemicals by Media
- Step 3—Compare Concentrations of Detected Chemicals to Preliminary Cleanup Levels

4.2 CHEMICALS IDENTIFIED IN SOIL, GROUNDWATER, AND AIR

4.2.1 Soil

Soil samples were analyzed for the following chemical groups:

- VOCs by USEPA Method 8260
- SVOCs by USEPA Method 8270
- TPH by various state methods, including NWTPH-G, NWTPH-Dx, NWTPH-HCI, NWTPH-EPH, and other older methods
- Glycols and alcohols by various methods
- Metals by various USEPA methods

The organic chemicals that were detected in 5 percent or more of the soil samples are presented in Table 4.1. Table 4.2 lists the metals that were detected in site soil samples. Those chemicals that were analyzed, but not detected in the soils are reported in Table F.1 in Appendix G with the soil reporting limits. Table F.2 lists additional chemicals that were detected, but in less than 5 percent of the samples. A review of the soil data presented in these tables indicates the following:

- PCE, TCE, and their degradation products are present throughout the Site and at very high concentrations in some of the soil samples. The primary DCE isomer is cis-1,2-DCE (detected in more than 60 percent of the samples as either the cis isomer or, in the older data, as total 1,2-DCE). The two other DCE isomers, trans-1,2-DCE and 1,1-DCE are both detected in less than 5 percent of the samples and at much lower concentrations.
- Methylene chloride and acetone, also solvents, were detected in more than 5 percent of the soil samples.
- Semivolatile chemicals detected in greater than 5 percent of the soil samples included 6 polycyclic aromatic hydrocarbons (PAHs), 2 phthalates, and 3 chlorinated phenols. The phthalates are common plasticizers. The chlorinated phenols are dominated by Penta and include lesser chlorinated phenols that are typically present in commercial-grade Penta (ATSDR 2001).
- TPH and its individual aromatic components (benzene, alkylated benzenes, and PAHs) were detected in a large number of samples in the source area of the Site. Benzene was detected in less than 5 percent of the samples, and the primary TPH concentrations are consistent with the presence of petroleum-based solvents (as mineral spirits, thinner, stoddard solvents, etc). The suite of alkylated benzenes and PAHs is also consistent with being associated with general “mineral spirits” range of petroleum products. This range contains much lower levels of benzene than gasoline, and is consistent with the limited occurrences of benzene at the Site (ATSDR 1995).
- The concentrations of aluminum, barium, chromium, and nickel are all within background ranges for their concentrations in soil and will not be discussed further.
- Arsenic, cadmium, copper, lead, mercury, and zinc all were detected at maximum concentrations greater than the background value for Puget Sound soils established by Ecology.

4.2.2 Groundwater

Groundwater samples were analyzed for the following chemical groups:

- VOCs by USEPA Method 8260
- SVOCs by USEPA Method 8270
- TPH by various state methods, including NWTPH-G, NWTPH-Dx, NWTPH-HCID, NWTPH-EPH, and other older methods
- Glycols and alcohols by various methods including USEPA Method 8015M
- Metals by various USEPA methods

Groundwater has been monitored at the Site since the late 1980s and a significant amount of data exists, although much of it predates the extensive interim measures conducted on the Site since 2000 and so is of very limited use in assessing current conditions.

Table 4.3 lists those organic chemicals that were detected in 5 percent or more of the groundwater samples since 1990. The table also lists the maximum detected concentration of each chemical since 2007.

Table 4.4 lists the frequency of detection and maximum concentrations for metals in groundwater in the same format as Table 4.3. Table 4.4 shows that the interim measures have had little to no effect on the metal concentrations. The 2000 SRI did not identify any metals as COCs for the Site, so no interim measure has targeted metals. It should be noted that the majority of metals data available for this Site are in the dissolved fraction because the surface water standards that form the basis for the site cleanup levels regulate the dissolved, not total fraction, in water.

Table F.3 in Appendix G lists the chemicals that were analyzed for, but never detected in groundwater and their reporting limits. Table F.4 lists additional organic chemicals that were detected, but in less than 5 percent of the samples. Table F.5 lists the organic chemicals that were detected in mussel tissue samples collected between 1990 and 2000. Table F.6 lists the organic chemicals that were not detected in the mussel tissue samples. PCE, TCE, cis-1,2-DCE, and VC were not detected in any of the mussel tissue samples.

Table F.7 in Appendix G lists the chemicals that were analyzed for, but never detected in seeps and their reporting limits. Table F.8 lists additional organic chemicals that were detected, but in less than 5 percent of the seep samples. Table F.9 lists the chemicals that were detected in 5 percent or more of the seep samples since 1990. Table F.10 in Appendix G lists the chemicals that were analyze for, but never detected in surface water. Table F.11 lists the chemicals that were detected in surface water.

A review of the groundwater data presented in these tables indicates the following:

- As with soil, PCE and TCE and their degradation products are the dominant contaminants in groundwater. Although concentrations have been significantly reduced by the interim measures at the Site, concentrations are still elevated for both parents and degradation products.
- A minor amount of the solvent 1,1,1-trichloroethane (1,1,1-TCA) and its degradation products (two dichloroethane isomers) are present in groundwater.

- The concentrations of two other chlorinated solvents, chloroform and methylene chloride, that were discovered in the early 1990s have decreased by several orders of magnitude. Methylene chloride is no longer detectable at a reporting limit of 1 µg/L.
- Petroleum contamination as measured by TPH, benzene, and alkylated benzenes, and PAHs has significantly decreased since the early 1990s due to a combination of natural degradation and interim measures; however, petroleum contamination still exists in groundwater.
- Penta was a COC for groundwater in the original RI. Its concentrations have decreased over time due to a combination of natural degradation and interim measures, but are still detectable within the Site.
- Glycols and alcohols were present in site groundwater during the original RI, but were not identified as COCs and have not been measured since.
- Metals were not found to be COCs in the original RI, but are still detected in groundwater and will be screened again in Sections 4.3.2 and 5.8.

4.2.3 Air

Indoor and ambient air samples were analyzed in 2000 at the Site for the following chemical group:

- VOCs by USEPA Method 8260

Table 4.5 lists organic chemicals that were detected in one or more air samples. Additional indoor sampling was performed in 2009 within the Cascade Columbia Building to specifically assess the potential for vapor intrusion from the contaminated vadose zone beneath the building. The 2009 sampling was limited to the COCs identified in 2000 (PCE, TCE, methylene chloride, and benzene). In addition, the 2010 URS study of indoor air at the Seattle Boiler Works facility was conducted to assess the potential for vapor intrusion from the downgradient groundwater plume. Sampling was limited to PCE, TCE, DCE, and VC. Sampling results from 2009 and 2010 are summarized in Section 4.4.4 below and in Table 4.6. Table F.12 in Appendix G lists the chemicals that were analyzed for, but never detected, in air during any of the above mentioned events, and their reporting limits.

A review of the air data presented in these tables indicates the following:

- PCE, TCE, DCE, and 1,1,1-TCA were detected in indoor air in 2000. PCE and TCE were detected within the Cascade Columbia warehouse in 2009 at concentrations greater than ambient levels. These two compounds were also detected in the downgradient Seattle Boiler Works Pipe Shop in 2010 greater than ambient levels.
- 1,1-DCE and VC were initially retained as COCs in 2000 because of their presence in soil and/or groundwater and their low cleanup level in indoor air; however, they were not detected in air samples taken later in 2000 and were therefore not analyzed in 2009.
- VC and cis-1,2-DCE were detected in samples collected at the Seattle Boiler Works facility in 2010 greater than laboratory detection limits. Also, trans-1,2-DCE was analyzed and not detected in any samples collected during the Seattle Boiler Works event.

- Benzene and several alkylated benzenes were detected in 2000. Based on the 2000 cleanup levels, only benzene was retained as a COC. Benzene was analyzed for and detected in the 2009 indoor air samples collected in the Cascade Columbia building.
- Several additional volatile organics were detected in 2000 and compared to indoor air cleanup levels, only methylene chloride was retained as a COC. It was analyzed for and detected in the 2009 indoor air samples.

4.3 PRELIMINARY CLEANUP LEVELS AND CHEMICALS OF CONCERN

4.3.1 Soil Preliminary Cleanup Levels and Chemicals of Concern

The following pathways were considered for the establishment of preliminary soil cleanup levels at the Site:

- Protection of human health via direct exposure using MTCA Method C for industrial workers.
- Protection of ecological receptors. Because the Cascade Columbia Facility is paved with active industrial operations, and will remain paved for the foreseeable future, an ecological evaluation is not required under MTCA. Institutional controls will ensure the industrial future use of the property.
- Protection of groundwater resources from chemicals leaching from soil.
- Protection of indoor air from vapor intrusion from contaminated soil.

In developing cleanup levels, the following site-specific information is relevant:

- The Fox LLC property and the adjacent properties that make up the Site are zoned industrial. This area has been an industrial area since the 1920s. Furthermore, the City of Seattle has identified this area for future industrial land use and redevelopment. For these reasons, industrial land use exposure assumptions have been applied to the Site.
- The Fox LLC property is presently covered with buildings or pavement. Although the direct exposure pathway will be considered in setting cleanup levels, it should be understood that direct exposure to contaminated soil is currently a “blocked” pathway.

Table 4.7 compares the concentration of chemicals detected in the upper 15 feet of the Site to cleanup levels based on direct contact with soil using both MTCA Method B (unrestricted land use) and MTCA Method C (industrial land use) values. The upper 15 feet of the Site is used because it is the standard point of compliance (POC) for soil under MTCA when considering direct contact risks. Only PCE has a maximum soil concentration that exceeds the Method C direct contact value and such soil only occurs within the Fox LLC property boundary as shown in the table below.

MTCA Method C Soil Cleanup Levels Based on Direct Contact

Chemical of Concern	Preliminary Cleanup Level	Maximum Detected Concentration Within Property	Maximum Detected Concentration Off Property
Tetrachloroethene (PCE)	240 mg/kg	3,930 mg/kg (under Flammables Shed)	18 mg/kg (along S. Willow Street)

The table above indicates that currently soil on-site is contaminated with PCE at concentrations that exceed the industrial Method C direct contact cleanup level; however, the MTCA Method C cleanup level of 240 mg/kg is not considered sufficiently protective of other media, such as groundwater and soil, and will not be selected as the final cleanup level for site soil.

4.3.1.1 Soil for Protection of Indoor Air and Groundwater

In Section 5.0, the COCs will be re-evaluated in regard to the potential for contaminants in one media to impact another media. As mentioned above, the preliminary PCE cleanup level for soil based on direct contact is not sufficient to protect groundwater or indoor air, so will not be selected as the final cleanup level. In addition, there are other VOCs in site soil that present risk to groundwater and/or indoor air. These cross-media issues will be identified and clarified, first in Section 5.0 where the nature and extent of these COCs are discussed, and then further in Section 6.0 where the conceptual site model is developed. Finally, Section 7.0 presents the proposed final COCs, cleanup levels, and points of compliance and identifies the areas on-site that require remedial action. As explained in Section 7.0, empirical groundwater and indoor air data will be used to demonstrate compliance with soil cleanup levels.

4.3.1.2 Dioxins

Because part of the Site contains Penta and dioxins/furans are a known contaminant of older grade commercial Penta, soil samples were collected in areas with high a concentration of Penta in soil and tested for dioxins as part of the 2000 SRI/FS. The concentrations were screened against risk-based exposure concentrations and were found not to exceed regulatory criteria. This screening was performed in the original RI; however, the method used for calculating toxicity equivalent concentrations under MTCA has changed in recent years, and Ecology requested that dioxins be evaluated again.

Dioxin/furan values were recalculated using the current MTCA Human Health Risk Assessment procedures as stated in WAC 173-340-708(8)(d). Dioxins/furans are generally present in the environment as a complex mixture of chemical congeners that differ in terms of the number and location of chlorine atoms. The most toxic and best-studied of the dioxin/furan congeners is 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD). Because of the need to evaluate the risks associated with the mixture of congeners, the toxic equivalency factor (TEF) methodology is used. A TEF value is assigned to each congener relative to the toxicity of TCDD. The total toxic equivalency quotient (TEQ) of a mixture is the sum of the products of the concentration of each congener in a sample and the congener’s corresponding TEF value. The TEF values used to calculate the TEQs are presented in MTCA Table 708-1 (Ecology 2007).

Table 4.8 presents the results for dioxin/furan congeners and the total TEQ for the detected dioxin/furan congeners in each sample from the original RI. Table 4.8 also presents the dioxin/furan TEQ for each sample using one-half the detection limit for each dioxin/furan congener that was not detected. The dioxin/furan TEQs calculated using just the detected dioxin/furan congeners are compared to screening criteria.

The TEQ results for dioxin/furan analyses are compared to MTCA Method C criterion of 1,500 picograms per gram (pg/g) for 2,3,7,8-TCDD that was provided in Ecology's CLARC database. The comparison indicates that the concentration of dioxin/furan (that only occurs as a trace contaminant in Penta) at the Site is significantly less than the applicable criterion, reconfirming that dioxin/furans are not a COC for the Site.

As discussed in Section 1.2, stormwater from the Cascade Columbia Facility historically and currently discharges to the sanitary sewer (and not to the Duwamish Waterway), therefore, the Penta/dioxin contamination in subsurface soil at the Site is not (and never was) transported via stormwater to the Duwamish Waterway.

4.3.1.3 Total Petroleum Hydrocarbons

TPH are present mostly at the Site as a mineral spirit-range hydrocarbon. Mineral spirits primarily consist of C_7-C_{12} alkanes, cycloalkanes, and aromatic hydrocarbons and are commonly referred to by their commercial names or mixtures such as Stoddard's solvent. Generally, the aromatic content of mineral spirits is between 5 and 15 percent and is dominated by the trimethylbenzenes (ATSDR 1995). The standard MTCA Method A Cleanup Level for TPH is based on the protection of groundwater for drinking water consumption, and is overly conservative if used for protection of workers via the direct contact pathway. However, a site-specific TPH cleanup level protective of human health via direct contact to workers can be determined if site-specific TPH fractionation data are available. Samples representative of mineral spirits were collected during the Supplemental Geoprobe Investigation in June 2009 and analyzed for TPH fractionation using standard Ecology methodologies (Floyd|Snider 2009b). Appendix H contains a summary of the data and the Ecology worksheets that input the fractionation data and calculate the site-specific values for mineral spirits as presented in Table 4.7. The results indicated a protective worker direct contact concentration of 41,500 mg/kg, higher than the maximum concentration reported at the Site of 6,500 mg/kg, detected in 1990 during the original removal of the USTs.

Site-specific cleanup levels were not derived for diesel-range or motor oil-range TPH. As presented in Table 4.7, the standard MTCA Method A cleanup level of 2,000 mg/kg was used for diesel-range and motor oil-range TPH. This cleanup level is not based on direct contact (that concentration is significantly higher), but is defined as the lowest concentration where free product might form (WAC 173-340-900 Table 740-1, footnote S). There were no exceedances of diesel-range TPH cleanup levels. There were three exceedances of the Method A level for motor oil-range TPH. Two of the exceedances were in surface soil and one exceedance was in subsurface soil, with all three exceeding samples in the railroad ROW. There is no indication of free product in adjacent groundwater wells.

4.3.2 Groundwater Preliminary Cleanup Levels and Chemicals of Concern

The following pathways were considered for the establishment of preliminary groundwater cleanup levels at the Site:

- Protection of surface water resources, based on the discharge of groundwater into the Duwamish River at the S. Myrtle Street Embayment. The surface water resources will be protected for both human health (via the consumption of VOC-contaminated aquatic organisms) and ecological receptors.

- Protection of indoor air at the Cascade Columbia Facility and downgradient properties from vapor intrusion from contaminated groundwater in the 1st WBZ (and overlying soil).
- Protection of sediment in the LDW was *not* considered a pathway because VOCs are not regulated under the Sediment Management Standards (SMS) due to their chemical properties that prevent them from partitioning to sediments.

In developing cleanup levels for the Site, the following site-specific information is relevant:

- Groundwater at the Site is within a tidally-influenced section of the Lower Duwamish Valley as is discussed in Sections 2.5 and 2.6. The section of the aquifer in which the Site is located is non-potable, and its maximum beneficial use is protection of adjacent surface water resources in the LDW.
- The Fox Avenue Building and the adjacent properties that make up the Site are zoned industrial. This area has been an industrial area since the 1920s. Furthermore, the City of Seattle has identified this area for future industrial land use and redevelopment. For these reasons, industrial land use exposure assumptions have been applied to the Site.
- The water in the LDW is saline and qualifies as a marine waterbody. However, the system is a layered system during most of the year with a thin layer of fresh water above a brackish mixing zone above the much larger saline zone.

4.3.2.1 Protection of Aquatic Species

The following promulgated standards were used to identify concentrations that would be protective of aquatic species in marine and/or freshwater environments:

- Washington State Surface Water Quality Standards WAC 173-201A
- National Toxics Rule 40 Code of Federal Regulations (CFR) 13
- National Recommended Water Quality Criteria

There are no promulgated standards available for the protection of aquatic organisms (i.e., toxicity) for most VOCs. However, there are some ecologically relevant toxicity data available in the literature. The Lower Duwamish Waterway Group (LDWG) conducted an extensive literature review of available VOC toxicity data as part of its porewater data and analysis document (Windward 2006). These VOC values identified by the LDWG were used for screening purposes as shown in Table 4.9.

4.3.2.2 Protection of Human Health

Consistent with MTCA requirements in WAC 173-340-730(3) for selecting Method B surface water cleanup levels, the following promulgated standards were used to identify concentrations that would be protective of human health based on the consumption of seafood:

- Washington State Surface Water Quality Standards WAC 173-201A
- National Toxics Rule 40 CFR 13
- National Recommended Water Quality Criteria

Consistent with the regulation, MTCA equations for the calculation of cleanup levels based on fish consumption were only used when there were no promulgated standards for that pathway.

4.3.2.3 Preliminary Groundwater and Seep Cleanup Levels

The applicable cleanup levels for groundwater are listed in Tables 4.10 and 4.11. Where multiple criteria were available for a chemical, the lowest value was selected, consistent with MTCA (WAC 173-340-730 (3)(i)). The following table contains a summary of those chemicals that were detected at concentrations greater than the proposed cleanup levels in groundwater samples collected since 2007.

Chemical of Concern	Preliminary Cleanup Level	Maximum Concentration Measured Since 2007
Tetrachloroethene	3.3 µg/L	64,000 µg/L
Trichloroethene	30 µg/L	44,000 µg/L
1,1-Dichloroethene	3.2 µg/L	110 µg/L
Vinyl Chloride	2.4 µg/L	15,600 µg/L
Benzene	51 µg/L	64 µg/L
Bis(2-ethylhexyl)phthalate	2.2 µg/L	1,900 µg/L[1]
TPH-Mineral Spirits Range	800 µg/L	6,400 µg/L
TPH-Heavy Oil Range	500 µg/L	1,100 µg/L
Pentachlorophenol	3.0 µg/L	116 µg/L
Copper	8.0 µg/L	55 µg/L
Nickel	8.2 µg/L	21 µg/L

Note:

1 Bis(2-ethylhexyl)phthalate concentrations are from the older (pre-2007) data; semivolatile organic compounds have not been measured in recent years. Refer to Section 5.0 for details.

Only a few compounds were detected in the seeps at concentrations greater than the proposed cleanup levels. These compounds are summarized in the following table.

Chemical of Concern	Preliminary Cleanup Level	Maximum Concentration Measured in Seeps Since 2007
Tetrachloroethene	3.3 µg/L	55 µg/L
Trichloroethene	30 µg/L	30 µg/L
1,1-Dichloroethene	3.2 µg/L	4.85 µg/L
Vinyl Chloride	2.4 µg/L	1,400 µg/L

4.3.2.4 Manganese and Iron

Iron and manganese groundwater concentrations at this Site are perturbed by the Interim Measures that have been performed at the Site, and will be further perturbed during remedial action. Iron and manganese are naturally-occurring major metals (those present at percent levels) in the soils. When redox conditions in groundwater are strongly reducing, iron and manganese will dissolve from native soils. At the Site, naturally-occurring biodegradation of petroleum products would consume the available oxygen in groundwater and drive the groundwater to reducing conditions. The reducing conditions would, in turn, result in the facilitated biological degradation of PCE and TCE and their degradation products. ERD interim measures further reduce the groundwater redox potential to intentionally drive VC degradation to the non-toxic ethene and ethane gases. Further, the ISCO interim measure added manganese (as permanganate) as a reagent to the groundwater.

Groundwater at the Site is in an anaerobic state (reducing conditions) hence, manganese and iron will remain dissolved in groundwater naturally. The redox/natural attenuation chemical data are presented in Table F.13 in Appendix G.

Iron was detected in 17 of 21 groundwater samples between 1992 and 2009 and the iron concentration in 15 samples exceeded the lowest proposed screening criterion of 1 mg/kg. Manganese was detected in 33 of 35 groundwater samples during this period, and the manganese concentration in 27 samples exceeded the lowest proposed screening criterion of 0.1 mg/kg.

The concentrations of both iron and manganese in groundwater are expected to return to background concentrations after perturbations to the local redox conditions have ceased and the redox potential returns to equilibrium conditions; background concentrations may remain greater than screening levels if equilibrium conditions are naturally-reducing due to natural organic matter in the aquifer. Iron and manganese are not considered COCs.

4.3.3 Preliminary Indoor Air Cleanup Levels and Chemicals of Concern

The following pathways were considered for the establishment of preliminary indoor air cleanup levels at the Site:

- Protection of human health via inhalation using MTCA Method C for industrial workers (at the Cascade Columbia building)
- Protection of human health via inhalation using MTCA Method B for Seattle Boiler Works

In developing cleanup levels for the Site, the following site-specific information is relevant:

- The Fox Avenue Building and the adjacent properties that make up the Site are zoned industrial. This area has been an industrial area since the 1920s. Furthermore, the City of Seattle has identified this area for future industrial land use and redevelopment. For these reasons, industrial land use exposure assumptions have been applied to the Fox LLC property.
- The Seattle Boiler Works property owner will not accept a covenant that restricts future property use to industrial; therefore, Ecology directed that MTCA Method B cleanup levels been applied to the Seattle Boiler Works property.
- Current uses at both the Cascade Columbia and Seattle Boiler Works properties are industrial, and both facilities are currently zoned for industrial use.

Standard MTCA Method B and Method C cleanup levels to protect air quality exist for the individual COCs as derived using the equations in WAC 173-340-750. The MTCA C levels are based on protection of industrial workers, which is the applicable current exposure scenario for this Site. The MTCA B levels are based on a residential exposure scenario, which is not the current exposure scenario for the downgradient Seattle Boiler Works facility.

Chemical of Concern	Unit	MTCA C Preliminary Cleanup Level	MTCA B Preliminary Cleanup Level[1]	Maximum Detected Concentration at Cascade Columbia 2009[2]	Maximum Detected Concentration at Seattle Boiler Works 2010[2]	Cascade Columbia/ Seattle Boiler Works Background
PCE	µg/m^3	4.2	0.42	**75**	**3.0**	0.37 to1.5
TCE	µg/m^3	1.0	0.10	**1.1**	**0.22**	<0.18 to 0.20
Methylene Chloride	µg/m^3	53	5.3	2.4	Not sampled	<0.23
Benzene	µg/m^3/	3.2	0.32	2.7	Not sampled	1.3

Notes:

Bold results indicate that the concentration exceeds the preliminary cleanup level.

1 MTCA Method B CULs were required for the Seattle Boiler Works property by Ecology because the property owner will not currently agree to a covenant restricting future use to industrial. MTCA Method C CULs are appropriate for the Fox LLC property assuming the property is restricted to industrial use.

2 The concentrations shown were adjusted downward to account for ambient concentrations at the time of sampling in accordance with the Draft 2009 Ecology Guidance for Evaluating Vapor Intrusion (Ecology 2009b).

Abbreviations:

PCE	Tetrachloroethene
TCE	Trichloroethane

The sampling results from the 2009 and 2010 events indicate that outdoor (ambient) air at Cascade Columbia was in compliance with Method C cleanup levels, but outdoor (ambient) air collected at the Seattle Boiler Works facility was not in compliance with MTCA B cleanup levels. Indoor air samples taken at the Cascade Columbia facility above the slab foundation of the office area exceeded the MTCA Method C standards for PCE and TCE. Benzene concentrations in indoor air at Cascade Columbia were less than MTCA C standards and consistent with the concentrations of benzene detected in outdoor ambient air.

PCE and TCE concentrations detected in indoor air in the Seattle Boiler Works Pipe Building were greater than Method B cleanup levels but less than Method C when results were corrected for background (in accordance with Section 3.2.3 of Ecology's *Guidance for Evaluating Soil Vapor Intrusion in Washington State: Investigation and Remedial Action*; Ecology 2009b). DCE and VC were detected, but at concentrations less than the MTCA Method B cleanup levels.

4.4 SUMMARY

The following chemicals have been identified as COCs for the Site and will be discussed in further detail in the Nature and Extent Section, Section 5.0.

Chemical of Concern	Soil-Protective Direct Contact	Groundwater-Protective of Surface Water	Air
Tetrachloroethene (PCE)	Yes	Yes	Yes
Trichloroethene (TCE)	No (less than CUL)	Yes	Yes
1,1-Dichloroethene (1,1-DCE)	No (less than CUL)	Yes	No, Not Detected
Vinyl Chloride	No (less than CUL)	Yes	No (less than CUL)
Benzene	No (less than CUL)	Yes	No (less than CUL)
Bis(2-ethylhexyl) phthalate	No (less than CUL)	Yes	No, Not Volatile
TPH	No (less than CUL)	Yes	No, Not Volatile
Pentachlorophenol	No (less than CUL)	Yes	No, Not Volatile
Copper	No (less than CUL)	Yes	No, Not Volatile
Nickel	Less than Background	Yes	No, Not Volatile

Abbreviations:

CUL Cleanup level

TPH Total petroleum hydrocarbons

5.0 Nature, Fate, and Extent of Chemicals of Concern

This section discusses the historical chemical usage and releases on-site and describes the primary source areas and the resultant groundwater plumes followed by the current nature, fate, and extent of the site COCs. Section 5.1 describes the historical chemical usage and releases on-site and describes the primary source areas and the groundwater plumes. The remaining sections describe the physical properties, current contamination extent, and behavior of each COC. Understanding the chemical-specific properties and the nature of the COCs—in addition to the site geologic conditions described in Section 2.0—are necessary to understanding the fate of the chemical contaminants.

5.1 HISTORICAL CHEMICAL USAGE

5.1.1 Chlorinated Volatile Organic Compounds

Historical operational releases, including UST and line leaks, appear to have contributed substantial contamination to the surrounding soil and groundwater in the areas on the Site near the former main UST area and the location of the drum shed, old tank farm, and associated underground piping near Frontenac Street. As discussed in Section 3.0, these areas have undergone several interim measures, including decommissioning of USTs and piping, removal of portions of the contaminated soil, and use of a soil vapor extraction system and in-situ chemical oxidation remove VOCs from the source areas. Although residual contamination exists in the vadose zone and the underlying saturated soil, there is no ongoing operational source of these compounds, as all of the USTs in the former main tank farm have been decommissioned, and the handling of chemical products for the dry cleaning business (the principal PCE source) was discontinued in 1992.

CEAs are also found in soil and groundwater near the loading dock. Although CEAs were not permanently stored in the loading dock, dry cleaning solvents were placed in bins and temporarily stored on the loading dock until customers picked them up. It is likely that spills occurred in this area over several years.

5.1.2 Total Petroleum Hydrocarbon

A variety of petroleum solvents in the mineral spirits family were historically stored in USTs at various times in the old tank farm area. These petroleum products were likely released to soil and groundwater during handling or storage on-site. Additionally, a small, leaking tank containing gasoline was located in the Loading Dock Area near Well B-10A. Because all of the USTs have been removed or decommissioned, there is no ongoing source of petroleum products. Based on product usage and a review of TPH chromatographs from across the Site, the primary petroleum products released would have been in the mineral spirits family of petroleum solvents, with a small release of gasoline at the loading dock.

5.1.3 Pentachlorophenol

Penta handling at the historical GWCC Facility began in approximately 1966 and ended in the early 1980s. No Penta has been stored or handled at GWCC since about 1985. The second Penta source area is outside of the Site and was identified during the installation of the groundwater well pair B-38 and B-39 in the 1990s. This second Penta source area is located near the dip tank at the former Tyee Lumber Facility adjacent to S. Myrtle Street (Figure 2.2).

This source area includes the previous location of a wood-treating dip-tank in which lumber was "dipped" into the Penta/petroleum spirits treating solution to preserve the wood. Additionally, the area included a UST for stored Penta that was removed from the Whitehead Property in 1986 (Section 3.0).

5.1.4 Phthalates

Phthalates are not known to have been produced or handled at the Site. No phthalates were identified as COCs for soil; bis(2-ethylhexyl)phthalate was identified as a possible COC for groundwater. Bis(2-ethylhexyl)phthalate was also a common lab contaminant in the groundwater samples, and it is not clear whether the detections represent environmental concentrations or lab contamination. The extent of bis(2-ethylhexyl)phthalate contamination is discussed below.

5.1.5 Metals

Metals are not known to have been historically handled or stored at the Site. No metals were identified as COCs for soil. Only two metals, copper and nickel, were detected in groundwater at concentrations greater than cleanup levels. However, their occurrence does not appear to be related to chemical releases at the Site. The occurrence of metals in groundwater will be discussed below.

5.2 SOURCE AREAS AND DOWNGRADIENT PLUMES

The majority of contamination at the Site originates from well-defined source areas. Volatile and other mobile chemicals have migrated in groundwater to the S. Myrtle Street Embayment, but non-mobile contaminants such as Penta, remain localized in their source area. The Site has been broken into the following areas to facilitate discussion of the nature and extent of contamination and the evaluation of remedial alternatives:

- **Main Source Area:** The Main Source Area consists of contaminated soil in the vadose zone, the 1stWBZ, and 2nd WBZ. The Main Source Area extends from under the Flammables Shed and Production Area to the southern part of the Site beneath the railroad tracks on Frontenac Street and under a small northern section of the Whitehead Property. Current and historical soil contamination in this area gives rise to groundwater plumes in the 1st and 2nd WBZs that extend cross the corner of the Whitehead Property that lies between the Fox Avenue ROW.

  The Loading Dock Source Area is a subarea of the Main Source Area. Contamination in this area is limited to the vadose zone and 1st WBZ, and does not extend to the 2nd WBZ.

- **Northwest Corner Source Area:** The Northwest Corner Source Area is located in the northwest corner of the Site in the parking lot. The soil source area is bounded by S. Willow Street to the north and Fox Avenue on the southwest side. The contamination in the northwest corner parking lot is likely due to scattered releases, none apparently substantial enough to create a definitive soil "hot spot." Vapor transport in the vadose zone may also have contributed to contamination in this area. The groundwater plume is limited to the 1st WBZ.

- **Downgradient Groundwater Plume:** The Downgradient Groundwater Plume extends from the source areas southwest towards the S. Myrtle Street Embayment, where it discharges into the LDW.

The extent of COCs in these areas is addressed further in the following sections.

5.3 CHEMICAL PROPERTIES

The site COCs are grouped by similarities in chemical and physical properties because these properties influence their fate and transport and the selection of remedial technologies. The following properties were considered especially relevant at this Site:

- **Volatility:** Chemicals with low boiling points and high vapor pressures are considered volatile and are likely to move from soil and shallow groundwater into the pores in the unsaturated vadose zone. Once they are present in soil gas, they have the potential to migrate in the vadose zone (from the source area) by diffusion and convection. They also have the potential to enter buildings through cracks in the foundation (vapor intrusion). PCE and its degradation products are volatile, with PCE the least volatile and VC (a gas at room temperature) the most volatile.
- **Solubility and Hydrophilic Properties:** Chemicals with high aqueous solubilities and low partitioning coefficients (Kd and/or Kow) tend to dissolve into groundwater and remain in groundwater for longer periods of time; increasing their ability to migrate in groundwater. VC is so hydrophilic that dissolved VC will migrate as fast as the groundwater moves because it does not partition to soil organic matter. Dioxins are so hydrophobic (very low solubilities and very high partitioning coefficients) that they do not dissolve or migrate with groundwater. Partitioning properties for metals are dependent on other properties of the water—pH, redox potential, and the presence of other ions in solution—so their behavior is more complex, but can still be predicted based on these properties.
- **Degradability:** Chemicals will degrade to other chemicals due to a host of processes, but the two that are most common are biological degradation and chemical degradation. Chemicals that do not degrade easily are referred to as persistent chemicals. Penta is an example of a persistent chemical. Many chemicals will rapidly degrade under one set of conditions but not under another, so discussions of degradation must include a clear understanding of the conditions necessary for the degradation to occur. PCE and TCE are good examples of chemicals that readily degrade under a range of anaerobic conditions (refer to Figure 5.1); toluene readily degrades under aerobic conditions (with oxygen present). VC will degrade rapidly under certain aerobic conditions and also degrades to ethene under strongly anaerobic conditions.

Table 5.1 presents the chemical-specific properties for the COCs.

5.4 NATURE, FATE, AND EXTENT OF THE CHLORINATED ETHENES AND ETHANES

The historical handling and storage of solvents on the Site led to substantial contamination of soil and groundwater. Extensive sampling has included analysis of over 1,000 groundwater samples and 400 soil samples since the 1990s. Focused sampling to locate and define areas of soil contamination was most recently conducted in December 2008, June 2009, and November 2010 (Floyd|Snider and CALIBRE 2009, Appendix D). The solvent source areas and groundwater plumes have been well defined and divided into specific areas as discussed below.

5.4.1 Current Extent of Chlorinated Ethenes and Ethanes Contamination

5.4.1.1 Chlorinated Ethenes and Ethanes Source Areas

- **Main Source Area:** This area represents the principal ongoing source of CEAs to groundwater at the Site. Soil containing PCE and TCE is found in the vadose zone, 1st WBZ, and 1st SH at intermittent locations along most of the rail spur and under the outside area of the warehouse. The highest PCE concentrations are found within the 1st SH, which exists to a depth of 20 feet bgs under the Flammables Shed. Deeper soil contamination is also present but at lower relative concentrations and occurs mainly between depths of 55–65 feet bgs under the Flammables Shed. The overall extent of this source area is shown on Figure 5.2 and the historical maxima are shown in Figure 5.3[3].
- **Loading Dock Plume:** Current concentrations of PCE and TCE in this area range up to 1,100 mg/kg. The soil beneath the Loading Dock Area is an ongoing source of CEAs in groundwater and the Downgradient Groundwater Plume. This plume was not identified prior to 2009.
- **Northwest Corner Plume:** This plume likely originated from scattered PCE spills along Willow Street. Historical data revealed most soil detections of PCE were at concentrations substantially less than 1 mg/kg. The few detections at concentrations greater than 1 mg/kg were primarily from vadose zone soil samples. The historical PCE detections in soil in this area are shown on Figure 5.3.

5.4.1.2 Extent of Soil Contamination

The footprint of soil contamination was determined by extensive sampling, including both soil samples and MIP readings. Figures 5.4a through 5.4h present the soil data on a series of concentration maps across successively deeper subsurface intervals using data collected between 2008 and 2010. Figure 5.5 presents the soil contour figures from Figures 5.4a through 5.4g on one panel figure. Figure 5.6 is a graph plotting total CEA concentrations vs. depth for all samples collected between 2008 and 2010. The following bullets summarize the most important aspects of the extent of current CEA contamination in soil based on the data tables (refer to Appendix F), graphs, and figures.

- PCE is the dominant CVOC found at the Site with a peak concentration of 3,930 mg/kg. TCE is also present in a majority of the samples containing PCE but at a much lower relative concentration (peak value of 280 mg/kg). The footprint of TCE is generally equivalent to that of PCE. The association of PCE and TCE is likely because both products were used (and spilled) by GWCC and/or PCE is the “parent” product to TCE, which can be formed by biodegradation of PCE. The DCE isomers and VC were never handled or spilled on-site and are only present due to biodegradation.
- The only other CVOC detected at a high frequency in the majority of samples was cis-1,2-DCE, a degradation or “daughter” product of PCE. The peak concentration of cis-1,2-DCE is 31 mg/kg.
- The remaining CVOCs detected in soil (e.g., VC, trans-1,2-dichloroethene, 1,1,1-trichloroethane, etc.) were all minor constituents due to their low detection

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[3] Within certain areas of the Site, pre-2007 data likely are not representative of current conditions due to the soil remedial actions (e.g., SVE) that have occurred since the samples were collected.

frequency (typically less than 5 percent) and low concentrations (typically less than 1 mg/kg).

- Soil with total CVOC concentrations over 1,000 mg/kg are limited to the upper 15 to 20 feet of the Site and include soil within the vadose zone, 1st WBZ, and 1st SH. Consistent with historical data, two areas of the Site contain soil with concentrations greater than 1,000 mg/kg: under the Loading Dock Area and under the current Flammables Shed (the location of former USTs and a pump house that pumped chemicals into and out of the tanks).
- In the area of the Flammables Shed, the highest concentrations of PCE are found in the 1st SH with lower concentrations in the soils of the vadose zone and sands of the 1st WBZ. In the Loading Dock Area, the reverse is true.
- Soil with total CVOC concentrations up to 547 mg/kg were detected along the railroad spur immediately south of the Cascade Columbia warehouse. The highest concentrations in this area occurred in vadose zone soils; the underlying 1st SH was relatively cleaner (maximum of 96 mg/kg).
- Soil with total CVOC concentrations up to 100 mg/kg occur in the deeper siltier soil of the 2nd WBZ. This deeper soil footprint lies under a portion of the Production Area and the Flammables Shed at depths between 45 to 65 feet bgs. Soil in the 2nd WBZ above and below this impacted 20-foot depth interval contains significantly less CVOCs, with a maximum concentration of 3 mg/kg. The occurrence of CVOCs at this depth indicates migration via a DNAPL phase, mostly likely as droplets released from the overlying 1st SH that migrated downwards to the clean sands of the upper part of the 2nd WBZ until encountering the siltier zones in the deeper part of the 2nd WBZ, which prevented further downward migration of the DNAPL droplets.
- Although a confining layer is not present in the 2nd WBZ to the deepest depths sampled, the observed decrease in CEA concentration between 60 and 70 feet bgs indicates a lower boundary of contamination.
- The silt layer under the Production Area contains a large mass of CEAs, indicating that it has retarded downward migration of DNAPL to deeper depths. Historical data indicate that soil contamination at several other locations, but the maximum concentrations are relatively low, with total CVOC concentration generally considerably less than 10 mg/kg. These areas include shallow soil along South Willow Street, in the Northwest Corner parking lot area, under the floor of the enclosed warehouse, and on the Whitehead Property.
- Soil with total CVOC concentrations less than 1 mg/kg are found in scattered locations and depths site-wide, including several downgradient locations along Fox Avenue and S. Myrtle Street. These very low-level detections include a significant fraction of cis-1,2-DCE. These low-level detections are not considered to represent individual spills or migration of DNAPL from an upgradient source, but rather CVOCs that have partitioned from contaminated groundwater to the natural organic matter in the aquifer soils.

The degradation products of PCE and TCE, including the DCE isomers and VC are more soluble, volatile, and mobile in water. As a result, the DCE isomers and VC have a tendency to partition from soil to water and were only detected at low concentrations in soil at the Site. The daughter product of the DCE isomers, VC, was detected in less than 10 percent of soil borings with a maximum concentration of 3.3 mg/kg.

In summary, the majority of the CVOC contamination in soil at the Site is PCE and TCE and the majority of contaminant mass is located in the upper 15 to 20 feet of soil found under the outside area of the Cascade Columbia warehouse, the adjacent Rail Spur Area, and the Loading Dock Area. The highest concentrations occur in the 1st SH near and under the former USTs in the Flammables Shed, with peak PCE + TCE concentration of 4,214 mg/kg and an approximate average concentration of 383 mg/kg[4]. Under this area of high concentration is a deeper zone of lower contamination soil that occurs mostly between 45 to 65 feet bgs. The peak total CVOC concentration in this deeper zone is 97 mg/kg.

CVOCs were also detected in soil outside of the three above areas, but at much lower concentrations (typically between 1 to 10 mg/kg) and in a “spotty” occurrence. These other areas include S. Willow Street, the Northwest Corner parking area, under the inside area of the Cascade Columbia warehouse and on the Whitehead Property. The extent of this low-level CVOC contamination in soil outside of the three areas above cannot be reliability estimated due to the limited number of detections, their random and widely spaced nature, the age of the data, and the recent treatment of these areas by permanganate.

Areas of CVOC soil contamination attributable to the releases at the Site have never been detected, nor are suspected to exist on any of the downgradient properties including Seattle Boiler Works, Seattle Iron and Metals Corporation, or Dawn Foods Distribution.

5.4.1.3 Extent of Groundwater Contamination

CEAs in groundwater have been well characterized on the Site over the previous 20 years. Over 1,000 groundwater samples have been analyzed since 1990 with over 450 of those samples collected since 2007. At many locations, discrete samples were collected at various depths in order to profile chemical concentration trends. The groundwater samples collected since 2007 are most representative of the current site conditions and will be discussed below.

Figures 5.7a through 5.7h present the groundwater data for PCE, TCE, 1,1-DCE, VC, and cis-1,2-DCE These figures display the concentration of parent (PCE and TCE) and daughter (cis-1,2-DCE, 1,1-DCE and VC) compounds, where the parent products are shown summed (PCE + TCE) and the daughter product concentrations are displayed individually. Additionally, Figures 5.8a and 5.8b show the maximum summed concentration of all four primary CEAs in groundwater at any depth for the entire Site. These figures also show concentration contours drawn based on the available data. Figures 5.9a through 5.9c present site cross sections that illustrate the extent of CEA contamination by depth. Figure 5.9a shows the CEA contamination extending from the Main Source Area to the S. Myrtle Street Embayment, Figure 5.9b shows the CEA contamination extending along Fox Avenue from the Northwest Corner to the south boundary of the Whitehead Property, and Figure 5.9c shows the CEA contamination in the Main Source Area underneath the Cascade Columbia Facility. The following discussion summarizes the most important aspects of the extent of CEA contamination in site groundwater.

1st Water Bearing Zone

Three distinct CEA plumes are found in groundwater within the 1st WBZ at the Site (Figure 5.8a). They include a plume originating from the northwest corner of the Cascade Columbia Facility (Northwest Corner Plume), a plume emanating from the Production Area/Rail Spur Area (Main Source Area), a plume emanating from the loading dock along Fox Avenue (Loading Dock Area Plume). The three plumes match well with the soil source areas, indicating that the

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[4] Average concentration based on source area data from 1st WBZ and 1st SH.

source areas are still present and leaching to groundwater. All plumes are moving in the direction of groundwater flow, toward the S. Myrtle Street Embayment. The concentrations of the CEA chemicals in the 1st WBZ plumes vary by plume, but generally, PCE and TCE are found in higher concentrations in the source areas and cis-1,2-DCE and VC are found in higher concentrations in the downgradient areas.

The most substantial plume emanates from the Main Source Area as it covers the largest area and also extends the deepest. The highest PCE + TCE concentration in this plume (64,000 µg/L) is found in Well B-46, in the Rail Spur Area. Historically, the Rail Spur Area was a location where a pure phase DNAPL was observed, including in Well B-12 located just west of Well B-46. PCE and TCE concentrations in the 1st WBZ groundwater drop sharply at Fox Avenue but the mobile degradation products are found at elevated concentrations (up to 7,600 µg/L for VC and up to 3,500 µg/L for cis-1,2-DCE) downgradient from Fox Avenue.

The Loading Dock Plume is much more localized and separate from the other plumes. Concentrations of PCE (up to 7,500 µg/L; Figure 5.7a) and daughter products (up to 19,200 µg/L cis-1,2-DCE and VC; Figures 5.7c and 5.7g) are still high in the 1st WBZ. The Loading Dock Plume is not completely defined downgradient from the loading dock due to intervening buildings.

The Northwest Corner Plume is only present in the 1st WBZ. The CEA concentrations are generally much lower than the in the Main Source Area or the Loading Dock Plume (Figure 5.9b). The peak PCE concentration in the Northwest Corner Plume is 1,640 µg/L[5] and only low concentrations of the daughter products (DCE isomers and VC) have been detected (Figures 5.7a and 5.7g). The extent of the Northwest Corner Plume is broad, extending across most of the Northwest Corner parking lot, the northwest corner of the warehouse and reaching north under S. Willow Street (Figure 5.8a). Like the Loading Dock Plume, the Northwest Corner Plume is not completely defined downgradient from Fox Avenue due to intervening buildings. However, Geoprobe samples collected by ERM in 2003 suggest that the Northwest Corner Plume extends under a portion of the current Dawn Foods Distribution property (ERM 2004).

2nd Water Bearing Zone

CEAs are found in groundwater throughout the full depth of the 2nd WBZ groundwater down to depths of approximately 75 feet bgs extending from the Cascade Columbia Warehouse and continuing downgradient to the S. Myrtle Street Embayment; however, concentrations taper off substantially at depths below 70 feet (maximum concentration of 40 µg/L total CEAs).

Elevated concentrations of CEAs were detected in the 2nd WBZ in the Main Source Area Plume, and to a much lesser degree, the Loading Dock Plume but not in the Northwest Corner Plume (Figure 5.8b). Peak PCE concentrations in the 2nd WBZ (up to 45,300 µg/L) are similar to those in the 1st WBZ and occur mostly at deeper depths of between 55 to 65 feet bgs, consistent with the soil data that indicated a deeper zone of soil contamination (Figure 5.7b). Similar to the 1st WBZ, the CEA groundwater plumes are moving in the direction of groundwater flow, towards the S. Myrtle Street Embayment. The peak concentrations of PCE + TCE are found under the Flammables Shed. There is comparatively little PCE + TCE contamination in groundwater downgradient from Fox Avenue.

The areas with elevated concentrations of degradation products, cis-1,2-DCE and VC (Figures 5.7d and 5.7h), are wider than those areas with elevated concentrations of PCE and

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[5] Data from 2007 as wells in the Northwest Corner of the Site were not sampled during the DGI.

TCE. For example, the cis-1,2-DCE and VC plume with concentrations greater than 1,000 µg/L is wider at Fox Avenue and extends from the loading dock to southwest of Monitoring Well B-63. There are several “hot spots” of cis-1,2-DCE with concentrations greater than 10,000 µg/L near the railroad spur, on the Whitehead Property, at Fox Avenue, and on Seattle Boiler Works. The maximum concentration of cis-1,2-DCE was measured in GP-42 at 50,000 µg/L. The maximum concentration of VC is consistently lower than cis-1,2-DCE across the entire Site with the recent maximum VC concentration at 13,000 µg/L measured in R1-IW7 and MW-10.

The 2nd WBZ Loading Dock Plume has lower concentrations of PCE + TCE (up to 1,900 µg/L) and cis-1,2-DCE + VC (up to 840 µg/L) as compared to the Main Source Area Plume. However, these detected chemicals are limited to deeper zones with concentrations in shallower sections of the 2nd WBZ significantly less or non-detect.

Because elevated concentrations of both parent and daughter products were detected in the 2nd WBZ Main Source Area Plume, Loading Dock Plume, and Downgradient Groundwater Plume, active degradation of parent products to daughter products is still occurring. PCE concentrations in the 2nd WBZ decrease substantially downgradient from the warehouse (through anaerobic degradation). The 2nd WBZ plume that continues beyond Fox Avenue to S. Myrtle Street is primarily composed of daughter products (DCE and VC).

Regarding the remaining CEA that is occasionally detected at low concentrations, there are more detections of 1,1-DCE in the 2nd WBZ than in the 1st WBZ (Figure 5.7e). The peak concentration of 1,1-DCE is 110 µg/L. The 1,1-DCE contamination in the 2nd WBZ extends from the Flammables Shed to the S. Myrtle Street Embayment. There was only once detection of 1,1-DCE in the Loading Dock Plume and there were no detections in the Northwest Corner Plume.

5.4.1.4 Chlorinated Ethenes and Ethanes in Indoor Air

Both past and recent testing of indoor air at the Cascade Columbia Warehouse indicates that the vapor pathway is of concern. Chemicals recently detected in indoor air at Cascade Columbia include PCE, TCE, methylene chloride, and benzene. PCE and TCE exceeded the MTCA Method C Industrial air quality concentrations. The presence of CEAs in indoor air is likely a result of vapor intrusion from nearby contamination found in the shallow soils and groundwater beneath the warehouse.

Recent testing of indoor air at the Seattle Boiler Works facility also detected concentrations of PCE, TCE, cis-1,2-DCE, and VC. PCE and TCE exceeded the MTCA Method B air cleanup level concentrations.

5.4.1.5 Chlorinated Ethenes and Ethanes in Seeps, Surface Water, and Sediments

CEAs are present in seep samples and occasionally in surface water samples in the S. Myrtle Street Embayment. CEAs were also detected in a limited number of porewater samples (peeper samples) but were not detected in any adjacent sediment samples. The presence of CEAs in the seeps and surface water are a direct result of groundwater contamination migration and discharge to the LDW. The seep and surface water data are included in Appendix F.

5.4.2 Nature and Fate of Chlorinated Ethenes and Ethanes

5.4.2.1 Physical Properties and Mobility

The mobility and solubility of PCE, TCE, the DCE isomers, and VC vary by compound and are a function of their physical properties (Table 5.1). At room temperature, PCE, TCE, and DCE isomers are liquids, but VC is a gas. PCE and TCE are less soluble therefore less mobile in water than the DCE isomers and VC. In addition to the physical properties of the CEAs, the geological conditions discussed earlier affect CEA extent. The following bullets summarize the major elements of the mobility of the four primary CEAs at the Site:

- PCE and TCE have high K_{oc} values and are only moderately mobile in water because they are retarded by adsorption to soil organic matter. This is demonstrated by the greatly decreased migration of PCE or TCE in groundwater downgradient from the source area.
- VC and the DCE isomers are also the most soluble CEAs in water and the least likely to partition onto soil (though they still prefer organic carbon to water). They travel further in groundwater and so spread more along the groundwater flow path due to dispersion, diffusion, and sorption/desorption. The migration of DCE and VC is clearly shown in Figure 5.9a.
- VC, TCE, and PCE have the largest Henry's Law constants, so although they prefer to dissolve in water rather than enter the vapor phase, they will partition into the vadose zone from groundwater sources more than the other chemicals. They may be detected in soil gas above groundwater plumes.
- As described below, VC degrades easily and rapidly when exposed to sunlight and oxygenated water. The VC that is discharged to the LDW via the seeps is rapidly diluted and degraded and due to its volatility, it is not expected to partition or condense to sediments.

5.4.2.2 Biodegradation of Chlorinated Ethenes and Ethanes

Since the early 1990s, the total concentrations of CEAs in both soil and groundwater have been substantially decreased due to interim measures, natural biodegradation, and advective transport and dissolution in groundwater. Of these methods, the most important is biodegradation because as it has significantly altered the chemical makeup of the groundwater plume across a very wide extent. The most important process for the natural biodegradation of the more highly chlorinated solvents is reductive dechlorination. During this process, the chlorinated hydrocarbon is used as an electron acceptor, not as a source of carbon, and a chlorine atom is removed and replaced with a hydrogen atom. In general, reductive dechlorination occurs by sequential dechlorination from PCE to TCE to DCE to VC to ethene. The main degradation sequence for reductive dechlorination is shown in Figure 5.1.

Reductive dechlorination affects each of the chlorinated ethenes differently. Of these compounds, PCE is the most susceptible to reductive dechlorination because it is the most oxidized. Conversely, VC is the least susceptible. Consequently, the rate of reductive dechlorination decreases as the degree of chlorination decreases. Reductive dechlorination of chlorinated solvent compounds is associated with the accumulation of daughter products and an increase in the concentration of chloride ions. This decrease in degradation rates may explain the accumulation of DCE and VC.

Because chlorinated solvents are used as electron acceptors rather than electron donors during reductive dechlorination, an appropriate source of carbon for microbial growth is required in order for this process to occur. Some of the carbon sources documented as supporting reductive dechlorination include low molecular weight organic compounds (lactate, acetate, methanol, glucose, etc.), fuel hydrocarbons (BTEX), by-products of fuel degradation (e.g., volatile fatty acids and methane), or naturally-occurring organic matter. It is thought that the mineral spirits released at the Site have helped increase the natural rates of anaerobic biodegradation.

Chlorinated ethenes can also degrade aerobically. VC is the most susceptible to aerobic biodegradation, PCE is the least susceptible. Of the chlorinated ethanes, 1,2-DCA is the most susceptible to aerobic biodegradation, while 1,1,1-TCA, tetrachloroethane, and hexachloroethane are less susceptible.

Using microcosms from two different sites with no prior history of exposure to DCE, Klier et al. (1998) showed that all three isomers of DCE (i.e., 1,1-DCE, cis-1,2-DCE, and trans-1,2-DCE) can be biodegraded in aerobic systems. In these experiments, it was observed that cis-1,2-DCE degraded more rapidly than the other isomers. Hartmans et al. (1985) and Hartmans and de Bont (1992) showed that VC can be used as a primary substrate under aerobic conditions, with VC apparently directly mineralized to chloride, carbon dioxide, and water. This has been also been reported by Davis and Carpenter (1990). Aerobic biodegradation is rapid relative to other mechanisms of VC degradation, especially reductive dehalogenation.

Aerobic conditions at this Site occur in limited areas, primarily the 1st WBZ, where it is not impacted by mineral spirits and also in the waters of the LDW.

5.4.2.3 Summary

Natural biodegradation is a significant process occurring at this Site. The more chlorinated ethenes (PCE and TCE) degrade best by reductive dechlorination under anaerobic conditions to form DCE and VC. Under these conditions, DCE and VC will continue to degrade to harmless metabolites, but at a slower rate than for PCE and TCE. This results in the following conditions:

- A net loss of parent chlorinated ethenes
- An accumulation of DCE and VC

However, DCE and VC can be promoted to degrade rapidly under strongly anaerobic conditions, when hydrogen is in supply (the establishment of such conditions is the aim of ERD). DCE and VC can also degrade naturally under aerobic conditions. Therefore, the best bioreactor (natural or man-made) consists of a strongly anaerobic cell to convert PCE and TCE to DCE and VC, followed by aerobic conditions to convert DCE and VC to ethane. It is thought that site conditions fit this model, with strongly reducing conditions in the aquifer promoting partial degradation followed by a change to aerobic conditions in the waters of the LDW, which rapidly degrade the DCE and VC. This process may explain why DCE and VC are rarely detected in the surface waters of the S. Myrtle Street Embayment.

5.5 NATURE, FATE, AND EXTENT OF PETROLEUM HYDROCARBONS AND THEIR CONSTITUENTS

5.5.1 Current Extent of TPH and BTEX Contamination in Soil

Mineral spirits and associated aromatic compounds—BTEX and naphthalene—are found in both groundwater and soil at the Site. Although the BTEX compounds make up only a minor component of mineral spirits (less than 5 to 15 percent), they are important because of their mobility in the environment.

TPH and the BTEX compounds are present in the Main Source Area and the Loading Dock Source Area. TPH and benzene are not present in the Northwest Corner. Figure 5.10 shows the maximum TPH-motor/heavy oil in soil for the most recent data (sampled in 1992). The locations where substantial detections were found are as follows:

- Vadose Zone/1st WBZ contamination (7 to 9 feet bgs) at B-24 located off-site along E. Marginal Way has a concentration of 12,600 mg/kg. The well at this location is intended to represent upgradient conditions to the Site. The shallow contamination at this location is believed to be due to heavy truck and railroad traffic in the area. The concentration of the next deeper (10.5 to 12 feet bgs) sample was 570 mg/kg, indicating that the concentrations were dropping rapidly with depth.
- Surface contamination at B-32 at the end of the railroad siding (2,900 mg/kg).
- Contamination from surface to 12 feet bgs at B-30 located within the Production Area adjacent to the railroad siding (3,000 to 3,900 mg/kg). By 14 feet bgs, the concentration had decreased to 740 mg/kg. Contamination at B-30 also contained mineral spirits, although the mineral spirits did not exceed the site-specific cleanup level.

It is important to note that some of the soil TPH data are very old; therefore, these concentrations should be considered the upper bounds for what may be present today in site soil.

The more volatile components of petroleum, the BTEX chemicals, have definitely been reduced in concentration since monitoring began in 1992. Figure 5.11 shows the extent of benzene contamination in soil for samples collected between 2008 and 2010. The footprint of detected benzene and total BTEX concentrations is consistent with the original releases occurring in the historical tank farm, the Loading Dock Area, and around B-30 (within the Production Area adjacent to the railroad siding). Between 1990 and 1992, the historical maximum benzene concentration measured in soil was 12,000 µg/kg, measured at 14 to 16 feet bgs under the Production Area. Today, no soil sample contains benzene at concentrations greater than the Method C cleanup level of 2,400 µg/kg.

5.5.2 Current Extent of TPH and BTEX Contamination in Groundwater

Figure 5.12 shows the TPH in groundwater data collected between 2007 and 2010 in the 1st and 2nd WBZ. The figure presents the analytical results for mineral spirits, diesel range, and heavy oil TPH constituents by depth. The TPH footprint is similar to the solvent footprint with the highest concentrations located near the railroad spur in the Production Area (near B-30) and in the Loading Dock Area (at B-10A). Concentrations decrease quickly downgradient from the Main Source Area and are in compliance with groundwater cleanup levels by Fox Avenue (with the possible exception of B-10A where downgradient data have not recently been collected). Groundwater concentrations are highest near known areas of soil contamination.

Figures 5.13a and 5.13b shows the concentration of benzene and total BTEX compounds in groundwater in the 1st WBZ and 2nd WBZ based on 2007 to 2010 data. As shown in Figure 5.13a virtually no BTEX remains in the 1st WBZ. This is not surprising since both the SVE and ISCO interim measures conducted at the Site would have been quite effective in reducing BTEX concentrations. A plume of BTEX does exist in the 2nd WBZ. Its source area is similar to soil contamination at B-30 and MW-13 that was carried into the 2nd WBZ by DNAPL droplets. Generally, BTEX concentrations are less than the proposed cleanup levels at and beyond Fox Avenue (1 of 16 locations showed an exceedance of the benzene cleanup level).

The occurrence of mineral spirits and BTEX at depth in the 2nd WBZ is unusual but readily explained by its commingling with PCE, which formed a heavier-than-water DNAPL that was able to penetrate deep within the 2nd WBZ and transported downgradient.

5.5.3 Nature and Fate

5.5.3.1 Physical Properties and Mobility

The BTEX family is moderate in solubility and volatility, with benzene being the most mobile in both air and water, and xylenes being the least. Benzene is the only member that is more mobile than PCE, which is the least mobile of the ethenes; consequently, BTEX will be less mobile than most CEAs.

5.5.3.2 Degradation of Petroleum Hydrocarbons

The BTEX family of VOCs are common petroleum constituents that are known to break down predictably, do not form more toxic daughter products, and tend not to migrate great distances. A wealth of information has been accumulated over the past 30 years by both industrial and academic researchers regarding the principle mechanisms influencing petroleum hydrocarbon biodegradation (e.g., refer to Das and Chandran 2010). Various biological processes have been identified that control the rate and extent by which petroleum hydrocarbons degrade under natural conditions. The following sections describe the primary metabolic routes for petroleum hydrocarbon bioremediation.

Aerobic Biodegradation of Petroleum Hydrocarbons

Fuel hydrocarbons are most rapidly biodegraded aerobic conditions. Biodegradation of fuel hydrocarbons occurs naturally when sufficient oxygen and nutrients are available in soil and groundwater systems. The rate of hydrocarbon biodegradation is generally limited by a lack of oxygen rather than a lack of nutrients such as nitrogen or phosphorus. Therefore, the rate of natural aerobic biodegradation in soil and groundwater systems is largely dependent upon the rate at which oxygen enters the contaminated media.

Biodegradation causes measurable changes in groundwater chemistry. During aerobic respiration, dissolved oxygen concentrations decrease. Concentrations of chemicals also decrease. Concentrations of the degradation products may increase, at least until they, in turn, are degraded. The aerobic degradation of petroleum hydrocarbons generally produces small, partially oxidized organic chemical intermediates, such as the volatile fatty acids, which are then readily converted to carbon dioxide and cellular bio-mass by a host of microorganisms.

Anaerobic Biodegradation of Petroleum Hydrocarbons

The depletion of dissolved oxygen, caused by aerobic biodegradation in soil and groundwater systems with high organic carbon concentrations, results in the establishment of anaerobic conditions. When oxygen is depleted and nitrate is present, some microorganisms will utilize nitrate (NO_3^{-1}) instead of oxygen as a terminal electron acceptor. Because nitrate has a lower electron potential than oxygen, this reaction, although still providing energy to the microorganisms involved, does not provide the same amount of energy. Therefore, anaerobic degradation is a less preferred metabolic route and is not expected to provide significant degradation of TPH or BTEX.

5.6 NATURE, FATE, AND EXTENT OF CHLORINATED PHENOLS

Penta, and also lesser chlorinated phenols (common by-products in Penta product), were detected in area soils and groundwater, as discussed below.

5.6.1 Original Penta Source Areas

As described above, two original source areas were identified for Penta. The first Penta source area is located on the south central portion of the Site, adjacent to the Frontenac Street ROW. The source of Penta on the Site includes the Penta storage and handling areas from the historical GWCC and in a low-lying area along the adjacent Frontenac Street. Specifically, the following original source areas were identified on the Site:

- Penta bulk storage in UST No. 22 located beneath the west end of the drum shed.
- Penta mixing with petroleum spirits in the area west of the drum shed (Penta is often sold as a 5 percent solution in a petroleum solvent such as kerosene).
- Penta/petroleum storage in the AST located west of the drum shed.
- The depression along the Frontenac Street ROW and the parallel railroad spur, where stormwater runoff from both the former Penta drumming area and large sections of the former Tyee Lumber property were collected and infiltrated.

The second Penta source area is off-site and located near the historical dip tank at on the Whitehead Property (Figure 2.2). This source area includes the previous location of a wood-treating dip-tank in which lumber was “dipped” into the Penta/petroleum treating solution to preserve the wood. The area also included a UST where Penta was stored.

5.6.2 Penta in Soil

The highest concentration of Penta detected in soil was 29 mg/kg found in the 1st WBZ soils in the outside area of the warehouse area where Penta mixing likely occurred. Penta has also been detected at lower concentrations in the Rail Spur Area. Penta has also been documented at higher concentrations at the location of the former Tyee Lumber site to the south and on the Whitehead Property (maximum concentration of 71 mg/kg in B-38).

No concentrations of Penta in soil exceed the MTCA Method C cleanup level of 1,100 mg/kg and as described in Section 4.0, Penta is not a COC in soil. The Penta found on the Whitehead Property is not commingled with the contaminant plumes associated with the Site and remediation of the separate former Tyee Lumber property is not considered in this RI/FS.

Lesser chlorinated phenols (common by-products in Penta product) were also detected in area soils, but at concentrations less than their proposed cleanup levels. The lesser chlorinated phenols are co-located with the Penta, which is consistent with either their presence in original technical grade Penta released or their formation as degradation products of Penta.

5.6.3 Penta in Groundwater

The most recent testing for Penta in groundwater was conducted by ERM in 2003, with follow-up testing through 2007. Figure 5.14 shows the Penta concentrations in the 1st WBZ collected in 2007 for the Site. The figure shows the elevated concentrations of Penta near the railroad spur (maximum concentration of 116 µg/L) and near the location of the historical Tyee dip tank (maximum concentration of 11,500 µg/L in B-38).

Penta occurs primarily in groundwater within the 1st WBZ; there were no exceedances of the proposed cleanup level in the 2nd WBZ after 2000. There were few measured Penta concentrations in the 1st WBZ in the Downgradient Groundwater Plume (maximum concentration of 3.2 µg/L in MW-3) or along Fox Avenue (all non-detects) in 2007. Penta has not been detected in the downgradient wells along S. Myrtle Street. The Penta data, well location, and groundwater flow direction suggests that the 3.2 µg/L detection of Penta in Monitoring Well MW-3 originated from the southern part of the Whitehead Property, near the historical location of the Tyee dip tank. The 2007 groundwater sampling event for Penta followed the injection of permanganate and a substantial decrease in Penta concentrations since 2003 has been observed.

5.6.4 Penta in the S. Myrtle Street Embayment

Seep samples (12 samples over multiple years) and surface water samples (6 samples over multiple years) were collected and analyzed for Penta. No Penta was detected at detection limits as low as 0.5 µg/L.

Five surface sediment samples and two sediment cores have been collected in the LDW in areas where groundwater from the Site could potentially discharge. No Penta was detected in the surface samples. No Penta was detected in Core LDW-SC42 in front of Seattle Iron & Metals; Penta was detected in Core LDW-SC41 at the S. Myrtle Street Embayment at concentrations between 16 and 40 µg/kg, considerably less than the SMS Sediment Quality Standard of 360 µg/kg and possible attributable to treated wood in the embayment. These data are presented in Appendix F.

5.6.5 Nature and Fate of Penta

5.6.5.1 Physical Properties and Mobility

Penta is a non-volatile solid that has a fairly low solubility and a strong preference for adsorption onto organic carbon. Its movement in the environment will be along the groundwater pathway only, and it will be slow and for short distances. The fraction of organic carbon in the soil will further limit its mobility.

5.6.5.2 Migration of Compounds

Penta releases to the subsurface are believed to have occurred in the 1970s and early 1980s, giving them sufficient time to have reached steady state conditions. Although concentrations in groundwater in the historical areas of Penta handling remain greater than the cleanup level of 3 µg/L, these concentrations are bounded by the Fox Avenue ROW (refer to Figure 5.14). Of the 9 groundwater samples collected along Fox Avenue and downgradient, only a single sample had detectable Penta at 3.2 µg/L (versus the cleanup level of 3.0 µg/L) and the rest were non-detect at 0.5 µg/L.

In summary, Penta is a COC for groundwater at the Site. Its concentrations are generally less than or equal to the cleanup level at the Fox Avenue ROW, with exceedances limited to historical usage areas upgradient from Fox Avenue.

5.7 NATURE, FATE, AND EXTENT OF PHTHALATES

The only phthalate with concentrations greater than its respective cleanup level is bis(2-ethylhexyl)phthalate, and its exceedances were in groundwater samples only. Bis(2-ethylhexyl)phthalate was not used or stored on-site, but is a common plasticizer and plastic containers were used on-site. It has a low solubility in water, adsorbs to soil particles, and is considered to be relatively immobile in groundwater (strongly retarded on the soil); therefore, groundwater plumes of bis(2-ethylhexyl)phthalate are extremely rare. Bis(2-ethylhexyl)phthalate is not a COC for soil.

There were 55 exceedances of the bis(2-ethylhexyl)phthalate groundwater cleanup level in 222 groundwater samples analyzed between 1992 and 2000. Of the 222 groundwater samples that were analyzed, approximately one-third had blank contamination and several of the other samples are suspected to have been contaminated at the laboratory. Because of the history of laboratory and blank contamination for the bis(2-ethylhexyl)phthalate groundwater samples and because bis(2-ethylhexyl)phthalate was not known to be handled or stored at the Site, bis(2-ethylhexyl)phthalate is no longer being retained as a COC.

5.8 NATURE, FATE, AND EXTENT OF METALS

As shown in Table 4.11, copper and nickel are the only two metals that exceed cleanup levels in groundwater.

5.8.1 Copper

The cleanup level for copper is based on the dissolved fraction of groundwater. In the 1990s, copper was measured in a number of wells in the Main Source Area (data are presented in Table 5.2) and was detected in 8 of 23 samples. However, only a single sample exceeded the cleanup level: 0.0082 mg/L in B-19 versus a cleanup level of 0.008 mg/L. The copper cleanup level is based on background, and the concentration in B-19 is not statistically different than background.

In 2009, copper concentrations were measured in eight downgradient wells as part of a suite of metal analyses. Copper was detected in 5 of the 8 wells at concentrations ranging from 0.009 to 0.055 mg/L. All of these locations are along the street ROWs of Fox Avenue and S. Myrtle Street, where infiltrating stormwater from the roadways contributes to groundwater. Because copper was not detected in groundwater at the Cascade Columbia Facility and is not elevated in site soils, the copper exceedances along the roadways are not considered to be related to the Site. Copper is not retained as a COC for groundwater.

5.8.2 Nickel

The cleanup level for nickel is based on the dissolved fraction of groundwater. Nickel has been detected in dissolved groundwater twice since 1992. In 2009, when the most recent data were collected, nickel was detected in one well, B-34, at 0.021 mg/L. This is the shallow well located adjacent to the S. Myrtle Street Embayment. Since nickel was not detected in other groundwater monitoring wells closer to the Site and nickel is not elevated in soil at the Site, this single detection at less than 3 times of the cleanup level of 0.0082 mg/L is not considered to be related to the Site. Nickel is not retained as a COC for groundwater.

6.0 Conceptual Site Model

MTCA Chapter 173-340-200 defines the conceptual site model as a "conceptual understanding of a site that identifies potential or suspected sources of hazardous substances, types and concentrations of hazardous substances, potentially contaminated media, and actual and potential exposure pathways and receptors." Sections 2.0 through 5.0 have described in detail the suspected sources of hazardous substances, how they were released, the types and concentrations of chemicals detected at the Site, the impacted media at the Site, and the actual and potential exposure pathways and receptors. This section provides a conceptual summary of the detailed information described in the previous sections. Figure 6.1 presents a graphical representation of the conceptual site model for the Site.

6.1 SOURCES OF HAZARDOUS SUBSTANCES

The sources of hazardous substances on the Site are the releases to the soil of chemical products that were stored and distributed by the former GWCC, including chlorinated solvents, mineral spirits, and inorganic chemicals including acids and bases from the 1950s until the mid to late 1990s. Releases of these chemicals occurred via leaks from AST and UST farms and piping, and as spills during the loading/unloading and repacking of chemicals. These releases were focused in several areas of the Site, primarily in the area of the current Flammables Shed, where the historical "original tank farm" (now closed in place) and pump house were located. Additional areas where significant contaminant releases occurred include the Rail Spur Area and the loading dock. There were likely also small, isolated spills in the northwest corner of the Site. No ongoing releases to soil exist at the Site since removal/abandonment of the tank farms; however, the contaminated soil continues to act as a secondary soil to soil vapor and groundwater. There is no evidence to suggest that the current chemical distribution company that occupies the facility, Cascade Columbia, has contributed to the release of hazardous chemicals.

The contamination that was released to the soil via leaks and spills contaminated the vadose zone soils and by gravity flow of pure products to underlying soils. This contamination then spread by vapor transport in the vadose zone and by partitioning from soil vapor into groundwater and direct leaching to groundwater from saturated soils. Most of the Site is paved or covered in buildings, but unpaved sections would also be subject to infiltration of rainwater that could leach chemicals from the soil or entrain soil vapors from chemicals and carry them downward to the water table.

Both PCE and TCE moved by gravity through the vadose zone into the 1st WBZ and to the underlying silt horizon. Where the release was large and the silt was thin, DNAPL stringers were able to penetrate the silt and migrate deep into the 2nd WBZ as droplets or stringers; however, no "pool" of DNAPL has ever been identified at the Site. When the DNAPL encountered other organic contamination, such as oil and mineral spirits, the organics would dissolve in the DNAPL and be carried downward with the DNAPL. This resulted in the presence of mineral spirits at depths of up to 45 feet bgs.

Over the years, the Cascade Columbia Facility has undergone renovation to its stormwater system and buildings. Today, much of the facility is under cover and not exposed to stormwater. Stormwater that falls on the remaining uncovered operational areas is combined with process water, neutralized, and discharged to the sanitary sewer under permit. Stormwater running off-site is limited to a small amount of pavement that drains to Fox Avenue.

6.2 CONTAMINATED MEDIA

Soil on the Site is contaminated with the following final list of COCs:

- **PCE, TCE, the three DCE isomers, and VC.** Of these only PCE exceeds the soil cleanup level based on direct contact. However, PCE and TCE concentrations in the vadose zone on-site are high enough to result in vapor intrusion into one of the Cascade Columbia Facility buildings. PCE and TCE soil concentrations are also high enough to act as an ongoing source to groundwater. For the rest of the report these are collectively referred to as CVOCs.
- **TPH and BTEX.** TPH and BTEX soil concentrations are less than the soil cleanup level based on direct contact. Concentrations are also low enough to protect indoor air concentrations; however, soil concentrations are high enough to act as ongoing source to groundwater contamination.
- **Penta** contamination remains in site soil. Concentrations are less than the soil cleanup level based on direct contact but are sufficient to act as an ongoing source to groundwater.

Soils beyond Fox Avenue are in compliance with soil cleanup levels and any residual contamination is too low to act as ongoing sources to indoor air or groundwater contamination.

Groundwater in the 1st and 2nd WBZ from the Main Source Area to discharge in the LDW is contaminated with CVOCs and benzene. Seeps in the S. Myrtle Street Embayment where this contamination discharges contain PCE and its degradation products, especially VC. Penta and TPH concentrations are either non-detect or in compliance with groundwater cleanup level by Fox Avenue. In comparison, benzene appears to have comingled with the CVOC plume, been transported downgradient, and discharged along with the CVOCs in the 2nd WBZ seeps.

PCE and TCE levels in indoor air are greater than the Method C cleanup levels in the downstairs office and restroom at Cascade Columbia. PCE and TCE levels in indoor air at the Seattle Boiler Works facility are greater than the Method B cleanup levels in the Pipe Shop building.

Sediments and surface water in the S. Myrtle Street Embayment are not contaminated by COCs associated with the Site and are not considered contaminated media for this RI/FS.

The stormwater from the operational areas of the Site is combined with process water, treated, and sent to the sanitary sewer under permit. Stormwater is not considered a contaminated media at this Site.

6.3 NATURE AND EXTENT OF CONTAMINATION

The nature and extent of contamination is well documented due to the extensive sampling conducted over the previous two decades. The contaminants are primarily composed of CVOCs, specifically the chlorinated ethenes PCE, TCE, and their degradation products (the three DCE isomers and VC) with lesser amounts of aromatic VOCs. The aromatic VOCs were primarily released as petroleum solvents, such as mineral spirits, which contain a fraction of light-end BTEX compounds. Additionally, a limited area of the Site is impacted by Penta.

The most significant of the COCs in terms of mass and distribution is PCE, which has impacted shallow and deeper soil under the Cascade Columbia Facility. At certain locations under the facility containing silt horizons, the PCE occurs as a separate phase DNAPL. The lesser concentrations of the other VOCs that are often detected in soil (e.g., TCE, benzene) are almost always found in association with higher concentrations of PCE. The historical releases of PCE and other chemicals have impacted the vadose zone soils and shallow and deep groundwater under the Cascade Columbia Facility. The groundwater plume has migrated downgradient and discharges to the LDW.

Significant degradation of PCE and TCE occurs in the 2nd WBZ as a result of reducing conditions. By the time the 2nd WBZ groundwater plume has reached the S. Myrtle Street Embayment, PCE and TCE have nearly completed their transformation to DCE, VC, and non-toxic ethene and ethane. The 1st WBZ plume does not undergo such a transformation due to less reducing conditions near the water table. Historically, this degradation process in the 1st WBZ has been aided by the presence of co-released mineral spirits, especially toluene.

Discharge of groundwater to the embayment occurs as a series of visible tidal seeps and also through porewater seepage through shallow sediments of the S. Myrtle Street Embayment. Most of the seepage occurs between -5 and +5 feet MLLW. Below approximately -5 feet MLLW, a permanent salt water wedge exists directly under the sediments. Groundwater flows up and over this wedge to discharge through the seeps. The DCE and VC discharging into the waterway are very volatile with very low affinities for sediments; therefore, these chemicals do not persist in the aquatic environment. These chemicals have never been detected in surface water or in resident mussels collected from the embayment.

6.4 AREAS OF CONTAMINATION

Three main areas of contamination, each with their own unique characteristics, have been defined for the Site and are discussed below.

6.4.1 Main Source Area

The Main Source Area represents those areas of the Site where the past releases have occurred and the underlying soil (including vadose, 1st WBZ, and 2nd WBZ) is now the source of the plume found in downgradient groundwater. Contaminants in soil and groundwater include PCE, TCE, the DCE isomers, VC, aromatic VOCs (e.g., BTEX), mineral spirits (TPH), and Penta. Only PCE exceeds the soil cleanup level; however, soil concentrations of the other chemicals are high enough to be of concern as a source to groundwater.

6.4.2 Downgradient Groundwater Plume

The Downgradient Groundwater Plume encompasses the zone of contaminated groundwater travelling under Fox Avenue and the downgradient properties until it is discharged to the S. Myrtle Street Embayment. There is no associated soil contamination in the Downgradient Groundwater Plume. The plume is comprised primarily of PCE and TCE in the 1st WBZ groundwater and DCE, and VC in the 2nd WBZ groundwater. There are also occurrences of 1,1-DCE, benzene, Penta, and TPH in this plume. The Penta is primarily found in 1st WBZ groundwater upgradient from Fox Avenue.

6.4.3 Northwest Corner Plume

The Northwest Corner Plume is a smaller separate plume that is not commingled with the Main Source Area. A distinct soil source has never been identified for the Northwest Corner Plume and its origin is thought to be related to several minor spills that occurred from tanker cars stored along the S. Willow Street rail line. The Northwest Corner Plume is composed primarily of PCE and TCE and is confined to 1st WBZ groundwater. Soil contamination greater than the proposed cleanup levels has not been identified in this area.

6.5 CHEMICAL FATE AND TRANSPORT

The fate and transport of the site COCs are governed by the specific properties of the chemicals and the surrounding environmental conditions at the Site. Of primary concern are the more chlorinated ethenes (PCE and TCE) that degrade best by reductive dechlorination under anaerobic conditions to form DCE and VC. Eventually, these daughter products degrade to ethene/ethane and then carbon dioxide but at a slower rate. DCE and VC are very mobile in groundwater but more susceptible to degradation under aerobic conditions than PCE and TCE. Petroleum products released at the site include mineral spirits (measured as TPH) and BTEX that break down predictably to less toxic and less mobile daughter products and biodegrade most rapidly under aerobic conditions. Under aerobic conditions, oxygen acts as the electron acceptor, but under anaerobic conditions, naturally occurring organic matter or volatile petroleum products can act as the electron acceptor.

At the Site, the most significant historical releases consisted primarily of PCE and mineral spirits in the same general area, resulting in comingling of chemicals that continue to this day to leach from soil to groundwater. In some areas, the commingling resulted in a DNAPL that likely carried some fraction of mineral spirits and benzene down to the 2nd WBZ.

The 1st WBZ is a more oxidizing environment than the 2nd WBZ and so not as prone to significant CVOC degradation resulting in a downgradient plume of mixed CEA parent and daughter products to the point of discharge in the seeps.

The more reducing 2nd WBZ is prone to faster CEA degradation. CEAs appear to be readily degrading to daughter products by the time they reach Fox Avenue. This faster degradation is driven by two conditions: the comingling of CVOCs and mineral spirits in the 2nd WBZ that resulted in a readily available hydrocarbon substrate source, and a naturally reducing aquifer. This is demonstrated by the chemicals in the 2nd WBZ downgradient from Fox Avenue primarily consisting of daughter products and no parent product.

Semivolatile compounds at the Site, primarily Penta, are much less mobile. Penta has a low solubility and high affinity for soil organic matter and does not easily degrade. Other compounds detected historically include scattered occurrences of low toxicity metals (such as copper) that have limited to no mobility.

6.6 EXPOSURE PATHWAYS AND RECEPTORS

6.6.1 Current Exposure Pathways and Receptors

The Site is within a heavy industrial area and includes operating industrial facilities, railroad lines, and public streets. The individual facilities are covered with buildings, pavements, and hard-packed surfaces. There is no terrestrial habitat in the area. There is no active groundwater use in the area. Current exposure pathways and receptors are limited to the following:

- Inhalation of indoor air by industrial workers.

- Incidental ingestion of surface soils by industrial workers (this pathway is blocked by pavement over the known contaminated soil areas of the Site).
- Direct contact by ecological receptors with contaminated groundwater seeps within the S. Myrtle Street Embayment.

Specific examples of exposure are discussed below by area.

6.6.1.1 Main Source Area

Indoor Air: Indoor air within the Cascade Columbia office has measureable PCE and TCE concentrations. The contaminated soil and shallow groundwater in the Main Source Area, especially the elevated levels of PCE in the vadose zone soils near the loading dock and office, are considered the sources of this indoor air intrusion. Cleanup levels have been developed for PCE and TCE in indoor air based on industrial work exposure (MTCA Method C).

Direct Contact: Although the entire Cascade Columbia Facility is paved, there is a potential future direct contact exposure pathway whereby construction workers digging in subsurface soil may be exposed to site COCs. Cleanup levels have been developed for all detected soil COCs based on industrial worker exposure (MTCA Method C). Only PCE in soil exceeds applicable cleanup levels.

6.6.1.2 Downgradient Groundwater Plume

Indoor Air: Indoor air within the Seattle Boiler Works Pipe Shop building show PCE and TCE concentrations exceeding the MTCA Method B cleanup levels for Seattle Boiler Works as selected by Ecology. Current land use and zoning of the property is industrial.

Direct Contact: There is no soil direct contact exposure pathway downgradient from Fox Avenue because there are no soil COCs in this area at concentrations greater than applicable MTCA Method B or C cleanup levels.

6.6.1.3 S. Myrtle Street Embayment

Seeps/Surface Water: A potential exposure pathway exists for ecological receptors (benthic infauna) to be exposed to contaminated groundwater in the S. Myrtle Street Embayment. However, there are no promulgated state or federal standards for protection of aquatic species for the majority of COCs at this Site. In lieu of established standards, Table 4.9 presents risk-based levels from existing literature studies. These literature values support that there are no toxic effects to aquatic fauna from existing discharges at the Site.

In addition to consideration of toxic effects to fish, the MTCA cleanup levels require consideration of the potential pathway comprising humans eating fish/shellfish that bioaccumulate COCs. However based on testing of mussel tissue collected in the embayment, COCs are not bioaccumulating. Regardless, the potential pathway to humans via fish/shellfish consumption has been retained and cleanup levels have been developed based on the presumption of bioaccumulation.

6.6.1.4 Northwest Corner Plume

Indoor Air: A potential exposure pathway exists for vapors emanating from contaminated 1st WBZ groundwater or soil to intrude into current and future structures built atop the Northwest Corner Plume.

Direct Contact: There is no soil direct contact exposure pathway because there are no soil COCs in this area at concentrations greater than applicable worker exposure cleanup levels.

6.6.2 Potential Future Exposures Pathways and Receptors

Future land use in the area is expected to remain heavy industrial and so MTCA Method C cleanup levels are applicable to this Site. No significant changes in land use are expected in the foreseeable future. Groundwater at the Site is considered non-potable due to its proximity to the LDW. In conclusion, the nature and extent of contamination at the Site has been sufficiently characterized for the purposes of assessing and selecting remedial alternatives.

7.0 Feasibility Study Introduction

Sections 7.0 through 12.0 comprise the FS portion of this document and discuss the remedies for the COCs at the Site. The FS begins with a discussion of the difficulties inherent in remediating solvent sites, identifies the remedial action objectives, divides the Site into distinct cleanup action areas, and identifies the points of compliance. Following this, technologies that are considered capable of achieving the remedial action objectives are identified. The most practical and effective of these technologies are described in detail and weighed against each other considering the MTCA evaluation criteria. The recommended alternative for the entire Site is then identified and described in detail along with a description of proposed compliance monitoring and contingency actions.

7.1 EXPECTATIONS FOR SOLVENT CLEANUP SITES

The cleanup of the Site primarily involves CVOCs and to a lesser degree aromatic compounds (e.g., benzene). The elevated concentrations observed in groundwater indicate the release and migration of DNAPLs. As discussed in the previous sections, most of the DNAPL mass resides with the vadose zone and 1st SH; however, some DNAPL has migrated deep into the 2nd WBZ where it primarily resides in silt lenses. As a result, this Site has a highly contaminated source areas for dissolved-phase groundwater contamination that has migrated downgradient and is discharging through seeps at the S. Myrtle Street Embayment. It is widely accepted that the implementation of conventional pump-and-treat remediation for such DNAPL source zones has been ineffective in reducing chemical concentrations to regulatory end points in acceptable time frames (MacDonald and Kavanaugh 1994, Travis and Doty 1990, USEPA 1996). Instead, direct treatment or full containment of source zones must be considered if cleanups are to be effective. Treatment of DNAPL source zones is complicated by two factors, one being the difficulty in identifying their existence and second, short of excavation, few technologies have demonstrated a proven ability to effectively remove or destroy in place enough source zone mass to fully restore sites in a reasonable time frame.

At best, applications of aggressive physical–chemical in-situ technologies may remove greater than 90 percent of the contaminant mass. The remaining contaminant mass; however, can create a rebounding of aqueous-phase concentrations within the treated zone. Undoubtedly, this is what occurred during the previous attempts at chemical oxidation at this Site in which multiple applications of permanganate were insufficient to significantly reduce the 1st WBZ source mass and so sustained rebound occurred.

Several decades of experience at hundreds of sites nationally have clearly demonstrated that full restoration is often not possible due to many factors, including the depth to which contamination extends, the unique and unpredictable behavior of DNAPL in the subsurface, and its persistence in low-permeability layers (USEPA 2003, ITRC 2002). As early as 1993, USEPA recognized the difficulty of DNAPL site restoration by issuing guidance on “technical impracticality” that acknowledges the inability of existing technologies to achieve full restoration at DNAPL sites within a reasonable restoration time frame (USEPA 1993).

Currently, source reduction is preferred over containment remedies because it will result in (1) a reduction in mass flux, (2) a reduction in source longevity, (3) a reduction in risk, and (4) a potential enhancement in post-treatment biodegradation potential (Jawitz et al. 2000, Londergan et al. 2001, Martel et al. 1998, Rao et al. 2002, Yang and McCarty 2003).

In recent years, in-situ technologies, such as thermal treatment, have evolved to the point where they now stand a reasonable chance of significantly reducing the mass of solvent in the source areas (up to 99 percent reductions are documented). Regardless, even with such large reductions in mass, the very low regulatory levels required to achieve compliance results in even a small remaining contaminant mass contributing as a source of downgradient contamination; thus further source-zone treatment or even containment may be required to achieve compliance with regulatory levels.

The current state of the art technology for solvent sites is moving towards a strategy of primary source-zone removal that results in significant (several orders of magnitude) reductions in post-treatment contaminant mass flux (Lemke and Abriola 2003, Rao et al. 2002, Rao and Jawitz 2003). Although a reduction in mass flux may not eliminate the need for further treatment, it could reduce concentrations to levels where microbial transformation of the dissolved-phase chlorinated solvents becomes feasible (Adamson et al. 2003, Nielsen and Keasling 1999, Sung et al. 2003, Yang and McCarty 2000). Biostimulation of source-zone microbial dechlorination activity may achieve attenuation of contaminant mass flux to levels that achieve regulatory compliance at a downgradient well, while the residual source areas remain greater than compliance levels.

Thus, combinations of aggressive source-zone treatment and post-treatment bioremediation are showing promise as attractive remediation alternatives to containment, resulting in reduced source longevity and lowered contaminant mass flux (de Blanc et al. 1997, Rao et al. 2002, Zoller 1998, Zoller and Rubin 2001). Coupling the removal of significant contaminant mass with a bioremediation “polishing step” to control the contaminant mass flux emanating from remaining DNAPL provides a synergism that cannot be obtained with other remediation strategies. This sequential treatment approach is not to be confused with natural attenuation, a remediation approach generally associated with bioremediation of low contaminant concentrations in a groundwater plume (Wiedemeier et al. 1999).

The FS describes how the above paradigm—using the synergism of aggressive source treatment with post-treatment biostimulation to achieve significant source mass reduction and downgradient contaminant concentration reduction—is applicable to the Site.

7.2 DEFINITION OF REMEDIAL ACTION OBJECTIVES

As mentioned in the previous section, although complete removal of contamination is not technically feasible due to the properties and behaviors of DNAPLs, protection of human health and the environment can be achieved by mass reduction and control of exposure, even if low levels of COCs remain on-site following implementation of the selected remedy. Remedial action objectives (RAOs) for the Site have been selected to ensure ongoing protection of human health and the environment, and include the following:

- *Reduce concentrations of COCs in shallow soils to protect worker health from direct contact exposure.*

  Of primary concern are chlorinated compounds in the shallow subsurface soil within the boundary of the Cascade Columbia Facility. COCs are not known to occur at concentrations greater than either industrial or residential soil cleanup levels in the top 15 feet of the subsurface at any of the downgradient properties.

- *Reduce concentrations of COCs in indoor air to protect worker health from vapor inhalation exposure.*

Vapors emanating from shallow subsurface contaminated soil and the 1st WBZ groundwater may affect enclosed facility structures, on-site or downgradient.

- *Reduce concentrations of COCs in groundwater to protect surface water quality in the S. Myrtle Street Embayment.*

  The highest beneficial use of groundwater at this Site is protection of human health and ecological receptors from chemicals in surface water. Currently, groundwater at the Site transports COCs downgradient where they discharge to the marine surface waters of the S. Myrtle Street Embayment.

- *Reduce, to the extent practicable, concentrations of COCs in soil at source areas within the Site that are long-term sources of continuing groundwater contamination.*

  Treatment of the solvent mass that remains at the Site, to depths of 65 feet or more, is necessary to result in acceptable levels of dissolved concentrations of COCs in groundwater in both the 1st and 2nd WBZs.

7.3 POINTS OF COMPLIANCE

Points of compliance (locations were the cleanup levels shall be achieved) are established for each impacted media at the Site. These impacted media include groundwater, air, soil, and surface water. The points of compliance for each medium are discussed separately below.

7.3.1 Groundwater Conditional Point of Compliance

The standard point of compliance for groundwater under MTCA is “throughout the site from the uppermost level of the saturated zone extending vertically to the lowest depth which could potentially be affected by the site” (WAC 173-340-720 (8)). However, per MTCA (WAC 173-340-720(8)), where it can be demonstrated that it is not practicable to meet the cleanup levels throughout the Site in a reasonable restoration time frame, a conditional point of compliance (CPOC) may be approved by Ecology. As discussed above in Section 7.1, no practicable technology yet exists to clean up the source areas at DNAPL sites in a reasonable restoration time frame to meet current regulatory levels. This is especially true at this Site due to the continued presence of DNAPL and the large mass of solvent released at this Site. Therefore, a CPOC is warranted.

MTCA requires that the CPOC “shall be as close as practicable to the source of the hazardous substances” (WAC 273-340-720(8)(c)). Typically, the CPOC cannot exceed the property boundary except if the property is abutting surface water, or near but not abutting surface water. The Site is near, but not abutting surface water and so this section of MTCA (WAC 173-340-720(8)(d)(ii)) applies. As required under this section, Ecology may approve of a CPOC located as close as practicable to the source, not to exceed the point or points where the groundwater flows into surface water. At the Site, source areas such as at the loading dock and rail spur lie at the property boundary (refer to Figure 7.1) making an off-property CPOC justifiable.

However, another requirement for an off-property CPOC is that the affected property owners between the source of contamination and the surface water body must agree in writing to its use. The owner of the downgradient Seattle Boiler Works property has indicated that they will not concur with an off-property CPOC beyond the Site’s property boundary (i.e., at the S. Myrtle Street Embayment). Therefore, the CPOC for groundwater shall be at Fox Avenue, along the downgradient property boundary of both the Fox LLC property and the Whitehead Property. These two properties encompass the full width of the plume.

In the future, should Seattle Boiler Works consent to use of an off-property CPOC, a request will be made to Ecology to move the conditional point of compliance from Fox Avenue to the S. Myrtle Street Embayment.

Compliance shall be measured by direct sampling of groundwater in the paired monitoring wells that lie on either side of Fox Avenue, as well as other downgradient well pairs. The existing well network along Fox Avenue is robust and well suited for paired compliance sampling in the 1st WBZ and upper part of the 2nd WBZ. To determine compliance, the concentrations of COCs in these wells will be directly compared to the proposed groundwater remediation and cleanup levels, as detailed in Section 11.0.

7.3.2 Air Point of Compliance

The point of compliance for ambient and indoor air is site-wide; however, vapor intrusion from subsurface contaminants occurs only in enclosed spaces and structures such as the Cascade Columbia office, or downgradient structures overlying the downgradient plume (Seattle Boiler Works facility). The remedial action proposed for the source areas is intended to significantly reduce soil and groundwater concentrations in the 1st WBZ such that the residual concentrations will be protective of air site-wide, including structures off-site overlying the Downgradient Groundwater Plume. Per direction from Ecology, compliance will be documented by measuring indoor air in the Cascade Columbia office, the downgradient Seattle Boiler Works buildings, and other potentially impacted structures prior to, during, and following source area and Downgradient Groundwater Plume remediation. Refer to Section 7.7 for discussion of interim measures for indoor air if it is found that the residual soil/groundwater concentrations still impact indoor air.

7.3.3 Soil Points of Compliance

The points of compliance for soil are based on three pathways of exposure:

1. **Soil direct contact.** The MTCA standard point of compliance for soil for direct contact is from the ground surface to a depth of 15 feet bgs. Compliance with the direct contact cleanup level for PCE will be determined by direct sampling of soil following source area remediation and comparing the post-cleanup soil concentrations to the PCE soil cleanup level set in Section 4.0.
2. **Soil leaching contaminants to groundwater**. This is a cross-media pathway that concerns all site soil that is a potential source of chemicals to groundwater. Compliance will be demonstrated by directly comparing groundwater concentrations at the conditional point of compliance following source area remediation to the proposed groundwater remediation levels. If groundwater at the conditional point of compliance meets the proposed groundwater remediation levels, this pathway will be empirically demonstrated to have met soil cleanup levels and will be in compliance.
3. **Soil in the vadose zone causing vapor intrusion**. For protection of this cross-media pathway, the point of compliance is from the surface to the uppermost groundwater table (approximately 10 feet bgs at the Site). Compliance will be demonstrated empirically by direct sampling of indoor air following source area remediation. If indoor air is in compliance with the proposed indoor air cleanup levels, then this pathway will be empirically demonstrated to have met soil cleanup levels and will be in compliance.

7.3.4 Surface Water/Seeps Point of Compliance

The point of compliance for groundwater discharging to surface water will be the seeps along the S. Myrtle Street Embayment. The point of compliance for surface water itself will be the water column within the embayment. While the seeps exhibit concentrations of COCs greater than proposed cleanup levels, past sampling of the adjacent surface water has not demonstrated an exceedance of the surface water cleanup standards so this media is assumed to currently be in compliance. The seeps will also be sampled and the concentrations directly compared to the groundwater cleanup standards that are protective of surface water.

7.4 LOCATION-SPECIFIC ARARS

Location-specific ARARs are restrictions placed upon the concentration of hazardous substances or the activities proposed for cleanup due to the location of the Site, such as in a wetland. There are no applicable location-specific ARARs for the Site.

7.5 DEFINITION OF CLEANUP ACTION AREAS

Due to the large size of this site and the various plumes and source areas, no single technology will be capable of effectively addressing contamination site-wide. To enable a better comparison and evaluation of technologies to occur in the FS, the Site is divided into three Cleanup Action Areas (CAAs) where the nature and fate of chemical contaminants are similar, and can be remediated by the same technologies. These CAAs were introduced in the Conceptual Site Model in Section 6.0, and are described in detail below. Remedial alternatives for addressing contamination in each CAA will be proposed and evaluated individually for each area. The technology that is identified by the evaluation process to provide the greatest degree of benefit compared to the cost for implementation will be assembled into the proposed preferred remedy for remediation of the Site.

7.5.1 Main Source Area Cleanup Action Area

The Main Source Area CAA encompasses the majority of soil contamination at the Site, and includes the entire Cascade Columbia Facility with the exception of the parking area in the northwest corner as shown on Figure 5.1. Historical operations in the Main Source Area include handling and storage of chemicals. Contamination within the Main Source Area includes vadose zone soil contamination, and saturated zone soil. Groundwater and soil have been detected at concentrations that indicate DNAPLs are likely present. The Main Source Area CAA also includes the railroad spur to the south of the Fox Avenue Building, where CVOCs are present in soil and groundwater at high concentrations, and the Loading Dock Area, where concentrations of CVOCs are present mainly in vadose zone soils, and groundwater in the 1st and 2nd WBZs. The Main Source Area extends from under the Flammables Shed and Production Area of the property to the southern part of the Site beneath the railroad spur and on the Whitehead Property. The Main Source Area CAA represents the principal ongoing source of chlorinated chemicals to groundwater at the Site.

7.5.1.1 Main Source Area Chemicals of Concern

The COCs within the Main Source Area CAA include PCE, TCE, VC, and cis-1,2-DCE in both soil and groundwater. Also present at elevated concentrations are mineral spirits, benzene, and Penta. The nature and extent of COCs are discussed in Section 5.0. The maximum concentration of PCE + TCE detected in the Main Source Area CAA soils exceeds 4,000 mg/kg (beneath the Flammables Shed). The maximum PCE + TCE concentration detected in vadose zone soils beneath the Loading Dock Area exceeds 1,100 mg/kg.

7.5.1.2 Main Source Area Points of Compliance

As discussed in Section 7.1, attainment of cleanup levels at DNAPL sites is often unachievable, due to the high concentrations of contaminants in the subsurface, and the limitations of existing technologies to remove or degrade to acceptable cleanup levels. As a result, the remediation goals for the Main Source Area are focused instead on compliance with the RAOs outlined in Section 7.2. The RAOs that apply to the Main Source Area include reducing concentrations of COCs in indoor air to protect worker health from inhalation, reducing COCs in soil that are long-term sources of continuing groundwater contamination, and reducing COCs in shallow soils to protect worker health from direct contact exposure.

A conditional point of compliance for groundwater at Fox Avenue will be used within the Main Source Area, as allowed by MTCA and discussed in Section 7.3. The applicable point of compliance for ambient air is site-wide, and applicable to locations where vapors may congregate in enclosed spaces, such as buildings and offices. The applicable point of compliance for soils within the Main Source Area include all three pathways of exposure discussed in Section 7.3, including the top 15-feet for direct contact, the vadose zone for soil vapor protection of indoor air, and saturated soil for protection of groundwater. The remedies proposed for the Main Source Area will be evaluated for their ability to comply with the RAOs, MTCA criteria, and attain cleanup levels at the points of compliance listed above.

7.5.2 Downgradient Groundwater Plume Cleanup Action Area

The Downgradient Groundwater Plume CAA includes the area to the southwest of the Fox Avenue Building from Fox Avenue to the S. Myrtle Street Embayment. The Downgradient Groundwater Plume CAA includes dissolved phase contamination in both the 1st and 2nd WBZs. There is no soil contamination of significance in the Downgradient Groundwater Plume. Figure 7.1 shows the extent of the CAA, which includes the Fox Avenue ROW, the downgradient Seattle Boiler Works facility, and the S. Myrtle Street ROW. There is no known historical use of solvents in this CAA, and all contamination in this location is assumed to be a result of chemical migration from the upgradient Main Source Area CAA. The ERD Interim Action discussed in Section 3.2.5 was implemented in the Downgradient Groundwater Plume CAA beginning in 2009 through injection of substrate in wells along Fox Avenue, and S. Myrtle Street, as shown in Figure 3.1. Preliminary results from ERD Interim Action monitoring indicate that chemical concentrations of parent compounds in both WBZs are degrading at in increased rate as compared to pre-ERD conditions.

7.5.2.1 Downgradient Groundwater Plume Chemicals of Concern

The COCs within the Downgradient Groundwater Plume CAA include CEA parent and daughter products in both the 1st and 2nd WBZ groundwater. Benzene is also present, as are a few limited occurrences of other solvents. The highest concentrations of parent CEAs are observed downgradient from the Loading Dock Area, and the Rail Spur Area, where high concentrations of PCE + TCE are present in soils in the Main Source Area. The maximum concentration of PCE + TCE detected in the Downgradient Groundwater Plume CAA exceeds 1,000 µg/L in the 1st WBZ beneath the Fox Avenue ROW immediately downgradient from the Main Source Area. Concentrations of PCE + TCE in the 2nd WBZ in this same area are slightly less than 1,000 µg/L. The groundwater plume of daughter product-CEAs, including cis-1,2 DCE, and VC expands to the southeast to encompass all of S. Myrtle Street west of the intersection with Fox Avenue in the 1st and 2nd WBZs.

7.5.2.2 Downgradient Groundwater Plume Point of Compliance

The groundwater cleanup levels developed for the Site as discussed in Section 4.0 are set for protection of surface water. Attainment of these low cleanup levels at DNAPL sites is often unachievable across the plume, due to the high concentrations of chemicals in the subsurface, and the limitations of existing technologies to remove or degrade to acceptable cleanup levels. A CPOC for groundwater at the Site has been set at Fox Avenue, upgradient from the Seattle Boiler Works facility and other downgradient properties. The chemicals that have migrated past the CPOC at concentrations greater than the site cleanup levels comprise the Downgradient Groundwater Plume. The point of compliance for groundwater is throughout the Downgradient Groundwater Plume.

Remedial technologies are proposed for the Downgradient Groundwater Plume that are expected to attain cleanup levels protective of surface water at the groundwater seeps at the S. Myrtle Street Embayment within a reasonable restoration time frame. These remedies will be evaluated on their ability to comply with RAOs and attain cleanup levels at the S. Myrtle Street Embayment.

Achieving the RAOs will result in control of existing risk and exposure pathways including: reducing concentrations of COCs in groundwater to protect indoor air, and reducing COCs in groundwater that discharge to surface water.

7.5.3 Northwest Corner Plume Cleanup Action Area

The Northwest Corner Plume CAA includes the area to the west of the Fox Avenue Building encompassing the triangular parking area bordered to the north by S. Willow Street, to the west by Fox Avenue, and to the east by the Cascade Columbia Warehouse Building (Figure 7.1). The Northwest Corner Plume CAA includes dissolved-phase contamination in the 1st WBZ and limited soil contamination in the vadose zone. There are no known historical operations in this CAA; however, the presence of scattered and diffuse vadose zone soil contamination suggests historical releases may have occurred in this area, and may be associated with the former rail line activities including transference of chemicals. The groundwater contamination in this area is limited to the 1st WBZ and so the remedial technologies that can be evaluated for this area may be different than those evaluated for the Main Source Area or Downgradient Groundwater Plume CAAs, which have chemical contamination at much deeper levels and much higher concentrations.

7.5.3.1 Northwest Corner Plume Chemicals of Concern

The COCs within the Northwest Corner Plume CAA are limited to CEA parent compounds because concentrations of daughter products in the CAA are typically less than the site groundwater cleanup levels. Low-level concentrations of PCE + TCE are present in vadose zone soils. The nature and extent of COCs are discussed in Section 5.0. The maximum concentration of PCE + TCE detected in the Northwest Corner Plume CAA groundwater exceeds 1,600 µg/L in the 1st WBZ beneath the Fox Avenue ROW. The maximum historical detected concentration of PCE in the vadose zone soils in the Northwest Corner Plume CAA was sampled in the S. Willow Street ROW at a concentration of 18 mg/kg. Recent sampling indicates that PCE + TCE concentrations are currently less than 1 mg/kg.

7.5.3.2 Northwest Corner Plume Point of Compliance

A CPOC for the Northwest Corner Plume CAA on the Site has been proposed at Fox Avenue, upgradient from the Seattle Boiler Works facility. Concentrations of CVOCs in groundwater must meet the cleanup levels in wells located along Fox Avenue and all points downgradient associated with this plume. The effectiveness of a remedy to comply with the RAOs will be the basis for evaluating remedial technologies proposed for the Northwest Corner Plume CAA. Achievement of the RAOs described in Section 7.2 will result in control of all existing risk and exposure pathways, including: reducing concentrations of COCs in indoor air to protect worker health from inhalation, reducing COCs in groundwater that may provide a source of contamination to indoor air quality, and reducing COCs in groundwater that may be discharging to surface water. The remedies proposed for Northwest Corner Plume CAA will be evaluated on their ability to comply with RAOs and attain cleanup levels at the CPOC discussed above.

7.6 FINAL CHEMICALS OF CONCERN AND CLEANUP LEVELS

The final site-wide COCs, as determined from the RI, to be considered during the FS evaluation of technologies include the following:

Chemical of Concern	Soil CUL—Protection of Groundwater	Groundwater CUL—Protection of Surface Water (µg/L)	MTCA Method B Indoor Air CUL[2] (µg/m^3)	MTCA Method C Indoor Air CUL[2] (µg/m^3)
Benzene	Empirical[1]	51	NA	NA
1,1-DCE	Empirical[1]	3.2	NA	NA
Pentachlorophenol	Empirical[1]	3.0	NA	NA
PCE	Empirical[1]	3.3	0.42[3]	4.2
TCE	Empirical[1]	30	0.10[3]	1.0
TPH (Mineral Spirits to Heavy Oil Range)	Empirical[1]	500	NA	NA
Vinyl Chloride	Empirical[1]	2.4	NA	NA

Notes:

1. CUL has no numeric value. Instead, soil will be empirically demonstrated to be in compliance with its CUL when groundwater at the CPOC meets its CULs within the estimated restoration time frame.
2. MTCA Method B CULs are applied at the Seattle Boiler Works property because the property owner will not agree to a covenant restricting future land to industrial purposes. MTCA Method C CULs are appropriate for the Fox LLC property assuming the property will be restricted by a covenant to industrial use. Protectiveness of the current receptors to indoor air at concentrations greater than the Method B formula values can consider adult worker exposure in lieu of residential exposure in accordance with Section 6.6.2 of Ecology's *Guidance for Evaluating Soil Vapor Intrusion in Washington State: Investigation and Remedial Action* (Ecology 2009b).
3. Ambient air samples collected at the Seattle Boiler Works facility in October 2010 indicated that ambient (background) PCE and TCE concentrations were greater than MTCA Method B CULs. Therefore, in accordance with Section 3.2.3 of Ecology's *Guidance for Evaluating Soil Vapor Intrusion in Washington State: Investigation and Remedial Action*, Draft October 2009, (Ecology 2009b) the sample results will be adjusted to account for background during each sampling event if ambient is higher than the CUL.

Abbreviations:

CUL	Cleanup level	PCE	Tetrachloroethene
DCE	Dichloroethene	Penta	Pentachlorophenol
MTCA	Model Toxics Control Act	TCE	Trichloroethene
NA	Not Applicable	TPH	Total petroleum hydrocarbons

7.7 REMEDIATION LEVELS

This section discusses the use of remediation levels at the Site. In accordance with WAC 173-340-200, a remediation level "means a concentration of a hazardous substance in soil, air, water, or sediment above which a particular cleanup action component will be required as part of a cleanup action at a site." Remediation levels are, by definition, concentrations that exceed cleanup standards and are used when a combination of cleanup action components are necessary to achieve cleanup levels at the point of compliance. Cleanup actions that use remediation levels to meet the cleanup standards at a CPOC are also considered to comply with the cleanup standards.

Remediation levels are applicable to this Site because implementation of multiple aggressive treatment technologies will likely be necessary to achieve cleanup levels for groundwater at the proposed CPOC, located along Fox Avenue and throughout the Downgradient Groundwater Plume. As explained in the RI, COC concentrations in soil and groundwater are elevated and occur deep within the aquifer. Attaining the proposed groundwater cleanup levels would require at least a four orders of magnitude reduction (99.99 percent) in the current concentrations in groundwater; a challenge that is beyond that ability of any single existing technology to achieve in a reasonable restoration time frame. Compounding the situation is the location of the source areas with respect to the proposed CPOC for groundwater. The Main Source and Loading Dock Areas lie very close to or abut Fox Avenue, leaving no room for attenuation between the soil source and the CPOC.

Given the above situation, a combination of cleanup technologies must be used at this Site in order to reduce concentrations of COCs to the lowest concentrations technologically achievable and practicable. Remediation levels, therefore, must be established that allow one cleanup technology to transition to another, as described later in this FS. The development of remediation levels is documented in Appendix I for both site soil and groundwater. The proposed RLs are summarized in the table below.

Groundwater Remediation Level	Basis	Soil Remediation Level	Basis
250 µg/L Total CVOCs (as measured in the designated monitoring well network)	1. Expected residual average concentration in source area groundwater following source area remedy implementation. 2. Concentration for ERD following thermal treatment will result in achieving cleanup levels at the seeps in a reasonable restoration time frame. 3. Concentration will not present a vapor intrusion risk in downgradient properties. 4. Cleanup levels will be attained at the CPOC over an extended restoration time frame via natural attenuation.	10 mg/kg (average soil concentration following source area treatment)	1. Technologically achievable; represents 98 percent reduction from source area average concentration. 2. Achieves MTCA Method C direct contact levels. 3. Expected to eliminate source of current vapor intrusion into Cascade Columbia office. 4. Expected to result in 98 percent reduction in source area groundwater concentrations in 1st and 2nd WBZs.

Abbreviations:

CPOC	Conditional point of compliance
CVOC	Chlorinated volatile organic compound
MTCA	Model Toxics Control Act
WBZ	Water Bearing Zone

The basis for the proposed source area soil and groundwater remediation levels is to achieve both short- and long-term goals. The short-term goals for the Site are to (1) eliminate the indoor air pathway, (2) eliminate the worker direct contact pathway and (3) achieve groundwater cleanup levels at the seeps (refer to the conceptual site model for the Site depicted in Figure 6.1). The long-term goals are to achieve compliance with the proposed cleanup levels in groundwater (as measured at the CPOC and throughout the downgradient groundwater).

Compliance with indoor air cleanup levels will be documented by measuring indoor air in the Cascade Columbia office and in one or more of the downgradient Seattle Boiler Works buildings before, during, and following source area remediation. Indoor air concentrations will be compared to the proposed site cleanup levels for indoor air quality to determine if additional remedial measures are required for the protection of indoor air. If an evaluation of the data indicates that an air quality risk exists based on current exposure assumptions, interim measures to address indoor air quality will be evaluated. Initial modeling completed as a screening evaluation of the vapor intrusion pathway does not indicate that an unacceptable risk to indoor air quality will occur (under current industrial facility use) once the proposed groundwater remediation levels are achieved. This evaluation is described in the remediation level appendix (Appendix I), and will be confirmed by data collection following source area treatment and/or achievement of the groundwater remediation levels.

8.0 Preliminary Technology Screening

This section identifies potentially applicable remedial technologies for cleanup of the COCs identified in Section 4.0. This section begins by reviewing potential remedial technologies, followed by a preliminary technology screening to eliminate technologies that clearly do not achieve the RAOs discussed in Section 7.0. Following the preliminary technology screening, a more detailed evaluation of the remaining technologies is conducted that considers site-specific conditions. Technologies determined to potentially achieve RAOs, given the site-specific conditions, were retained for the detailed evaluation presented in Section 9.0.

Common approaches to remediate CVOCs in soils and groundwater range from passive technologies, such as monitored natural attenuation, to containment of the plume and/or source area, to aggressive technologies that treat or remove the source, such as excavation, in-situ chemical oxidation, or in-situ thermal treatment. As discussed in Section 7.1, even with aggressive technologies, “full restoration” of DNAPL sites to meet applicable groundwater standards is often not possible due to many factors, including the depth to which contamination can extend, the unique and unpredictable behavior of DNAPL in the subsurface, and its persistence in low-permeability layers. In 1993, USEPA recognized the difficulty of DNAPL site restoration by issuing guidance on “technical impracticality” that acknowledges the inability of existing technologies to achieve “full restoration” at a DNAPL site within a “reasonable restoration time frame” (USEPA 1993). This FS also acknowledges the technical impracticability of “full restoration” by setting technologically achievable RAOs in conjunction with a CPOC, as discussed in Section 7.3.

The following section identifies and briefly describes the most common remedial technologies for the site-specific COCs (CVOCs, benzene, and mineral spirits) without consideration of the site-specific RAOs or site conditions, which is done in the subsequent section. For purposes of the preliminary screening of technologies, those technologies with significant incremental costs are identified herein but actual estimated costs for technologies selected for detailed evaluation are discussed later in Section 10.0.

8.1 IDENTIFICATION AND DESCRIPTION OF TECHNOLOGIES

The identification and description of the most common technologies for VOC sites is presented below, with technologies sorted into broad categories, including passive, containment, source reduction, and groundwater treatment categories.

8.1.1 Passive Technologies

8.1.1.1 No Action

No action as a remedial technology involves no further actions at the Site (i.e., no monitoring, maintenance, or implementation of a remedial technology). No action is typically used as a baseline technology for comparison of the benefits of other remedial technologies.

8.1.1.2 Monitored Natural Attenuation

Monitored natural attenuation involves regular groundwater sampling and analysis to monitor the results of one or more naturally-occurring physical, chemical, or biological processes that reduce the mass, toxicity, volume, or concentration of chemicals in site soils and/or groundwater. These in-situ processes may include biodegradation; dispersion; dilution; sorption; volatilization; and chemical or biological stabilization, transformation, or destruction of contaminants. Monitored natural attenuation may be implemented as a standalone remedial technology or in combination with other remedial technologies, such as excavation of soil contamination and removal of light non-aqueous phase liquid (LNAPL) from groundwater.

8.1.1.3 Permeable Reactive Barrier Wall

Permeable Reactive Barrier (PRB) walls intercept and treat chlorinated solvent-contaminated groundwater flowing from an upgradient source. Groundwater flows through a treatment wall of reactive material, which for CVOCs is typically composed of zero-valent iron (ZVI) mixed with sand. Barrier walls are generally constructed in one of two configurations, either as a "funnel and gate" configuration that employs angled wing walls to capture and direct the contaminated groundwater to a central treatment unit, or as a linear trench intersecting the plume. Groundwater flows under its natural gradient through the PRB, where the reactive media within the wall reacts with the dissolved chemicals in groundwater. Restoration time frames for DNAPL sites with barrier walls are often very long if the upgradient source remains untreated. The life span and effectiveness of a PRB wall is also dependant on the mass of chemicals passing through the wall. PRB walls do not remediate the source area itself, but dechlorinate chemicals migrating from the source area with the groundwater.

8.1.2 Containment Technologies

8.1.2.1 Low-permeability Barrier Wall

Barrier wall containment technologies are implemented to contain chemicals in place and typically do not involve further source area treatment. Vertical containment barriers such as slurry walls are placed in the subsurface to cut off groundwater flow and stop chemical migration. Slurry walls are typically constructed vertically from the ground surface to a depth greater than the chemical plume in soil and groundwater, or until the wall encounters a confining layer. The slurry wall is constructed of a low-permeability material, typically a soil and bentonite clay mixture, that does not degrade in the environment. Containment remedies are often implemented in combination with permanent pumping remedies to maintain inward gradients within the contained area and provide hydraulic control. Barrier walls and hydraulic control requires maintenance and monitoring in perpetuity.

8.1.2.2 Surface Capping

Containment remedies typically include the use of surface caps, such as concrete or asphalt, to control surface infiltration. Surface capping also provides a barrier to direct contact to receptors including ecological and human receptors. Surface capping requires maintenance to maintain the integrity of the cap.

8.1.2.3 Pump and Treat

Pump and treat involves pumping of contaminated groundwater from the subsurface. Groundwater is then treated before it is discharged. Treatment is generally conducted by air stripping or filtration via activated carbon. Pump and treat is the most common form of groundwater remediation for DNAPL sites with plumes that have migrated off-site and threaten water supply wells because it typically is very effective in stopping migration of the plume.

Groundwater pump and treat can reduce chemical concentrations in saturated soils, but only slowly by increasing the diffusion of soil contamination into groundwater. Extraction system design and treatment are dependent on the site characteristics and chemical type. Extraction wells may be screened at different levels or intervals to maximize the system effectiveness; however, restoration time frames for pump and treat systems installed at DNAPL sites are often very long because pump and treat cannot significantly accelerate the removal of mass from solvent source areas, which are often large enough to leach chemicals into groundwater for decades.

8.1.3 Contaminant Mass Reduction Technologies

8.1.3.1 Thermal Treatment

Thermal treatment (which is commonly applied via electrical resistance heating or thermal conduction) is a process that quickly and evenly heats the subsurface to volatilize chemicals with low boiling points (e.g., PCE) by passing electrical current or direct heat through zones of contaminated soil and groundwater. With electrical resistance heating, a current is delivered to the subsurface through a series of closely spaced electrodes. Resistance to the flow of electricity between electrodes via the natural resistance of the soil matrix generates heat in the subsurface. Silty zones of soil can be heated as effectively as sandier zones due to the superior electrical resistance properties of silt or clay. If heated close to the boiling point of water, the heating process volatilizes chemical droplets embedded in soil into a vapor phase. The contaminated vapors, along with steam produced by the boiling of groundwater, are recovered by a subsurface network of vapor recovery wells. The steam that is removed from the subsurface through the vapor recovery network is condensed and treated. Chemicals in the vapor stream are typically treated using activated carbon or thermal oxidation.

8.1.3.2 Excavation and Landfill Disposal

Excavation of shallow areas of soil contamination using standard construction equipment is a common method to achieve remediation goals near ground surface in accessible areas. Excavated soil is transported either by truck or rail to an appropriate landfill, or can be handled on-site in a soil treatment cell. Following soil removal, excavated areas are subjected to confirmation soil sampling prior to backfill, compaction, and site restoration. Excavation may require relocation of structures, shoring to maintain sidewall stability, and may require dewatering, or drawdown of the groundwater table, if excavation is to occur below the groundwater table. Excavation is often impractical at active facilities with deep contamination.

8.1.3.3 Soil Vapor Extraction

SVE is a process that extracts soil vapor from unsaturated soils in the vadose zone by applying vacuum to the subsurface. Vacuum is applied via a blower connected to extraction wells screened in the area of contamination. The controlled flow of air removes accumulated volatile vapors from the unsaturated zone, which causes additional volatilization of chemicals in the soil to the vapor phase. Soil vapor extracted from the subsurface is processed through a treatment system, typically including filters for particulate removal, condensate removal, and treatment by oxidation or carbon filtration. SVE systems may be enhanced with air sparging or groundwater extraction, if contamination extends below the water table.

8.1.3.4 Chemical Oxidation/Permanganate Injection

Chemical oxidation involves injecting oxidizing agents such as ozone, hydrogen peroxide, or permanganate into the subsurface to rapidly destroy organic chemicals. Injection can be applied in both vadose and saturated zones, but is most effective in treating chemicals in groundwater. Applicability of chemical oxidation is dependent on soil types and the homogeneity of the subsurface, as injected solutions tend to follow preferential pathways through heterogeneous soils. Volumes of injected agent and rate of chemical injection is dependent on the subsurface conditions at the site. Injection points may be installed as permanent injection wells or may be injected via temporary borings. The effectiveness of injections is very dependent on site conditions, which typically are heterogeneous and present difficulties to obtaining an even and effective distribution of the oxidant. Further, a high soil oxidant demand may significantly reduce the effectiveness of chemical oxidants. Prior efforts at chemical oxidation at the Site were ineffective due to these constraints.

8.1.3.5 Soil Flushing

Soil flushing involves injecting water, or water containing an additive to enhance chemical solubility, into the subsurface to “flush” chemicals out of the soil pore space. In many instances, surfactants or solvents are used are used as the additive. The flushing solution is either directly applied to the soil via injection wells or injected into the groundwater in the zone of contamination. Chemicals are then leached from the soil into the solution, which is then extracted by a downgradient series of wells, treated, and re-injected. The effectiveness of the soil flushing process is dependent on hydrogeologic variables such as soil types, soil moisture, and chemical characteristics. The ability to capture the flushing solution in the downgradient network to avoid downgradient transport of the “flushed” soil contamination is critical to the applicability of this technology.

8.1.3.6 Soil Mixing by Auger

Soil mixing is a process that treats the subsurface soil by mixing amended soil in overlapping soil columns. The soil columns are formed by advancing a large-diameter auger into the subsurface, in combination with a series of mixing shafts. As the mixing shafts are advanced into the soil, grout or slurry with a reactant that destroys the organic chemical (for example, zero-valent iron or a chemical oxidant) is pumped through the hollow stem of the shaft and injected into the soil. The auger flights and mixing blades on the shafts blend the soil with the grout or slurry in pug-mill fashion. This process generates a large amount of spoils that are very difficult to handle, and can also leave wedges of untreated soil in the spaces between the installed soil columns.

8.1.3.7 Dual-phase Extraction

Dual-phase extraction (DPE) technology involves chemical removal from the subsurface in two separate phases—vapor and groundwater—from a single well. Generally, a high vacuum system is used to withdraw both soil vapors and droplets of any separate-phase product that may be present (LNAPLs) and groundwater from the subsurface. Extracted liquids and vapor are then treated prior to disposal. This technology is used primarily in cases where LNAPL is present at shallow depths or contamination is present in soils in the top few feet of the saturated zone, where dewatering a limited extent of the subsurface allows for a greater degree of contamination to be removed through the vapor phase.

8.1.3.8 Enhanced Reductive Dechlorination

ERD is typically applied to moderate to low concentrations of dissolved chlorinated solvents in contaminated aquifers. ERD enhances the naturally anaerobic reductive dechlorination process that is found at many DNAPL sites. A carbon source, termed a “substrate” and/or a microbial inoculation culture, is injected into the affected groundwater zone. Microbes ferment the primary substrate as a carbon and energy source, generating hydrogen and producing enzymes that sequentially dechlorinate the compounds present in the groundwater. Reductive dechlorination describes the oxidative-reductive (redox) process by which chlorine atoms are stripped from CVOCs and replaced with hydrogen. Each stripping of a chlorine atom transforms “parent” chlorinated compounds to “daughters” through a series of dechlorination reactions. For example, if PCE was the chemical spilled at a site, PCE is the “parent” containing four chlorine atoms. PCE is first reduced to TCE, then cis-1,2-DCE, then to VC. Subsequently, VC dechlorinates to ethene, which is a non-toxic gas that rapidly degrades. Each biologically-mediated step requires a lower redox potential than the prior step. ERD is most effective in aquifers with the appropriate microbial types, permeable soil conditions, and presence of naturally reducing conditions in the aquifer. While this process naturally occurs in the subsurface (if naturally-reducing conditions exist), ERD is the process of expediting this naturally-occurring process by providing the existing microbes with a vastly increased energy source to increase the size of the microbial community and hence the rate of biodegradation.

8.1.3.9 Air Sparging

Air sparging is used to treat groundwater contaminated with volatile and certain semivolatile chemicals. Air is injected into the contaminated aquifer through injection wells, where it bubbles upward through channels in the soil column, creating an air stripping effect that moves chemicals in groundwater to the air bubble that migrates to the vadose zone where it can be recovered and treated. Air sparging is limited by contaminant depths and works best in homogenous sandy soil formations that limit preferential pathways for air flow.

8.2 PRELIMINARY SCREENING OF TECHNOLOGIES

Under MTCA WAC 173-340-350(8), a preliminary screening of the technologies identified above was conducted to reduce the number of alternatives for detailed evaluation. The screening is presented in Table 8.1 and includes information regarding technology benefits and constraints. Table 8.1 documents why certain technologies were rejected from further evaluation (e.g., technically infeasible to implement given site conditions or incapable of achieving RAOs). Technologies that were screened out of detailed evaluation include no action, pump and treat, excavation and landfill disposal, chemical oxidation/permanganate injection, soil flushing, soil mixing by auger, and DPE.

8.3 EVALUATION OF RETAINED TECHNOLOGIES

Following the preliminary technology screening presented in Table 8.1, eight technologies were retained for further evaluation. The following sections contain a more detailed discussion of each of the retained technologies and how they could be applied at the Site. Technologies that pass this further evaluation are discussed and compared to the MTCA evaluation criteria in Section 10.0.

8.3.1 Monitored Natural Attenuation

MNA is retained both as a baseline technology (for comparison purposes) and also in combination with more active remedial technologies. MNA as a baseline technology, however, does not significantly reduce contaminant mass at DNAPL sites, and so cannot meet the site RAOs within a reasonable restoration time frame. However, because natural attenuation processes will continue to occur at the Site due to aquifer conditions regardless of what active remedial technologies are implemented at the Site, this FS considers monitored natural attenuation a realistic long-term component of any remedy considered for this Site.

8.3.2 Permeable Reactive Barrier

Effective implementation of a PRB at the Site as a source area treatment with the current soil and groundwater concentrations is limited by a number of factors. Groundwater velocity coupled with the elevated concentrations present is a major concern, as the approximate 2 feet per day of groundwater migration demands an exceptionally thick treatment wall to obtain sufficient treatment time of the groundwater. Such a wall may be technologically difficult and costly to construct. The length of the treatment zone would also have to be substantial, extending for 450 feet along Fox Avenue from S. Willow Street to S. Myrtle Street. In addition, the plume has migrated off the property and is widespread. Installation of a barrier wall downgradient from the contaminant plume is not feasible, given the tidal and saltwater wedge effects at the S. Myrtle Street Embayment.

PRB technology does not directly address source area contamination, where the majority of contamination is known to exist. A PRB would also not be able to address the soil in the source areas that pose a direct contact risk to workers or eliminate the vapor pathway that exists upgradient from the PRB. The PRB would have to operate in perpetuity if implemented as a standalone remedy. Similar to the barrier wall technology, additional controls (capping, ventilation improvements, and institutional controls) would be necessary to address the worker exposure and indoor air intrusion risks that would not be addressed by the PRB.

In limited areas of the Site, such as the Northwest Corner Plume CAA, PRB may be an effective remedy, because the existing chemical concentrations in groundwater in the 1st WBZ are significantly lower than in the source area, the groundwater flow rate is much lower (as compared to the 2nd WBZ), and the extent of the plume is much more restricted. A PRB in this area may be an effective method of intercepting and treating migrating groundwater. PRBs may also be an alternative for treating limited areas of groundwater that exceed cleanup levels following completion of a more aggressive treatment remedy in the source area. If other technologies are successful in reducing source mass and dissolved groundwater concentrations, but are not able to achieve cleanup goals within a reasonable time frame, PRBs may be more effective at reducing groundwater concentrations if the initial concentrations are reduced. This would improve the effectiveness, life span, and extent of the PRB, causing it to be a more effective technology.

The life span of a PRB is typically limited to 20 years or less. If implemented in the source area, without more aggressive source area treatment, a PRB would likely require frequent replacement at high cost in perpetuity. Due to these limitations, PRB technology is carried forward only for further evaluation in Section 10.0 for the Northwest Corner Plume CAA and the Downgradient Groundwater Plume CAA, or as a contingent action implemented in the Main Source Area CAA following completion of more aggressive remedial technologies.

8.3.3 Low-permeability Barrier Wall

Containment technologies are not permanent because they do not reduce contaminant mass, toxicity, or volume. When effectively implemented, containment remedies may eliminate chemical migration; however remedy maintenance and monitoring is required in perpetuity to ensure continued function of the remedy. Due to the location of the chemical plumes at the Site, a barrier wall to contain the source soil and groundwater from further chemical migration would be constructed outside the property boundary and would likely require easements from adjacent property owners and in public right-of-ways, along with extensive utility relocation. The wall would not be capable of containing the entire Downgradient Groundwater Plume, as it has migrated well beyond the site boundaries.

At this Site, there are several implementability concerns associated with a barrier wall. Subsurface investigations at the Site have not encountered a confining layer beneath the 2nd WBZ that a barrier wall would key into. This would require constructing a deeper hanging wall that extends considerably less than the base of contamination (minimum 70 to 90 feet).

Given that the site source areas are separate and found mostly within the warehouse footprint, the Cascade Columbia Facility prevents construction of a barrier wall that can tightly encircle the source areas. Instead, the alignment of the barrier wall would have to encompass the approximate entire warehouse perimeter, resulting in a much larger area being contained that would include a considerable volume of clean areas.

The groundwater velocity of 2 feet per day would require significant hydraulic control systems to maintain an inward gradient to prevent contaminated groundwater from seeping outside of the base of the barrier over time. With a larger enclosed area as discussed above, hydraulic control of a larger volume of water would be required, and result in a larger volume of water requiring treatment and disposal. Operations and maintenance of these hydraulic control systems would be required in perpetuity. In addition, handling, treatment, and discharge of the extracted groundwater stream may result in substantial costs for system operation. A barrier wall would also not be able to address the soil in the source areas that pose a direct contact worker risk nor eliminate the vapor pathway that exists in the office area, requiring that these pathways be managed by a different technology, such as surface capping.

Finally, since groundwater contamination has already migrated downgradient, over a wide area, a barrier wall would not be capable of encapsulating the entire plume, which would leave a portion of the contaminated groundwater plume outside of the containment area and not addressed by the technology.

Given these constraints, once constructed, a barrier wall would immediately provide control of ongoing migration of chemicals from the Site, and would result in achieving the RAOs, assuming treatment of the Downgradient Groundwater Plume is addressed with a different technology, such as ERD. Although cleanup levels will not be achieved at the Site by implementing a containment remedy, ongoing chemical migration would be eliminated and exposure pathways would be controlled.

A barrier wall by itself does not address the soil exposure risk to workers, and would require implementation in coordination with other technologies to address the vapor pathway and direct worker contact. To address these risks, surface capping (as already implemented at the Cascade Columbia Facility) would need to be maintained in the long-term. Maintenance of surface capping at the facility will block the direct contact pathway for workers and reduce surface water infiltration into contaminated areas, which will, in-turn, reduce the potential for chemical migration. Caps require maintenance and monitoring in perpetuity. Institutional controls would be required to ensure maintenance obligations. To address the vapor pathway, improved ventilation would likely be required, and again, institutional controls would be necessary to ensure long-term maintenance and proper operation of the improved ventilation system.

Containment with a barrier wall system is retained for evaluation because this is the only containment remedy proposed that would comply with RAOs when implemented in combination with other technologies in the Main Source Area CAA and Downgradient Groundwater Plume CAA.

8.3.4 Surface Capping

Containment technologies are not permanent as they do not reduce contaminant mass, toxicity, or volume. When effectively implemented, containment remedies may eliminate contaminant migration and control exposure pathways, however remedy maintenance and monitoring is required in perpetuity to ensure continued function of the remedy.

Existing exposure pathways at the Site that can be addressed by surface capping include direct worker contact, and vapor intrusion. To address these risks, surface capping (as already implemented at the facility) would need to be maintained in the long-term. Maintenance of surface capping at the facility will block the direct contact pathway for workers, control the vapor migration pathway, and reduce surface water infiltration into contaminated areas, which will, in-turn, reduce potential for migration of contaminants. Caps require maintenance and monitoring. Institutional controls would be required to assure maintenance obligations. When used in combination with other technologies, surface capping may be an effective technology for control of direct contact and vapor pathways. Surface capping is retained for evaluation in combination with other technologies, but would not be implemented as a standalone technology. The Site is currently capped as nearly 100 percent of the surface is paved or covered by structures.

8.3.5 Thermal Treatment

Thermal treatment technology effectively removes volatile contaminants in soil and groundwater that have boiling points less than that of water. It can also address separate phase NAPLs (LNAPL and DNAPL). Thermal treatment can be effectively implemented to the depths contamination is present at the Site if a sufficient power supply is available and not impeded by facility activities. Thermal treatment has a short restoration time frame, as contaminant removal from the subsurface is typically complete in one year or less of active heating. Due to the high maximum concentrations present at the Site (approximately 4,000 mg/kg PCE), and the large quantity of remaining source mass, thermal treatment is likely not be capable of removal of all of the source mass and so may require use of other technologies following completion of thermal treatment to continue degradation of low-level CVOC concentrations.

Based on review of numerous sites nationwide where thermal has been implemented, thermal treatment may be capable of reducing average starting concentrations in soil by 95–99 percent, which if achieved, will eliminate the soil currently in excess of Method C cleanup levels and also eliminate the solvent mass in soil now contributing to the soil vapor pathway in the office area. Achievement of this degree of source reduction would also significantly reduce the restoration time frame for reaching groundwater cleanup levels at the CPOC. Institutional controls to prohibit the use of groundwater from residually-contaminated areas would be required; however, following thermal treatment.

Implementation of thermal treatment technology would require numerous electrode installations and substantial piping and trenching throughout the treatment area, causing considerable disruption to facility operations. In some areas, facility activities and utilities and underground structures may limit access and therefore effectiveness of the thermal technology. Thermal treatment may also increase temperatures at the paved ground surface to as hot as 50-degrees Celsius. This surface temperature will require temporary relocation of areas that store and handle flammable materials and/or require upgrades in facility electrical wiring to be intrinsically safe. There are short-term risks associated with the application of high voltage to the subsurface that can be effectively managed by proper grounding and use of safe engineering practices and design.

Thermal treatment is an expensive technology to implement and operate and consumes large amounts of electricity. In addition, thermal oxidizers used to destroy the extracted vapors use natural gas as a heat source and so generate large quantities of carbon dioxide, a greenhouse gas. For these reasons, thermal treatment is rarely applied outside of source areas because the cost associated with removal of the low amount of contaminant in fringe areas or Downgradient Groundwater Plume is highly disproportionate to the resulting benefits.

A unique advantage of thermal treatment is the proven ability to achieve a very high degree of cleanup on chlorinated solvent sites. This is because of the technology which distributes current uniformly in both silty and sandy soil as well as in either vadose zone or saturated zone soil.

The amount of cleanup depends on the subsurface temperature reached and the time the subsurface is maintained at that target temperature. Typically, a model is run that takes into account the resistive properties of the soil, the groundwater conductivity, organic carbon content, and contaminant types and concentrations. The model determines the target temperature and the time required to volatilize (or boil off) the contaminant mass to reach the desired cleanup goal, based on the average and peak contaminant concentrations.

Once the subsurface has been heated to the target temperatures for the predicted amount of time, the subsurface is allowed to cool down and samples are collected to verify attainment of cleanup objectives. If objectives are not reached, an evaluation is conducted to assess the magnitude and extent of residual contamination and whether it is practicable and cost-effective to reheat the subsurface or whether other treatment technologies should be used to attain cleanup objectives. Due to the effectiveness of thermal treatment to address Site COCs, in the majority of source soil areas, thermal treatment is retained for further evaluation in the following sections for application in the Main Source Area CAA.

8.3.6 Soil Vapor Extraction

SVE is an effective method for removing volatile contaminants from shallow unsaturated soils. SVE removes chemicals that have partitioned to the soil vapor by applying a vacuum to the subsurface soil. SVE was previously implemented in the Main Source Area at the Site and removed an estimated 12,000 pounds of CVOCs from the subsurface. However, after several years of operation, the system became asymptotic and removal rates dropped to a level that did not justify continued operation of the system. Testing conducted during the Data Gaps Investigation subsequently revealed that elevated levels of chemicals remained in the unsaturated zone in the area where the SVE system operated.

The geologic conditions at the Site are partially conducive to SVE, as the vadose zone soils are comprised in part of permeable sands. SVE is not as effective at removing chemicals from finer-grained material, such as silt. SVE systems are also not capable of treating saturated soils or chemicals in groundwater. Implementation of SVE is also limited by site activities and existing structures, as extraction wells and system piping must be installed across the treatment area.

The contamination in the Northwest Corner Plume CAA was investigated and identified as being limited to the vadose zone soils; however, chemical concentrations are low and randomly distributed, and a distinct and identifiable source of soil contamination in the area was never identified. An SVE pilot study was conducted in the Northwest Corner in 2010, resulting in PCE removal rates of approximately 1.5 pounds per day. Ongoing groundwater contamination in this area exists at concentrations that indicate equilibration with the vapor concentration extracted during the SVE pilot test. SVE is amenable in this situation because the technology has a large radius of influence that can encompass a diffuse and scattered source area. Soil types in this area are sands that are favorable for SVE. As a standalone technology at this Site, SVE is not likely to achieve remedial goals within a reasonable restoration time frame. However, SVE could be implemented in shallow, sandy vadose zone soils (e.g., in the Northwest Corner Plume CAA) and may also effectively control vapor intrusion risk in the office area following implementation of a Main Source Area treatment, if the selected source area treatment is not effective at mitigating vapor intrusion risk. SVE is retained for further evaluation.

8.3.7 Enhanced Reductive Dechlorination

ERD was implemented in 2009 as an interim action to treat the Downgradient Groundwater Plume. Initial monitoring indicates that the process is effective and is increasing the rate of natural attenuation in the Downgradient Groundwater Plume. Description of the scope of the ERD interim action and initial results is included in Section 3.2.4.

ERD was developed as an approach to remediate dissolved-phase CVOC plumes in groundwater and has proven successful at many sites in providing permanent destruction of mobile CVOCs through the reductive dechlorination processes (ITRC 2008). No waste stream is generated by ERD and implementation is fairly simple, involving periodic injection of substrate through injection wells. However, without source control actions, continued substrate injections and monitoring would be required in perpetuity to continue to degrade chemical concentrations in downgradient groundwater. ERD as a standalone technology is not capable of reducing high concentrations of CVOCs in source areas down to cleanup levels. ERD is more effective in downgradient plumes for this reason.

ERD application to source areas is currently considered an evolving technology that works primarily by accelerating the dissolution of solvent from soil, thereby reducing restoration time frames (ITRC 2008). As with any in-situ technology, success is highly dependent on the ability to deliver the substrate to the affected areas. At the Site, given the high starting concentrations of chemicals in source area soils and the nature of the 1st SH, where a large amount of contaminant mass exists, ERD as a standalone technology to remediate the source areas is not expected to reduce chemical concentrations to acceptable levels in a reasonable restoration time frame; however, ERD is retained as a technology for comparison to other source control alternatives in the following sections. ERD as a source control measure may be more useful when applied in combination with other technologies, or if implemented when initial chemical concentrations in soil are low, enabling a reduced restoration time frame to be potentially achieved. For example, ERD may be applied in low concentration soil zones source areas following thermal treatment when subsurface temperatures are elevated and greatly promote bacterial growth and accelerated degradation of the remaining residually-contaminated areas.

8.3.8 Air Sparging

The applicability of air sparging at the Site is limited by site conditions to the shallow 1st WBZ groundwater. Air sparging is not a vadose zone technology, nor is it effective in very deep groundwater plumes, eliminating it from use in the Main Source Area and Downgradient Groundwater Plume CAAs. However, it may be applicable in the Northwest Corner Plume CAA 1st WBZ groundwater or applied as a sparge curtain to intercept and treat shallow groundwater in focused situations. One disadvantage to air sparging is that it introduces oxygen into the groundwater and so does not work well with sites using ERD. Implementation of air sparging is retained for evaluation as a treatment technology for certain areas of the Downgradient Groundwater Plume that are not affected by ERD and are shallow. A potential application would be to the end of a plume area where the shallow 1st WBZ groundwater may be able to be treated by air sparging, if necessary, prior to discharge to the seeps.

8.4 SUMMARY OF RETAINED TECHNOLOGIES

Technologies retained for potential implementation in one or more of the site cleanup areas include the following:

- Monitored natural attenuation, as a baseline for comparison, or in combination with other more aggressive technologies.
- PRB, for application in the Northwest Corner Plume CAA, or for implementation following more aggressive source area treatments in other areas.
- Low-permeability barrier wall, for application in the Main Source Area CAA.
- Surface capping, in combination with other remedial technologies.
- Thermal treatment, for application in the Main Source Area CAA.
- SVE, for application in areas with vadose zone soil contamination.
- ERD, for low to moderate concentration groundwater and soil.
- Air sparging, for shallow groundwater contamination only in areas not in competition with ERD application.

These technologies may be implemented in combination with other technologies, or as standalone treatments in particular areas, depending on conditions. These retained technologies are evaluated in Section 10.0 according to the MTCA evaluation criteria to determine the technology for each CAA that best satisfies the RAOs presented in Section 7.0 and summarized in Table 8.2.

9.0 Remedial Alternatives Selection and Description

Remedial alternatives have been selected for each CAA discussed in Section 7.0 above based on the results of the preliminary technology screening conducted in Section 8.0. Since a permanent cleanup action, as defined by MTCA (WAC 173-340-200) is not technically feasible at the Site, the remedial alternatives discussed below include alternatives that are permanent to the maximum extent practicable, but do not include a "permanent cleanup action."

The following sections discuss the conditions and constraints for each CAA, including applicable points of compliance and remediation levels, and then select the technologies most applicable to each CAA to be retained for evaluation.

9.1 MAIN SOURCE AREA CLEANUP ACTION AREA

9.1.1 Main Source Area CAA Conditions and Constraints

The Main Source Area CAA is located in the east-central and southern portion of the Site (as shown on Figure 7.1) and includes portions of the existing Production Area, Alkaline Shed, Flammables Shed, the Rail Spur Area south of the building, and the Loading Dock Area. It also includes the Whitehead Property. The Main Source Area CAA is bounded by Fox Avenue, where the CPOC has been set for achieving groundwater cleanup levels. The following bullets outline the major constraints, and area-specific considerations for alternative selection in the Main Source Area CAA.

- PCE and TCE are present in soil within the vadose zone, 1st WBZ, and 1st SH with concentrations ranging up to 4,200 mg/kg, and in the 2nd WBZ soils with concentrations ranging up to approximately 100 mg/kg. The extent of contamination is primarily present within the area of the Alkaline Shed, Flammables Shed, and along the railroad spur area.
- Separate phase droplets comprised of mineral spirits and PCE were observed within the soils of the 1st SH.
- CEAs are present in groundwater within the 1st and 2nd WBZs throughout the Main Source Area at concentrations exceeding 50,000 µg/L.
- Mineral spirits have been identified within the Main Source Area CAA in the 1st and 2nd WBZs and 1st SH.
- BTEX compounds are present in soil and groundwater in both the 1st and 2nd WBZs.
- Penta has also been detected in soil and groundwater, primarily in former operational areas where it was mixed with mineral spirits.
- Contaminant depths reach greater than 65 feet below ground surface in the Main Source Area CAA.
- The majority of the Main Source Area CAA footprint is located over an active, industrial, chemical storage and processing facility, that will continue operation during and following installation of a remedy.

9.1.2 Main Source Area CAA Remediation Levels

As discussed in Section 7.6.1, remediation levels will be used at the Site to guide transition from technologically achievable short-term aggressive technologies to longer-term more passive technologies.

The remediation level for the Main Source Area CAA is a soil concentration of 10 parts per million (ppm) total of PCE + TCE, which represents approximately a 99 percent reduction in source mass. Achieving 99 percent reduction in source mass is expected to result in reduction of total CVOCs in downgradient groundwater to concentrations less than or equal to 250 µg/L. This groundwater concentration is such that, together with further treatment in the Downgradient Groundwater Plume CAA, the applicable cleanup standard at the point of discharge of groundwater to surface water at the S. Myrtle Street Embayment will likely be attained within a reasonable time frame.

9.1.3 Technologies Retained for Alternative Development

The following remedial technologies, which are also presented in Table 8.1 and discussed in Section 8.0, have been retained for developing remedial alternatives within the Main Source Area CAA:

- **Monitored Natural Attenuation.** The MNA remedial alternative has been retained to provide a baseline comparison for all other technologies and in combination with more active remedial technologies.
- **Low-Permeability Barrier Wall.** A barrier wall has been retained for evaluation of a containment remedy. Containment technologies are often implemented at chlorinated DNAPL sites. A barrier wall is the only technology capable of containment at this Site.
- **Surface Capping.** Surface capping has been retained for use in combination with other more aggressive technologies in the Main Source Area CAA to address the direct contact and vapor intrusion pathways at the Site.
- **Enhanced Reductive Dechlorination.** ERD has been retained for treatment of saturated zone soil and groundwater. ERD is primarily a groundwater cleanup technology that can also clean up soil by accelerating the desorption of PCE from soil to groundwater, where it is destroyed in-situ.
- **Soil Vapor Extraction.** SVE is retained for treatment of vadose zone soil contamination in the Main Source Area CAA. The existing SVE system does not cover a sufficient area for treatment and removal of vadose zone contamination, and would be expanded to cover a larger footprint within the Main Source Area CAA. SVE would be implemented in combination with other technologies, because it does not address saturated zone soil or groundwater contamination.
- **Thermal Treatment.** The thermal remediation technology is retained to address soil and groundwater contamination in the vadose zone, 1st SH, and 1st and 2nd WBZs. This technology is well suited to high-concentration VOC source areas; conversely, it is not practical for areas of low-level soil contamination. Due to the high groundwater flow velocities at the Site, hydraulic controls may be required to slow the natural groundwater velocity to prevent undue heat loss downgradient.

9.1.4 Technologies Not Retained for Alternative Development

Remedial technologies not retained for alternative development within the Main Source Area CAA include:

- **PRB.** A PRB wall was not retained for evaluation in the Main Source Area CAA because the concentrations present and the depths of contamination would require a wall to be constructed to great depths. In addition, the life span of the wall would be decreased due to the high concentrations flowing through the wall. Given the anticipated short life span of the wall and requirements for replacement within 10 to 20 years, this technology is not considered technically feasible for implementation in the Main Source Area CAA.
- **Air Sparging.** Air sparging was not retained for evaluation in the Main Source Area CAA because of the chemical concentrations, depth of contamination, and location of contamination beneath occupied structures limit the feasibility of an air sparging system. The required spacing of sparge points, necessity to include SVE for vapor capture, and inapplicability of the technology to the depth of contamination make air sparging infeasible. For these reasons, air sparging was not retained for alternative development in the Main Source Area CAA.

9.1.5 Proposed Main Source Area CAA Remedial Alternatives

The following remedial alternatives are proposed for evaluation within the Main Source Area CAA:

- **Alternative 1—Monitored Natural Attenuation.** This alternative proposes use of MNA as a standalone technology for the purpose of baseline comparison to other alternatives within the Main Source Area CAA. This alternative does not involve source control; instead it relies entirely on the ongoing natural dechlorination processes.
- **Alternative 2—Shallow and Deep Soil and Groundwater Treatment by ERD, Vadose Zone Soil Treatment by SVE.** This alternative includes treatment of the Main Source Area CAA via SVE in vadose zone soils, and ERD in saturated zone soil and groundwater. The reliability of ERD for source soil treatment at DNAPL sites is not well documented, and this is reflected in the assumed restoration time frame for this alternative.
- **Alternative 3—Shallow and Deep Soil and Groundwater Treatment by Thermal Remediation and ERD Polish.** This alternative includes treatment of vadose and saturated zone soil and groundwater by thermal remediation using electrical resistance heating followed by treatment of any residually-contaminated areas by ERD.
- **Alternative 4—Source Area Containment by Low-permeability Barrier Wall.** This alternative includes containment of Main Source Area CAA contamination through construction of a barrier wall completely surrounding the Main Source Area CAA, capping for control of direct-contact, and mitigation measures for vapor intrusion control.

The detailed evaluation of the proposed remedial alternatives for the Main Source Area CAA according to the MTCA Disproportionate Cost Analysis (DCA) is presented in Table 10.1 and discussed in Section 10.0.

9.2 DOWNGRADIENT GROUNDWATER PLUME CAA

9.2.1 Downgradient Groundwater Plume CAA Conditions and Constraints

The Downgradient Groundwater Plume CAA includes all areas downgradient from Fox Avenue with groundwater contamination in the 1st and/or 2nd WBZs at concentrations exceeding the groundwater cleanup levels. This CAA includes the public ROWs of Fox Avenue, S. Myrtle Street, and downgradient properties including Seattle Boiler Works as shown on Figure 7.1. The following bullets outline the major constraints and area-specific considerations for alternative selection in the Downgradient Groundwater Plume CAA.

- Soil contamination is not present in this CAA at concentrations that exceed cleanup levels.
- The alternatives discussed for remediation of this CAA assume access to downgradient properties.
- The groundwater plumes that continue beyond Fox Avenue to S. Myrtle Street are primarily composed of daughter products (cis-1,2-DCE and VC).
- The majority of the Downgradient Groundwater Plume CAA footprint is located over active industrial or warehousing facilities.
- VC and cis-1,2-DCE are found in groundwater throughout the full depth of the 2nd WBZ groundwater down to depths of approximately 75 feet bgs. Concentrations taper off significantly at depths below 70 feet.
- PCE + TCE concentrations in the Downgradient Groundwater Plume range from 25 µg/L to over 1,000 µg/L.
- Concentrations of daughter products in the Downgradient Groundwater Plume CAA are generally less than 48 µg/L for 1,1-DCE, 23,000 µg/L for cis-1,2-DCE, and 9,800 µg/L for VC. These concentrations are higher than the concentrations of daughter products observed in the Main Source Area CAA.
- BTEX compounds (primarily benzene) are present in groundwater at concentrations greater than cleanup levels.

9.2.2 Downgradient Groundwater Plume CAA Remediation Levels

As discussed in Section 7.6.1, groundwater remediation levels as measured at—and downgradient from—the groundwater CPOC at Fox Avenue will be used at the Site when transitioning between technologies that achieve short-term compliance and long-term compliance. Long-term compliance with the cleanup levels protective of groundwater discharging to surface water must be met throughout the Downgradient Groundwater Plume CAA. Short-term compliance in downgradient groundwater will be measured by achieving a remediation level of 250 µg/L, assuming groundwater at the point of discharge to the S. Myrtle Street Embayment is in compliance with cleanup levels. The assumption is that achieving the groundwater remediation level (which represents a 95 to 99 percent overall reduction in current concentrations) will allow all groundwater within the Downgradient Groundwater Plume CAA to come into compliance with cleanup standards in approximately 50 years via monitored natural attenuation.

9.2.3 Technologies Retained for Alternative Development

The following remedial technologies, which are also presented in Table 8.1 and discussed in Section 8.0, have been retained for developing remedial alternatives within the Downgradient Groundwater Plume CAA:

- **Monitored Natural Attenuation.** The MNA remedial alternative has been retained as a standalone technology to provide a baseline comparison for all other technologies. MNA may also be used in combination with other more active technologies.
- **PRB.** A PRB was retained for evaluation as a point of discharge treatment for shallow groundwater contamination immediately before discharge as seeps to the S. Myrtle Street Embayment.
- **Enhanced Reductive Dechlorination.** ERD has been retained for treatment of groundwater. ERD has successfully been implemented in the Downgradient Groundwater Plume CAA as part of the ongoing ERD interim action.
- **Air Sparging.** Air sparging was retained for evaluation as a point of discharge treatment, in a wall or curtain formation intersecting shallow groundwater prior to discharge to the S. Myrtle Street Embayment.

9.2.4 Technologies Not Retained for Alternative Development

Remedial technologies not retained for alternative development within the Downgradient Groundwater Plume CAA include:

- **Soil Vapor Extraction.** SVE is not retained for application in the Downgradient Groundwater Plume CAA, as this technology is applicable to areas of vadose zone soil contamination, and does not apply to the Downgradient Groundwater Plume.
- **Thermal Treatment.** The thermal remediation technology is not retained to address groundwater contamination in the Downgradient Groundwater Plume, as the footprint and depth of contamination is extensive, and this technology is not applicable for remediating extensive groundwater contamination downgradient from source soils. The cost associated with installing and operating the system for removing dissolved phase contamination in widespread plumes becomes prohibitively expensive and impractical to implement due to the infrastructure and energy required to volatilize a relatively small mass of contaminants over a very wide area.
- **Low-Permeability Barrier Wall.** A low-permeability barrier wall is not retained for evaluation as an alternative for the Downgradient Groundwater Plume CAA, due to the large footprint of the plume and its location in relation to off-site properties. The cost of installing and operating such a barrier would be prohibitively expensive and impractical to construct.
- **Surface Capping.** Surface capping has not been retained for application in the Downgradient Groundwater Plume CAA, as this technology would not provide any benefit over existing conditions.

9.2.5 Proposed Downgradient Groundwater Plume CAA Remedial Alternatives

The following remedial alternatives are proposed for evaluation within the Downgradient Groundwater Plume CAA:

- **Alternative 1—Monitored Natural Attenuation.** This alternative proposes use of MNA as a standalone technology for the purpose of baseline comparison to other alternatives within the Downgradient Groundwater Plume CAA. This alternative relies entirely on the success of the natural dechlorination processes.
- **Alternative 2—Shallow and Deep Groundwater Treatment by ERD.** This alternative includes treatment of the Downgradient Groundwater Plume CAA via ERD injection through multiple locations along the groundwater flow path between the CPOC at Fox Avenue, and the point of groundwater discharge to surface water at the S. Myrtle Street Embayment.
- **Alternative 3—Shallow Groundwater Treatment at the Point of Discharge by Air Sparging.** This alternative includes treatment of shallow groundwater via stripping by air sparging immediately prior to discharge to the S. Myrtle Street Embayment. Air sparge points would be constructed in a “curtain” formation to treat groundwater as it migrates along the natural flow path.
- **Alternative 4—Shallow Groundwater Treatment at the Point of Discharge by Permeable Reactive Barrier Wall.** Similar to Alternative 3, this alternative provides treatment at the point of discharge through installation of a PRB wall to passively treat migrating groundwater immediately prior to discharge to the S. Myrtle Street Embayment.

The detailed evaluation of the proposed remedial alternatives for the Downgradient Groundwater Plume CAA according to the MTCA DCA is presented in Table 10.2 and discussed in Section 10.0.

9.3 NORTHWEST CORNER PLUME CAA

9.3.1 Northwest Corner Plume CAA Conditions and Constraints

The Northwest Corner Plume CAA is located in the northwest portion of the Site (as shown on Figure 7.1) and is generally bounded by S. Willow Street to the north, Fox Avenue to the south and southwest, and the existing office building to the east. The existing operational use within the cleanup area is primarily parking for the Cascade Columbia employees. The following bullets outline the major constraints and area-specific considerations for alternative selection in the Northwest Corner Plume CAA.

- The extent of PCE/TCE in soil and groundwater at concentrations greater than cleanup levels is primarily located within the existing parking lot area, and along S. Willow Street and beneath the northwest corner of the office building.
- PCE/TCE is assumed to be present in soil in diffuse and scattered silty lenses in the vadose zone, which is indicative of minor spills of PCE. The average detected PCE + TCE concentration encountered in vadose zone soils in the Northwest Corner Plume CAA is less than 1 mg/kg.
- PCE + TCE and breakdown products are present in 1st WBZ groundwater at concentrations exceeding 1,000 µg/L in the Northwest Corner Plume CAA, with the highest detections located along the Fox Avenue ROW at the south end of the parking area.
- There is not a strong correlation between the location of historical PCE detections in soil and the current associated plume in groundwater.

- CEAs in soil and groundwater have <u>not</u> been identified below the bottom of the 1^{s} WBZ.
- Mineral spirits and Penta have not been identified within the Northwest Corner Plume CAA.
- In-situ treatment via permanganate injections was completed in 2005 by ERM within the Northwest Corner Plume CAA. Results of this remediation effort indicate that the in-situ treatment was successful at reducing groundwater concentrations in most wells by approximately 50 percent over baseline levels.
- Results of recent ERD injections in the Northwest Corner Plume CAA indicate that the subsurface conditions are conducive to ERD substrate injection. Results of the recent SVE pilot study indicate that residual PCE mass is present in vadose soils and subsurface conditions are conducive to SVE (Appendix D).

9.3.2 Northwest Corner Plume CAA Remediation Levels

The proposed soil remediation level for the Site is not applicable to the Northwest Corner Plume CAA because the average soil concentration of PCE + TCE is significantly less than the remediation level of 10 mg/kg. The applicable groundwater remediation level is 250 µg/L total CVOCs, the same as that proposed for the Main Source Area CAA. Compliance will be measured in wells along Fox Avenue.

9.3.3 Technologies Retained for Alternative Development

The following remedial technologies, also presented in Table 8.1 and discussed in Section 8.0 have been retained for developing remedial alternatives within the Northwest Corner Plume CAA:

- **Monitored Natural Attenuation.** The MNA remedial alternative has been retained as a standalone technology to provide a baseline comparison for all other technologies, and for use in combination with more active remedial technologies.
- **Permeable Reactive Barrier Wall.** PRB technology has been retained for treatment of 1st WBZ groundwater at this CAA.
- **Soil Vapor Extraction.** Historical explorations located in the Northwest Corner Plume CAA have encountered low-level soil contamination in the vadose zone, and recent testing indicates that SVE may be effective in removing much of this residual source mass.
- **Enhanced Reductive Dechlorination.** ERD has been retained as a cleanup alternative in the Northwest Corner Plume CAA to reduce chemical concentrations in the 1st WBZ groundwater. ERD is currently being successfully applied to similar chemicals in 1st WBZ groundwater in other areas of the Site.

9.3.4 Technologies Not Retained for Alternative Development

Remedial technologies not retained for alternative development within the Northwest Corner Plume CAA include:

- **Low-permeability Barrier Wall.** Due to the location of the chemical plumes in relation to buildings and public ROWs, encapsulation of the Northwest Corner Plume CAA would not be a feasible alternative. A majority of the Northwest Corner Plume would likely be included in a low-permeability barrier wall constructed for containment of the Main Source Area Plume. However, as a standalone technology to address contamination in the Northwest Corner Plume CAA, this technology is not feasible given the construction cost and the availability of other more permanent technologies.

- **Surface Capping.** Surface capping has not been retained for application in the Northwest Corner Plume CAA, as concentrations in soils are already less than the direct contact pathway cleanup level, and capping will not provide any degree of risk reduction to the vapor intrusion pathway or to the Downgradient Groundwater Plume.
- **Air Sparging.** Although the contamination in the Northwest Corner Plume is located for the most part in shallow groundwater and vadose soils, application of air sparging was not retained for this area due to the very thin nature of the 1st WBZ, which is not conducive for SVE applications.
- **Thermal Remediation.** The thermal remediation technology has not been retained for alternative development within the Northwest Corner Plume CAA as the cost associated with implementation is excessive, given the low-levels of existing contamination, and the diffuse and scattered chemical conditions of the CAA.

9.3.5 Proposed Northwest Corner Plume CAA Remedial Alternatives

The following remedial alternatives are proposed for evaluation within the Northwest Corner Plume CAA:

- **Alternative 1—Monitored Natural Attenuation.** This alternative proposes use of MNA as a standalone technology for the purpose of baseline comparison to other alternatives within the Northwest Corner Plume CAA. This alternative does not involve source control, and instead relies entirely on the success of natural dechlorination processes that are not as dynamic in the 1st WBZ as they are in the 2nd WBZ.
- **Alternative 2—Soil and Groundwater Treatment by ERD.** This alternative includes treatment of PCE- and TCE-impacted groundwater within the 1st WBZ using the ERD process. ERD does not provide treatment of vadose zone soils.
- **Alternative 3—Permeable Reactive Barrier Wall.** This alternative includes treatment of migrating 1st WBZ groundwater through a PRB wall. PRB does not provide active treatment of vadose zone soils and instead removes contamination from groundwater as it migrates through the PRB.
- **Alternative 4—Soil and Groundwater Treatment by SVE and ERD.** This alternative includes treatment of PCE- and TCE-impacted vadose zone soils through SVE, and saturated zone soil and groundwater within the 1st WBZ via the ERD process.

The detailed evaluation of the proposed remedial alternatives for the Northwest Corner Plume CAA according to the MTCA DCA is presented in Table 10.3 and discussed in Section 10.0.

10.0 Alternatives Evaluation

10.1 MODEL TOXICS CONTROL ACT EVALUATION CRITERIA

This section provides a summary of the remedial alternatives evaluation conducted for each CAA. As part of the evaluation process, each of the proposed remedial alternatives is screened relative to MTCA Threshold Requirements and other MTCA requirements for evaluation, leading to a selection of a preferred alternative based on the screening results. Tables 10.1, 10.2, and 10.3 provide detailed evaluation and scoring of the proposed remedial alternatives in each CAA for attainment of MTCA requirements. Tables 10.4, 10.5, and 10.6 provide a summary of the MTCA DCA based on the results of the screening conducted in the previous tables. The following sections describe the MTCA threshold requirements and other requirements used for evaluation of the proposed alternatives. A summary of the detailed evaluation is provided in Section 10.3 below, while the detailed evaluations are provided in the tables.

10.1.1 Model Toxics Control Act Threshold Requirements

MTCA WAC 173-340-360(2) states that when multiple cleanup action components are implemented for a single site, the overall cleanup action components shall also meet the minimum requirements discussed below:

- **Protect Human Health and the Environment.** Protection of human health and the environment shall be achieved through implementation of the selected remedial action.
- **Comply with Cleanup Standards.** Cleanup standards, as defined by MTCA, include cleanup levels for hazardous substances present at the site, the location, or point of compliance where the cleanup levels must be met, and any regulatory requirements that may apply to the site due to the type of action being implemented and/or the location of the site.
- **Comply with Applicable State and Federal Laws.** MTCA WAC 173-340-710 states that cleanup standards shall comply with legally ARARs. Section 11.0 identifies the ARARs for the preferred alternative for this Site.
- **Provide for Compliance Monitoring.** MTCA requires that all selected cleanup alternatives provide for compliance monitoring as described in WAC 173-340-410. Compliance monitoring includes protection monitoring during remedial implementation to monitor short-term risks and confirm protection of human health and the environment during construction activities. Performance monitoring will assess short-term remedy effectiveness and confirm compliance with the site cleanup levels immediately following remedial implementation. Confirmational monitoring will evaluate long-term effectiveness of the remedial action following attainment of the cleanup standards.

10.1.2 Other Model Toxics Control Act Requirements

Cleanup alternatives that meet the threshold requirements must also fulfill other requirements described in WAC 173-340-360(2)(b). These additional requirements include the following:

- **Use Permanent Solutions to the Maximum Extent Practicable.** The use of permanent solutions to the maximum extent practicable for a cleanup action is analyzed according to the procedure described in WAC 173-340-360(3). Preference is given to alternatives that implement permanent solutions, defined in MTCA as actions that can meet cleanup standards “without further action being required at the site being cleaned up or any other site involved with the cleanup action, other than the approved disposal of any residue from the treatment of hazardous substances (WAC 173-340-200).” As required under WAC 173-340-360(2)(h), a DCA is required for a cleanup action that uses remediation levels.

- **Provide for a Reasonable Restoration Time Frame.** A cleanup action shall provide for a reasonable restoration time frame. The factors to be considered when determining the reasonable restoration time frame are listed in WAC 173-340-360(4)(b) include the potential risks posed by the site; the practicability of achieving a shorter restoration time frame; and the current and expected future use of the site.
- **Consideration of Public Concerns.** Public involvement must be initiated according to the requirements set forth in WAC 173-340-600. Ecology’s decision on alternative selection will be presented for public comment in the draft CAP.

10.1.3 Model Toxics Control Act Disproportionate Cost Analysis

The MTCA DCA is used to evaluate whether a cleanup action uses permanent solutions to the maximum extent practicable as determined by the level of attainment of specific criterion defined within WAC 173-340-360(3)(f). The relative benefits and costs associated with each alternative are compared using seven evaluation criteria. As stated in MTCA, the cost of an individual alternative is determined disproportionate “if the incremental costs of the alternative over that of a lower cost alternative exceed the incremental degree of benefits achieved by the alternative over that of the other lower cost alternative” (WAC 173-340-360(3)(e)(i)).

Evaluation of disproportionate cost compares each alternative against the most permanent alternative presented, as determined by attainment of MTCA criteria, which factor into the overall permanence of each alternative. This can be a qualitative or quantitative analysis, and in the instance that multiple alternatives possess equivalent benefits, the lower-cost alternative will be selected. The seven criteria defined in MTCA (WAC 173-340-360(f)) include protectiveness, permanence, cost, effectiveness over the long-term, management of short-term risks, technical and administrative implementability, and considerations of public concerns.

The remedial alternative evaluation process, discussed in Section 10.2 below, presents a DCA for the Main Source Area CAA, Downgradient Groundwater Plume CAA, and Northwest Corner Plume CAA. Results of the DCA conducted in each area are then used to compile the proposed preferred alternative for the entire Site, as presented in Section 11.0.

10.2 DETAILED EVALUATION OF REMEDIAL ALTERNATIVES

The remedial alternatives discussed in Section 9.0 are evaluated and screened by cleanup area in Tables 10.1, 10.2, and 10.3 according to MTCA requirements described above, and the MTCA threshold requirements in the following sections. Proposed remedial alternatives are evaluated for permanence within the Main Source Area, Downgradient Groundwater Plume, and Northwest Corner Plume CAAs, according to the MTCA DCA process described above. The results of the alternative evaluation and relative ranking for these CAAs are summarized in Tables 10.4 through 10.6.

As the ability of the proposed alternatives to meet the site RAOs is not specifically discussed in the MTCA DCA, this discussion is included in the paragraphs below.

10.2.1 Main Source Area CAA Remedial Alternatives Evaluation

As described in Section 9.0, the following remedial alternatives have been proposed for the Main Source Area CAA:

- Alternative 1—Monitored Natural Attenuation, retained as a baseline alternative.
- Alternative 2—Shallow and Deep Soil and Groundwater Treatment by ERD injection, vadose zone soil treatment by SVE.
- Alternative 3—Shallow and Deep Soil and Groundwater Treatment by Thermal Remediation with an ERD polish following thermal treatment.
- Alternative 4—Source Area Containment by Low-permeability Barrier Wall.

The following sections discuss the MTCA threshold requirements, restoration time frame, and DCA evaluation criteria for the alternatives listed above.

10.2.1.1 MTCA Threshold Requirements

- **Protection of Human Health and the Environment.** Of the alternatives proposed, Alternatives 2, 3, and 4 provide varying degrees of protection of human health and the environment either through containment of contamination, or mass removal through thermal destruction, ERD, and/or SVE.
- **Compliance with Cleanup Standards.** It is anticipated that Alternatives 2, 3, and 4 will comply with the groundwater cleanup levels at the proposed CPOC for the Site over varying time frames. It is anticipated that all three proposed remedial alternatives will provide reduction or containment of source mass CVOC concentrations to acceptable remediation levels at the CPOC for groundwater.
- **Compliance with Applicable State and Federal Laws.** Alternatives 2, 3, and 4 address and comply with all relevant and applicable state and federal laws relevant to this project.
- **Provisions for Compliance Monitoring.** Alternatives 2, 3, and 4 provide for compliance monitoring throughout the cleanup area as discussed in MTCA 173-340-410. For any alternative selected as the preferred, a Compliance Monitoring Plan will be submitted as part of the Engineering Design Report. Long-term monitoring will be required for all alternatives proposed, and will be conducted following completion of treatment activities to ensure compliance with the remediation levels and cleanup levels.

10.2.1.2 Restoration Time Frame

Restoration time frame is a critically important consideration when comparing remedial alternatives. Because the DCA tables include only a summary of the overall restoration time frames associated with each of the proposed alternatives, a detailed discussion is included below. The following section provides detail on the anticipated restoration time frames associated with the various technologies proposed and impacted media. The following restoration time frames are anticipated for the alternatives proposed in the Main Source Area CAA:

- Alternative 1 includes monitoring natural attenuation processes for destruction of soil and groundwater contamination. With the levels of contamination present in soil and groundwater, the following restoration time frames for soil and groundwater are anticipated:

  - Achievement of soil cleanup levels—Indefinite.
  - Achievement of 1st and 2nd WBZ groundwater cleanup levels—Indefinite.

- Alternative 2 includes implementing ERD treatment for saturated zone soil and groundwater contamination, and SVE for treatment of vadose zone soil contamination. The following restoration time frames for soil and groundwater are anticipated:
  - Achievement of vadose zone soil contamination cleanup levels protective of direct worker contact and vapor intrusion through SVE treatment—5 to10 years.
  - Achievement of groundwater remediation levels in the 1st and 2nd WBZs via ERD treatment is uncertain because this is an evolving technology for use in source areas, but based on review of similar sites, the anticipated restoration time frame is approximately 50 years.
  - Achievement of groundwater cleanup levels at the CPOC at Fox Avenue—Indefinite.
- Alternative 3 includes implementing thermal treatment for vadose and saturated zone soil and groundwater contamination, followed by ERD treatment for continued mass reduction of low-concentration contamination throughout the source area. The following restoration time frames for soil and groundwater are anticipated:
  - Achievement of soil cleanup levels in vadose soils protective of direct worker contact and vapor intrusion through thermal treatment are anticipated immediately following completion of thermal implementation in 1 to 2 years.
  - Achievement of groundwater remediation levels in the 1st and 2nd WBZs via thermal and ERD treatments is anticipated in approximately 5 years. It is anticipated that thermal treatment will operate until significant mass reduction has occurred, and soil remediation levels set during design are achieved. ERD will be conducted for approximately 5 years until compliance with groundwater remediation levels are achieved.
  - Achievement of groundwater cleanup levels at the Fox Avenue CPOC is anticipated to occur in approximately 50 years.
- Alternative 4 includes implementation of a containment remedy through construction of a low-permeability barrier wall surrounding the Main Source Area CAA. The following restoration time frames for soil and groundwater are anticipated.
  - Achievement of vadose zone soil contamination cleanup levels protective of direct worker contact and vapor intrusion through use of existing capping, and construction of a barrier wall is indefinite.
  - Achievement of cleanup levels in saturated soils protective of downgradient groundwater will not be achieved with implementation of this alternative; however, since groundwater migration will be controlled, the ongoing pathway of source soil to groundwater will be eliminated.
  - Achievement of remediation levels at the groundwater CPOC for 1st and 2nd WBZ groundwater is anticipated shortly following construction in approximately 1 to 2 years because the contaminant plume outside the barrier wall will begin to degrade and breakup with no ongoing source. Complete containment of chemicals will control migration out of the source area, resulting in compliance at

the groundwater CPOC, while concentrations in soil and groundwater remain greater than cleanup levels indefinitely inside the containment wall.

- Achievement of groundwater cleanup levels at the CPOC is anticipated within approximately 5 years.

10.2.1.3 Remedial Action Objectives

Alternatives 2, 3, and 4 meet site RAOs for the Main Source Area CAA as follows:

- Alternative 2 addresses direct contact and vapor inhalation risks through removal or treatment of contaminated soil and groundwater in the vadose and 1st WBZ through SVE. Alternative 2 addresses long-term sources of contamination to downgradient groundwater through remediation of source area soil and groundwater in the 1st and 2nd WBZs through implementation of ERD.
- Alternative 3 addresses direct contact and vapor inhalation risks through removal or treatment of contaminated soil and groundwater in the vadose and 1st and 2nd WBZs through thermal treatment followed by additional mass removal via ERD injection. Alternative 3 addresses long-term sources of contamination to downgradient groundwater through remediation of source area soil and groundwater in the 1st and 2nd WBZs through implementation of thermal treatment and ERD.
- Alternative 4 addresses direct contact and vapor inhalation risks through capping and institutional controls of contaminated soil and 1st WBZ groundwater posing risk to indoor air quality, and direct worker contact. Alternative 4 addresses long-term sources of contamination to downgradient groundwater through containment of source area soil and groundwater.

10.2.1.4 MTCA Evaluation Criteria (Disproportionate Cost Analysis)

Table 10.1 presents the DCA criteria evaluation completed for the Main Source Area CAA. The table evaluates the four proposed remedial alternatives for this CAA for each of the evaluation criteria. A relative score is assigned to each of the evaluation criteria for each proposed remedial alternative, and a summary of the remedial alternatives scoring process and evaluation is provided in Table 10.4.

10.2.2 Downgradient Groundwater Plume CAA Remedial Alternatives Evaluation

As described in Section 9.0, the following remedial alternatives have been proposed for the Downgradient Groundwater Plume CAA:

- Alternative 1—Monitored Natural Attenuation (retained as a baseline alternative).
- Alternative 2—Shallow and Deep Groundwater Treatment by ERD injections.
- Alternative 3—Shallow Groundwater Treatment at the Point of Discharge by Air Sparging.
- Alternative 4—Shallow Groundwater Treatment at the Point of Discharge by a PRB Wall.

The following sections discuss the MTCA threshold requirements, restoration time frame, and DCA evaluation criteria for the above alternatives.

10.2.2.1 MTCA Threshold Requirements

- **Protection of Human Health and the Environment.** Of the alternatives proposed, Alternatives 2, 3, and 4 provide varying degrees of protection of human health and the environment through varying methods of mass removal via ERD, passive treatment with a PRB wall, or contaminant removal via air sparging. Alternative 1 does not provide protection of human health and the environment, and is retained as a baseline for comparison of the other alternatives. In combination with upgradient source controls, all of the alternatives proposed are capable of achieving the proposed cleanup levels for protection of groundwater discharge to surface water, as measured at the seeps.
- **Compliance with Cleanup Standards.** It is anticipated that Alternatives 2, 3, and 4 will comply with the cleanup levels throughout the CAA over a very long time frame, and at the point of groundwater discharge to surface water within a more reasonable restoration time frame.
- **Compliance with Applicable State and Federal Laws.** Alternatives 2, 3, and 4 address and comply with all relevant and applicable state and federal laws relevant to this project.
- **Provisions for Compliance Monitoring.** Alternatives 2, 3, and 4 provide for compliance monitoring throughout the cleanup area as discussed in MTCA 173-340-410. For any alternative selected as the preferred, a Compliance Monitoring Plan will be submitted as part of the Engineering Design Report. Long-term monitoring will be required for all alternatives proposed, and will be conducted following completion of treatment activities to ensure compliance with cleanup levels.

10.2.2.2 Restoration Time Frame

Restoration time frame is a critically important consideration when comparing remedial alternatives. As the DCA tables include only a summary of the overall restoration time frames associated with each of the proposed alternatives, a detailed discussion is included below. The following section provides anticipated restoration time frames for the alternatives proposed within the Downgradient Groundwater Plume CAA. These restoration time frame estimates assume that source control within the Main Source Area CAA will be addressed, and that continued ongoing migration of contamination from the Main Source Area will not occur:

- Alternative 1 includes monitoring natural attenuation processes for destruction of groundwater contamination. With the current chemical concentrations, the following restoration time frames for groundwater are anticipated:
  - Achievement of groundwater cleanup levels at the S. Myrtle Street Embayment—Indefinite.
  - Achievement of groundwater cleanup levels throughout the CAA—Indefinite.
- Alternative 2 includes implementation of ERD for treatment of 1st and 2nd WBZ groundwater contamination. Achievement of groundwater cleanup levels in the 1st and 2nd WBZs via ERD treatment is expected with confidence, as the technology has been shown effective at mass reduction through interim actions within the Downgradient Groundwater Plume. The following restoration time frames for groundwater are anticipated:
  - Achievement of groundwater cleanup levels at the seeps to the S. Myrtle Street Embayment—10 to 15 years.

  - Achievement of groundwater remediation levels throughout the plume—approximately 10 to 15 years.
  - Achievement of groundwater cleanup levels throughout the plume—approximately 50 years.
- Alternative 3 includes implementation of an air sparging curtain at the downgradient point of discharge of the 1st WBZ.
  - Achievement of groundwater cleanup levels at the S. Myrtle Street Embayment is estimated to occur within 1 year immediately following construction.
  - Achievement of groundwater cleanup levels throughout the CAA is not expected to occur in a reasonable restoration time frame, as treatment will be implemented at the point of discharge only. Estimated restoration time frame is indefinite.
- Alternative 4 includes implementation of a PRB wall at the downgradient point of discharge of the 1st WBZ.
  - Achievement of groundwater cleanup levels at the S. Myrtle Street Embayment is estimated to occur within 1 year immediately following construction.
  - Achievement of groundwater cleanup levels throughout the CAA is not expected to occur in a reasonable restoration time frame, as treatment will be implemented at the point of discharge only. Estimated restoration time frame is indefinite.

10.2.2.3 Remedial Action Objectives

The Site RAOs that apply to the Downgradient Groundwater Plume CAA include reducing concentrations of COCs in indoor air to protect work health from inhalation exposure, and reducing concentrations of COCs in groundwater to protect surface water quality in the S. Myrtle Street Embayment. Initial investigation of indoor air quality conducted at Seattle Boiler Works in 2010 indicates that current concentrations of PCE and TCE exceed the MTCA Method B cleanup levels, but when adjusted for background concentrations, are less than the MTCA Method C cleanup levels. Initial screening of the vapor intrusion pathway using the Johnson & Ettinger vapor intrusion model indicates that groundwater in compliance with the remediation level of 250 µg/L total CVOCs will protect indoor air quality while the site use remains industrial. As there is no shallow or deep soil contamination within the CAA, protection of direct worker contact and protection of long-term sources of soil to groundwater are not relevant RAOs. Alternatives 2, 3, and 4 meet site RAOs for the Downgradient Groundwater Plume CAA as follows:

- Alternative 2 addresses vapor inhalation risks through reduction of contaminated groundwater concentrations in the 1st WBZ by ERD. Alternative 2 addresses protection of water quality at the S. Myrtle Street Embayment through reduction of groundwater concentrations in the 1st and 2nd WBZs through ERD processes.
- Alternative 3 does not directly address any potential vapor intrusion risks, as plume-wide concentrations are not reduced by means other than natural attenuation processes. If future evaluation indicates vapor intrusion issues in buildings within the Downgradient Groundwater Plume CAA, appropriate mitigation measures will be evaluated. Risk of groundwater discharge at the S. Myrtle Street Embayment is reduced through groundwater treatment via air sparging prior to discharge at the downgradient edge of the Downgradient Groundwater Plume CAA.
- Alternative 4 does not directly address any potential vapor intrusion risks, as plume-wide concentrations are not reduced by means other than natural attenuation

processes. If future evaluation identifies vapor intrusion issues in buildings within the Downgradient Groundwater Plume CAA, appropriate mitigation measures will be evaluated. Risk of groundwater discharge at the S. Myrtle Street Embayment is reduced through groundwater treatment via migration through a PRB prior to discharge at the downgradient edge of the Downgradient Groundwater Plume CAA.

10.2.2.4 MTCA Evaluation Criteria (Disproportionate Cost Analysis)

Table 10.2 presents the DCA criteria evaluation completed for the Downgradient Groundwater Plume CAA. The table evaluates the four proposed remedial alternatives for this CAA for each of the evaluation criteria. A relative score is assigned to each evaluation criterion for each proposed remedial alternative, and a summary of the remedial alternatives scoring process and evaluation is provided in Table 10.5.

10.2.3 Northwest Corner Plume CAA Remedial Alternatives Evaluation

As described in Section 9.3, the following remedial alternatives have been proposed for the Northwest Corner Plume CAA:

- Alternative 1—Monitored Natural Attenuation (retained as a baseline alternative).
- Alternative 2—Soil and Groundwater Treatment by ERD.
- Alternative 3—PRB Wall.
- Alternative 4—Soil and Groundwater Treatment by SVE and ERD.

The following sections discuss the MTCA threshold requirements and restoration time frame for Alternatives 2 through 4.

10.2.3.1 MTCA Threshold Requirements

- **Protection of Human Health and the Environment.** Of the alternatives proposed, Alternatives 2, 3, and 4 provide varying degrees of protection of human health and the environment through ERD, passive treatment with a PRB wall, or soil vapor extraction of vadose zone soil.
- **Compliance with Cleanup Standards.** It is anticipated that Alternatives 2, 3, and 4 will comply with the groundwater cleanup levels at the proposed CPOC for the Site over varying time frames. It is anticipated that all three proposed remedial alternatives will provide compliance by reducing CVOC concentrations to acceptable remediation levels within the CAA that will result in compliance at the CPOC for groundwater at the property line over time.
- **Compliance with Applicable State and Federal Laws.** Alternatives 2, 3, and 4 address and comply with all relevant and applicable state and federal laws relevant to this project.
- **Provisions for Compliance Monitoring.** Alternatives 2, 3, and 4 provide for compliance monitoring throughout the cleanup area as discussed in MTCA 173-340-410. For any alternative selected as the preferred, a Compliance Monitoring Plan will be submitted as part of the Engineering Design Report. Long-term monitoring will be required for all alternatives proposed, and will be conducted following completion of

treatment activities to ensure compliance with the remediation levels and cleanup levels.

10.2.3.2 Restoration Time Frame

Restoration time frame is a critically important consideration when comparing remedial alternatives. As the DCA tables include only a summary of the overall restoration time frames associated with each of the proposed alternatives, a detailed discussion is included below. Since soil concentrations in the Northwest Corner Plume CAA are currently less than the soil direct contact cleanup levels for the Site, the restoration time frames are based on achieving groundwater compliance at the CPOC. The following bullets discuss the anticipated restoration time frame information for the alternatives proposed within the Northwest Corner Plume CAA:

- Alternative 1 includes monitoring natural attenuation processes for destruction of soil and groundwater contamination. With the levels of contamination present in soil and groundwater, the following restoration time frames for groundwater are anticipated:
    - Achievement of groundwater remediation level at the CPOC—Indefinite.
    - Achievement of groundwater cleanup levels at the CPOC—Indefinite.
- Alternative 2 includes implementation of ERD for treatment of saturated zone soil and groundwater. This alternative does not specifically address vadose zone soil contamination, and the following restoration time frames for groundwater are anticipated:
    - Achievement of groundwater remediation levels in the 1st WBZ via ERD treatment is expected with confidence, as the technology has been shown effective at mass reduction through interim actions at the Site in areas with similar chemical concentrations. Achievement of the groundwater remediation level at the CPOC is anticipated within 10 to 15 years.
    - Achievement of the groundwater cleanup levels at the CPOC—Indefinite.
- Alternative 3 includes implementation of a PRB wall downgradient from the Northwest Corner Plume, before the CPOC at Fox Avenue for passive treatment of contaminated groundwater as it migrates through the PRB. The following restoration time frame for groundwater is anticipated:
    - Achievement of the groundwater remediation level at the CPOC for 1st WBZ groundwater is anticipated immediately following construction within 1 to 2 years.
    - Achievement of the groundwater cleanup level at the CPOC is also anticipated in approximately 5 years.
- Alternative 4 includes implementation of ERD treatment for saturated zone soil and groundwater contamination, and SVE for treatment of vadose zone soil contamination. Combining SVE with ERD for removal of soil source concentrations will decrease the restoration time frame over ERD as a standalone technology, as proposed in Alternative 2. The following restoration time frame for groundwater is anticipated:
    - Achievement of groundwater remediation levels in the 1st WBZ via ERD treatment is more certain, as ERD has been implemented successfully at the Site as an Interim Action. The anticipated restoration time frame for compliance with the remediation level at the CPOC is approximately 5 years.
    - Achievement of the groundwater cleanup level at the CPOC is anticipated to occur in approximately 50 years.

10.2.3.3 Remedial Action Objectives

Alternatives 2, 3, and 4 meet site RAOs for the Northwest Corner Plume CAA as follows:

- Alternative 2 addresses vapor inhalation risks through treatment of contaminated groundwater in the 1st WBZ through ERD. Alternative 2 addresses long-term sources of contamination to downgradient groundwater through remediation of source area soil and groundwater in the 1st WBZ through implementation of ERD.
- Alternative 3 does not directly address direct contact and vapor inhalation risks, but lowers the overall risk through treatment of contaminated groundwater in the 1st WBZ through installation of a PRB at the downgradient edge of the Northwest Corner Plume CAA. Alternative 3 addresses long-term sources of contamination to downgradient groundwater through remediation of groundwater in the 1st WBZ via a PRB wall at the CAA boundary.
- Alternative 4 addresses vapor inhalation risks by reducing chemical concentrations in vadose zone soil and 1st WBZ groundwater posing risk to indoor air quality. Alternative 4 addresses long-term sources of contamination to downgradient groundwater through treatment via ERD of soil and groundwater migrating to the Downgradient Groundwater Plume.

10.2.3.4 MTCA Evaluation Criteria (Disproportionate Cost Analysis)

Table 10.3 presents the DCA criteria evaluation completed for the Northwest Corner Plume CAA. The table evaluates the four proposed remedial alternatives for this CAA for each of the evaluation criteria. A relative score is assigned to each evaluation criterion for each proposed remedial alternative and a summary of the remedial alternatives scoring process and evaluation is provided in Table 10.6.

10.3 REMEDIAL ALTERNATIVES EVALUATION SUMMARY

Based on the analysis presented in the tables and text above, including the overall benefit provided by the alternative, compliance with the MTCA threshold requirements, and other requirements including restoration time frame, the preferred set of alternatives is identified below, and discussed in detail in Section 11.0. The following sections briefly introduce the preferred alternative for each CAA and summarize the benefits provided by that alternative.

10.3.1 Main Source Area CAA

Results of the evaluation of alternatives for the Main Source Area CAA support the recommendation of Alternative 3—Shallow and Deep Soil and Groundwater Treatment by Thermal Remediation and ERD Polish as the Preferred Remedial Alternative for this CAA:

- Alternative 3 is the most overall protective and permanent alternative proposed for the Main Source Area CAA because it removes the most source mass in the shortest restoration time frame.
- Alternative 3 provides the highest degree of long-term effectiveness as the technology has been proven effective at permanently removing source mass from soil and groundwater. The reliability of the other technologies is less documented and is impacted by subsurface conditions (i.e., DNAPL in silt layers) that are effectively addressed by thermal treatment.

- Alternative 3 provides a similar degree of short-term risk as the other proposed alternatives because any technology implemented would have a similar degree of short-term risk associated with mass removal, system construction, implementation, and generation of waste streams.
- Alternative 3 can be implemented with acceptable disruption to facility operations and structures, so long as safe engineering practices are utilized.
- Alternative 3 extracts and destroys solvent mass from the entire zone of the thermally-heated soil mass, giving more assurance that the source mass will be mostly eliminated within the entire footprint of the heated area.
- Alternative 3 is expected to be especially effective in low-permeability silt lenses where the bulk of the solvent mass resides in both the shallow and deep zones.
- Alternative 3 further addresses the source area with a post-thermal ERD treatment that takes advantage of a post-thermal “cool down” phase in which the elevated subsurface temperatures allow accelerated biodegradation of any areas of residual soil and groundwater contamination. The ERD injections can be accomplished cost-effectively using the existing thermal vapor recovery wells. The ERD treatment is expected to destroy additional solvent mass and add more certainty that both source area soil remediation levels (and groundwater remediation levels) can be met in a reasonable restoration time frame at the CPOC.
- Alternative 3 also removes the bulk of the mass of the light-end hydrocarbons (including benzene, a site COC) present in both the 1st and 2nd WBZs.

Additional details associated with the Preferred Remedial Alternative for the Main Source Area CAA are presented in Section 11.0.

10.3.2 Downgradient Groundwater Plume CAA

Results of the evaluation of alternatives for the Downgradient Groundwater Plume CAA support the recommendation of Alternative 2—Groundwater Treatment by ERD as the Preferred Remedial Alternative for this CAA:

- Alternative 2 is the most overall protective and permanent alternative proposed for the Downgradient Groundwater Plume CAA because it removes the most source mass in the shortest restoration time frame and is the only alternative proposed to treat groundwater concentrations throughout the CAA.
- Alternative 2 provides the highest degree of long-term effectiveness, as the technology has been proven effective at permanently destroying source mass from groundwater. The reliability of the other technologies is reduced because continued function of the treatment infrastructure in perpetuity is required to maintain compliance with cleanup levels. The design life of the other proposed alternatives will expire before chemical concentrations are in compliance with cleanup standards through the CAA.
- Alternative 2 provides a similar degree of short-term risk as the other proposed alternatives because as any technology implemented would have a similar degree of short-term risk associated with implementation and operation of the system infrastructure.

- Alternative 2 can be easily implemented because the complexity of the infrastructure required for ERD is substantially less than required for the other alternatives; however, access is required for injections on downgradient properties.
- Alternative 2 destroys solvent mass from the entire CAA, giving more assurance that concentrations will meet cleanup standards by the time they reach the point of discharge in the S. Myrtle Street Embayment in a reasonable restoration time frame.
- Alternative 2 is expected to be especially effective in the naturally-reducing aquifer conditions and permeable sands encountered throughout the 1st and 2nd WBZs in the Downgradient Groundwater Plume CAA.
- Alternative 2 is implemented in conjunction with the alternative proposed for the Main Source Area CAA, especially immediately following thermal treatment processes, where groundwater temperatures will be elevated, encouraging degradation processes in the area of the plume with increased temperature. ERD will be applied within the Main Source Area, Northwest Corner Plume and Downgradient Groundwater Plume CAAs as a combined large zone of treatment.

Additional details associated with the Preferred Remedial Alternative for the Downgradient Groundwater Plume CAA are presented in Section 11.0.

10.3.3 Northwest Corner Plume CAA

Results of the evaluation of alternatives for the Northwest Corner Plume CAA support the recommendation of Alternative 4—Shallow Soil Treatment by SVE, and 1st WBZ Groundwater Treatment by ERD as the Preferred Remedial Alternative for this CAA:

- Alternative 4 is the most overall protective and permanent alternative proposed for the Northwest Corner Plume CAA as it removes the most source mass in the shortest restoration time frame, and is the only alternative proposed to treat both vadose zone soil and 1st WBZ groundwater concentrations throughout the CAA.
- Alternative 4 provides the highest degree of long-term effectiveness, as the technologies have been proven effective at this Site at permanently removing source mass from soil and groundwater. The reliability of the other technologies is reduced because continued function of the treatment infrastructure in perpetuity is required to maintain compliance with cleanup levels. The design life of the other proposed alternatives will expire before chemical concentrations are in compliance with cleanup standards throughout the CAA.
- Alternative 4 provides a similar degree of short-term risk as the other proposed alternatives in terms of implementation, operation, and generation of waste streams during construction and/or operation.
- Alternative 4 can be implemented with acceptable disruption to facility operations and structures, and the infrastructure required for implementation is not complex.
- Alternative 4 destroys solvent mass from both the vadose soils and contaminated groundwater, giving more assurance that concentrations in groundwater will meet cleanup standards at the CPOC at Fox Avenue.
- Alternative 4 is implemented in conjunction with the alternative proposed for the Downgradient Groundwater Plume and Main Source Area CAAs, as ERD is proposed for implementation site-wide.

Additional details associated with the Preferred Remedial Alternative for the Northwest Corner Plume CAA are presented in Section 11.0.

11.0 Preferred Remedy

The selection and description of the preferred remedy is presented in this section along with an explanation of how it complies with MTCA, the cost to implement, and the associated ARARs.

11.1 SELECTION OF THE PREFERRED REMEDY

The preferred remedy is comprised of the highest ranking and most permanent remedial alternatives evaluated for each of the three CAAs. The preferred remedy is a comprehensive final remedy for the Site that is compliant with all of the applicable remedy selection requirements under MTCA. The remedy is described below and summarized in the table that follows. Figure 11.1 displays the locations and major elements of the preferred remedy.

11.1.1 Main Source Area Cleanup Action Area

- **Groundwater/Soil:** To treat the CVOCs in the groundwater and soil in the Main Source Area CAA, thermal treatment by Electrical Resistance Heating (ERH) will occur until the soil in the treatment area meets, on average, the 10 mg/kg remediation level. This will be followed by post-thermal application of ERD as a polish to further destroy contaminant mass in the source areas. The predicted time frame for soil to achieve compliance with remediation level is expected to be 1 year.

11.1.2 Downgradient Groundwater Plume CAA

- **Groundwater:** The preferred technology for groundwater treatment is ERD. ERD will occur until the proposed groundwater remediation level of 250 µg/L total CVOCs is achieved throughout the downgradient plume and the seeps are in compliance with the proposed cleanup levels. This remedy is expected to require approximately 10 to 15 years of ERD injections. It is anticipated that ERD will continue throughout the majority of the Downgradient Groundwater Plume for approximately 10 years, then will be phased out as areas come into compliance with the remediation level over the following 5 years. Following attainment of the remediation levels, monitored natural attenuation of groundwater will occur until the cleanup levels are achieved throughout the Downgradient Groundwater Plume CAA, which may take an additional 50 years due to the very low regulatory levels and the high starting concentrations.
- **Soil:** There are no technologies proposed for soil treatment in the Downgradient Groundwater Plume CAA, as there are no soil cleanup level exceedances in the downgradient area related to the Site.

11.1.3 Northwest Corner Plume CAA

- **Groundwater:** The preferred technology for groundwater treatment is ERD. ERD has shown to be effective at the Site, based on results of the ERD Interim Action. ERD will be used to treat groundwater where concentrations of total CVOCs are greater than the remediation level of 250 µg/L, which is limited to the 1st WBZ. The predicted time frame for groundwater to achieve compliance with the 250 µg/L total CVOC remediation level at the CPOC is expected to be approximately 5 years.

- **Soil:** The preferred technology for treatment of vadose zone soil is SVE. SVE is expected to operate for approximately 1 year or until asymptotic levels of extraction of PCE are achieved. This action is expected to remove several hundred pounds of PCE from the subsurface, thereby reducing the mass of contamination in soils leaching to groundwater, and reducing the restoration time frame for groundwater compliance.

Summary of Selected Remedy Elements

Cleanup Action Area	Applied To	Technology	Implemented until Compliance with RL or CUL Achieved	Approximate Time Frame Required
Main Source Area	Vadose, 1st WBZ, 1st SH, 2nd WBZ (to 65 feet bgs)	Electrical Resistance Heating (Primary)	RL: 10 mg/kg Total PCE + TCE in soil	1 year of active heating
	1st and 2nd WBZ soil > 10 mg/kg or groundwater > 1,000 µg/L	ERD (Polish)	RL: 250 µg/L Total CVOCs in groundwater (measured at CPOC)	5 years (post-thermal)
Downgradient Groundwater Plume	1st and 2nd WBZ groundwater (to 70 feet bgs) with total CVOCs greater than 100 µg/L at Fox Avenue	ERD	RL: 250 µg/L Total CVOCs in groundwater (as measured in the designated monitoring well network)	10–15 years (post-thermal)
		MNA	CUL: Refer to table in Section 4.3.2 (cleanup levels measured in all downgradient wells)	50 years (post ERD)
Northwest Corner Plume	1st WBZ groundwater with total CVOC concentrations > 250 µg/L	ERD/SVE	RL: 250 µg/L Total CVOCs in groundwater (measured at CPOC)	5 years (post-SVE)
	1st WBZ groundwater with total CVOC concentrations < 250 µg/L	MNA	CUL: Refer to table in Section 4.3.2 (measured at CPOC)	50 years (post-ERD)
	Vadose Soil	SVE	RL: Not applicable, soil already in compliance with RL	Not applicable

Abbreviations:

bgs	Below ground surface
CVOC	Chlorinated volatile organic carbon
CPOC	Conditional point of compliance
CUL	Cleanup level
ERD	Enhanced reductive dechlorination
MNA	Monitored natural attenuation
PCE	Tetrachloroethene
RL	Remediation level
SH	Silt Horizon
SVE	Soil vapor extraction
TCE	Trichloroethene
WBZ	Water Bearing Zone

11.2 COMPLIANCE WITH MTCA REQUIREMENTS

The preferred remedy meets the following minimum requirement for selection of a cleanup action under MTCA WAC 173-340-360(2)(a):

(i) **Protect Human Health and the Environment.** The preferred remedy will protect human health and the environment in both the short-term and long-term. The remedy will permanently reduce the identified risks presently posed to human health (worker exposure to soil and indoor air) and the environment (discharge of the seeps to surface water) through a combination of source area treatment via thermal treatment followed by ERD polish, and downgradient ERD treatment and natural attenuation of groundwater.

(ii) **Comply with Cleanup Standards.** The preferred remedy is expected to comply with the cleanup and remediation levels for groundwater, soil, and indoor air. While standard POCs are appropriate for soil, indoor air, and surface water, a CPOC at Fox Avenue is proposed for groundwater.

(iii) **Comply with Applicable State and Federal Laws.** The preferred remedy is expected to comply with all state and federal laws and regulations as discussed in Section 11.5, below.

(iv) **Provide Compliance Monitoring.** The preferred remedy will include rigorous compliance monitoring for soil, indoor air, groundwater, and seeps to judge the effectiveness and permanence of each remedy element in each CAA. The monitoring is expected to be more intensive for the initial years of remedy implementation, with less frequent monitoring in the future.

The preferred remedy also meets the other requirements for selection under MTCA WAC 173-340-360(2)(b), which includes the following:

(i) **Using Permanent Solutions to the Maximum Extent Practicable.** The preferred remedy utilizes permanent solutions to the degree practical. Thermal treatment will remove a large portion of the existing contaminant mass from subsurface soil and will destroy it in a thermal oxidizer, or in the case of SVE in the Northwest Corner Plume CAA, capture it in activated carbon that will be regenerated. ERD destroys contaminant mass in groundwater in-situ by biological transformation of COCs into harmless by-products.

(ii) **Providing for Reasonable Restoration Time Frame.** The thermal element of the preferred remedy will require approximately 1 year to construct and complete the heating phase. Remediation levels in soil are expected to be attained following thermal shutdown. This will achieve restoration of soil for protection of workers (via direct contact to soil and also indoor air exposure from soil). The time frame for post-thermal treatment via ERD to achieve groundwater remediation levels at the CPOC is anticipated to be approximately 5 years, and compliance with cleanup levels at the point of discharge to surface water at the S. Myrtle Street Embayment is expected within approximately 10 to 15 years through a combination of ERD and MNA, assuming no access limitations. Once accomplished, this will eliminate all existing ecological risk from the migration of site contaminants. Attainment of the cleanup levels in the entire groundwater plume will take considerably longer, approximately 50 years. Assuming, however, site use at the Seattle Boiler Works facility downgradient remains industrial, no risk to human health and the environment has been identified by the Downgradient Groundwater Plume (except at the seeps) because this section of the aquifer is considered non-potable.

(iii) **Considering Public Concerns.** This document will be presented to the public and stakeholders through a public comment process. A public meeting will be held if sufficient requests are received. Ecology will prepare a responsiveness summary as part of the CAP that documents how each of the public comments were considered and addressed.

Finally, because this remedy relies on a CPOC due to the impracticality of attaining cleanup levels throughout the source area, this cleanup action is not considered permanent under WAC 173-340-360(2). The preferred alternative complies with the following requirements for non-permanent groundwater cleanup actions under MTCA WAC 173-340-360(2)(c)(ii):

A. **Treatment or Removal of the Source Including LNAPL and DNAPL.** This will be done to the extent practical by using thermal treatment in the source areas, followed by ERD to address any residually-contaminated areas.

B. **Groundwater Containment, Including Barriers, to Avoid Spreading of the Groundwater Plume.** This will be done by the use of ERD that will, in effect, create a “biological barrier” that will prevent spreading of the plume and treat CVOCs within the plume.

The preferred remedial alternative also meets the RAOs discussed in Section 7.0.

11.3 IMPLEMENTATION DETAILS

The details of the preferred remedy are presented in this section. Additional details will be provided in the Engineering Design Report.

11.3.1 Main Source Area Cleanup Action Area Implementation Detail

This remedy consists of two components, thermal treatment and post-thermal ERD. The major elements of each are described below.

11.3.1.1 Thermal Treatment Area

The soil in the Main Source Area CAA will be treated using thermal heating via electrical resistance heating, which is ideally suited to site conditions. The area to be thermally treated is defined by the 1 mg/kg total PCE + TCE contour in soil that occurs within the Fox Avenue Building footprint, as shown on Figure 5.2. It is the large mass of solvent within this contour that is contributing to the longevity and magnitude of the plumes found primarily in 1st WBZ groundwater downgradient from the Loading Dock Area, Rail Spur Area, Flammables Shed, and in 2nd WBZ groundwater downgradient from primarily the Flammables Shed.

11.3.1.2 Penta and Mineral Spirits

The mass of mineral spirits at the Site, which includes a large BTEX fraction, also resides within this zone. Given that the most toxic light-end component of the mineral spirits present is benzene, which volatilizes at 80 degrees centigrade, it is expected that the benzene fraction will also be treated by the thermal process that will reach temperatures close to the boiling point of water. However, the heavier end of mineral spirits, such as xylene and heavy organics such as Penta, found primarily in 1st WBZ groundwater, volatilize at temperatures greater than the boiling point of water and so will not be as effectively treated by the thermal process as the lighter more volatile chlorinated solvents. Penta will not be remediated by the thermal or ERD treatment processes; however, the current data do not indicate significant migration of TPH or Penta. TPH and Penta will be monitored in groundwater following remedial actions to confirm that concentrations of these COCs are stable in groundwater, or are reducing over time.

Concentrations of PCE and TCE in soil less than 1 mg/kg occur across a much larger portion of the Site but represent a very minor amount of solvent mass rendering thermal treatment impractical. Additionally, these concentrations are found primarily in 1st WBZ soil downgradient from the Main Source Area CAA and are suspected to result of solvent migration from upgradient source areas and subsequent adsorption of the PCE and TCE in soil organic matter. These areas of low PCE and TCE concentrations in soil will be addressed by the remedy for the Downgradient Groundwater Plume CAA.

11.3.1.3 Thermal Treatment Zones

The area with concentrations of PCE + TCE in soil greater than 1 mg/kg will be thermally treated within the footprint shown on Figure 11.2. This footprint has been divided into five zones, each with a unique treatment depth that captures the depth range of soil contamination greater than 1 mg/kg PCE + TCE as follows:

1. Loading Dock Area: 2,300 square feet, treat to 15 feet bgs.
2. West Rail Area: 4,500 square feet, treat to 17 feet bgs.
3. East Rail Area/East Flammables Shed Area: 4,600 square feet, treat to 22 feet bgs.
4. Former Pump House and West Flammables Shed Area: 7,500 square feet, treat 1 to 65 feet bgs.
5. Alkaline Shed and Production Area: 4,460 square feet, treat 15 to 65 feet bgs.

Together, these areas represent a soil volume of approximately 33,000 cubic yards that will be treated; however, as shown in Figure 5.5, a significant fraction of this soil volume is actually free of contamination or exhibits very low concentrations. This is primarily a consequence of having two depth zones to treat, one shallow and widespread, and one much deeper and confined, with a relatively non-impacted zone in between. These two areas are separated by approximately 20 to 30 feet of relatively clean soil. This cleaner intermediate zone must be heated to boiling in order for the solvent mass liberated from the deep zone to rise and be captured by the vapor recovery wells located in the vadose zone. If heating is not equal throughout the treatment zone, liberated solvent mass may recondense prior to recovery, causing significant risk of solvent mass loss to downgradient groundwater. The benefit of this approach is to provide a high level of assurance that all solvent mass (whether in soil or groundwater) within each zone will be treated. Because all soil within the treatment zone will be treated, it will result in significant reductions in those areas of soil with chemical concentrations now close to or less than the remediation level (i.e., the 1 to 10 ppm contour); resulting in significantly less residual source mass following thermal treatment.

11.3.1.4 System Layout and Vapor Treatment

Figure 11.3 displays the expected layout of the thermal system, including the electrode locations and temperature monitoring points, which are used to verify that the subsurface soil has achieved its boiling point of the PCE and water mixture. Figure 11.3 also shows the halo of soil lying outside of the immediate treatment zone that will also be heated to the boiling point and subject to cleanup. This additional 5- to 7-foot buffer provides added confidence that the limits of source area contamination (as defined by the Data Gaps Investigation soil samples collected in 2009–2010) are within the proposed treatment area.

The electrodes (which are steel pipe surrounded by graphite) will be designed to function as steam/condensate extraction wells and will include the ability to remove free product mineral spirits should any be captured by the system. Electrodes are in effect remediation wells with the added capacity to direct electrical current to the proper depth for subsurface heating. Electrodes can serve as vapor and steam recovery points, or can operate as multiphase extraction wells for the recovery of vapor, steam, water, and NAPL from the subsurface. The steam and vapors will be removed via a large blower using standard PVC piping that will be manifolded and will run to the treatment compound. The extracted steam and vapor stream will pass through a condenser. The steam will condense back to water that will be relatively clean and either be treated with liquid phase carbon and disposed via sanitary sewer or dripped back into the vadose zone to prevent the soil from drying out, which would stop the flow of electrical current and hence the subsurface heating.

The vapor stream flowing out of the condenser will be chemical-rich and will be directed to a thermal oxidizer with an acid gas scrubber for destruction of the chlorinated and aromatic compounds extracted. The aboveground equipment will be located in a treatment compound located to the east side of the warehouse, as shown in Figure 11.3.

11.3.1.5 Electrical Service

A new electrical service supplying 13.8 kilovolts (KV) of power will be required to operate the remediation system. This large amount of power will require a temporary high voltage electrical service be brought into the Site. Specialized power control units will transform that voltage and feed it into the ground via copper cabling that services each electrode.

11.3.1.6 Post-thermal ERD

Following shutdown of the thermal treatment system, the steam within the treatment area will re-condense to groundwater, but will still be quite warm for several months. During this cool-down period, an assessment will be made of post-thermal groundwater quality within the treatment area. This will be done using a Geoprobe to collect samples at multiple depth intervals from 10 to 12 locations. Also, during the cool-down phase, the microbial community will be reestablished, and the environment will be amenable to accelerated biodegradation. The injection of ERD substrate into the thermal zone (using the existing steel electrodes that will be slotted to allow injection of substrate) will assist in promoting the correct conditions for anaerobic biodegradation of the residual chlorinated solvent that remains in the treatment area. As explained above, it is expected that the zone of residually-contaminated soils will be much smaller than the current footprint.

Following receipt of the groundwater data, a targeted ERD treatment plan will be designed based on the site-specific conditions at that time. If any areas are found to be residual “hot spots,” they will likely be targeted for injection of edible oil substrate (EOS). EOS has a very limited zone of influence since it does not readily dissolve into groundwater, so it is long lasting and ideal for source area treatments in areas with residual source that is expected to “bleed” solvent for an extended time period. In addition to the EOS, depending on site conditions, a more soluble substrate may be used—possibly combined with nano scale ZVI, or other substrates that would increase the rate or effectiveness of the ERD injections. This post-thermal ERD will initially be applied to the majority of the residual treatment area, but subsequent treatments will be focused on any remaining smaller sub-areas that are found to be continuing sources of downgradient groundwater exceedances.

11.3.2 Downgradient Groundwater Plume Cleanup Action Area Implementation Detail

The remedy for the Downgradient Groundwater Plume CAA consists of two components—ERD as it currently is being implemented, followed by MNA. The ERD component of the Downgradient Groundwater Plume remedy is intended to clean up the plume to the proposed remediation level of 250 µg/L total CVOCs and the seeps to the proposed cleanup levels in a short time frame (anticipated in a proximately 10 to 15 years). The MNA component will be used to reach the proposed cleanup levels in groundwater upgradient from the seeps up to the CPOC in a longer time frame (approximately 50 years).

11.3.2.1 Enhanced Reductive Dechlorination

The full implementation of ERD will commence in parallel with the construction of the thermal remediation system. The goal of full implementation is to have a complete ERD network installed and functioning by the time the thermal treatment zone is undergoing heating. This will add protectiveness to the remedy because the full ERD network can act in its full capacity to destroy any unanticipated loss of solvent from the Main Source Area CAA during thermal remediation. A portion of the ERD network directly downgradient from the thermal heating zones will also benefit from the increased microbial activity that will occur because groundwater leaving the thermal treatment zone will be heated above ambient temperature for up to an estimated 200 feet downgradient.

The full implementation of the ERD remedy will require installing an estimated 10 additional "Row 1" ERD wells along Fox Avenue to complement the existing 7 wells. The addition of these new wells will result in an ERD network along Fox Avenue that will treat the full width and depth of the current plume that lies within the 100 µg/L total CVOC contour. Locations for these additional "Row 1" wells are shown on Figure 11.1. Up to seven "Row 2" ERD wells may also be installed further downgradient, on Seattle Boiler Works and Dawn Foods Distribution Warehouse, to extend the existing Row 2 well network across the full width of the plume prior to its discharge to the S. Myrtle Street Embayment. These two rows of ERD injection wells will aggressively remediate the downgradient plume, which will be without a significant source following thermal remediation. Access for installation and injection of the ERD wells located on private property is discussed below. Once the groundwater remediation level is achieved in wells downgradient from Fox Avenue, ERD injections will decrease in frequency, or cease. Further details will be provided in the Engineering Design Report. Contingent actions that address the inability of ERD to achieve the remediation levels in groundwater and the cleanup levels in the seeps are discussed in Section 12.0.

11.3.2.2 Monitored Natural Attenuation

The ERD injections are expected to decrease in frequency and stop after 10 to15 years. Following ERD injections, the aquifer is expected to remain adequately reducing for a significant time frame into the future. This condition will promote the continued natural attenuation of the residual concentrations of chlorinated solvents in the downgradient plume. Measurements will be collected regularly to determine if natural attenuation is occurring. However, given the very low cleanup levels, and the tendency for PCE and TCE in groundwater to adsorb to soil organic matter and then slowly release back to groundwater, it is expected that the full restoration of the downgradient plume to the proposed cleanup levels for all COCs will be a long process, estimated to be 50 years or longer. Regardless, all risk to human health and the environment will have been addressed following achievement of cleanup levels at the seeps and elimination of the vapor intrusion pathway, if determined to exist downgradient.

11.3.3 Northwest Corner Plume Cleanup Action Area Implementation Detail

The remedy for the Northwest Corner Plume CAA consists of two components: SVE and ERD. Each are described separately below.

11.3.3.1 Soil Vapor Extraction

The SVE remedy element will remove PCE from the vadose zone that otherwise would act as a long-term source of groundwater contamination. The SVE system is expected to consist of approximately four SVE wells placed in the parking lot located in the Northwest Corner Plume CAA and along S. Willow Street. The wells will be tied together via subsurface piping to a central blower. The blower exhaust will be vented through activated carbon vessels prior to discharge to the atmosphere under a Puget Sound Clean Air Agency permit. It is expected that the footprint of the aboveground components of the SVE system will be small and so be able to fit within a portable trailer or shed located adjacent to the Cascade Columbia warehouse. An electrical power line will be extended from the warehouse to service the blower. A tentative layout of the SVE system is shown on Figure 11.1.

The SVE system will be run until asymptotic concentrations are achieved. Because previous investigations have determined that there is not substantial source mass in this area, achieving asymptotic concentrations is expected to occur within 1 year of operation. The effectiveness of the SVE system will primarily be determined by the total mass of PCE removed and its impact upon groundwater concentrations in this area.

11.3.3.2 Enhanced Reductive Dechlorination

Groundwater impacts are limited to the 1st WBZ in the Northwest Corner Plume CAA. ERD injections upgradient from Fox Avenue will occur in a series of three shallow wells recently installed in the parking lot area. These three wells plus the Row 1 ERD wells along Fox Avenue further downgradient are expected to adequately treat the plume within the 100 µg/L total CVOC contour. A conceptual layout is presented in Figure 11.1. The substrate injections will be more frequent at first due to the need to convert the currently aerobic or slightly anaerobic groundwater to strongly anaerobic conditions, a process that will require approximately 1 to 2 years of injections on a regular basis (2 to 3 times per year). The addition of nano-scale ZVI particles to the fermentable substrate may be considered to accelerate the promotion of strongly-reducing conditions. It is expected that once sufficient biogeochemical conditions are achieved in the treatment area, the frequency of injections will diminish to one to two times per year.

ERD will continue until the remediation level for groundwater of 250 µg/L total CVOCs is reached at the CPOC at Fox Avenue. The percent reduction in current concentrations necessary to achieve the remediation level is approximately 75 percent, which is well within the range of the ERD technology. Therefore, the expected period of performance for ERD injections is 5 years. Current groundwater and ERD monitoring practices will continue as part of the ERD Interim Action and results will be provided regularly to Ecology.

Following 5 years of active treatment, if ERD has not achieved compliance with the 250 µg/L total CVOCs remediation level (as measured within the treatment area), then contingent actions will be evaluated as discussed in the next section.

11.4 PERMISSION, ACCESS, AND INSTITUTIONAL CONTROLS

As discussed in Section 7.3, the use of a CPOC for properties near, but not abutting surface water requires the written consent of affected property owners. The proposed CPOC along Fox Avenue will require that written permission be obtained from the owners of the Whitehead Property. Access will also be required to allow for groundwater sampling at the Whitehead Property as well as other downgradient properties with monitoring and ERD injection wells (i.e., Seattle Iron and Metals, Seattle Boiler Works).

Access will be required from Seattle Boiler Works and other downgradient properties to allow for injection of ERD substrate into existing and new ERD wells, as well as access to sample indoor air and install additional ERD wells necessary to optimize the Downgradient Groundwater Plume remediation following completion of source area thermal treatment. Should access to downgradient properties be denied, the remedy for the Downgradient Groundwater Plume CAA will not be fully implemented, likely resulting in increases to the restoration time frame of the Downgradient Groundwater Plume and seeps.

Following achievement of remediation levels for groundwater, implementation of institutional controls will be required on those portions of affected properties (i.e., Fox LLC and Whitehead) where chemical concentrations in groundwater or air exceed applicable cleanup levels and are expected to remain greater than cleanup levels for an extended time frame. Institutional controls (in the form of an environmental covenant) will likely include the following:

- Restriction in withdrawal of groundwater from the affected property for drinking purposes.
- Consent to long-term access for environmental monitoring and maintenance.

Additionally, the Environmental Covenant for the Fox LLC and Whitehead properties will require that the properties be maintained for industrial use only, in a manner consistent with applicable zoning requirements. The owner of the downgradient Seattle Boiler Works property is not willing to accept a restrictive covenant limiting the site to industrial uses at this time.

11.5 SUMMARY OF THE ESTIMATED REMEDY COSTS

The estimated cost for the preferred remedy is $9.4 million including a $2.8 million contingency. This cost estimate is a “feasibility level” estimate and is not based on firm contractor quotes. Cost documentation backup worksheets are presented in Appendix J. The long-term monitored natural attenuation costs included in the above estimate are based on the assumption that monitoring will continue for an estimated 50 years following cessation of ERD.

11.6 APPLICABLE OR RELEVANT AND APPROPRIATE REQUIREMENTS

The preferred alternative complies with the legally ARARs under WAC 173-340-710, as described below.

11.6.1 Chemical-specific ARARs

The preferred alternative is predicted to attain concentration-based cleanup levels developed under MTCA for the COCs in applicable media at the Site. Please refer to Section 4.0 for a detailed discussion of how cleanup levels were identified.

11.6.1.1 Sediment Management Standards (WAC 173-204)

SMS are not applicable at this Site because none of the COCs currently discharging to surface water at concentrations greater than applicable cleanup standards have established cleanup criteria under the SMS.

11.6.1.2 Water Quality Standards for Washington Surface Waters (WAC 173-201A)

The preferred alternative will comply with Washington State Surface Water Standards that apply to the following site-related surface waters:

- Groundwater seeps that discharge to the Duwamish Waterway
- Stormwater discharges during remedial construction

While there are no promulgated surface water standards for the site COCs, standards that control discharge of other pollutants to stormwater generated during construction would be applicable.

11.6.1.3 National Toxics Rule

This rule sets numeric criteria for several priority toxic pollutants in marine surface waters, including several VOCs. The National Toxics Rule was used to develop cleanup levels.

11.6.2 Location-specific ARARs

No location-specific ARARs have been identified that apply to the preferred remedy.

11.6.3 Action-specific ARARs

Action-specific ARARs are requirements that define acceptable management practices and are usually specific to certain kinds of activities that occur or are specific to the technologies that are used during the implementation of cleanup actions. These preferred alternatives will comply with the requirements discussed below.

11.6.3.1 Washington Dangerous Waste Regulations (WAC 173-303)

These requirements potentially apply to the identification, generation, accumulation, and transport of hazardous/dangerous wastes at the Site during remediation. It is likely that some of the soil cuttings generated by the drilling of wells will be designated as hazardous waste if disposed of off-site. Federal land disposal restrictions (LDRs) under 40 CFR Part 268 require that hazardous wastes be treated prior to being disposed of in a land-based disposal unit. USEPA has developed special LDRs for contaminated soil and debris. The treatment standards for these substances are expressed as numerical limits and treatment methods, respectively. These standards are applicable to any soil wastes that are taken off-site for disposal.

11.6.3.2 Water Quality Standards for Surface Waters of the State of Washington (RCW 90.48 and 90.54; WAC 173-201A)

The preferred alternative will comply with surface water quality standards such as turbidity and pH that apply to certain construction elements (e.g., drilling of thermal wells and cutting and pouring of concrete). The area of construction for thermal wells and equipment staging will likely be greater than 1 acre, and so will require a National Pollution Discharge Elimination System (NPDES) Stormwater Construction Permit to control discharge of pollutants from the construction activities.

11.6.3.3 Federal, State, and Local Air Quality Protection Programs

Regulations promulgated under the federal Clean Air Act (42 USC 7401) and the Washington State Clean Air Act (RCW 70.94) govern the release of airborne contaminants from point and non-point sources. Local air pollution control authorities such as the Puget Sound Clean Air Authority (PSCAA) have also set forth regulations for implementing these air quality requirements. These requirements are applicable to the Site because the preferred alternative will extract and treat CVOCs via a thermal oxidizer and carbon, and discharge the treated air, which requires permitting. Additionally, any construction activities associated with the selected alternatives will need to meet all federal, state, and local air quality requirements to control fugitive dust and other emissions.

11.6.3.4 Federal and State of Washington Worker Safety Regulations

The safety of workers implementing remedies at hazardous waste sites are covered by the following regulations:

- Health and Safety for Hazardous Waste Operations and Emergency Response (HAZWOPER), WAC 296-62 and Health and Safety 29 CAR 1901.120
- Occupational Safety and Health Act (OSHA)
- Washington Industrial Safety and Health Act (WISHA), WAC 296-62, WAC 296-155, RCW 49.1

The HAZWOPER regulates health and safety operations for hazardous waste sites. The health and safety regulations describe federal requirements for health and safety training for workers at hazardous waste sites.

OSHA provides employee health and safety regulations for construction activities and general construction standards, as well as regulations for fire protection, materials handling, hazardous materials, personal protective equipment, and general environmental controls. Hazardous waste site work requires employees to be trained prior to participation in site activities, medical monitoring, monitoring to protect employees from excessive exposure to hazardous substances, and decontamination of personnel and equipment.

Washington State adopted the standards that govern the conditions of employment in all work places under its WISHA regulations. The regulations encourage efforts to reduce safety and health hazards in the work place and set standards for safe work practices for dangerous areas such as trenches, excavations, and hazardous waste sites.

11.6.3.5 Underground Injection Well Registration

The Underground Injection Control Program (UIC) protects groundwater quality by regulating discharges to UIC wells. UIC wells are manmade structures used to discharge fluids into the subsurface. Examples are drywells, infiltration trenches with perforated pipe, and any structure deeper than the widest surface dimension. The majority of UIC wells in Washington State are used to manage stormwater (i.e., drywells) and sanitary waste (large on-site systems), return water to the ground, and help clean up contaminated sites. The potential for groundwater contamination from injection wells depends on well construction and location; quality of the fluids injected; and the geographic and hydrologic settings in which the injection occurs.

Currently, the injection of substrate into the injection wells for the ERD interim action is being conducted under a UIC Permit. Continued injections into existing wells will be carried out in the future under this permit, and any new injection wells will be included in an updated permit registration. Additionally, reinjection of a part of the vapor condensate from the thermal treatment process may need to be reinjected into the source areas undergoing treatment in order to maintain adequate production of steam.

11.6.3.6 Sanitary Sewer Discharge

The preferred alternative will result in discharge of condensate during thermal heating. Condensate will likely be treated and discharged to the sanitary sewer under applicable permits from King County. It is expected that the existing waste discharge authorization currently held by the Cascade Columbia Facility will be modified for this purpose.

12.0 Performance Monitoring, Compliance Sampling, and Contingency Actions

Performance and compliance monitoring will be conducted within each of the CAAs as described in general terms below. Contingency actions are also discussed that identify actions to be taken should the remediation and cleanup levels not be met in the predicted restoration time frames. Details will be provided in a Compliance Monitoring Plan to be submitted in the Engineering Design Report.

12.1 MAIN SOURCE AREA THERMAL REMEDIATION

The performance monitoring associated with the thermal remedy will consist of several data types, including system operational data and soil compliance data.

12.1.1 Operational Data

One of the most important operational data types is the soil temperature, which will be constantly monitored at over 100 individual temperature sensors (thermistors) installed in borings throughout the full width and depth of the subsurface treatment zone. The temperature data will document the rise of the subsurface temperature during the heating phase and identify areas of uneven heating, in which case additional current or other modifications will be directed to those areas. The temperature data will also confirm that the entire thermal treatment area has reached its design temperature and stays at this temperature for the predicted period of time necessary to treat the Main Source Area to achieve the soil remediation level.

Additional performance measures include the electricity used (tracked daily), and the influent and effluent concentrations of the vapor stream being fed to the thermal oxidizer. It is expected that influent concentrations will rise slowly as the subsurface is heated, then rise to a maximum value as the subsurface is at the boiling point, and then drop off quickly as the contaminant source mass is depleted.

12.1.2 Soil Compliance Testing

Soil samples will be collected to assess remedy compliance with the remediation level of 10 mg/kg PCE + TCE as well as compliance with the cleanup level protective of workers (Method C industrial direct contact). These soil samples will be collected at two stages. The Site, like many sites, is composed of a large volume of soil with relatively low chemical concentrations and a much smaller volume of “hot spot” soil with high chemical concentrations. The hot spot areas contain the bulk of the contaminant mass. Given that the energy needed to vaporize the contaminant mass in areas with low chemical concentrations is less than the energy needed in the higher concentration areas, the lower concentrated areas are expected to come into compliance well before the hot spot areas. Additional heating of these low concentration areas once they are in compliance does not provide any additional benefit, so evaluation of these areas will be conducted mid-way through the heating process to determine the need for continued heating. These intermediate compliance samples will be collected following temporary shutdown of the thermal system, so that steam is not being generated in the subsurface. Areas that are found to be in compliance after this intermediate testing will no longer be heated. The remaining energy will be directed to the higher concentration unsampled areas and any sampled areas found to be greater than the remediation level.

A second round of compliance samples will be collected in the remaining heating areas after 100 percent of the predicted total energy demand has been utilized and the chemical concentrations in the effluent vapor has decreased significantly.

Contingency Actions: If concentrations in soil remain greater than the 10 ppm remediation level after 100 percent of the predicted energy load has been utilized, then an engineering assessment of various options to attain the compliance level will be undertaken. These options may include additional heating, installation of additional electrodes, potential limited excavation, or other similar technologies. Compliance sampling of these areas will occur following any contingency actions until compliance has been demonstrated site-wide.

12.1.3 Compliance Testing Scheme

The proposed compliance testing scheme is rigorous and expected to include the following elements:

1. Soil samples will be obtained in each of the five treatment areas by Geoprobe to collect continuous cores. Sample cores will be chilled, spilt open, screened with a photoionization detector (PID), and sampled for analysis from the interval with the highest observed PID reading.
2. Boring locations will be uniformly located within each of the 5 areas excluding areas within the 1 to 10 mg/kg contour since these areas are already in compliance with the 10 ppm remediation level.
3. The approximate number of soil borings per zone, sample interval, and number of samples collected for analysis is defined in the table below. For the deep treatment areas, the intermediate zone of soil between elevations 0 to -20 feet will not be sampled because this elevation interval is currently in compliance site-wide.[6]
4. Each zone will be evaluated for compliance with the remediation level separately.

The 95 percent upper confidence level (UCL) of the mean concentration shall be compared to the remediation level to judge compliance.[7]

Treatment Area	Square Footage	Treatment Interval (feet bgs)	Number of Borings	Samples Per Boring	Total
Loading Dock	2,300	0 to 15 feet	5	1 per vadose zone 1 per 1st WBZ 1 per 1ST SH, if present	15
West Rail Siding	4,500	0 to 17 feet	8	1 per vadose zone/1st WBZ 1 per 1ST SH/ 2nd WBZ	16

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[6] In the event of an elevated PID reading in soil collected from this zone, a sample will be collected and added to the compliance dataset.

[7] The determination of the 95 percent UCL shall be in accordance with current Ecology guidance.

Treatment Area	Square Footage	Treatment Interval (feet bgs)	Number of Borings	Samples Per Boring	Total
East Rail/ East Flammables	4,600	0 to 22 feet	8	1 per vadose zone/1st WBZ 1 per 1ST SH/ 2nd WBZ	16
Former Pump House/Flammables Shed	7,500	0 to 65 feet	10	1 per vadose zone/1st WBZ 1 per 1ST SH/ top 2nd WBZ 3 (every 5 feet starting at 45 feet bgs)	50
Production Area/Alkaline Shed	4,400	15 to 65 feet	7	3 (every 5 feet, starting at 45 feet bgs)	21
		TOTAL	**38**		**118**

Note:
The numbers in the above table are approximate. Actual numbers to be determined based on field conditions.

Abbreviations:

bgs	Below ground surface
SH	Silt Horizon
WBZ	Water Bearing Zone

12.2 MAIN SOURCE AREA ENHANCED REDUCTIVE DECHLORINATION

As described in Section 11.2, groundwater quality within the thermal treatment zone will be assessed following thermal shutdown and a plan for ERD substrate injections developed. Following the initial substrate injections, performance monitoring will occur to assess the effectiveness of post thermal ERD. The performance monitoring will be similar to that described for the Northwest Corner Plume CAA and ongoing Interim Action. This includes regular measurements (typically semi-annually) of water quality parameters (e.g., dissolved oxygen, Eh, pH, and conductivity from selected injection and monitoring wells) and collection of water samples from for total organic carbon (to judge substrate levels), volatile organic compounds (to judge concentration trends) and the dissolved gases ethane and ethene (the by-products of VC degradation).

The goal of the post-thermal ERD will be to achieve remediation levels for site groundwater in wells along Fox Avenue within 5 years following thermal treatment. If achieved in less than 5 years, then the frequency of injections may be reduced or discontinued. Should monitoring indicate rebound of groundwater concentrations, then additional ERD injections will occur for an approximate 2-year period until remediation levels are achieved.

If following additional ERD injections, monitoring indicates continued exceedances of the groundwater remediation level of 250 µg/L total CVOCs at the CPOC, contingency actions will be evaluated for implementation. Evaluation is expected to first include investigations to identify the source of the exceedance. Depending on the magnitude, concentration, and extent of any identified soil source mass, contingency actions such as excavation, PRB wall installation, or continued ERD will be considered. For example, if shallow soils are identified, excavation may be considered. If chemical source soils are found to be more extensive, a PRB may be installed downgradient from the area causing the exceedance subject to the location of existing utilities. Should the exceedances be confined to the 2nd WBZ soils, then additional ERD injection wells and/or injection of nano-scale ZVI and/or bacterial inoculation (by adding cultured dechlorinating bacteria) into existing wells may be considered depending on the site-specific conditions.

12.3 DOWNGRADIENT GROUNDWATER PLUME ENHANCED REDUCTIVE DECHLORINATION

The implementation of ERD in the Downgradient Groundwater Plume CAA will consist of performance monitoring identical to that described for the Northwest Corner Plume CAA ERD below. This includes regular measurements (typically semi-annually) of water quality parameters (e.g., dissolved oxygen, Eh, pH, conductivity) from selected injection and monitoring wells and collection of water samples for total organic carbon (to judge substrate levels), volatile organic compounds (to judge concentration trends), and the dissolved gases ethane and ethene (the by-products of VC degradation).

ERD will be terminated when groundwater concentrations in all monitoring wells downgradient from Fox Avenue are less than or equal to the 250 µg/L total CVOC remediation level AND the seeps in the S. Myrtle Street Embayment are in compliance with the surface water cleanup levels. It is expected that ERD injections will be phased out from individual wells and sub-areas over time, in the 10- to 15-year time frame as sub-areas of the Site come into compliance with the 250 µg/L remediation level for total CVOCs.

Contingent actions will be implemented if any of the downgradient wells remain greater than the 250 µg/L remediation level following 15 years of ERD and MNA remediation. The specific contingent action to be implemented is dependent upon the location, magnitude, and scale of the exceedance. Possible contingent actions include:

- Installation of additional ERD wells
- Use of different ERD substrates
- Injection of cultured dechlorinating bacteria
- Injection of nano-scale ZVI

Contingent actions to be considered if the seeps do not comply with surface water cleanup levels depend upon the magnitude and nature of the exceedance. The first step in evaluating potential contingency actions will be an assessment of the actual (not predicted) concentrations of COCs in shellfish near the seeps, the primary environmental exposure pathway. If actual concentrations are detected in shellfish posing a risk to human health and the environment, then a plan will be developed to identify a range of options for addressing the exposure. This plan may include some of the following:

- Use of new science to reexamine current exposure assumptions and cleanup levels
- Use of Shellfish Consumption Advisories expected to be in place in the LDW
- Further investigation to identify and address in-situ the source of the seep exceedance
- Interception and treatment of the groundwater immediately prior to discharge to the seeps

It is also possible that in the future, the seeps will no longer be present as a result of future restoration projects in the S. Myrtle Street Embayment. Restoration actions may involve cutting back the current steep slope and removal of the concrete debris in the 1st WBZ that is thought to be causing the channelization and seepage of groundwater flow. Should the seeps be permanently lost as part of a habitat restoration, or other redevelopment activity, compliance at the seeps will be measured at the closest upgradient groundwater monitoring well. If this occurs, per WAC 173-340-720(8)(e)(ii), an estimate of the natural attenuation occurring between the monitoring well and the point or points of discharge should be considered when evaluating whether compliance in surface water has been achieved.

12.4 DOWNGRADIENT GROUNDWATER PLUME CLEANUP ACTION AREA MONITORED NATURAL ATTENUATION

Following attainment of the groundwater remediation level in the Downgradient Groundwater Plume wells and attainment of the cleanup levels at the seeps, the Site will transition to monitored natural attenuation. The former ERD injection wells will become monitoring wells. ERD wells will be useful for monitoring as they are screened in deeper portions of the 2nd WBZ, unlike existing monitoring wells.

Performance monitoring will be nearly identical to the performance monitoring conducted for ERD. However, measurements of total organic carbon (to assess substrate levels) will no longer be necessary.

Given the long time frame necessary for monitored natural attenuation to obtain cleanup levels site-wide in groundwater, monitoring will occur on an annual or biannual basis using a select subset of wells in the Downgradient Groundwater Plume CAA. Once all of these wells are in compliance with the cleanup levels, the restoration of the Site will be considered complete.

Contingency actions for this portion of the remedy include restarting the ERD process for any areas of the Downgradient Groundwater Plume that show rebound following termination of ERD or remain out of compliance.

12.5 NORTHWEST CORNER PLUME CLEANUP AREA SOIL VAPOR EXTRACTION AND ENHANCED REDUCTIVE DECHLORINATION

12.5.1 Soil Vapor Extraction

Performance monitoring of the SVE system will consist of monthly readings of influent and effluent vapor concentrations to demonstrate removal of solvent mass and compliance with the air discharge permit. Quarterly progress reports will be submitted to Ecology that track the mass of CVOCs extracted from the vadose zone. The SVE system is expected to operate until asymptotic discharge concentrations are reached and sustained for a 2-month period. The system will then be shut down for 1 month and then restarted to monitor rebound. If rebound does not occur, the system will be decommissioned. If rebound does occur, SVE system operation will continue, likely in cycles of on then off, with monitoring for rebound during the off cycles. The results of the SVE pilot test conducted in 2010 indicate that asymptotic conditions may be achieved within 1 year of operation as there is thought to be a limited amount of solvent mass in this area (Appendix D).

12.5.2 Enhanced Reductive Dechlorination

Performance monitoring of ERD will be initiated following the beginning of substrate injections. The monitoring will be similar to what is currently being done for the ERD interim action. This includes regular measurements (typically semi-annually) of water quality parameters (e.g., dissolved oxygen, Eh, pH, conductivity) from injection wells and selected monitoring wells. Samples will also be collected for analysis of total organic carbon (to evaluate substrate levels), VOC (to evaluate concentration trends), and the dissolved gases ethane and ethene (the by-products of VC degradation).

The frequency of ERD injections will be based upon the rate at which substrate is fermented by the microbes. It is expected that injections will be more frequent in the first year and less frequent in the subsequent years as the aquifer becomes more anaerobic. The VOC concentration trends of the existing monitoring wells located in the parking lot area of the Northwest Corner Plume CAA and downgradient along Fox Avenue will be used to judge the effectiveness of this remedy element. Substrate injections will continue for an expected 5 years or until concentration of total CVOCs along the Fox Avenue wells in this area are in compliance with the proposed groundwater remediation level of 250 µg/L (total CVOCs). Following that, the groundwater in this area will continue to be monitored semiannually until concentrations have stabilized at concentrations less than the remediation level, then the monitoring frequency shall decrease to annual or less frequent, depending on site conditions and Ecology approval.

Several contingent actions will be considered for implementation should the 250 µg/L (total CVOCs) remediation level not be reached within the expected 5 years. These include the following:

- Continue ERD injections. This contingency is appropriate if concentrations are on a downward trend and close to the remediation levels.
- Continue SVE system operation. This contingency is appropriate if the operation of the SVE system can be correlated with a decrease in groundwater concentrations, and mass removal is still occurring via SVE.
- Install a PRB wall along Fox Avenue downgradient from those areas of the plume not in compliance with the remediation level. The PRB wall would be similar to that evaluated in the analysis of remedial alternatives for this area. The PRB wall would be designed to treat the chemicals in the 1st WBZ groundwater as contamination is not present in the 2nd WBZ.

12.6 INDOOR AIR

Current data indicate indoor air concentrations in the Cascade Columbia office exceed the MTCA Method C cleanup level for PCE and TCE. An interim mitigation measure, which included upgrading the size of the bathroom fan and re-wiring it to run continuously during the work day, was completed in May 2011. Pre-remediation sampling will be used to evaluate the effectiveness of this interim measure. Additional mitigation measures may be evaluated if the implementation of the exhaust fan does not appear effective at reducing indoor air concentrations of PCE and TCE. In addition, active soil and groundwater remediation will reduce source area concentrations, which will mitigate soil gas and indoor air concentrations.

Compliance with the indoor air cleanup levels will be determined by direct measurement of indoor air inside the Cascade Columbia office before, during, and following completion of thermal remediation. Sampling methodologies are expected to be consistent with the methods implemented in 2009 to assess current conditions. Sample concentrations will be directly compared to the MTCA Method C indoor air cleanup levels.

Additional samples will be collected at Seattle Boiler Works before, during, and after thermal remediation, likely within the Pipe Building located immediately downgradient from the Main Source Area CAA. Additional samples may also be collected from other buildings of potential concern. Access to the Seattle Boiler Works facility is required for sample collection.

Contingency actions will be evaluated if the post-remedy air samples in the Cascade Columbia building or other downgradient buildings (i.e., Seattle Boiler Works) exceed the site cleanup levels. Selection and implementation of contingency actions is dependent on the magnitude of the exceedance, and may include the following:

- Modification to ventilation systems
- Sealing of floors and foundation cracks
- Installation of a passive or active subslab ventilation system or building perimeter ventilation system

It should be noted that current use of the Seattle Boiler Works property is industrial; therefore, in accordance with Ecology's soil vapor intrusion guidance (Ecology 2009b), the protective air levels that take into account exposures to adult workers may be utilized to determine the need for interim measures (i.e., worker exposure versus residential exposure).

12.7 SUMMARY OF PROPOSED REMEDIAL ACTIONS, COMPLIANCE TESTING, AND CONTINGENCIES

The above paragraphs describe details of the proposed compliance testing and contingency actions for each of the CAAs. Figure 12.1 summarizes the information presented in this section in a flow chart-type format. Table 12.1 presents similar information in a tabular format that is organized by impacted media (e.g., soil, air, groundwater) and exposure pathways. Table 12.1 also includes summary information on the COCs, the cleanup levels, points of compliance, and restoration time frame.

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Fox Avenue Site
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Remedial Investigation/ Feasibility Study

Tables

FINAL

Table 3.1

Pre- and Post-ERD Ethane Concentrations Measured in Monitoring and Injection Wells

		Sample Date					
Well ID	**Units**	**January 2009 (Baseline)**	**April 2009**	**October 2009**	**January 2010**	**February 2010**	**April 2010**
B-33A	mg/L	<0.005	0.19	-	0.003	0.18	14
B-65	mg/L	<0.005	0.07	3.8	0.13	0.22	-
MW-4	mg/L	-	-	-	0.016	-	-
R1-IW4A	mg/L	-	0.024	-	-	-	<0.005
R1-IW4B	mg/L	-	0.05	-	-	0.41	<0.005
R1-IW7-45	mg/L	-	-	-	-	0.38	13
R2-IW3-30	mg/L	-	0.18	-	-	0.035	0.26
B-59	mg/L	<0.005	-	-	-	-	0.01
B-61	mg/L	<0.005	0.01	2.3	-	-	-

Abbreviation:

ERD Enhanced Reductive Dechlorination

Table 4.1
Frequency of Detection and Maximum Concentration of Organic Compounds Detected in 5 Percent or More of Soil Samples
All Dates

Chemical	Units	Number of Results	Number of Detects	Percent Detects	Minimum Detected Value	Maximum Detected Value	Location of Maximum Detect	Date of Maximum Detect	Number of Non–Detects	Percent Non–Detects	Minimum Reporting Limit	Maximum Reporting Limit
Volatile Organic Compounds												
Chlorinated Ethenes & Ethanes												
Tetrachloroethene	µg/kg	485	294	61%	1	18,000,000	SB-10	1/24/1991	191	39%	1	200
Trichloroethene	µg/kg	485	171	35%	1	1,100,000	SB-10	1/24/1991	314	65%	1	24,000
cis-1,2-Dichloroethene	µg/kg	381	141	37%	1	32,000	GP-85	6/17/2009	240	63%	2	47,000
1,2-Dichloroethene (total	µg/kg	94	23	24%	10	57,000	B-30	4/7/1992	71	76%	2	17,000
Vinyl chloride	µg/kg	489	47	10%	0.1	3,300	WH-1	8/9/2000	442	90%	0.2	70,000
Other Volatile Organic Compounds												
Acetone	µg/kg	186	24	13%	10	47,000	B-30	4/2/1992	162	87%	20	84,000
Methylene chloride	µg/kg	485	31	6%	2	780,000	SB3	10/12/1990	454	94%	1	16,000
Total Petroleum Hydrocarbons, Benzene, Toluene, Ethylbenzene, Xylene, & Alkylated Benzenes												
Total Petroleum Hydrocarbons (by boiling point range)												
TPH-Mineral Spirits Rang	mg/kg	210	47	22%	2	6,500	B-2/S-3	5/11/1990	163	78%	5	144
TPH-Diesel	mg/kg	104	10	10%	142	770	B-32/S-1	8/28/1992	94	90%	20	287
TPH-Motor Oil	mg/kg	86	11	13%	458	3,900	B-30	4/2/1992	75	87%	5	107
Benzene, Toluene, Ethylbenzene, Xylene												
Benzene	µg/kg	501	23	5%	1	12,000	B-30	4/7/1992	478	95%	1	24,000
Ethylbenzene	µg/kg	500	92	18%	2	470,000	SB-10	1/24/1991	408	82%	1	24,000
Toluene	µg/kg	501	111	22%	11	1,800,000	PT-3	10/3/1990	390	78%	1	24,000
Xylene (total)	µg/kg	475	106	22%	1	1,200,000	SB-10	1/24/1991	369	78%	1	5,000
Xylene (ortho)	µg/kg	115	6	5%	67	150	WH-5	8/9/2000	109	95%	50	5,000
Alkylated Benzenes												
1,2,4-Trimethylbenzene	µg/kg	349	38	11%	2	110,000	GP-72	6/15/2009	311	89%	2	200
1,3,5-Trimethylbenzene	µg/kg	349	51	15%	1	150,000	GP-72	6/15/2009	298	85%	2	200
4-Isopropyltoluene	µg/kg	328	34	10%	20	14,000	GP-77	6/18/2009	294	90%	2	200
iso-Propylbenzene	µg/kg	349	32	9%	1	6,000	GP-72	6/15/2009	317	91%	8	800
n-Butylbenzene	µg/kg	349	22	6%	38	17,000	GP-77	6/18/2009	327	94%	2	200
n-Propylbenzene	µg/kg	349	45	13%	2	27,000	GP-72	6/15/2009	304	87%	2	200
sec-Butylbenzene	µg/kg	349	26	7%	20	11,000	GP-77	6/18/2009	323	93%	2	200
Semivolatile Organic Compounds												
High Molecular Weight Polycyclic Aromatic Hydrocarbons												
Fluoranthene	µg/kg	127	10	8%	60	2,400	B-22	3/27/1992	117	92%	30	3,800
Pyrene	µg/kg	127	9	7%	110	3,100	B-22	3/27/1992	118	93%	30	3,800
Chrysene	µg/kg	127	7	6%	110	1,000	B-22	3/27/1992	120	94%	30	3,800
Low Molecular Weight Polycyclic Aromatic Hydrocarbons												
Naphthalene	µg/kg	476	52	11%	3	43,000	GP-72	6/15/2009	424	89%	3	3,800
2-Methylnaphthalene	µg/kg	127	10	8%	80	2,800	B-38	8/27/1992	117	92%	30	3,800
Phenanthrene	µg/kg	127	9	7%	120	2,400	B-22	3/27/1992	118	93%	30	3,800
Phthalates												
bis(2-ethylhexyl)phthalat	µg/kg	127	34	27%	50	140,000	SB-10	1/24/1991	93	73%	40	1,100
Di-n-butyl phthalate	µg/kg	126	16	13%	40	200,000	SB-10	1/24/1991	110	87%	30	40,000

Table 4.1
Frequency of Detection and Maximum Concentration of Organic Compounds Detected in 5 Percent or More of Soil Samples
All Dates

Chemical	Units	Number of Results	Number of Detects	Percent Detects	Minimum Detected Value	Maximum Detected Value	Location of Maximum Detect	Date of Maximum Detect	Number of Non–Detects	Percent Non–Detects	Minimum Reporting Limit	Maximum Reporting Limit
Semivolatile Organic Compounds (continued)												
Chlorinated Phenols												
Pentachlorophenol	µg/kg	190	57	30%	2.2	71,000	B-38	8/27/1992	133	70%	2	19,000
2,4-Dichlorophenol	µg/kg	181	18	10%	28	2,100	B-21	4/8/1992	163	90%	30	19,000
Tetrachlorophenols (total	µg/kg	57	5	9%	20	38,000	B-38	8/27/1992	52	91%	6	700
Glycols & Alcohols												
Glycols												
Diethylene glycol	µg/kg	6	4	67%	10	11,000	25-S	8/31/1990	2	33%	5	5
Ethylene glycol	µg/kg	6	2	33%	10	12,000	21-C	8/31/1990	4	67%	5	10,000
Propylene glycol	µg/kg	6	1	17%	12	12	15/16N	9/19/1990	5	83%	5	10,000

Table 4.2
Frequency of Detection and Maximum Concentration of Metals Detected in 5 Percent or More of Soil Samples
All Dates

Chemical	Units	Number of Results	Number of Detects	Percent Detects	Minimum Detected Value	Maximum Detected Value	Location of Maximum Detect	Date of Maximum Detect	Number of Non–Detects	Percent Non–Detects	Minimum Reporting Limit	Maximum Reporting Limit	Puget Sound Background Concentration[1]	Typical Soil Ranges for Continental United States[2]
Aluminum	µg/kg	59	59	100%	1,400,000	16,000,000	B-30	4/2/1992						5,000,000 to > 100,000,000
Arsenic	µg/kg	79	77	97%	460	43,000	B-28	4/7/1992	2	2.53%	50	310	7,300	
Barium	µg/kg	59	59	100%	7,400	1,700,000	B-29	4/8/1992						10,000 to 5,000,000
Cadmium	µg/kg	79	76	96%	10	4,300	SB-10	1/24/1991	3	3.80%	10	10	800	
Chromium	µg/kg	79	79	100%	3,300	42,000	B-31	4/2/1992					48,200	
Copper	µg/kg	79	79	100%	2,500	210,000	B-29	4/8/1992					36,400	
Lead	µg/kg	80	67	84%	260	500,000	B-28	4/7/1992	13	16.25%	1,100	10,000	16,800	
Mercury	µg/kg	78	12	15%	100	8,800	B-16	8/16/1991	66	84.62%	70	250	70	
Nickel	µg/kg	79	79	100%	3,000	30,000	B-22	3/27/1992					38,200	
Zinc	µg/kg	79	79	100%	8,200	880,000	B-05	4/9/1992					85,100	

Notes:

1 Background values are from *Natural Background Soil Metals Concentrations in Washington State* (Ecology 1994).

2 Table 1-2 from *Handbook of Soil Science* by (Sumner 1999).

Table 4.3
Frequency of Detection and Maximum Concentration of Organic Chemicals Detected in 5 Percent or More of Groundwater Samples
All Dates

Chemical	Units	Number of Samples	Number of Detects	Percent Detects	Minimum Detected Value	Maximum Detected Value	Location of Maximum Detect	Date of Maximum Detect	Maximum Detected Value Since 2007	Location of Maximum Detect Since 2007	Date of Maximum Detect Since 2007
Volatile Organic Compounds											
Chlorinated Ethenes & Ethanes											
Tetrachloroethene	µg/L	1,194	850	71%	0.006	1,900,000	B-12	10/15/1990	64,000	B-46	1/28/2009
Trichloroethene	µg/L	1,194	867	73%	0.3	94,000	B-43	6/29/1993	44,000	GP-42	12/11/2008
1,1-Dichloroethene	µg/L	749	177	24%	0.49	810	B-43	6/29/1993	110	R1-IW2	7/23/2009
cis-1,2-Dichloroethene	µg/L	1,042	906	87%	0.21	75,000	B-47	7/9/1993	50,000	GP-42	12/11/2008
trans-1,2-Dichloroethene	µg/L	604	220	37%	0.55	680	B-58	10/14/1999	240	GP-38	12/8/2008
Vinyl chloride	µg/L	1,303	847	65%	0.01	25,000	B-33A	10/13/1999	15,600	PTM-2U	8/9/2007
1,1,1-Trichloroethane	µg/L	749	140	19%	1	18,000	B-31	9/15/1992	1,400	B-30	1/27/2009
1,1-Dichloroethane	µg/L	749	231	31%	0.58	2,500	B-08	9/28/1990	130	GP-38	12/8/2008
1,2-Dichloroethane	µg/L	749	76	11%	0.8	300	B-10/10A	10/15/1990	29	GP-102	10/26/2010
Other Volatile Organic Compounds											
1,2-Dichlorobenzene	µg/L	773	151	21%	0.5	1,000	B-42	11/3/1998	400	B-47	1/29/2009
1,3-Dichlorobenzene	µg/L	773	46	7%	0.5	91	B-29	5/6/1992	14	B-39	10/20/2010
1,4-Dichlorobenzene	µg/L	773	76	11%	0.5	290	B-42	11/3/1998	58	B-39	10/20/2010
Acetone	µg/L	283	46	18%	6	30,000	B-30	9/17/1992	Not Measured		
Chloroform	µg/L	749	59	8%	0.66	13,000	B-07	10/8/1990	24	B-60	2/16/2010
Methyl ethyl ketone	µg/L	283	18	8%	6	170,000	B-15	4/29/1992	Not Measured		
Methyl isobutyl ketone	µg/L	283	29	12%	5	12,000	B-30	9/17/1992	Not Measured		
Methylene Chloride	µg/L	754	65	9%	3	43,000	B-08	9/28/1990	Not Detected at 1.0 µg/L		
Total Petroleum Hydrocarbons, Benzene, Toluene, Ethylbenzene, Xylene, & Alkylated Benzene											
Total Petroleum											
TPH-Mineral Spirits Range	µg/L	234	74	32%	50	230,000	B-12	10/15/1990	6,400	B-30	1/29/2010
TPH-Diesel Range	µg/L	123	8	7%	360	5,000	B-30	9/17/1992	360	B-30	1/29/2010
TPH-Heavy Oil	µg/L	138	6	4%	130	1,100	B-30	1/29/2010	1,100	B-30	1/29/2010
Benzene, Toluene, Ethylbenzene, Xylene											
Benzene	µg/L	732	228	31%	0.75	1,500	B-30	9/17/1992	64	GP-26	12/1/2008
Toluene	µg/L	732	242	34%	0.37	53,000	B-49	10/25/1995	3,100	GP-38	12/8/2008
Ethylbenzene	µg/L	732	202	28%	0.8	4,500	B-07	10/8/1990	1,000	MW-10	1/26/2009
Xylene (total)	µg/L	723	202	28%	0.7	14,000	B-07	10/8/1990	920	GP-38	12/8/2008
Xylene (meta & para)	µg/L	174	41	23%	2.3	5,300	B-47	6/22/1998	Not Measured		
Xylene (ortho)	µg/L	174	41	23%	1	2,500	B-49	11/3/1998	Not Measured		
Alkylated Benzenes											
1,2,4-Trimethylbenzene	µg/L	160	31	19%	1.2	11,000	B-49	10/18/1999	Not Measured		
1,3,5-Trimethylbenzene	µg/L	160	17	11%	18	9,600	B-49	10/18/1999	Not Measured		
iso-Propylbenzene	µg/L	160	6	4%	5.3	100	B-47	6/22/1998	Not Measured		
n-Propylbenzene	µg/L	160	1	1%	9.8	2,200	B-49	10/18/1999	Not Measured		
sec-Butylbenzene	µg/L	160	5	3%	4.7	2,300	B-49	10/18/1999	Not Measured		
Styrene	µg/L	317	29	9%	15	1,800	B-49	11/3/1998	Not Measured		

Table 4.3
Frequency of Detection and Maximum Concentration of Organic Chemicals Detected in 5 Percent or More of Groundwater Samples
All Dates

Chemical	Units	Number of Samples	Number of Detects	Percent Detects	Minimum Detected Value	Maximum Detected Value	Location of Maximum Detect	Date of Maximum Detect	Maximum Detected Value Since 2007	Location of Maximum Detect Since 2007	Date of Maximum Detect Since 2007
Semivolatile Organic Compounds											
High Molecular Weight Polycyclic Aromatic Hydrocarbons											
Benzofluoranthenes (total)	µg/L	1	1	100%	2.0	2	B-12	12/19/1997	Not Measured		
Pyrene	µg/L	216	8	4%	0.55	23	B-12	6/29/1998	Not Measured		
Low Molecular Weight Polycyclic Aromatic Hydrocarbons											
2-Methylnaphthalene	µg/L	218	41	19%	0.5	130	B-10A	10/25/1995	Not Measured		
Acenaphthene	µg/L	216	22	10%	0.5	17	B-12	6/29/1998	Not Measured		
Fluorene	µg/L	216	14	6%	0.5	32	B-49	7/9/1993	Not Measured		
Naphthalene	µg/L	377	64	17%	0.5	6,700	B-44	6/22/1998	Not Measured		
Phenanthrene	µg/L	216	22	10%	0.4	46	B-12	6/29/1998	Not Measured		
Phthalates											
bis(2-ethylhexyl)phthalate	µg/L	217	63	29%	1.0	1,900	B-30	10/25/1995	Not Measured		
Butyl benzyl phthalate	µg/L	216	42	19%	0.5	400	B-27	9/3/1992	Not Measured		
Diethylphthalate	µg/L	216	29	13%	0.27	27	B-30	10/25/1995	Not Measured		
Di-n-butyl phthalate	µg/L	216	42	19%	0.3	880	B-30	9/17/1992	Not Measured		
Chlorinated Phenols											
2,4,5-Trichlorophenol	µg/L	371	17	5%	0.31	5	B-20	10/21/1998	Not Measured		
Pentachlorophenol	µg/L	471	270	57%	0.01	31,000	B-38	9/14/1992	11,500	B-38	8/9/2007
Tetrachlorophenols (total)	µg/L	91	14	15%	0.74	600	B-31	5/4/1992	Not Measured		
Other Semivolatile Organic Compounds											
2,4-Dimethylphenol	µg/L	216	48	22%	0.5	500	B-29	5/6/1992	Not Measured		
2-Methylphenol	µg/L	214	62	29%	0.5	750	B-29	5/6/1992	Not Measured		
3-Methylphenol	µg/L	8	3	38%	11	130	B-12	12/19/1997	Not Measured		
4-Methylphenol	µg/L	205	55	27%	0.5	650	B-39	10/25/1995	Not Measured		
Benzoic acid	µg/L	206	21	10%	1	1,700	B-39	8/13/1993	Not Measured		
Benzyl alcohol	µg/L	211	18	9%	0.5	260	B-12	9/17/1992	Not Measured		
Carbazole	µg/L	123	3	2%	0.5	23	B-49	7/9/1993	Not Measured		
Dibenzofuran	µg/L	216	11	5%	0.5	24	B-49	7/9/1993	Not Measured		
Phenol	µg/L	216	14	6%	0.5	140	B-27	7/9/1993	Not Measured		
Glycols & Alcohols											
Glycols											
Diethylene glycol	µg/L	67	6	9%	700	8,100	B-33A	9/21/1992	Not Measured		
Ethylene glycol	µg/L	66	11	17%	500	22,000	B-15	4/29/1992	Not Measured		
Alcohols											
Methanol	µg/L	68	15	22%	2,300	72,000	B-30	9/17/1992	Not Measured		
Ethanol	µg/L	68	7	10%	2,100	30,000	B-11	9/15/1992	Not Measured		
iso-Propanol	µg/L	68	10	15%	2,900	23,000	B-30	9/17/1992	Not Measured		
1-Propanol	µg/L	68	5	7%	2,000	6,700	B-11	9/15/1992	Not Measured		

Table 4.4
Frequency of Detection and Maximum Concentration of Metals Detected in 5 Percent or More of Groundwater Samples
All Dates

Chemical[1]	Units	Number of Results	Number of Detects	Percent Detects	Minimum Detected Value	Maximum Detected Value	Location of Maximum Detect	Date of Maximum Detect	Maximum Detected Value Since 2007	Location of Maximum Detect Since 2007	Date of Maximum Detect Since 2007
Aluminum	µg/L	17	6	35%	40	190	B-15	9/14/1992	Not Measured		
Antimony	µg/L	8	1	13%	3.0	3.0	B-34	1/26/2009	3.0	B-34	1/26/2009
Arsenic	µg/L	45	11	24%	2.0	8.8	B-15	9/14/1992	5.0	B-59	1/27/2009
Barium	µg/L	17	7	41%	10	80	B-29	5/6/1992	Not Measured		
Beryllium	µg/L	8	3	38%	2.7	7.0	B-33A	1/26/2009	7.0	B-33A	1/26/2009
Cadmium	µg/L	25	5	20%	0.20	0.50	B-19	5/5/1992	Not Detected at 0.4 µg/L		
Chromium	µg/L	25	9	36%	4.00	41	B-34	1/26/2009	41	B-34	1/26/2009
Copper	µg/L	31	14	45%	1.72	55	B-34	1/26/2009	55	B-34	1/26/2009
Molybdenum	µg/L	8	1	13%	98	98	B-34	1/26/2009	98	B-34	1/26/2009
Nickel	µg/L	25	2	8%	21	90	B-15	9/14/1992	21	B-34	1/26/2009
Selenium	µg/L	8	1	13%	4.0	4.0	B-33A	1/26/2009	4	B-33A	1/26/2009
Silver	µg/L	8	2	25%	0.40	0.40	B-60, B-65	1/26-27/2009	0.4	B-60, B-65	1/26-27/2009
Zinc	µg/L	25	13	52%	10	110	B-15	9/14/1992	23	B-65	1/26/2009

Note:

1 Three metals have not been discussed in this table (potassium, manganese, and iron) because their groundwater concentrations are being manipulated as part of interim measures and do not represent COC concentrations. Refer to Section 5.5.1 for details.

Table 4.5
2000 Ambient Air Data
Detected Chemicals Only

Chemical	CAS Number	Units	Number of Results	Number of Detects	Percent Detects	Minimum Detected Value	Maximum Detected Value	Location of Maximum Detect	Date of Maximum Detect	Number of Non–Detects	Percent Non–Detects	Minimum Reporting Limit	Maximum Reporting Limit
Volatile Organic Compounds													
Chlorinated Ethenes & Ethanes													
Tetrachloroethene	127-18-4	μg/m^3	11	11	100%	0.76	140	Wrhs-	7/12/2000				
Trichloroethene	79-01-6	μg/m^3	11	6	50%	11	33	Wrhs-	7/12/2000	5	42%	1	1
cis-1,2-Dichloroethene	156-59-2	μg/m^3	11	6	50%	2.9	14	Multiple[2]	7/12/2000	5	42%	1	1
1,1,1-Trichloroethane	71-55-6	μg/m^3	11	6	50%	0.94	2.3	Wrhs-	7/12/2000	5	42%	1	1
Freons													
Trichlorotrifluoroethane	76-13-1	μg/m^3	11	9	83%	0.69	0.82	Wrhs-Office	6/9/2000	2	17%	1	1
Trichlorofluoromethane	75-69-4	μg/m^3	11	11	100%	2.3	130	B-63 Upwind[3]	6/9/2000				
Other Volatile Organic Compounds													
1,4-Dichlorobenzene	106-46-7	μg/m^3	11	1	8%	1.4	1.4	Wrhs-	6/9/2000	10	83%	1	1
Acetone	67-64-1	μg/m^3	11	11	100%	7.4	47	Wrhs-	7/12/2000				
Carbon Disulfide	75-15-0	μg/m^3	11	4	33%	1.8	4.1	Wrhs-Office 6-	7/12/2000	7	58%	1	1
Carbon Tetrachloride	56-23-5	μg/m^3	11	4	33%	0.67	1.1	Multiple[2]	7/12/2000	7	58%	1	1
Chloroform	67-66-3	μg/m^3	11	6	50%	4.6	25	Multiple[2]	7/12/2000	5	42%	1	1
Methyl ethyl ketone	78-93-3	μg/m^3	11	11	100%	3.4	16	Wrhs-Office 6-	7/12/2000				
Methyl isobutyl ketone	108-10-1	μg/m^3	11	6	50%	0.93	3.4	Wrhs-Office 6-	7/12/2000	5	42%	1	1
Methylene chloride	75-09-2	μg/m^3	11	11	100%	2.6	58	Wrhs-	7/12/2000				
Total Petroleum Hydrocarbons, Benzene, Toluene, Ethylbenzene, Xylene, & Alkylated Benzenes													
Benzene, Toluene, Ethylbenzene, Xylene													
Benzene	71-43-2	μg/m^3	11	11	100%	2	14	Multiple[2]	7/12/2000				
Toluene	108-88-3	μg/m^3	11	11	100%	20	98	Wrhs-	7/12/2000				
Ethylbenzene	100-41-4	μg/m^3	11	11	100%	4.8	20	Multiple[2]	7/12/2000				
Xylene (ortho)	95-47-6	μg/m^3	11	11	100%	6.3	24	Multiple[2]	7/12/2000				
Xylenes (meta and para)	1330-20-7	μg/m^3	11	11	100%	20	87	Wrhs-	7/12/2000				
Alkylated Benzenes													
Styrene	100-42-5	μg/m^3	11	10	92%	0.87	4.6	At well B-58	6/9/2000	1	8%	1	1

Notes:

1 Inside warehouse in change room, at a height of 5 feet above the floor.
2 Wrhs-ChangeRm 5ft and Wrhs-ChangeRm 6-12in.
3 Upwind of facility on Fox Avenue near railroad tracks. Location is 158 inches to tracks on Fox Ave, perpendicular to tracks, 176 inches from Well B-63.
4 Inside warehouse in office, at a height of 6 to12 inches above the floor.

Table 4.6
Chemicals Detected in Indoor Air--Cascade Columbia 2009 and Seattle Boiler Works 2010

Chemical	Units	Number of Results	Number of Detects	Percent Detect	Minimum Detected Value	Maximum Detected Value	Location of Maximum Detect	Date of Maximum Detect	Number of Non–Detects	Percent Non–Detects	Minimum Reporting Limit	Maximum Reporting Limit
Volatile Organic Compounds												
Chlorinated Ethenes & Ethanes[1]												
Tetrachloroethene	µg/m^3	7	7	100%	3.2	75	IA-1 (CC)	3/26/2009				
Trichloroethene	µg/m^3	7	7	100%	0.2	1.1	IA-1 (CC)	3/26/2009				
cis-1,2-dichloroethene	µg/m^3	3	3	100%	0.22	0.42	SBW-IA-SSVB (SBW)	12/12/2010				
Vinyl Chloride	µg/m^3	3	3	100%	0.13	0.22	SBW-IA-SSVB (SBW)	12/12/2010				
Other Volatile Organic Compounds												
Methylene Chloride	µg/m^3	4	3	75%	1.6	2.4	IA-3 (CC)	3/26/2009	1	25%	1.1	1.2
Total Petroleum Hydrocarbons, Benzene, Toluene, Ethylbenzene, Xylene, & Alkylated Benzenes												
Benzene	µg/m^3	4	4	100%	1.7	2.7	IA-3 (CC)	3/26/2009				

Notes:

1 CC = Cascade Columbia facility; SBW = Seattle Boiler Works facility.

2 The indoor air samples collected at Seattle Boiler Works were also analyzed for trans-1,2-dichloroethene, but it was not detected.

Table 4.7
Comparison of Maximum Soil Concentrations in Upper 15 Feet of Soil to MTCA Cleanup Levels for Direct Contact with Soil
All Dates

			Maximum Detected Value			MTCA Method B (Unrestricted) Direct Contact			MTCA Method C (Industrial) Direct Contact		
Chemical	**CAS Number**	**Units**	**Value**	**Location**	**Date**	**Cancer**	**Non-cancer**	**Exceeds?**	**Cancer**	**Non-cancer**	**Exceeds?**
Volatile Organic Compounds											
Chlorinated Ethenes & Ethanes											
Tetrachloroethene	127-18-4	µg/kg	18,000	SB-10	1/24/1991	1.9	800	**YES**	240	35,000	**YES**
Trichloroethene	79-01-6	µg/kg	1,100	SB-10	1/24/1991	11	24	**YES**	1,500	1,100	No
cis-1,2-Dichloroethene	156-59-2	µg/kg	32	GP-85	6/17/2009	-	800	No	-	35,000	No
1,2-Dichloroethene (total)	540-59-0	µg/kg	57	B-30	4/7/1992	-	720	No	-	32,000	No
Vinyl chloride	75-01-4	µg/kg	3.3	WH-1	8/9/2000	0.67	240	**YES**	88	11,000	No
Other Volatile Organic Compounds											
Acetone	67-64-1	µg/kg	47	B-30	4/2/1992	-	8,000	No	-	350,000	No
Methylene chloride	75-09-2	µg/kg	780	SB3	10/12/1990	133	4,800	**YES**	18,000	210,000	No
Total Petroleum Hydrocarbons, Benzene, Toluene, Ethylbenzene, Xylene, & Alkylated Benzenes											
Total Petroleum Hydrocarbons											
TPH-Mineral Spirits Range		mg/kg	6,500	B-2/S-3	5/11/1990	-	2,000	**YES**	-	41,500 [1]	No
TPH-Diesel Range[2]		mg/kg	770	B-32/S-1	8/28/1992	-	2,000	No	-	2,000	No
TPH-Motor Oil Range		mg/kg	3,900	B-30	4/2/1992	-	2,000	**YES**	-	2,000	**YES**
Benzene, Toluene, Ethylbenzene, Xylene											
Benzene	71-43-2	µg/kg	12,000	B-30	4/7/1992	18	320	**YES**	2,400	14,000	**YES**
Toluene	108-88-3	µg/kg	1,800	PT-3	10/3/1990	-	6,400	No	-	280,000	No
Ethylbenzene	100-41-4	µg/kg	470	SB-10	1/24/1991	-	8,000	No	-	350,000	No
Xylene (total)	1330-20-7	µg/kg	1,200	SB-10	1/24/1991	-	16,000	No	-	700,000	No
Xylene (ortho)	95-47-6	µg/kg	0.15	WH-5	8/9/2000	-	160,000	No	-	7,000,000	No
Alkylated Benzenes											
1,2,4-Trimethylbenzene	95-63-6	µg/kg	110	GP-72	6/15/2009	-	4,000	No	-	180,000	No
1,3,5-Trimethylbenzene	108-67-8	µg/kg	150	GP-72	6/15/2009	-	4,000	No	-	180,000	No
4-isopropyltoluene	99-87-6	µg/kg	14	GP-77	6/18/2009	-	-		Included in TPH		
iso-Propylbenzene	98-82-8	µg/kg	6	GP-72	6/15/2009	-	8,000	No	-	350,000	No
n-Butylbenzene	104-51-8	µg/kg	17	GP-77	6/18/2009	-	-		Included in TPH		
n-Propylbenzene	103-65-1	µg/kg	27	GP-72	6/15/2009	-	-		Included in TPH		
sec-Butylbenzene	135-98-8	µg/kg	11	GP-77	6/18/2009	-	-		Included in TPH		
Semivolatile Organic Compounds											
High Molecular Weight Polycyclic Aromatic Hydrocarbons											
Chrysene[3]	218-01-9	µg/kg	1,000	B-22	3/27/1992	14,000	-	No	1,800,000	-	No
Fluoranthene	206-44-0	µg/kg	2,400	B-22	3/27/1992	-	3,200,000	No	-	140,000,000	No
Pyrene	129-00-0	µg/kg	3,100	B-22	3/27/1992	-	2,400,000	No	-	105,000,000	No
Low Molecular Weight Polycyclic Aromatic Hydrocarbons											
2-Methylnaphthalene	91-57-6	µg/kg	2,800	B-38	8/27/1992	-	320,000	No	-	14,000,000	No
Naphthalene	91-20-3	µg/kg	43,000	GP-72	6/15/2009	-	1,600,000	No	-	70,000,000	No
Phenanthrene	85-01-8	µg/kg	2,400	B-22	3/27/1992	-	-		-	-	

Table 4.7
Comparison of Maximum Soil Concentrations in Upper 15 Feet of Soil to MTCA Cleanup Levels for Direct Contact with Soil
All Dates

			Maximum Detected Value			MTCA Method B (Unrestricted) Direct Contact			MTCA Method C (Industrial) Direct Contact		
Chemical	**CAS Number**	**Units**	**Value**	**Location**	**Date**	**Cancer**	**Non-cancer**	**Exceeds?**	**Cancer**	**Non-cancer**	**Exceeds?**
Phthalates											
bis(2-ethylhexyl)phthalate	117-81-7	µg/kg	140,000	SB-10	1/24/1991	71	1,600,000	No	9,400,000	70,000,000	No
Di-n-butyl phthalate	84-74-2	µg/kg	200,000	SB-10	1/24/1991	-	8,000,000	No	-	350,000,000	No
Chlorinated Phenols											
2,4-Dichlorophenol	120-83-2	µg/kg	2,100	B-21	4/8/1992	-	240,000	No	-	11,000,000	No
Pentachlorophenol	87-86-5	µg/kg	71,000	B-38	8/27/1992	8,333	2,400,000	No	1,100,000	110,000,000	No
Tetrachlorophenols (total)	58-90-2	µg/kg	38,000	B-38	8/27/1992	-	2,400,000	No	-	110,000,000	No
Glycols and Alcohols											
Glycols											
Diethylene glycol	111-46-6	µg/kg	11,000	25-S	8/31/1990	-	160,000,000	No	-	7,000,000,000	No
Ethylene glycol	107-21-1	µg/kg	12,000	21-C	8/31/1990	-	160,000,000	No	-	7,000,000,000	No
Propylene glycol	57-55-6	µg/kg	12	15/16N	9/19/1990	-	1,600,000,000	No	-	70,000,000,000	No
Metals											
Metals, Dissolved											
Arsenic	7440-38-2	µg/kg	43,000	B-28	4/7/1992	7,300	24,000	**YES**	87,500	1,100,000	No
Cadmium	7440-43-9a	µg/kg	4,300	SB-10	1/24/1991	-	80,000	No	-	3,500,000	No
Copper	7440-50-8	µg/kg	210,000	B-29	4/8/1992	-	3,000,000	No	-	130,000,000	No
Lead[4]	7439-92-1	µg/kg	500,000	B-28	4/7/1992	-	250,000	**YES**	-	1,000,000	No
Mercury	7439-97-6	µg/kg	8,800	B-16	8/16/1991	-	24,000	No	-	1,050,000	No
Zinc	7440-66-6	µg/kg	880,000	B-05	4/9/1992	-	24,000,000	No	-	1,100,000,000	No

Notes:

– A dash in the MTCA criteria column indicates that a MTCA CUL listed for that compound has not been researched.
1 TPH MTCA CUL is a site-specific total petroleum hydrocarbon value (refer to Appendix O).
2 TPH-Diesel Range is the higher boiling tail of the mineral spirits and is not Diesel No. 2; therefore, it has been compared to the risk-based value in Note 1.
3 The chrysene CUL values were calculated using the TEF for benzo(a)pyrene.
4 Under MTCA, the Method A residential soil value is used for Method B and the Method A industrial soil value is used for Method C.

Abbreviations:

MTCA	Model Toxics Control Act
CUL	Cleanup level
TEF	Toxic equivalency factor

Table 4.8
Dioxin/Furan Soil Sample Results

Analyte	Supplemental Remedial Investigation/ Feasibility Study Sample[1]			Screening Criteria
	B-30 Surface Total (0–0.5 ft bgs)	B-30/S9 (14.5–16 ft bgs)	B-31/S8 (10.5–12 ft bgs)	MTCA Method C Standard[2]
Dioxins (pg/g)				
2,3,7,8-TCDD	0.007 U	0.0006 U	0.0003 U	
1,2,3,7,8-PeCDD	0.0113	0.0055	0.0003 U	
1,2,3,4,7,8-HxCDD	0.0389	0.0241	0.0014	
1,2,3,6,7,8-HxCDD	0.203	0.178	0.0096	
1,2,3,7,8,9-HxCDD	0.103	0.0744	0.0038	
1,2,3,4,6,7,8-HpCDD	8	7	0.269	
OCDD	84	52	3	NA
Furans (pg/g)				
2,3,7,8-TCDF	0.0125	0.0017	0.0003 U	
1,2,3,7,8-PeCDF	0.0071	0.0039	0.0004 U	
2,3,4,7,8-PeCDF	0.0073	0.004	0.0004 U	
1,2,3,4,7,8-HxCDF	0.0484	0.0384	0.0018	
1,2,3,6,7,8-HxCDF	0.0422	0.0317	0.001	
2,3,4,6,7,8-HxCDF	0.0735	0.061	0.0021	
1,2,3,7,8,9-HxCDF	0.0163 U	0.0216	0.0007 U	
1,2,3,4,6,7,8-HpCDF	1	0.981	0.0333	
1,2,3,4,7,8,9-HpCDF	0.0987	0.0786	0.004	
OCDF	5	3	0.177	NA
Human Health Dioxin/Furan TEQs (pg/g)				
Summed Dioxin/Furan TEQ[3]	0.2	0.15	0.0060	1,500
Summed Dioxin/Furan TEQ with One-Half of the Detection Limits[3]	0.2	0.15	0.0064	1,500

Notes:

1 Terra Vac and FSI 2000.
2 MTCA Method C Soil Carcinogen Standard for direct contact industrial land use (Chapter 173-340 WAC).
3 van den Berg et al. 2006.

Abbreviations:

bgs	Below ground surface
ft	Feet
MTCA	Model Toxics Control Act
NA	Not applicable
pg/g	Picogram/gram
TEQ	Toxic equivalency quotient

Qualifier:

U Value is not detected at given reporting limit

Table 4.9
Surface Water Concentrations Protective of Surface Water Uses

Chemical	Units	Protection of Aquatic Species		Human Health	Proposed Surface Water Cleanup Level	Maximum Measured at Shoreline Wells (Data from 2005–2009)[3]	Maximum Measured at Seeps (2009 Data)
		Lowest Promulgated Standard[1]	Lowest Risk-Based Level (Literature)[2]	Lowest Promulgated Standard[1]			
Tetrachloroethene	µg/L	none	331	3.3	3.3	**37**	**73**
Trichloroethene	µg/L	none	2,200	30	30	18	30
1,1,1-Trichoroethane	µg/L	none	1,300	none	1,300[4]	200 U	1 U
cis-1,2-Dichloroethene	µg/L	none	6,785	none	6,785[4]	4,080	1800
trans-1,2-Dichloroethene	µg/L	none	6,785	10,000	6,785[4]	1.2 J	7
1,1-Dichloroethene	µg/L	none	2,400	3.2	3.2	**6.6 J**	**4.9**
1,1-Dichloroethane	µg/L	none	7,800	none	7,800[4]	26	16
1,2-Dichloroethane	µg/L	none	6,927	3.7	3.7	200 U	1 U
Vinyl chloride	µg/L	none	12,800	2.4	2.4	**6,240**	**1,400**
Methylene chloride	µg/L	none	none	590	590	200 U	1 U
Benzene	µg/L	none	none	51	51	8.5	8.4
Toluene	µg/L	none	737	15,000	7374	200 U	1 U
Ethyl benzene	µg/L	none	none	2,100	2,100	200 U	1 U
Xylene	µg/L	none	1,168	none	1,168[4]	2.9	1 U
1,2-Dichlorobenzene	µg/L	none	none	1,300	1,300	200 U	1 U
1,4-Dichlorobenzene	µg/L	none	none	190	190	200 U	1 U
Total petroleum hydrocarbons as mineral spirits	µg/L	none	none	500–1,000	500	3000[5]	NM
Pentachlorophenol	µg/L	7.9[6]	none	3.0	3.0	5 U	NM

Notes:

Bold Indicates exceedance.

1 Lowest of WAC 173-201A, National Toxics Rule, and National Recommended Water Quality Criteria.

2 Appendix C of *Lower Duwamish Waterway Remedial Investigation Draft Final Data and Analysis Report: Porewater Sampling of Lower Duwamish Waterway* (Windward 2006).

3 Shoreline wells are MW-33A and MW-34.

4 Proposed cleanup level is based on the literature value.

5 2003 ERM data from wells along Fox Avenue (ERM 2004); total petroleum hydrocarbon sampling has not been performed at shoreline wells.

6 Marine Standard given.

Abbreviations:

NM Not measured

Qualifiers:

J Value given is an estimate.

U Value is not detected at given reporting limit.

Table 4.10
Groundwater Cleanup Levels for Organic Compounds[1]

			Protection of Aquatic Species						Protection of Human Health									
			Federal Standards				Washington		Federal Standards		Washington							
			National Recommended Water Quality[2] Criteria CWA §304		National Toxics Rule[2] 40 CFR 131		Surface Water Quality Standards[2] WAC 173-201A		National Recommended Water Quality Criteria CWA §304	National Toxics Rule 40 CFR 131	MTCA Method B Surface Water WAC 173-340-730	Screening Criterion (Lowest Standard)	Maximum Detected in Groundwater Since Measurements Began			Maximum Detected Since 2007 (Post ChemOx Interim Measures)			Maximum Post-IM Concentration Exceeds Criterion?[5]
Chemical	CAS	Units	Marine Chronic	Fresh Chronic	Marine Chronic	Fresh Chronic	Marine Chronic	Fresh Chronic	Marine (Organism Only)	Marine (Organism Only)	Fish Consumption		Value	Location	Date	Value	Location	Date	
Volatile Organic Compounds																			
Chlorinated Ethenes & Ethanes																			
Tetrachloroethene	127-18-4	µg/L	-	-	-	-	-	-	3.3	8.9	Use Standard	**3.3**	1,900,000	B-12	10/15/1990	64,000	B-46	1/28/2009	**YES**
Trichloroethene	79-01-6	µg/L	-	-	-	-	-	-	30	81	Use Standard	**30**	94,000	B-43	6/29/1993	44,000	GP-42	12/11/2008	**YES**
1,1-Dichloroethene	75-35-4	µg/L	-	-	-	-	-	-	7,100	3.2	Use Standard	**3.2**	810	B-43	6/29/1993	110	R1-IW2	7/23/2009	**YES**
cis-1,2-Dichloroethene	156-59-2	µg/L	-	-	-	-	-	-	-	-	-	**No Tox Data**	75,000	B-47	7/9/1993	50,000	GP-42	12/11/2008	**no**
trans-1,2-Dichloroethene	156-60-5	µg/L	-	-	-	-	-	-	10,000	No data	Use Standard	**10,000**	680	B-58	10/14/1999	240	GP-38	12/8/2008	**no**
Vinyl chloride	75-01-4	µg/L	-	-	-	-	-	-	2.4	530	Use Standard	**2.4**	25,000	B-33A	10/13/1999	15,600	PTM-2U	8/9/2007	**YES**
1,1,1-Trichloroethane	71-55-6	µg/L	-	-	-	-	-	-	-	-	930,000	**930,000**	18,000	B-31	9/15/1992	1,400	B-30	1/27/2009	**no**
1,1-Dichloroethane	75-34-3	µg/L	-	-	-	-	-	-	-	-		**No Tox Data**	2,500	B-08	9/28/1990	130	GP-38	12/8/2008	**no**
1,2-Dichloroethane	107-06-2	µg/L	-	-	-	-	-	-	37	99	Use Standard	**37**	300	B-10/10A	10/15/1990	29	GP-102	10/26/2010	**no**
Other Volatile Organic Compounds																			
1,2-Dichlorobenzene	95-50-1	µg/L	-	-	-	-	-	-	1,300	17,000	Use Standard	**1,300**	1,000	B-42	11/3/1998	400	B-47	1/29/2009	**no**
1,3-Dichlorobenzene	541-73-1	µg/L	-	-	-	-	-	-	960	2,600	Use Standard	**960**	91	B-29	5/6/1992	14	B-39	10/20/2010	**no**
1,4-Dichlorobenzene	106-46-7	µg/L	-	-	-	-	-	-	190	2,600	Use Standard	**190**	290	B-42	11/3/1998	58	B-39	10/20/2010	**no**
Acetone	67-64-1	µg/L	-	-	-	-	-	-	-	-	-	**No Tox Data**	30,000	B-30	9/17/1992	Not Measured			**no**
Chloroform	67-66-3	µg/L	-	-	-	-	-	-	470	470	Use Standard	**470**	13,000	B-07	10/8/1990	24	B-60	2/16/2010	**no**
Methyl ethyl ketone	78-93-3	µg/L	-	-	-	-	-	-	-	-	-	**No Tox Data**	170,000	B-15	4/29/1992	Not Measured			**no**
Methyl isobutyl ketone	108-10-1	µg/L	-	-	-	-	-	-	0	-	-	**No Tox Data**	12,000	B-30	9/17/1992	Not Measured			**no**
Methylene chloride	75-09-2	µg/L							590	1,600	Use Standard	**590**	43,000	B-08	9/28/1990	Non Detect			**no**
Total Petroleum Hydrocarbons, Benzene, Toluene, Ethylbenzene, Xylene & Alkylated Benzenes																			
Total Petroleum Hydrocarbons[2]																			
TPH-Mineral Spirits Range		µg/L	-	-	-	-	-	-	-	-	800	**800**	230,000	B-12	10/15/1990	6,400	B-30	1/29/2010	**YES**
TPH-Diesel Range		µg/L	-	-	-	-	-	-	-	-	500	**500**	5,000	B-30	9/17/1992	360	B-30	1/29/2010	**no**
TPH-Heavy Oil		µg/L	-	-	-	-	-	-	-	-	500	**500**	1,100	B-30	1/29/2010	1,100	B-30	1/29/2010	**YES, at 1 well**
Benzene, Toluene, Ethylbenzene, Xylene																			
Benzene	71-43-2	µg/L	-	-	-	-	-	-	51	71	Use Standard	**51**	53,000	B-49	10/25/1995	64	GP-26	12/1/2008	**YES**
Toluene	108-88-3	µg/L	-	-	-	-	-	-	15,000	200,000	Use Standard	**15,000**	1,500	B-30	9/17/1992	3,100	GP-38	12/8/2008	**no**
Ethylbenzene	100-41-4	µg/L	-	-	-	-	-	-	2,100	29,000	Use Standard	**2,100**	4,500	B-07	10/8/1990	1,000	MW-10	1/26/2009	**no**
Xylene (total)	1330-20-7	µg/L	-	-	-	-	-	-	-	-	-	**No Tox Data**	14,000	B-07	10/8/1990	920	GP-38	12/8/2008	**no**
Xylene (meta & para)		µg/L	-	-	-	-	-	-	-	-	-	**No Tox Data**	5,300	B-47	6/22/1998	Not Measured			**no**
Xylene (ortho)	95-47-6	µg/L	-	-	-	-	-	-	-	-	-	**No Tox Data**	2,500	B-49	11/3/1998	Not Measured			**no**
Alkylated Benzenes																			
1,2,4-Trimethylbenzene	95-63-6	µg/L	-	-	-	-	-	-	-	-	-	**No Tox Data**	11,000	B-49	10/18/1999	Not Measured			**no**
1,3,5-Trimethylbenzene	108-67-8	µg/L	-	-	-	-	-	-	-	-	-	**No Tox Data**	9,600	B-49	10/18/1999	Not Measured			**no**
Styrene	100-42-5	µg/L	-	-	-	-	-	-	-	-	-	**No Tox Data**	1,800	B-49	11/3/1998	Not Measured			**no**
n-Propylbenzene	103-65-1	µg/L	-	-	-	-	-	-	-	-	-	**No Tox Data**	2,200	B-49	10/18/1999	Not Measured			**no**
iso-Propylbenzene	98-82-8	µg/L	-	-	-	-	-	-	-	-	-	**No Tox Data**	100	Multiple[3]	Multiple[3]	Not Measured			**no**
sec-Butylbenzene	135-98-8	µg/L	-	-	-	-	-	-	-	-	-	**No Tox Data**	2,300	B-49	10/18/1999	Not Measured			**no**
Semivolatile Organic Compounds																			
High Molecular Weight Polycyclic Aromatic Hydrocarbons																			
Benzofluoranthenes (total)	56832-73-6	µg/L										**No Tox Data**	2	B-12	12/19/1997	Not Measured			**no**
Pyrene	129-00-0	µg/L	-	-	-	-	-	-	4,000	11,000	Use Standard	**4,000**	23	B-12	6/29/1998	Not Measured			**no**
Low Molecular Weight Polycyclic Aromatic Hydrocarbons																			
2-Methylnaphthalene	91-57-6	µg/L	-	-	-	-	-	-	-	-	-	**No Tox Data**	130	B-10A	10/25/1995	Not Measured			**no**
Acenaphthene	83-32-9	µg/L	-	-	-	-	-	-	990	-	Use Standard	**990**	17	B-12	6/29/1998	Not Measured			**no**
Fluorene	86-73-7	µg/L	-	-	-	-	-	-	5,300	14,000	Use Standard	**5,300**	32	B-49	7/9/1993	Not Measured			**no**
Naphthalene	91-20-3	µg/L	-	-	-	-	-	-	-	-	4,900	**4,900**	6,700	B-44	6/22/1998	Non Detect			**no**
Phenanthrene	85-01-8	µg/L	-	-	-	-	-	-	-	-	-	**No Tox Data**	46	B-12	6/29/1998	Not Measured			**no**
Phthalates																			
bis(2-ethylhexyl)phthalate	117-81-7	µg/L	-	-	-	-	-	-	2.2	5.9	Use Standard	**2.2**	1,900	B-30	10/25/1995	Not Measured			**YES (old data)**
Butyl benzyl phthalate	85-68-7	µg/L	-	-	-	-	-	-	1,900	No data	Use Standard	**1,900**	400	B-27	9/3/1992	Not Measured			**no**
Diethylphthalate	84-66-2	µg/L	-	-	-	-	-	-	44,000	120,000	Use Standard	**44,000**	27	B-30	10/25/1995	Not Measured			**no**
Di-n-butyl phthalate	84-74-2	µg/L	-	-	-	-	-	-	4,500	12,000	Use Standard	**4,500**	880	B-30	9/17/1992	Not Measured			**no**
Chlorinated Phenols																			
Pentachlorophenol	87-86-5	µg/L	7.9	15.0	7.9	13.0	7.9	12.8	3.0	8.2	Use Standard	**3.0**	31,000	B-38	9/14/1992	116	B-49	8/6/2007	**YES**
2,4,5-Trichlorophenol	95-95-4	µg/L	-	-	-	-	-	-	3,600	-	Use Standard	**3,600**	5.1	B-20	10/21/1998	Not Measured			**no**
Tetrachlorophenols (total)	58-90-2	µg/L	-	-	-	-	-	-	-	-	-	**No Tox Data**	600	B-31	5/4/1992	Not Measured			**no**

Table 4.10

Groundwater Cleanup Levels for Organic Compounds[1]

			Protection of Aquatic Species						Protection of Human Health			Screening Criterion (Lowest Standard)	Maximum Detected in Groundwater Since Measurements Began			Maximum Detected Since 2007 (Post ChemOx Interim Measures)			Maximum Post-IM Concentration Exceeds Criterion?[5]
			Federal Standards				Washington		Federal Standards		Washington								
			National Recommended Water Quality[2] Criteria CWA §304		National Toxics Rule[2] 40 CFR 131		Surface Water Quality Standards[2] WAC 173-201A		National Recommended Water Quality Criteria CWA §304	National Toxics Rule 40 CFR 131	MTCA Method B Surface Water WAC 173-340-730								
Chemical	CAS	Units	Marine Chronic	Fresh Chronic	Marine Chronic	Fresh Chronic	Marine Chronic	Fresh Chronic	Marine (Organism Only)	Marine (Organism Only)	Fish Consumption		Value	Location	Date	Value	Location	Date	
Other Semivolatile Organic Compounds																			
2,4-Dimethylphenol	105-67-9	µg/L	-	-	-	-	-	-	850	No Data	Use Standard	**850**	500	B-29	5/6/1992	Not Measured			**no**
2-Methylphenol	95-48-7	µg/L	-	-	-	-	-	-	-	-	-	**No Tox Data**	750	B-29	5/6/1992	Not Measured			**no**
3-Methylphenol	108-37-4	µg/L	-	-	-	-	-	-	-	-	-	**No Tox Data**	130	B-12	12/19/1997	Not Measured			**no**
4-Methylphenol	106-44-5	µg/L	-	-	-	-	-	-	-	-	-	**No Tox Data**	650	B-39	10/25/1995	Not Measured			**no**
Benzoic acid	65-85-0	µg/L	-	-	-	-	-	-	-	-	-	**No Tox Data**	1,700	B-39	8/13/1993	Not Measured			**no**
Benzyl alcohol	100-51-6	µg/L	-	-	-	-	-	-	-	-	-	**No Tox Data**	260	B-12	9/17/1992	Not Measured			**no**
Carbazole	86-74-8	µg/L	-	-	-	-	-	-	-	-	-	**No Tox Data**	23	B-49	7/9/1993	Not Measured			**no**
Dibenzofuran	132-64-9	µg/L	-	-	-	-	-	-	-	-	-	**No Tox Data**	24	B-49	7/9/1993	Not Measured			**no**
Phenol	108-95-2	µg/L	-	-	-	-	-	-	1,700,000	4,600,000	Use Standard	**1,700,000**	140	B-27	7/9/1993	Not Measured			**no**
Glycols & Alcohols																			
Glycols																			
Ethylene glycol	107-21-1	µg/L	-	-	-	-	-	-	-	-	-	**No Tox Data**	22,000	B-15	4/29/1992	Not Measured			**no**
Diethylene glycol	111-46-6	µg/L	-	-	-	-	-	-	-	-	-	**No Tox Data**	8,100	B-33A	9/21/1992	Not Measured			**no**
Alcohol																			
Methanol	67-56-1	µg/L	-	-	-	-	-	-	-	-	-	**No Tox Data**	72,000	B-30	9/17/1992	Not Measured			**no**
Ethanol	64-17-5	µg/L	-	-	-	-	-	-	-	-	-	**No Tox Data**	30,000	B-11	9/15/1992	Not Measured			**no**
iso-Propanol	67-63-0	µg/L	-	-	-	-	-	-	-	-	-	**No Tox Data**	23,000	B-30	9/17/1992	Not Measured			**no**
1-Propanol	71-23-8	µg/L	-	-	-	-	-	-	-	-	-	**No Tox Data**	6,700	B-11	9/15/1992	Not Measured			**no**

Notes:

1 The 2007-2010 maximum concentration is compared to the lowest screening criteria or background.
2 Criteria Chronic Concentration used unless otherwise noted.
3 No surface water criteria are available for the TPH fractions; therefore MTCA Method A values for groundwater have been used as surrogates.
4 Well B-47 (6/22/1998), Wells B-18, WH-10, WH-11, WH-12, and WH-8 (8/11/10).

Abbreviations:

CFR	Code of Federal Regulations
CWA	Clean Water Act
IM	Interim measure
MTCA	Model Toxics Cleanup Act
WAC	Washington Administrative Code

Table 4.11
Groundwater Cleanup Levels for Metals

				Protection of Aquatic Species						Protection of Human Health									
				Federal Standards				Washington Standards		Federal Standards		Washington							
				National Recommended Water Quality[1] Criteria CWA §304		National Toxics Rule[1] 40 CFR 131		Surface Water Quality Standards[1] WAC 173-201A		National Recommended Water Quality[1] Criteria CWA §304	National Toxics Rule[1] 40 CFR 131	MTCA Method B Surface Water[1] WAC 173-340-730	Screening Criterion (Lowest Standard Corrected for Background)	Maximum Detected in Groundwater Since Measurements Began			Maximum Detected Since 2007 (Post ChemOx Interim Measures)			Maximum Post-IM Concentration Exceeds Criterion?[4]
Chemical	**CAS Number**	**Units**	**Lower Duwamish Corridor Grounwater Metals Background**	**Marine Chronic**	**Fresh Chronic**	**Marine Chronic**	**Fresh Chronic**	**Marine Chronic**	**Fresh Chronic**	**Fish Consumption**	**Fish Consumption**	**Fish Consumption**		**Value**	**Location**	**Date**	**Value**	**Location**	**Date**	
Antimony	7440-36-0	µg/L		-	-	-	-	-	-	640	4,300	Use Standard	**640**	3.0	B-34	1/26/2009	3.0	B-34	1/26/2009	No
Arsenic	7440-38-2	µg/L	8.0	36	150	36	190	36	190	0.14	0.14	Use Standard	**8**	8.8	B-15	9/14/1992	5.0	B-59	1/27/2009	No
Barium	7440-39-3	µg/L		-	-	-	-	-	-	-	-	No tox data	**No data**	80	B-29	5/6/1992	Not Measured			-
Beryllium	7440-41-7	µg/L		-	-	-	-	-	-	-	-	270	**270**	7.0	B-33A	1/26/2009	7.0	B-33A	1/26/2009	No
Cadmium	7440-43-9	µg/L		8.8	0.25	9.3	1	9.3	0.37	-	-	20	**0.25**	0.50	B-19	5/5/1992	Not Detected at 0.4 µg/L			No
Chromium	7440-47-3	µg/L		-	-	-	-	-	-	-	-	No tox data	**No data**	41	B-34	1/26/2009	41	B-34	1/26/2009	No
Copper	7440-50-8	µg/L	8.0	3.1	9	2.4	11	3.1	3.5	-	-	2,700	**8.0**	55	B-34	1/26/2009	55	B-34	1/26/2009	**YES**
Molybdenum	7439-98-7	µg/L		-	-	-	-	-	-	-	-	No tox data	**No data**	98	B-34	1/26/2009	98	B-34	1/26/2009	No
Nickel	7440-02-0	µg/L		8.2	52	8.2	160	8.2	49	4,600	4,600	Use Standard	**8.2**	90	B-15	9/14/1992	21	B-34	1/26/2009	**YES**
Selenium	7782-49-2	µg/L		71	5	71	5	71	5	4,200	-	Use Standard	**5.0**	4.0	B-33A	1/26/2009	4.0	B-33A	1/26/2009	No
Silver	7440-22-4	µg/L		-	-	-	-	-	-	-	-	26,000	**26,000**	0.40	B-65,B-60	1/26–27/2009	0.40	B-65,B-60	1/26–27/2009	No
Zinc	7440-66-6	µg/L		81	120	81	100	81	32	26,000	No data	Use Standard	**32**	110	B-15	9/14/1992	23	B-65	1/26/2009	No

Notes:

1 Criteria Chronic Concentration used unless otherwise noted.
2 Wells B-18, WH-10, WH-11, WH-12, and WH-8.
3 Well B-47 (6/22/1998), Wells B-18, WH-10, WH-11, WH-12, and WH-8 (8/11/10).
4 The 2007-2010 maximum concentration is compared to the lowest screening criteria or background.

Abbreviations:

CFR	Code of Federal Regulations
CWA	Clean Water Act
IM	Interim measure
MTCA	Model Toxics Cleanup Act
WAC	Washington Administrative Code

Table 5.1
Chemical-specific Properties for Chemicals of Concern

Chemical	CAS Number	Boiling Point (°C)	Melting Point (°C)	Specific Gravity	Form at 20°C	Vapor Pressure (atm)	Volatile	Solubility at 20°C (mg/L)	Henry's Law Constant (atm-m^3/mol)	Partitioning Coeffiecient Organic Carbon to Water (K_{oc}) (cm^3/g)	Mobility in Water
Volatile Organic Compounds											
Chlorinated Ethenes and Ethanes											
Tetrachloroethene	127-18-4	121 [1]	-19 [1]	1.623 [6]	liquid	0.02 [2]	moderate	200 [4]	1.84E-02 [4]	3.64E+02 [5]	moderate
Trichloroethene	79-01-6	87 [1]	-73 [1]	1.462 [6]	liquid	0.08 [2]	moderate	1,100 [4]	1.03E-02 [4]	1.26E+02 [5]	high
cis-1,2-Dichloroethene	156-59-2	60 [1]	-80 [1]	1.284 [6]	liquid	0.26 [3]	high	3,500 [4]	4.07E-03 [4]	49 [5]	high
trans-1,2-Dichloroethene	156-60-5	48 [1]	-50 [1]	1.257 [6]	liquid	0.43 [3]	high	6,300 [4]	9.39E-03 [4]	59 [5]	high
Vinyl chloride	75-01-4	-14 [1]	-153.2 [1]	NA	gas	3.3 [2]	very high	2,760 [4]	2.71E-02 [4]	1.86E+01 [4]	very high
1,1-Dichloroethene	75-35-4	32 [1]	-122.5 [1]	1.213 [6]	liquid	0.78 [3]	high	2,250 [4]	2.61E-02 [4]	5.89E+01 [4]	high
Total Petroleum Hydrocarbons, Benzene, Toluene, Ethylbenzene, Xylene, & Alkylated Benzenes											
Benzene, Toluene, Ethylbenzene, Xylene											
Benzene	71-43-2	80 [1]	5.5 [1]	0.8786 [6]	liquid	0.1 [2]	moderate	1,750 [4]	5.56E-03 [4]	5.89E+01 [4]	high
Semivolatile Organic Compounds											
Chlorinated Phenols											
Pentachlorophenol	87-86-5	309 [1]	174 [1]	1.979 [6]	solid	1.30E-07 [2]	no	14 [4]	2.44E-08 [4]	2.00E+03 [7]	low
Other Semivolatile Organic Compounds											
Bis(2-ethylhexyl)phthalate	117-81-7	384 [8]	-47 [8]	0.984 [8]	liquid	1.31E-10 at 25°C [8]	no	6.00E-04 [9]	1.71E-05 [8]	4.9 - 6.0 [8]	

Notes:

1 From CRC Handbook of Chemistry and Physics published by Cleveland Chemical and Ruber Company.

2 From NIOSH pocket guide to Chemical Hazards, distributed and published by Center for Diseases Control and Prevention, DHHS (NIOSH) Publication No. 97-140.

3 From USEPA Treatability Study Data Base Version 6.0.

4 From Johnson and Ettinger (1991) Model for Subsurface Vapor Intrusion into Buildings.

5 From A Review of Immiscible Fluids in the Subsurface, Journal of Contaminant Hydrology, Mercer and Cohen, 1990.

6 From htpp://www.chemfinder.com.

7 Estimate based on regression calculations in the Handbook of Chemical Property Estimation Methods, Lymann et al., 1990, published by the American Chemical Society, and solubilities.

8 From ASTDR CDC Toxicity Profiles website: http://www.atsdr.cdc.gov/toxprofiles/index.asp Toxicity profiles also available on CD.

9 From the JRC European Commission: Institute for Health and Consumer Protection Toxicology and Chemical Substance (TCS) European Chemicals Bureau's Summary Risk Assessment Report on Bis(2-ethylhexyl)phthalate.

Abbreviations:

NA	Not available
NIOSH	The National Institute for Occupational Safety and Health
USEPA	U.S. Environmental Protection Agency

Table 5.2
Dissolved Copper Groundwater Results (mg/L)

Proposed Copper Cleanup Level: 0.008 mg/L

Monitoring Well	Sampling Date	Dissolved Copper Concentration	Qualifer
B-01	5/6/1992	0.005	U
B-18	5/5/1992	0.0054	
B-19	5/5/1992	**0.0082**	
B-21	5/1/1992	0.005	U
B-22	5/1/1992	0.005	U
B-29	5/6/1992	0.005	U
B-01	9/9/1992	0.005	U
B-09	9/16/1992	0.005	U
B-09	9/16/1992	0.005	U
B-15	9/14/1992	0.005	U
B-19	9/10/1992	0.005	U
B-21	9/10/1992	0.005	U
B-22	9/11/1992	0.0072	
B-23	9/11/1992	0.005	U
B-33A	9/21/1992	0.005	U
B-33A	9/21/1992	0.005	U
B-37	9/14/1992	0.005	U
HC-1	12/12/1997	0.00269	
HC-1	2/2/1998	0.00204	
HC-1	3/3/1998	0.00238	
HC-2	12/12/1997	0.00182	
HC-2	2/2/1998	0.00205	
HC-2	3/3/1998	0.00172	
B-33A	1/26/2009	**0.017**	
B-34	1/26/2009	**0.055**	
B-58	1/27/2009	0.005	U
B-59	1/27/2009	**0.021**	
B-60	1/27/2009	0.005	U
B-61	1/27/2009	0.005	U
B-64	1/26/2009	**0.009**	
B-65	1/26/2009	**0.022**	

Abbreviations:

Bold results indicate an exceedance of the proposed copper cleanup level.

Table 8.1
Preliminary Screening of Technologies

Remedial Technology	Media	Benefits	Constraints	Site-specific Considerations	Technology Retained/Rejected for Further Evaluation
No Action	• Soil • Groundwater	• No cost to implement. • No long-term monitoring cost. • Does not cause significant impacts to site operations.	• Does not reduce or remove chemical concentrations. • Does not protect human health and the environment. • Does not meet cleanup goals in a reasonable restoration time frame.	• Does not meet RAOs or minimum threshold requirements of the Model Toxics Control Act.	• **No Action is Rejected** as it does not meet RAOs.
Monitored Natural Attenuation	• Groundwater	• Low cost associated with implementation. • Does not cause impacts to site operations.	• Long-term monitoring required in perpetuity. • Does not increase rate of contaminant mass removal occurring through reductive dechlorination. • Does not control chemical migration.	• Chemicals in groundwater have migrated off-site. • Existing impacts to surface water (Duwamish River) will not be addressed by MNA.	• **Monitored Natural Attenuation is Retained** for application in combination with other more aggressive technologies, and as a baseline for comparison of other technologies, but as a stand-alone remedy, does not address RAOs, or achieve cleanup goals.
Permeable Reactive Barrier Wall	• Groundwater	• Passively treats contaminated groundwater as it passes through the reactive barrier area. • Can be straightforward to implement, except at significant depths. • Is relatively inexpensive to implement at shallow depths and does not cause significant disruption to site operations.	• PRB technology does not address cleanup of contaminated soil. • PRB can become “clogged” depending on migration of fines in groundwater and can be costly to maintain. • Depending on the concentrations in groundwater, the PRB may require replacement once the reaction capacity of the material in the wall is reached or the wall pores become clogged. • PRB does not address contamination that has already migrated past the point of treatment.	• Site conditions would require construction of a deep and wide PRB wall to capture all site groundwater exiting the source area. • Groundwater may require further downgradient treatment (ERD) to meet remediation objectives, and address contamination that has migrated off-site.	• **Permeable Reactive Barrier Wall is Retained** for further evaluation for shallow 1st WBZ groundwater, assuming design criteria for treatment of contamination does not make construction of the wall infeasible.

Table 8.1
Preliminary Screening of Technologies

Remedial Technology	Media	Benefits	Constraints	Site-specific Considerations	Technology Retained/Rejected for Further Evaluation
Low Permeability Barrier Wall	• Groundwater	• Attains RAOs by containing soil and groundwater contaminants, and restricting continued migration of contaminated groundwater.	• Is relatively costly to implement. • May impact site operations, or require relocation of existing operations and/or utilities. • Requires hydraulic control (pumping) inside the barrier wall to maintain an inward gradient of groundwater in perpetuity.	• Groundwater contamination has already migrated downgradient, so any containment wall installed would not fully encapsulate all contamination at the Site. • Site use and the location of multiple utilities surrounding the Site would complicate installation, and may require utility relocation or replacement. • Additional treatment technologies would be required to address the downgradient groundwater plume. • Site geology does not allow for complete isolation of COCs; hanging wall structure would be constructed and issues with groundwater migration would need to be addressed. • Pumping to maintain hydraulic control and an inward groundwater gradient would generate large volumes of contaminated groundwater requiring treatment and disposal in perpetuity.	• **Barrier Wall technology is Retained** for further evaluation as the only feasible containment technology proposed, assuming construction of a hanging wall system is feasible, and hydraulic control is obtainable.
Surface Capping	• Soil	• Contains contaminated soil below the ground surface and provides protective barrier from surface water infiltration.	• Chemicals remain in place and are not removed/destroyed. • Surface Cap maintenance required in perpetuity.	• The Site is currently nearly 100 percent paved or covered by existing structures.	• **Surface Cap technology is Retained** for further evaluation.
Pump and Treat	• Groundwater	• Removes dissolved-phase chemicals from groundwater. • Technology will result in minimal impacts to site operations.	• Does not treat soil source contamination. • High groundwater pumping rates may be required resulting in high volumes of groundwater for treatment and disposal. • Significant cost associated with treatment and discharge of treated waste stream. • Long-term operation and maintenance required for extraction system in perpetuity.	• A high volume of mass present in soil will not be addressed by this technology alone. • The groundwater plume footprint is expansive at this Site, and treatment of the entire plume area would generate large volumes of water.	• **Pump and Treat is Rejected** from further evaluation because the technology is not effective at treating soil source, the volume of water extracted across the entire groundwater plume would be substantial, is expensive to treat and dispose, and this technology does not meet the RAOs.

Table 8.1
Preliminary Screening of Technologies

Remedial Technology	Media	Benefits	Constraints	Site-specific Considerations	Technology Retained/Rejected for Further Evaluation
Thermal Treatment	• Soil • Groundwater	• Capable of removal of majority of CEA contaminant mass within treatment area. • Can be implemented in 1–2 years. • Proven effective at sites with similar conditions. • Can be implemented at depth. • Treats both soil and groundwater contamination simultaneously. • No long-term maintenance required.	• High cost associated with implementation. • Does not treat pentachlorophenol or metals contamination, or heavy end mineral spirits. • Polishing with another remedial technology may be required following thermal treatment to further reduce chemical concentrations to achieve cleanup goals.	• Requires temporary relocation of some site activities (i.e., flammables storage and rail loading/unloading over heated area). • Installation complicated by active facility.	• **Thermal Treatment is Retained** for further evaluation. Technology has been proven effective at sites with similar conditions and COCs.
Excavation and Landfill Disposal	• Soil	• Results in immediate removal of chemicals from the Site, reducing mass in a short time frame. • Effectively removes all COCs associated with soil contamination. • Does not require long-term monitoring and maintenance.	• Expensive to implement due to high landfill disposal costs of hazardous materials. • Technology is limited by contaminant depth. • May require shoring for stability if open cuts cannot be made. • Can present short-term risk to workers via exposure to contaminated soil, groundwater, and DNAPLs. • Technology does not address remediation of groundwater beyond the excavation area.	• Large percentage of contaminant source area is located beneath active facility buildings and active rail spurs. • Technology requires destruction and relocation of all operational areas where it will be implemented. • Site structures will require removal/replacement for access to source area contamination. • Shoring and building support will be required for excavations near structures left in place.	• **Excavation and Landfill Disposal is Rejected** because the majority of shallow source soils are located beneath buildings and are inaccessible. Excavation of limited areas would still require implementation of other remedial actions for the remainder of the soil and groundwater plume, and excavation of these limited areas would not improve the environmental benefit of applying other technologies site wide. Excavation is also infeasible for removal of deep soil contamination.
Soil Vapor Extraction	• Soil	• Can be implemented with limited disturbance to existing facilities. • System can be easily turned on and off to optimize performance and cost.	• Limited to treatment of vadose zone soils. • Relatively expensive to install and maintain. • Does not address groundwater contamination.	• The majority of the Site contains contamination that is below groundwater and unaffected by this technology. • SVE may be applicable in areas where low to moderate amounts of vadose zone contamination is present, such as the NW Corner plume. • Site also contains soil and groundwater contamination that cannot be addressed by SVE.	• **Soil Vapor Extraction is Retained** for site areas with shallow, vadose zone soil contamination only that have not yet been subject to SVE and where SVE may be used in conjunction with other technologies for remediation of the Site.

Table 8.1
Preliminary Screening of Technologies

Remedial Technology	Media	Benefits	Constraints	Site-specific Considerations	Technology Retained/Rejected for Further Evaluation
Chemical Oxidation / Permanganate Injection	• Soil • Groundwater	• Technology reduces chemical concentrations and mass in place. • Low cost associated with implementation (i.e., no landfill disposal fees). • Technology does not cause significant impacts to site operations.	• Technology does not treat all soil—injected solutions can follow preferential pathways. • Effectiveness limited by subsurface conditions and site heterogeneity. • Requires multiple rounds of injection. • Contaminant rebound may be observed when source concentrations are elevated and insufficient source treatment has occurred.	• Chemical Oxidation as been implemented unsuccessfully at the Site in the past and did not reduce chemical concentrations to acceptable levels.	• **Chemical Oxidation is Rejected** from further evaluation because the technology has been applied at the Site in the past and did not result in measurable reduction of chemical concentrations/mass.
Soil Flushing	• Soil	• In-situ technology that can be implemented with minimal disturbance to existing operations.	• Requires injection of large volumes of water and surfactant to release soil contamination into groundwater. • Requires downgradient capture via pumping and treatment of impacted water. • High risk associated with capturing all downgradient groundwater/surfactant to insure chemicals are not mobilized, then transported downgradient. • Technology is expensive to implement due to requirement for pumping and treatment of water.	• Depth of contamination at this Site will require significant volumes of water to be pumped for flushing treatment. • Subsurface conditions are not supportive of a downgradient groundwater capture system due to depth and wide extent of contamination. • High risk associated with inability to capture downgradient groundwater due to the Site's location relative to a surface water body.	• **Soil Flushing is Rejected** for further evaluation because of the significant level of pumping and treatment that would be required (resulting in excessive waste streams and difficulty of flushing chemicals from siltier soil lenses), and the risk associated with capture of all downgradient groundwater.
Soil Mixing by Auger	• Soil	• Technology promotes in-situ destruction of contaminant mass by addition of zero-valent iron or oxidants directly to contaminated soil brought up by augers. • Can reach soil contamination at depth.	• Technology will require destruction and relocation of facility operations during implementation. • Technology results in generation of excess contaminated soil that must be disposed of in a landfill facility. • Disposal of contaminated material at a landfill facility can result in significant cost. • Wedges of contaminated material may be left in place between auger locations, depending on the degree of overlap of locations.	• Site operations will be difficult to relocate to accommodate full implementation of this remedy. • Depth of contamination will result in generation of significant volumes of contaminated soil requiring landfill disposal.	• **Deep Soil Mixing is Rejected** from further evaluation because of the impracticability of relocating site facilities and disposing of contaminated soil. Deep soil mixing would also likely not be effective in meeting site RAOs.

Table 8.1
Preliminary Screening of Technologies

Remedial Technology	Media	Benefits	Constraints	Site-specific Considerations	Technology Retained/Rejected for Further Evaluation
Dual-phase Extraction	• Soil • Groundwater	• Removes contamination from vadose zone soil and shallow groundwater. • Technology is moderate in cost to implement. • Technology is capable of treating source soils together with groundwater at shallow depth.	• Implementation results in extraction of contaminated groundwater that requires treatment prior to disposal. • Cost of treatment and disposal of extracted water can be significant. • Technology typically has high maintenance costs. • Technology cannot treat source at deeper intervals in primary source area.	• Technology will not be beneficial for treatment of the primary source area because contamination extends to depths greater than 20 feet below ground surface. Significant water volumes would be generated and require treatment if this technology was selected for implementation.	• **Dual Phase Extraction is Rejected** from further evaluation, because this technology is not applicable to DNAPL contamination , and would only be applicable in very limited areas of the Site for vadose soil treatment only.
Enhanced Reductive Dechlorination	• Soil • Groundwater	• Technology will result in minimal impacts to site operations. • Technology is comparatively inexpensive to implement. • ERD can serve as a long-term treatment technology when used in combination with other aggressive source control remedial technologies. • Technology is an effective treatment mechanism for groundwater contamination.	• The effectiveness of ERD for treatment of soils with DNAPL-level concentrations is unknown, but not expected to be effective in a reasonable restoration time frame. • Technology takes a long period of time to meet remediation levels or cleanup levels when used as a stand-alone technology. • Technology is still in the development stage.	• ERD is currently being implemented for treatment of downgradient groundwater at the Site, and data indicates accelerated destruction of dissolved plume contamination is occurring.	• **ERD is Retained** for further evaluation because current implementation suggests ERD is effectively reducing chemical concentrations at the Site in downgradient groundwater:
Air Sparging	• Groundwater	• Removes dissolved-phase chemicals from groundwater. • Strips dissolved-phase chemicals from groundwater and transmits to vadose soil. • Relatively low cost to implement technology.	• Technology has limited benefit in areas with elevated groundwater contamination concentrations. • Implementation does not result in destruction of contamination. • Significant reductions in contamination concentration may be difficult to achieve. • Air sparge points typically have a small radius of influence, requiring a large network of wells to implement.	• Technology is not efficient at treating to the depths of contamination at the Site. • Technology may be applicable in limited applications such as a point of discharge treatment option in shallow groundwater. • Technology adds oxygen to subsurface so does not work well with ERD.	• **Air Sparging is Retained** for further evaluation as a point of discharge treatment in a curtain or wall type scenario for 1st WBZ groundwater only.

Abbreviations:

COC	Chemical of concern
CVOC	Chlorinated volatile organic compound
DNAPL	Dense non-aqueous phase liquid
ERD	Enhanced reductive dechlorination
LNAPL	Light non-aqueous phase liquid
MNA	Monitored Natural Attenuation
PRB	Permeable reactive barrier
RAO	Remedial Action Objective
SVE	Soil vapor extraction
WBZ	Water Bearing Zone

Table 8.2
Summary of Retained Technologies by Cleanup Action Area

Remedial Technology	Main Source Area	Downgradient Groundwater Plume	Northwest Corner Plume
Monitored Natural Attenuation *(retained for baseline comparison)*	X	X	X
Permeable Reactive Barrier Wall		X	X
Low Permeability Barrier Wall	X		
Surface Capping	X		
Thermal Treatment	X		
Soil Vapor Extraction	X		X
Enhanced Reductive Dechlorination	X	X	X
Air Sparging		X	X

Table 10.1
Alternatives Evaluation—Main Source Area Cleanup Action Area

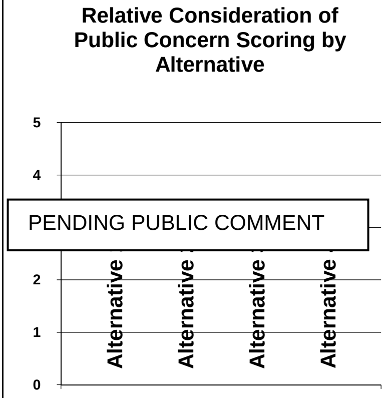
Alternative	Alternative 1: Monitored Natural Attenuation	Alternative 2: Shallow and Deep Soil and Groundwater Treatment by ERD, Vadose Zone Treatment by SVE	Alternative 3: Shallow and Deep Soil and Groundwater Treatment by Thermal Remediation and ERD Polish	Alternative 4: Source Area Containment by Low-Permeability Barrier Wall	Relative Alternative Scoring
Alternative Description	The MNA alternative is included for the purpose of baseline comparison to other alternatives within the Main Source Area CAA. This alternative will entirely rely on the success of downgradient treatment technologies if implemented, and provides no benefit or improvement in environmental condition.	This alternative includes (1) treatment of vadose zone soil contamination via SVE, and (2) treatment of soil and groundwater below the water table via ERD injection. The applicability of ERD to soil and groundwater with DNAPL has not been proven effective at sites with similar conditions; therefore, the level of confidence associated with this technology is low, which is reflected in the evaluation of this alternative.	This alternative includes treatment of impacted soil and groundwater within the vadose zone, 1st and 2nd WBZs by thermal remediation, followed by ERD injection for treatment of low-level residual contamination following completion of thermal treatment.	This alternative includes containment of the Main Source Area CAA through construction of a low-permeability barrier wall surrounding the Site. The wall will encapsulate soil and groundwater contamination within the Main Source Area, controlling the on-going source of contamination to the downgradient plume. This alternative will require hydraulic controls (pumping) to maintain an inward groundwater gradient.	
Consideration of Public Concerns - *Whether the community has concerns* - *Degree to which the alternative addresses those concerns*	Public concerns will be reviewed following the public comment period and addressed in the final remedial alternative selection and design.	Public concerns will be reviewed following the public comment period and addressed in the final remedial alternative selection and design.	Public concerns will be reviewed following the public comment period and addressed in the final remedial alternative selection and design.	Public concerns will be reviewed following the public comment period and addressed in the final remedial alternative selection and design.	

Table 10.1
Alternatives Evaluation—Main Source Area Cleanup Action Area

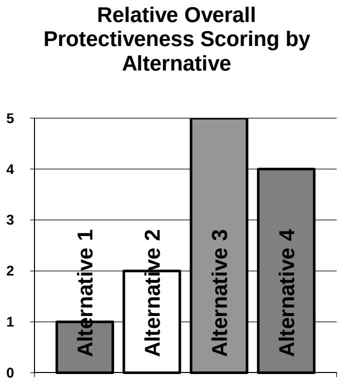
Alternative	Alternative 1: Monitored Natural Attenuation	Alternative 2: Shallow and Deep Soil and Groundwater Treatment by ERD, Vadose Zone Treatment by SVE	Alternative 3: Shallow and Deep Soil and Groundwater Treatment by Thermal Remediation and ERD Polish	Alternative 4: Source Area Containment by Low-Permeability Barrier Wall	Relative Alternative Scoring
Overall Protectiveness - *Degree to which existing risks are reduced* - *Time required to reduce risks and attain cleanup standards* - *On- and off-site risks resulting from alternative implementation* - *Improvement in overall environmental quality*	This alternative provides no reduction to existing risk. Time required to reduce risks and attain cleanup standards is not within a reasonable time frame, and may not be achievable. No on- or off-site risks result from implementation of MNA as no actions are required for implementation. On- and off-site risks remain the same as currently exist. MNA provides no improvement in overall environmental quality when implemented as a stand-alone technology because no actions are conducted as part of implementation. Remedial action objectives are not achieved.	This alternative provides a moderate degree of reduction of existing risk through destruction of contaminant mass in the vadose zone through SVE, and in the 1st WBZ and 2nd WBZ through ERD. The time required to reduce risk and achieve cleanup levels is less certain because the application of ERD in the presence of DNAPL is not well documented. It is anticipated that the increased rate of reductive dechlorination in groundwater will in turn reduce soil concentrations through equilibrium diffusion; however, given the mass of contaminant present in the source area soils, compliance with cleanup levels is expected to take 50+ years. SVE in the vadose zone is anticipated to comply with air intrusion and direct worker contact points of compliance within a few years; however, the groundwater will remain out of compliance for much longer. Vapor extracted from the subsurface during SVE will generate a treatment waste stream that must be managed either on-site or off-site. This alternative provides a moderate degree of improvement in overall environmental quality through mass reduction in the vadose zone, and slow dechlorination of source mass in the saturated zone. RAOs for the Main Source Area CAA are expected to be reached within a reasonable time frame; with the exception of soil protection of groundwater, which will require 50+ years to attain.	This alternative provides a high degree of reduction of existing risk through destruction of contaminant mass in the vadose zone, 1st WBZ, and 2nd WBZ through thermal remediation; and further reduction of contaminant mass through the use of ERD as a remedial polish. The source area mass will be significantly reduced, following implementation of the thermal remedy. Cleanup standards are expected to be met at the seeps within several years following source treatment, and remediation levels at the conditional point of compliance for groundwater are expected to be met within 10–15 years following completion of thermal treatment. Compliance with soil and indoor air points of compliance are anticipated to be met immediately following completion of thermal treatment. This alternative is expected to achieve RAOs in the shortest time frame. Implementation of this alternative will generate risk through potential loss of contaminant mass downgradient during the thermal process. Vapor extracted from the subsurface during the thermal treatment process will also generate a treatment waste stream that must be managed, either on-site or off-site. This alternative provides a high degree of improvement in overall environmental quality through mass reduction of a substantial volume of contaminants in the subsurface. RAOs are expected to be reached within a few years following implementation, and remediation levels at the conditional point of compliance are expected to be achieved within an accelerated time frame compared to other proposed alternatives.	This alternative provides a moderate to high degree of overall protection through immediate containment of the majority of source mass at the Site. Risk to ongoing migration of contaminants from the Main Source Area will be significantly reduced through construction of a barrier wall; however, risk to indoor air quality may not be immediately addressed by barrier wall construction, and may require abatement. Risk to worker contact with contaminated soil will be addressed through surface capping; however, because the Site is currently capped, this does not provide a greater degree of risk reduction than currently exists. The time required to reduce risk is immediate, as migration of source soil contamination to groundwater will be eliminated, direct worker contact will be addressed through capping, and indoor air quality will be addressed via mitigation measures. Contamination will remain contained on-site above cleanup levels in perpetuity. The on-site risks associated with this alterative are high, because no contaminant mass is removed from the Site with this alternative. The potential for leaks in the barrier wall, or inability to capture groundwater and maintain an inward gradient, are a potential concern. In addition, indoor air mitigation measures will require maintenance in perpetuity. This alternative provides a moderate to high improvement in overall environmental quality through immediate containment of the majority of contaminant mass at the Site.	 **Relative Overall Protectiveness Scoring by Alternative**

Table 10.1
Alternatives Evaluation—Main Source Area Cleanup Action Area

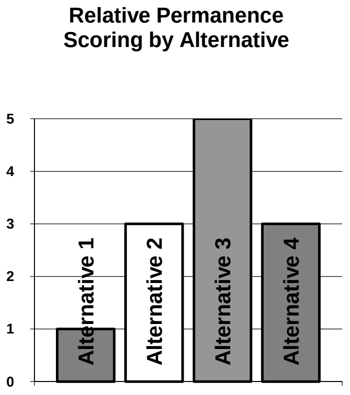
Alternative	Alternative 1: Monitored Natural Attenuation	Alternative 2: Shallow and Deep Soil and Groundwater Treatment by ERD, Vadose Zone Treatment by SVE	Alternative 3: Shallow and Deep Soil and Groundwater Treatment by Thermal Remediation and ERD Polish	Alternative 4: Source Area Containment by Low-Permeability Barrier Wall	Relative Alternative Scoring
Permanence - *Degree of reduction of contaminant toxicity, mobility, and volume* - *Adequacy of destruction of hazardous substances* - *Reduction or elimination of substance release, and source of release* - *Degree of irreversibility of waste treatment processes* - *Volume and characteristics of generated treatment residuals*	This alternative provides no reduction of contaminant toxicity, mobility, or volume. The destruction of hazardous substances is not adequate because it is conducted solely by natural processes that currently occur at the Site. This alternative does not reduce, eliminate, or control sources as all soil contamination is currently in place resulting in risk of worker exposure via direct contact and indoor air. Off-site contaminated groundwater migration remains in place in current concentrations and volumes. There are no treatment residuals generated by implementation of an MNA alternative.	This alternative provides a moderate degree of contaminant toxicity, mobility, and volume reduction. The majority of mass is located in the vadose zone and 1st WBZ, and additional mass will be removed from the vadose zone by SVE. The mobility and toxicity of the contaminant plume will not be impacted by this alternative with the exception of a slight reduction in toxicity as concentrations decrease over time due to the ERD treatment. Destruction of hazardous substances resulting from implementation of SVE and ERD is adequate, because contaminants are either removed through SVE or through dechlorination. This alternative will eventually reduce the source of releases to downgradient groundwater over time, but does not provide for a significant short term reduction of source releases, except for the mass removed from the vadose zone via SVE. The destruction of contaminants resulting from SVE and ERD is permanent and irreversible. Treatment residuals are limited to vapors collected during SVE treatment. Generated waste will require maintenance during implementation over the short term. Soil cuttings generated during well installation can be disposed of at a landfill and, depending on concentrations, may be considered hazardous waste.	This alternative provides a high degree of reduction of contaminant toxicity, mobility, and volume through immediate removal and destruction of source area contaminants with thermal technology. Destruction of hazardous substances resulting from implementation of thermal treatment is immediate, and source removal is more complete than the other proposed remedies. This alternative provides a high degree of source control through destruction of source soil contamination pathways for indoor air quality, direct contact, and leaching to downgradient groundwater. The destruction of contaminants resulting from thermal treatment and ERD is permanent, and irreversible. Treatment residuals are limited to condensate collected during thermal treatment. Soil cuttings can be disposed of at a landfill and, depending on concentrations, may be considered hazardous waste.	This alternative provides a high degree of reduction of contaminant toxicity, mobility, and volume through immediate control of contaminant mobility from the source area to the downgradient groundwater plume. Destruction of hazardous substances resulting from implementation of this remedy occurs slowly over time because of natural processes, and is not increased by implementation of a containment remedy. This alternative provides a high degree of source control through containment of the majority of source mass present at the Site, however The containment of contaminants does not provide permanent removal of contamination. Maintenance will be required to maintain control of the source contaminants, or migration of source contaminants to the downgradient plume may once again occur. Treatment residuals generated during construction of a barrier wall can be disposed of at a landfill and, depending on concentrations, may be considered hazardous waste. The overall permanence of this alternative is moderate, because it does effectively and immediately control contaminant mobility, but does not result in permanent destruction of contaminants.	

Table 10.1
Alternatives Evaluation—Main Source Area Cleanup Action Area

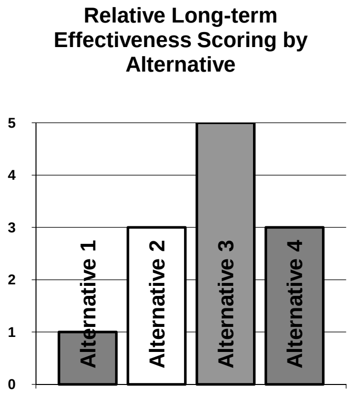
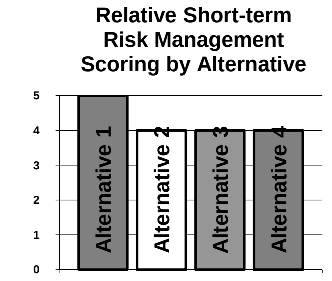
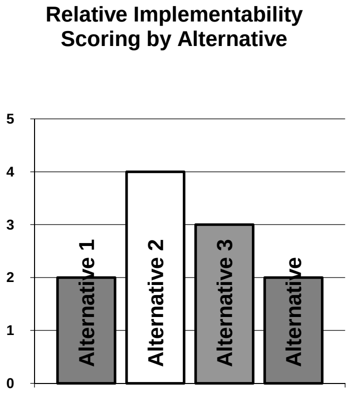
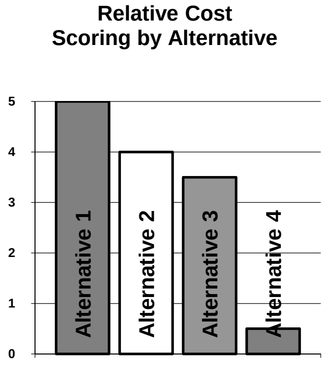
Alternative	Alternative 1: Monitored Natural Attenuation	Alternative 2: Shallow and Deep Soil and Groundwater Treatment by ERD, Vadose Zone Treatment by SVE	Alternative 3: Shallow and Deep Soil and Groundwater Treatment by Thermal Remediation and ERD Polish	Alternative 4: Source Area Containment by Low-Permeability Barrier Wall	Relative Alternative Scoring
Effectiveness over the Long-term • *Degree of certainty of alternative success* • *Reliability while contaminants remain on-site greater than cleanup levels* • *Magnitude of residual risk* • *Effectiveness of controls implemented to manage residual risk*	This alternative provides a low degree of alternative success. It is not expected to achieve cleanup goals. This alternative is not reliable because it does not manage contaminants on-site to any greater degree than existing conditions. The magnitude of residual risk with this alternative is high because there is little to no reduction in risk resulting from implementation of an MNA technology. The controls implemented to manage risk include surface capping, which adequately manages direct-contact risk; however, there are no controls to manage ongoing migration of soil to groundwater contamination.	This alternative provides a moderate degree of certainty of success because SVE and ERD have both been implemented at the Site and resulted in removal of contaminant mass. ERD technology has been successfully implemented for groundwater remediation at sites with similar conditions, but is still considered an emerging technology for cleanup in source areas because it depends on the rate of contaminant diffusion from soil back into groundwater where the microbial destruction process occurs at a much slower rate than offered by thermal treatment. SVE application at the Site resulted in removal of contaminant mass from the subsurface in the area where applied. SVE and ERD technologies are both reliable with measurable success. Monitoring will be conducted in the long term to confirm performance. The magnitude of residual risk associated with this alternative is moderate because of the time the contaminant mass will remain on-site. Contamination in groundwater will remain greater than remediation levels for a longer period of time and will continue to generate risk through migration to downgradient groundwater. Institutional controls may be required on properties or portions of properties with residual concentrations in groundwater greater than cleanup levels.	This alternative provides a high degree of certainty of success because thermal remediation has been successfully implemented at sites with similar conditions. The ERD technology has been successfully implemented at sites with similar conditions for treatment of groundwater contamination. The interim action currently underway in the downgradient plume cleanup area also indicates successful application of the ERD technology. Thermal and ERD technologies are both reliable with measurable success. Monitoring will be conducted for a shorter period of time in the long term to confirm conditions while contaminants remain on-site. The magnitude of residual risk associated with this alternative is low as contaminant mass will be substantially removed from both the shallow and deep zones. This alternative also has the shortest restoration time frame. Institutional controls may be required on properties or portions of properties with residual concentrations in groundwater greater than cleanup levels.	This alternative provides a moderate to high degree of certainty of success because containment remedies, when designed and installed properly, can immediately eliminate migration of contamination from the source area. However, due to the depth required for installation, and site conditions with existing infrastructure, successful implementation may be jeopardized by site conditions. Assuming a barrier wall is installed successfully, this alternative provides a high degree of reliability while contaminants remain on-site. The magnitude of residual risk associated with this alternative is high, as all contaminant mass remains on-site. Institutional controls may be required on properties or portions of properties with residual concentrations in soil and groundwater greater than cleanup levels.	
Short-term Risk Management • *Risk to human health and the environment associated with alternative construction* • *The effectiveness of controls in place to manage short-term risks*	There is no short-term risk associated with construction of this alternative because no construction activities will be conducted. Existing risk remains consistent with the current site risks. This alternative does not include controls for management of existing risk.	This alternative will generate a potential direct-contact risk to workers during implementation, extraction, and injection well installation, trenching, and system operation. Site activities will require appropriate PPE, BMPs, and appropriate training requirements for management of risk. These controls are highly effective and anticipated to adequately manage short-term risk.	This alternative will generate a potential direct-contact risk to workers during implementation, electrode and injection well installation, trenching, and system operation. Site activities will require appropriate PPE, BMPs, and appropriate training requirements for management of risk. These controls are highly effective, and anticipated to adequately manage short-term risk.	This alternative will generate a potential direct-contact risk to workers during implementation, barrier wall construction, utility and infrastructure relocation/ replacement. Site activities will require appropriate PPE, BMPs, and appropriate training requirements for management of risk. These controls are highly effective, and anticipated to adequately manage short-term risk.	

Table 10.1
Alternatives Evaluation—Main Source Area Cleanup Action Area

Alternative	**Alternative 1: Monitored Natural Attenuation**	**Alternative 2: Shallow and Deep Soil and Groundwater Treatment by ERD, Vadose Zone Treatment by SVE**	**Alternative 3: Shallow and Deep Soil and Groundwater Treatment by Thermal Remediation and ERD Polish**	**Alternative 4: Source Area Containment by Low-Permeability Barrier Wall**	**Relative Alternative Scoring**
Technical and Administrative Implementability Ability of alternative to be implemented considering: • *Technical possibility* • *Availability of off-site facilities, services, and materials* • *Administrative and regulatory requirements* • *Schedule, size, and complexity of construction* • *Monitoring requirements* • *Site access for construction, operations, and monitoring* • *Integration with existing site operations or other current and potential future remedial action*	This alternative is technically possible to implement and involves no construction. No facilities, services, or materials are needed for alternative implementation because no construction will be performed. This alternative is not administratively implementable because it does not meet any of the regulatory requirements for a cleanup action. Monitoring requirements are expected to be greater than for other alternatives because risks will not be reduced with this alternative. There are no concerns with site access because no construction is associated with this alternative. This alternative does not impact existing site operations.	This alternative is moderately complex to implement but technically possible given site conditions. All necessary off-site facilities, materials, and services are available within the region. This alternative meets all administrative and regulatory requirements. This alternative is anticipated to require 3 months for construction, followed by 3–5 years of SVE system operation, and an anticipated 25–50 years of ERD injection. The alternative will be managed and constructed by specialty professionals familiar with the type of work. Long-term monitoring will be required for an extended time frame. Site access for construction is moderately complex because of active site uses, but can be implemented with limited access drilling rigs, and will not shut down site operations. Access for operations and maintenance during ERD injections will require coordination with facilities operations, but should not be greatly impacted by facility operations. This alternative is somewhat easily integrated with existing site operations and will require trenching for SVE system utilities.	This alternative is complex but technically possible to implement, and appropriate given site conditions. All necessary off-site facilities, materials, and services are available within the region. This alternative meets all administrative and regulatory requirements. This alternative is anticipated to require 3–6 months for construction, followed by 1 year of thermal treatment, and an anticipated 5 years of ERD polish. The alternative is complex but will be managed and constructed by specialty professionals familiar with the type of work. Long-term monitoring will be required for an extended time frame. Site access for construction is complex because of active site uses. Temporary relocation of site activities may be required to safely store flammable liquids. Access for operations and maintenance will temporarily be restricted by facility operations during installation of the thermal system. This alternative is not easily integrated with existing site use and will require complex construction and coordination to allow for continued facility operation.	This alternative is complex but technically possible to implement, but will highly impact site operations given the location of contamination in relation to property boundaries and the location of off-site contamination. All necessary off-site facilities, materials, and services are available within the region. This alternative meets all administrative and regulatory requirements. This alternative is anticipated to require 6–12 months for construction. The alternative is complex but will be managed and constructed by specialty professionals familiar with the type of work. Long-term monitoring will be required for an extended time frame. Site access for construction is complex because of active site uses. The barrier wall will likely be constructed in public right-of-ways, requiring permission and permits from adjacent property owners and utility districts for construction. In addition, relocation of multiple utilities will also be required for implementation. Temporary relocation and/or restriction of right-of-way use and access to adjacent properties may be required during construction. This alternative is not easily integrated with existing site operations and adjacent properties and will require complex construction to allow for continued operation and site uses at the facility and adjacent properties.	
Cost • *Cost of construction* • *Long-term monitoring, operations, and maintenance costs* • *Agency oversight costs*	This criterion includes construction cost and contingency, and includes estimated long-term maintenance and monitoring. Agency oversight costs are not included and are expected to be consistent for all proposed alternatives. The cost associated with an MNA alternative is expected to be low.	This criterion includes construction cost and contingency, and includes estimated long-term maintenance and monitoring. Agency oversight costs are not included, and are expected to be consistent for all proposed alternatives. The overall cost associated with this alternative is expected to be high, as SVE system O&M will be required for a number of years, and deep ERD system operations will be required, with an extended period of long-term monitoring, maintenance, and continued ERD treatment.	This criterion includes construction cost and contingency, and includes estimated long-term maintenance and monitoring. Agency oversight costs are not included and are expected to be consistent for all proposed alternatives. The overall cost associated with this alternative is expected to be moderately high, with a substantial fraction of the cost incurred during thermal implementation. The scope and needs of long-term monitoring, maintenance, and continued ERD polish are lower than that of Alternative 2, as the length of time required for O&M is substantially reduced.	This criterion includes construction cost and contingency, and includes estimated long-term maintenance and monitoring. Agency oversight costs are not included, and are expected to be consistent for all proposed alternatives. The overall cost associated with this alternative is expected to be extremely high, with a substantial fraction of the cost incurred during barrier wall construction, long-term monitoring in perpetuity, and eventual wall replacement at the end of its design lifespan.	

Abbreviations:

BMP	Best management practice
CAA	Cleanup action area
CVOC	Chlorinated volatile organic compound
DNAPL	Dense non-aqueous phase liquid
ERD	Enhanced reductive dechlorination
MNA	Monitored Natural Attenuation
O&M	Operations & maintenance
PCE	Tetrachloroethene
PPE	Personal protective equipment
RAO	Remedial action objective
SVE	Soil vapor extraction
TCE	Trichloroethene
WBZ	Water bearing zone

Table 10.2
Alternatives Evaluation—Downgradient Groundwater Plume Cleanup Action Area

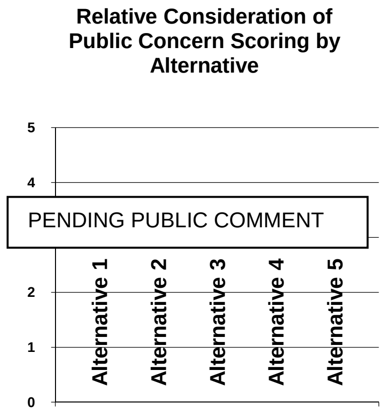
Alternative	**Alternative 1: Monitored Natural Attenuation**	**Alternative 2: Groundwater Treatment by ERD**	**Alternative 3: Point of Discharge Treatment by Air Sparging**	**Alternative 4: Point of Discharge Treatment by Permeable Reactive Barrier Wall**	**Relative Alternative Scoring**
Alternative Description	The MNA alternative is included for the purpose of baseline comparison to other alternatives within the Downgradient Groundwater Plume Cleanup Action Area. This alternative will rely entirely on natural attenuation of chlorinated contaminants over time.	This alternative includes treatment of groundwater in the 1st and 2nd WBZs through substrate injection at multiple points throughout the Downgradient Groundwater Plume to increase the rate of natural reductive dechlorination.	This alternative includes treatment of 1st and 2nd WBZ groundwater discharging at the Myrtle Street Embayment with air sparging before discharge as seeps into the embayment. This Alternative provides treatment at the end of plume only, prior to discharge to surface water.	This alternative includes treatment of shallow groundwater at the Myrtle Street Embayment immediately before discharge through seeps into the embayment via treatment with a permeable reactive barrier wall installed between the edge of the Downgradient Groundwater Plume and the embayment. This alternative provides treatment at the end of plume only, prior to discharge to surface water.	
Consideration of Public Concerns • *Whether the community has concerns* • *Degree to which the alternative addresses those concerns*	Public concerns will be reviewed following the public comment period and will be addressed in the final remedial alternative selection and design.	Public concerns will be reviewed following the public comment period and will be addressed in the final remedial alternative selection and design.	Public concerns will be reviewed following the public comment period and will be addressed in the final remedial alternative selection and design.	Public concerns will be reviewed following the public comment period and will be addressed in the final remedial alternative selection and design.	

Table 10.2
Alternatives Evaluation—Downgradient Groundwater Plume Cleanup Action Area

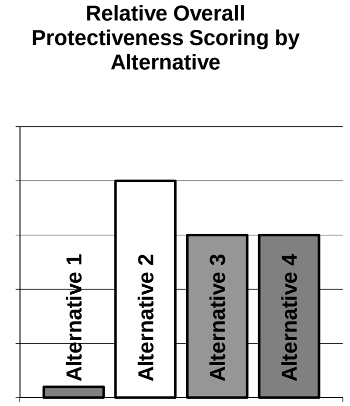
Alternative	Alternative 1: Monitored Natural Attenuation	Alternative 2: Groundwater Treatment by ERD	Alternative 3: Point of Discharge Treatment by Air Sparging	Alternative 4: Point of Discharge Treatment by Permeable Reactive Barrier Wall	Relative Alternative Scoring
Overall Protectiveness • *Degree to which existing risks are reduced* • *Time required to reduce risks and attain cleanup standards* • *On- and off-site risks resulting from alternative implementation* • *Improvement in overall environmental quality*	This alternative provides no reduction to existing risk. Time required to reduce risks and attain cleanup standards is not within a reasonable time frame, and attainment of cleanup levels may not be achievable. No additional on- or off-site risks result from implementation of MNA, because no actions are required for implementation. However, on- and off-site risks remain the same as currently exist. MNA provides no improvement in overall environmental quality and remedial action objectives will not be met.	This alternative provides a high degree of reduction of existing risk through removal of contaminant mass in the 1st and 2nd WBZ through ERD. Cleanup standards for the seeps are expected to be met at the Myrtle Street Embayment (where groundwater discharges to surface water) within a moderate time frame following treatment in the 1st and 2nd WBZs via ERD; however, achievement of cleanup levels throughout the Downgradient Groundwater Plume will have a much longer time frame, but this is acceptable because groundwater at the Site is considered non-potable. Low levels of on- and off-site risks are expected to result from alternative implementation. This alternative provides a moderate to high degree of improvement in overall environmental quality through accelerated mass reduction within the Downgradient Groundwater Plume which will lead to attainment of cleanup standards at the seeps where environmental exposure risk exists. Remedial action objectives are expected to be reached within a reasonable time frame; however, attainment of cleanup levels throughout the plume will require a long time frame, but does not result in risk because the groundwater is considered non-potable.	This alternative provides a moderate degree of reduction of existing risk through elimination of discharge of contaminated groundwater (above the cleanup standards) to surface water at the Myrtle Street embayment. Contaminant concentrations throughout the rest of the Downgradient Groundwater Plume will remain above the cleanup standards at the concentrations that currently exist, until eventually degraded through natural processes. Risks from groundwater discharging to surface water will be reduced immediately following implementation of the end of plume air sparging treatment. Cleanup standards are expected to be met at the at the point of discharge to surface water within a few months following construction. Implementation of this alternative will generate risk for contaminant release and migration should the air sparging treatment be ineffective at removing mass at the end of plume or if the system should shut down and treatment is halted. There is also a potential for vapor release during treatment if volatiles stripped from the groundwater are not effectively vented or captured from the subsurface. This alternative provides a moderate degree of improvement in overall environmental quality through control of risk at the point of discharge from groundwater to surface water. RAOs are expected to be reached within a reasonable time frame. Attainment of cleanup levels throughout the plume will require a long time frame, but does not result in risk because the groundwater is considered non-potable.	This alternative provides a moderate degree of reduction of existing risk through elimination of discharge of contaminated groundwater (above the cleanup standards) to surface water at the Myrtle Street embayment, and reduction in contaminant mass at the end of the Downgradient Groundwater Plume. Contaminant concentrations throughout the rest of the Downgradient Groundwater Plume will remain above the cleanup standards, at the concentrations that currently exist, until eventually degraded through natural processes. Risks from groundwater discharging to surface water will be reduced immediately following implementation of the end of plume PRB treatment. Cleanup standards are expected to be met at the at the point of discharge to surface water within a few months following construction. Implementation of this alternative will generate risk for contaminant release and migration should the PRB be ineffective at removing mass at the end of plume, or if the system should become clogged or ineffective over time. This alternative provides a moderate degree of improvement in overall environmental quality through control of risk at the point of discharge from groundwater to surface water. RAOs are expected to be reached within a reasonable time frame. Attainment of cleanup levels throughout the plume will require a long time frame, but does not result in risk because the groundwater is considered non-potable.	**Relative Overall Protectiveness Scoring by Alternative** 

Table 10.2
Alternatives Evaluation—Downgradient Groundwater Plume Cleanup Action Area

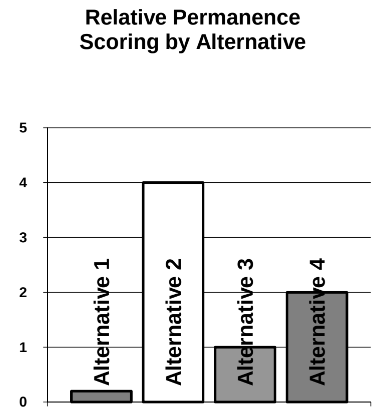
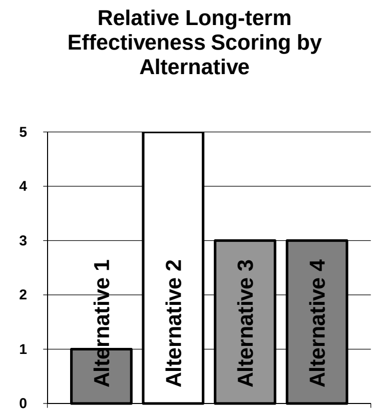
Alternative	Alternative 1: Monitored Natural Attenuation	Alternative 2: Groundwater Treatment by ERD	Alternative 3: Point of Discharge Treatment by Air Sparging	Alternative 4: Point of Discharge Treatment by Permeable Reactive Barrier Wall	Relative Alternative Scoring
Permanence - *Degree of reduction of contaminant toxicity, mobility, and volume* - *Adequacy of destruction of hazardous substances* - *Reduction or elimination of substance releases and source of release* - *Degree of irreversibility of waste treatment processes* - *Volume and characteristics of generated treatment residuals*	This alternative provides no reduction of contaminant toxicity, mobility, or volume. The destruction of hazardous substances is not adequate, because it is conducted solely by natural processes that are currently occurring at the Site. This alternative does not reduce, eliminate, or control sources, as all soil contamination currently in place that results in off-site contaminated groundwater migration remains in place in current concentrations and volumes. Because no waste treatment processes are included in this alternative, the degree of irreversibility cannot be measured.	This alternative provides a moderate to high degree of contaminant toxicity, mobility, and volume reduction. Assuming source control of the Main Source Area is achieved, concentrations in the Downgradient Groundwater Plume will be permanently reduced via natural processes enhanced by ERD injection. This alternative provides destruction of dissolved contamination in the 1st and 2nd WBZs. The destruction of contaminants resulting from degradation process associated with ERD is permanent. No waste treatment residuals are generated with ERD injections.	This alternative provides a moderate to low degree of contaminant toxicity, mobility, and volume reduction. Assuming source control of the Main Source Area is achieved, concentrations in the Downgradient Groundwater Plume will be permanently reduced via natural processes, over time, and through air sparging at the end of plume prior to discharge to surface water. This alternative provides adequate destruction of dissolved contamination immediately prior to discharge through seeps at the Myrtle Street Embayment. The destruction and removal of contaminants resulting from air sparging is permanent. Depending on the implementation method and system design, vapors may be collected from the air sparging treatment, generating a waste stream requiring treatment and disposal.	This alternative provides a low degree of contaminant toxicity, mobility, and volume reduction. Assuming source control of the Main Source Area is achieved, concentrations in the Downgradient Groundwater Plume will be permanently reduced via natural processes, over time, and through treatment with a PRB at the end of plume prior to discharge to surface water. This alternative provides adequate destruction of dissolved contamination immediately prior to discharge through seeps at the Myrtle Street Embayment. The destruction and removal of contaminants resulting from a PRB is permanent. No waste treatment residuals are generated with a PRB.	**Relative Permanence Scoring by Alternative** 
Effectiveness over the Long-term - *Degree of certainty of alternative success* - *Reliability while contaminants remain on-site greater than cleanup levels* - *Magnitude of residual risk* - *Effectiveness of controls implemented to manage residual risk*	This alternative provides a low degree of alternative success. It is not expected to achieve cleanup goals. This alternative is not reliable, because it does not manage contaminants on site to any greater degree than existing conditions. The magnitude of residual risk with this alternative is high, because there is little to no reduction in risk resulting from implementation of an MNA technology.	This alternative provides a high degree of certainty of success as ERD has been successfully implemented at other sites with similar conditions, and at this Site as part of the downgradient interim measure. ERD is a reliable technology, and its success can be reliably measured during remediation and in the long term. The magnitude of residual risk associated with this alternative is low, because attainment of cleanup levels at the seeps is expected within a reasonable time frame, and concentrations throughout the rest of the Downgradient Groundwater Plume do not pose risk via any other pathway if concentrations are in compliance at the seeps. Institutional controls may be required on properties with residual concentrations in groundwater greater than cleanup levels.	This alternative provides a moderate degree of certainty of success because air sparging has been successfully implemented at multiple sites with similar conditions. Air sparging is a reliable technology with measurable success. Monitoring will be conducted during remediation and in the long term to confirm conditions while contaminants remain on-site. The magnitude of residual risk associated with this alternative is low, because attainment of cleanup levels at the seeps is expected within a reasonable time frame, and concentrations throughout the rest of the Downgradient Groundwater Plume do not pose risk via any other pathway if concentrations are in compliance at the seeps. Institutional controls may be required on properties or portions of properties with residual concentrations in groundwater greater than cleanup levels.	This alternative provides a moderate degree of certainty of success as PRBs have been successfully implemented at multiple sites with similar conditions. Design of the PRB will need to account for site conditions, including salt water intrusion and placement of the wall in relation to the adjacent surface water body. PRB is a reliable technology with measurable success. Monitoring will be conducted during remediation and in the long term to confirm conditions while contaminants remain on-site. The magnitude of residual risk associated with this alternative is low, as attainment of cleanup levels at the seeps is expected within a reasonable time frame, and concentrations throughout the rest of the Downgradient Groundwater Plume do not pose risk via any other pathway if concentrations are in compliance at the seeps. Institutional controls may be required on properties or portions of properties with residual concentrations in groundwater greater than cleanup levels.	**Relative Long-term Effectiveness Scoring by Alternative** 

Table 10.2
Alternatives Evaluation—Downgradient Groundwater Plume Cleanup Action Area

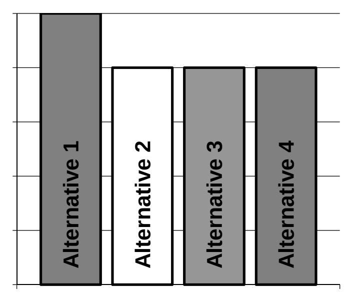
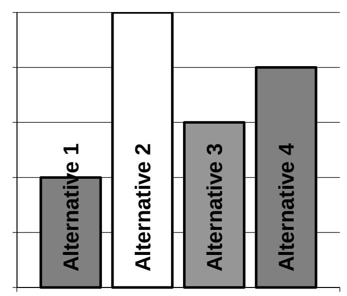
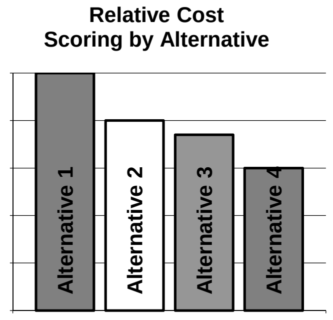
Alternative	**Alternative 1: Monitored Natural Attenuation**	**Alternative 2: Groundwater Treatment by ERD**	**Alternative 3: Point of Discharge Treatment by Air Sparging**	**Alternative 4: Point of Discharge Treatment by Permeable Reactive Barrier Wall**	**Relative Alternative Scoring**
Short-term Risk Management • *Risk to human health and the environment associated with alternative construction* • *The effectiveness of controls in place to manage short-term risks*	There is no short-term risk associated with construction of this alternative as no construction activities will be conducted.	Site activities will require appropriate PPE, BMPs, and appropriate training requirements for management of risk. These controls are highly effective, and anticipated to adequately manage short-term risk.	Site activities will require appropriate PPE, BMPs, and appropriate training requirements for management of risk. These controls are highly effective, and anticipated to adequately manage short-term risk.	Site activities will require appropriate PPE, BMPs, and appropriate training requirements for management of risk. These controls are highly effective, and anticipated to adequately manage short-term risk.	**Relative Short-term Risk Management Scoring by Alternative** 
Technical and Administrative Implementability Ability of alternative to be implemented considering: • *Technical possibility* • *Availability of off-site facilities, services, and materials* • *Administrative and regulatory requirements* • *Schedule, size and complexity of construction* • *Monitoring requirements* • *Site access for construction, and operations and monitoring* • *Integration with existing site operations or other current and potential future remedial action*	No facilities, services, or materials are needed for this alternative implementation because no construction will be completed. This alternative is not administratively implementable because it does not meet any of the regulatory requirements for a cleanup action. There is no schedule or complexity associated with implementation. Monitoring requirements are expected to be greater than for other alternatives because risks will not be reduced with this alternative. There are no concerns with site access as no construction is associated with this alternative. This alternative does not impact existing site operations.	This alternative is technically possible to implement and appropriate given site conditions. All necessary off-site facilities, materials, and services are available within the region. This alternative meets all administrative and regulatory requirements. This alternative is anticipated to require less than 1 month for construction, followed by 10–15 years of ERD treatment. Long-term monitoring will be required for an extended time frame to ensure that groundwater concentrations at the seeps remain at or less than the cleanup levels and that concentrations throughout the plume are decreasing. Construction requires site access to install additional injection wells across the plume and approval from downgradient property owners. To achieve optimal performance, access for well installation and ERD injections must not be restricted by site activities. This alternative can be integrated with existing site operations.	This alternative is technically possible to implement and appropriate given site conditions. All necessary off-site facilities, materials, and services are available within the region. This alternative meets all administrative and regulatory requirements. This alternative is anticipated to require 1–3 months for construction, followed by continued treatment, and long-term monitoring in perpetuity. The alternative is moderately complex. Long-term monitoring will be required for an extended time frame to ensure that groundwater concentrations at the seeps remain at or less than the cleanup levels. Access for sparging system installation is not restricted by site activities, because it will be installed in undeveloped right of way areas. This alternative can be integrated with existing site operations.	This alternative is technically possible to implement and appropriate given site conditions. All necessary off-site facilities, materials, and services are available within the region. This alternative meets all administrative and regulatory requirements. This alternative is anticipated to require 1–3 months for construction, followed by long-term monitoring in perpetuity. The alternative is moderately complex. Long-term monitoring will be required for an extended time frame to ensure that groundwater concentrations at the seeps remain at or less than the cleanup levels. Access for PRB installation is not restricted by site activities, because it will be installed, for the most part, in undeveloped right of way areas. This alternative can be integrated with existing site operations.	**Relative Implementability Scoring by Alternative** 

Table 10.2
Alternatives Evaluation—Downgradient Groundwater Plume Cleanup Action Area

Alternative	**Alternative 1: Monitored Natural Attenuation**	**Alternative 2: Groundwater Treatment by ERD**	**Alternative 3: Point of Discharge Treatment by Air Sparging**	**Alternative 4: Point of Discharge Treatment by Permeable Reactive Barrier Wall**	**Relative Alternative Scoring**
Cost • *Cost of construction* • *Long-term monitoring, and operations and maintenance costs* • *Agency oversight costs*	This criterion includes estimated long-term maintenance and monitoring. Agency oversight costs are not included and are expected to be consistent for all proposed alternatives. The cost associated with an MNA alternative is expected to be low.	This criterion includes construction cost and contingency, and 15 years of injection and 50 years of long term monitoring. Agency oversight costs are not included and are expected to be consistent for all proposed alternatives. The cost associated with this alternative is expected to be low, and include and an extended period of long-term monitoring.	This criterion includes construction cost and contingency, and includes estimated long-term maintenance and monitoring. Agency oversight costs are not included and are expected to be consistent for all proposed alternatives. The cost associated with this alternative is expected to be moderate, because a substantial fraction of the cost is incurred during remedial implementation of the Air Sparge system, and an extended period of system O&M, long-term monitoring, and maintenance.	This criterion includes construction cost and contingency, and includes estimated long-term maintenance and monitoring. Agency oversight costs are not included, and are expected to be consistent for all proposed alternatives. The cost associated with this alternative is expected to be moderate to low, because a substantial fraction of the cost is incurred during PRB installation, and an extended period of long-term monitoring.	

Abbreviations:

BMP	Best management practice
CAA	Cleanup Action Area
CVOC	Chlorinated volatile organic compound
ERD	Enhanced reductive dechlorination
O&M	Operations & maintenance
MNA	Monitored Natural Attenuation
PCE	Tetrachloroethene
PPE	Personal protective equipment
PRB	Permeable reactive barrier
RAO	Remedial Action Objective
SVE	Soil vapor extraction
TCE	Trichloroethene
WBZ	Water bearing zone

Table 10.3
Alternatives Evaluation—Northwest Corner Plume Cleanup Action Area

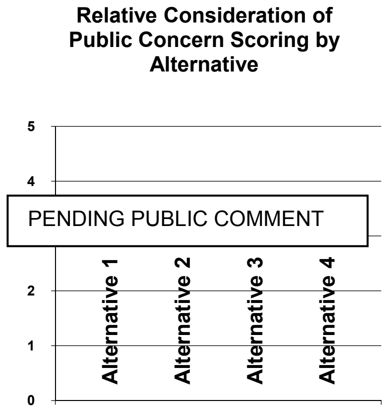
Alternative	**Alternative 1: Monitored Natural Attenuation**	**Alternative 2: Groundwater Treatment by ERD**	**Alternative 3: Permeable Reactive Barrier Wall**	**Alternative 4: Shallow Soil Treatment by SVE and Groundwater Treatment by ERD**	**Relative Alternative Scoring**
Alternative Description	The MNA alternative is included for the purpose of baseline comparison to other alternatives within the Northwest Corner Plume CAA. This alternative will rely entirely on natural attenuation of chlorinated contaminants over time.	This alternative includes treatment of PCE and TCE in the 1st WBZ groundwater via ERD injections.	This alternative includes treatment of contaminated 1st WBZ groundwater through installation of a PRB Wall along Fox Avenue.	This alternative includes treatment of impacted vadose zone soil via implementation of an SVE system and treatment of groundwater in the 1st WBZ via ERD injections.	
Consideration of Public Concerns • *Whether the community has concerns* • *Degree to which the alternative addresses those concerns*	Public concerns will be reviewed following the public comment period and will be addressed in the final remedial alternative selection and design.	Public concerns will be reviewed following the public comment period and will be addressed in the final remedial alternative selection and design.	Public concerns will be reviewed following the public comment period and will be addressed in the final remedial alternative selection and design.	Public concerns will be reviewed following the public comment period and will be addressed in the final remedial alternative selection and design.	

Table 10.3
Alternatives Evaluation—Northwest Corner Plume Cleanup Action Area

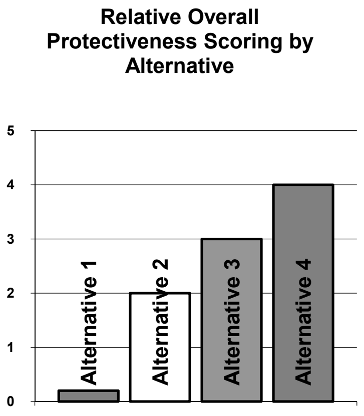
Alternative	**Alternative 1: Monitored Natural Attenuation**	**Alternative 2: Groundwater Treatment by ERD**	**Alternative 3: Permeable Reactive Barrier Wall**	**Alternative 4: Shallow Soil Treatment by SVE and Groundwater Treatment by ERD**	**Relative Alternative Scoring**
Overall Protectiveness - *Degree to which existing risks are reduced* - *Time required to reduce risks and attain cleanup standards* - *On- and off-site risks resulting from alternative implementation* - *Improvement in overall environmental quality*	This alternative provides no reduction to existing risk. Time required to reduce risks and attain cleanup standards is not within a reasonable time frame, and attainment of cleanup levels may not be achievable. No additional on- or off-site risks result from implementation of MNA, because no actions are required for implementation. However, on- and off-site risks remain the same as currently exist. MNA provides no improvement in overall environmental quality and remedial action objectives will not be met.	This alternative provides a low to moderate degree of reduction of existing risk through destruction of dissolved phase contaminants in the groundwater plume through enhancement of the naturally occurring dechlorination process. This alternative does not provide a high degree of protectiveness because the source of groundwater contamination will not be addressed and will continue to leach for a long time period. Risks to the downgradient groundwater will be reduced in a reasonable time frame; however, as no reduction in source soils is proposed, achievement of cleanup levels at the conditional point of compliance is not expected to be permanent. Implementation of this alternative does not generate on-site of off-site risks. This alternative provides a low to moderate degree of improvement in overall environmental quality by decreasing contaminant concentrations in groundwater and complying with RAOs and the proposed remediation levels in a reasonable time frame, but does not achieve the cleanup levels for groundwater in a reasonable time frame.	This alternative provides a moderate degree of reduction of existing risk through destruction of contaminant mass in groundwater in the 1st WBZ through construction of a PRB intercepting the Northwest Corner Plume. Risks will be reduced in a rapid time frame following implementation of the PRB, through reduction in groundwater contamination migrating to the Downgradient Groundwater Plume. Cleanup standards are expected to be met at the conditional point of compliance almost immediately following implementation. Implementation of this alternative will not generate significant risk to workers. This alternative provides a moderate degree of improvement in overall environmental quality through contaminant mass reduction of groundwater contamination in the 1st WBZ. Groundwater RAOs and cleanup levels are expected to be reached within a reasonable time frame.	This alternative provides a moderate to high degree of reduction of existing risk through removal of source contaminant mass in the vadose zone by SVE, and degradation of existing contaminant mass in groundwater in the 1st WBZ through ERD. Risks will be reduced in a moderate time frame following implementation of the SVE technology in the vadose zone. The ERD process will remediate groundwater contaminants in the 1st WBZ in a moderate time frame. While remediation levels for groundwater are expected to be met in a reasonable time frame, groundwater cleanup standards are expected to be met at the conditional point of compliance within a long time frame. Implementation of this alternative will not generate significant risk to workers during SVE system installation, operation, and maintenance. Vapor extracted from the subsurface during the SVE process will generate a treatment waste stream that must be managed either on- or off-site. This alternative provides a moderate to high degree of improvement in overall environmental quality through mass reduction of a substantial volume of contaminants in the subsurface. The existing vadose zone contamination is low level, and the majority of the soil vapor mass is expected to be removed. RAOs are expected to be reached within a reasonable time frame.	

Table 10.3
Alternatives Evaluation—Northwest Corner Plume Cleanup Action Area

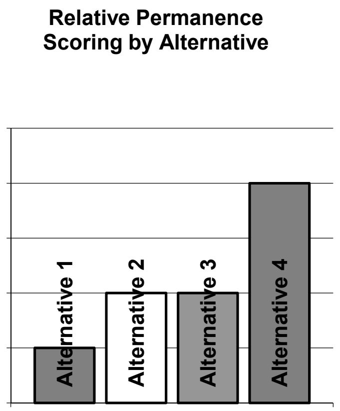
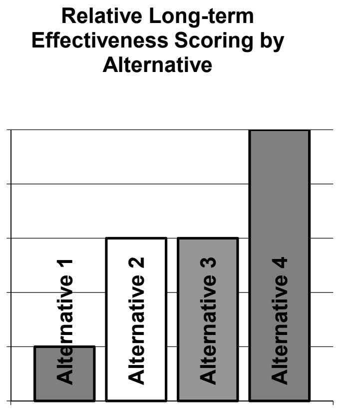
Alternative	Alternative 1: Monitored Natural Attenuation	Alternative 2: Groundwater Treatment by ERD	Alternative 3: Permeable Reactive Barrier Wall	Alternative 4: Shallow Soil Treatment by SVE and Groundwater Treatment by ERD	Relative Alternative Scoring
Permanence • *Degree of reduction of contaminant toxicity, mobility, and volume* • *Adequacy of destruction of hazardous substances* • *Reduction or elimination of substance releases and source of release* • *Degree of irreversibility of waste treatment processes* • *Volume and characteristics of generated treatment residuals*	This alternative provides no reduction of contaminant toxicity, mobility, or volume. The destruction of hazardous substances is not adequate, because it is conducted solely by natural processes that are currently occurring at the Site. This alternative does not reduce, eliminate, or control sources, because all soil contamination currently in place that results in off-site contaminated groundwater migration remains in place in current concentrations and volumes. Since no waste treatment processes are included in this alternative, the degree of irreversibility cannot be measured. No treatment residuals are generated by implementation of an MNA alternative.	This alternative provides a moderate degree of contaminant volume, toxicity, and mobility reduction by reducing concentrations in groundwater at an increased rate than currently existing. This alternative does not reduce vadose zone contaminant concentrations. The destruction of hazardous substances is adequate, but limited to groundwater. This alternative does not adequately reduce or eliminate source contamination in vadose soils which will continue to leach to groundwater. The destruction of contaminants resulting from ERD is permanent and irreversible. There are no treatment residuals generated by ERD.	This alternative provides a moderate degree of contaminant volume, toxicity, and mobility reduction by reducing concentrations in groundwater at the conditional point of compliance. This alternative does not reduce vadose zone contaminant concentrations. The destruction of hazardous substances is adequate, but limited to groundwater. This alternative does not adequately reduce or eliminate source contamination in vadose soils which will continue to leach to groundwater. The destruction of contaminants resulting from construction of a PRB (likely with zero-valent iron) is permanent and irreversible.	This alternative provides a moderate to high degree of contaminant toxicity, mobility, and volume reduction. The majority of mass located in the vadose zone will be removed via the SVE process, while dissolved phase concentrations will be reduced via ERD. The destruction of hazardous substances resulting from implementation is adequate, and both vadose soils and 1st WBZ contaminants are reduced. This alternative provides source control through removal of shallow source contamination in the vadose zone which acts as a future source to groundwater contamination. The destruction of contaminants resulting from SVE and the degradation process associated with ERD is permanent. Treatment residuals are limited to vapors collected during SVE. Generated waste such as soil cuttings will require maintenance during implementation over the short term.	
Effectiveness over the Long-term • *Degree of certainty of alternative success* • *Reliability while contaminants remain on-site greater than cleanup levels* • *Magnitude of residual risk* • *Effectiveness of controls implemented to manage residual risk*	This alternative provides a low degree of alternative success. It is not expected to achieve cleanup goals. This alternative is not reliable because it does not manage contaminants on-site to any greater degree than existing conditions. The magnitude of residual risk with this alternative is high because there is little to no reduction in risk resulting from implementation of an MNA technology.	This alternative provides a moderate degree of certainty of success because ERD has been successfully implemented at the Site for remediation of groundwater. ERD technology is reliable for remediation of groundwater contamination; however, because this alternative does not address vadose zone contamination, the overall reliability of this alternative is decreased. Contaminants will remain on-site at levels greater than cleanup levels in perpetuity. The residual risk associated with this alternative is potentially high because vadose zone contamination is not addressed, which results in on-going migration to groundwater in perpetuity.	This alternative provides a moderate degree of certainty of success, as PRBs have been successfully implemented at sites with similar conditions. PRB technology is reliable for remediation of groundwater contamination; however, because this alternative does not address vadose zone contamination, the overall reliability of this alternative is decreased. Contaminants will remain on-site greater than cleanup levels in perpetuity. The residual risk associated with this alternative is potentially high, because vadose zone contamination is not addressed, which results in on-going migration to groundwater in perpetuity.	This alternative provides a high degree of certainty of success by combining proven technologies to address all contamination in the Northwest Corner Plume via SVE and ERD. SVE and ERD have both been successfully implemented at the Site as interim measures. SVE and ERD technologies are reliable with measurable success. Monitoring will be conducted during remediation and in the long term to confirm conditions while contaminants remain on-site. The magnitude of residual risk associated with this alternative is low because contaminant mass will be substantially removed from the 1st WBZ and vadose zone. Institutional controls may be required on properties with residual concentrations in groundwater greater than cleanup levels.	

Table 10.3
Alternatives Evaluation—Northwest Corner Plume Cleanup Action Area

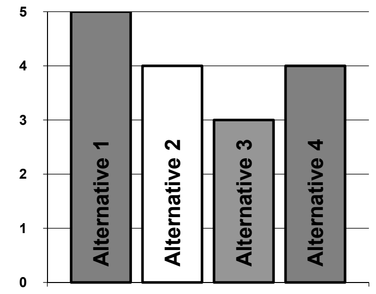
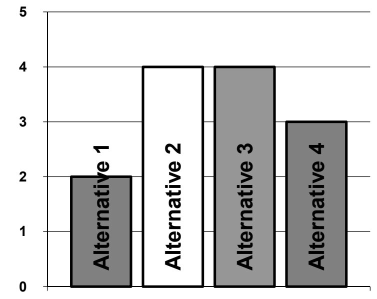
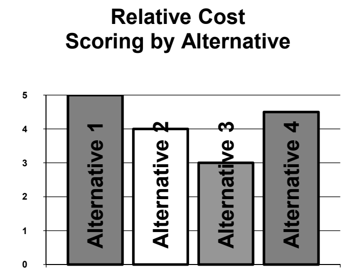
Alternative	**Alternative 1: Monitored Natural Attenuation**	**Alternative 2: Groundwater Treatment by ERD**	**Alternative 3: Permeable Reactive Barrier Wall**	**Alternative 4: Shallow Soil Treatment by SVE and Groundwater Treatment by ERD**	**Relative Alternative Scoring**
Short-term Risk Management • *Risk to human health and the environment associated with alternative construction* • *The effectiveness of controls in place to manage short-term risks*	There is no short-term risk associated with construction of this alternative because no construction activities will be conducted. Risk to human health and the environment are consistent with existing risk.	Site activities will require appropriate PPE, BMPs, and appropriate training requirements for management of risk. These controls are highly effective, and anticipated to adequately manage short-term risk.	Site activities will require appropriate PPE, BMPs, and appropriate training requirements for management of risk. These controls are highly effective, and anticipated to adequately manage short-term risk.	Site activities will require appropriate PPE, BMPs, and appropriate training requirements for management of risk. These controls are highly effective, and anticipated to adequately manage short-term risk.	**Relative Short-term Risk Management Scoring by Alternative** 
Technical and Administrative Implementability Ability of alternative to be implemented considering below: • *Technical possibility* • *Availability of off-site facilities, services, and materials* • *Administrative and regulatory requirements* • *Schedule, size, and complexity of construction* • *Monitoring requirements* • *Site access for construction, and operations and monitoring* • *Integration with existing site operations or other current and potential future remedial action*	No facilities, services, or materials are needed for this alternative implementation as no construction will be conducted. This alternative is not administratively implementable as it does not meet any of the regulatory requirements for a cleanup action. There is no schedule or complexity associated with implementation. Monitoring requirements are expected to be greater than for other alternatives because risks will not be reduced with this alternative. There are no concerns with site access because no construction is associated with this alternative. This alternative does not impact existing site operations.	This alternative is technically possible to implement and appropriate given site conditions. All necessary off-site facilities, materials, and services are available within the region. This alternative meets all administrative and regulatory requirements. This alternative is anticipated to require approximately 1 month for construction, followed by an anticipated 5 years of ERD treatment and long-term monitoring. This alternative can be integrated with existing site operations but will require construction sequencing to allow for continued use of the parking lot.	This alternative is technically possible to implement and appropriate given site conditions. All necessary off-site facilities, materials, and services are available within the region. This alternative meets all administrative and regulatory requirements. This alternative is anticipated to require approximately 1 month for construction, followed by an anticipated 5 years of ERD treatment and long-term monitoring. This alternative can be integrated with existing site operations but will require construction sequencing to allow for continued use of the parking lot.	This alternative is technically possible to implement and appropriate given site conditions. All necessary off-site facilities, materials, and services are available within the region. This alternative meets all administrative and regulatory requirements. This alternative is anticipated to require approximately 1 month for construction, followed by 2–3 years of SVE system operation, an anticipated 5 years of ERD treatment, and long-term monitoring and maintenance. The alternative is moderately complex. Long-term monitoring will be required for an extended time frame to ensure that source area concentrations remain at or less than remediation levels. This alternative can be integrated with existing site operations but will require construction sequencing to allow for continued use of the parking lot.	**Relative Implementability Scoring by Alternative** 

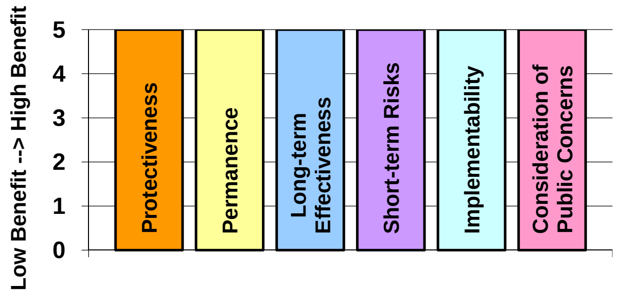
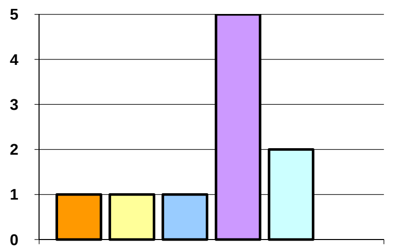
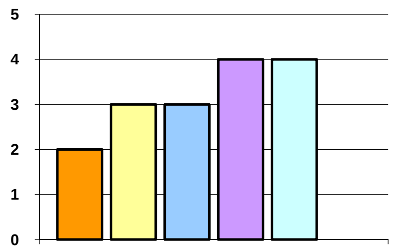
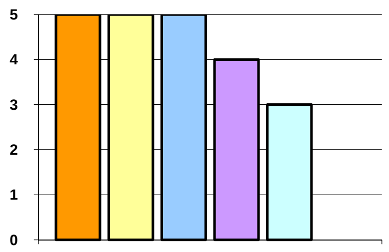
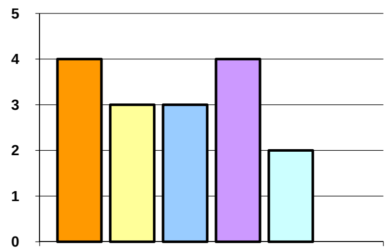
Table 10.3
Alternatives Evaluation—Northwest Corner Plume Cleanup Action Area

Alternative	Alternative 1: Monitored Natural Attenuation	Alternative 2: Groundwater Treatment by ERD	Alternative 3: Permeable Reactive Barrier Wall	Alternative 4: Shallow Soil Treatment by SVE and Groundwater Treatment by ERD	Relative Alternative Scoring
Cost • *Cost of construction* • *Long-term monitoring, and operations and maintenance costs* • *Agency oversight costs*	This criterion includes estimated long-term maintenance and monitoring. Agency oversight costs are not included and are expected to be consistent for all proposed alternatives. The cost associated with an MNA alternative is expected to be low.	This criterion includes construction cost and contingency, and includes estimated long-term maintenance and monitoring. Agency oversight costs are not included and are expected to be consistent for all proposed alternatives. The cost associated with this alternative is expected to be moderate, and a substantial fraction of the cost is incurred during remedial implementation and long-term monitoring.	This criterion includes construction cost and contingency, and includes estimated long-term maintenance and monitoring. Agency oversight costs are not included and are expected to be consistent for all proposed alternatives. The cost associated with this alternative is expected to be moderate, and a substantial fraction of the cost is incurred during remedial implementation and long-term monitoring.	This criterion includes construction cost and contingency, and includes estimated long-term maintenance and monitoring. Agency oversight costs are not included and are expected to be consistent for all proposed alternatives. The cost associated with this alternative is expected to be moderate, because a substantial fraction of the cost is incurred during remedial implementation of SVE and an extended period of long-term monitoring, maintenance, and continued ERD treatment.	

Abbreviations:

BMP	Best management practice
CAA	Cleanup Action Area
CVOC	Chlorinated volatile organic compound
ERD	Enhanced reductive dechlorination
MNA	Monitored Natural Attenuation
PCE	Tetrachloroethene
PPE	Personal protective equipment
PRB	Permeable reactive barrier
RAO	Remedial Action Objective
SVE	Soil vapor extraction
TCE	Trichloroethene
WBZ	Water Bearing Zone

Table 10.4
Disproportionate Cost Evaluation—Main Source Area Cleanup Action Area

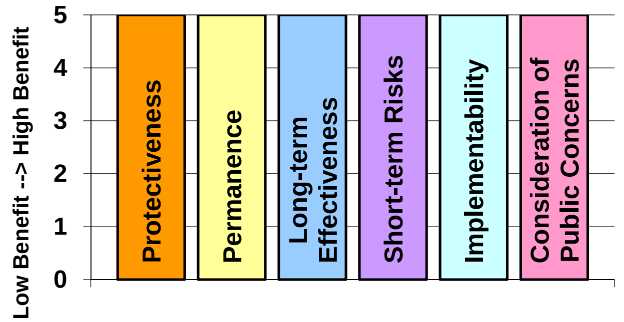
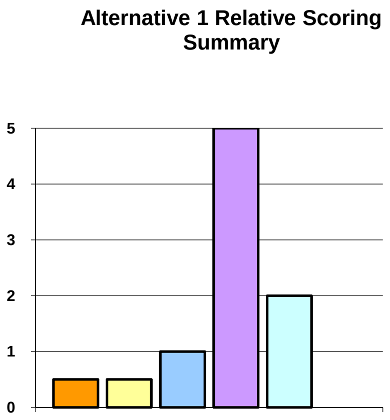
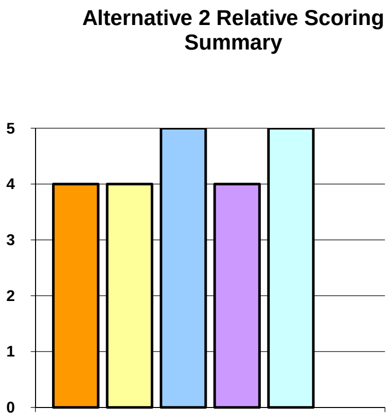
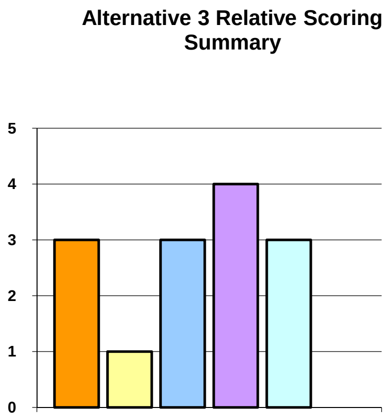
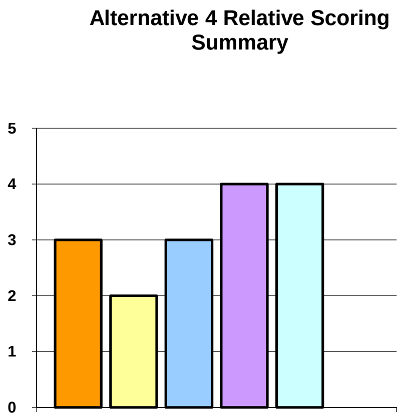
Alternative	**Alternative 1:** **Monitored Natural Attenuation**	**Alternative 2:** **Shallow and Deep Soil and Groundwater Treatment by ERD, Vadose Zone Treatment by SVE**	**Alternative 3:** **Shallow and Deep Soil and Groundwater Treatment by Thermal Remediation and ERD Polish**	**Alternative 4:** **Source Area Containment by Low-Permeability Barrier Wall**
Alternative Description	The MNA alternative is included for the purpose of baseline comparison to other alternatives within the Main Source Area CAA. This alternative provides no benefit or improvement in environmental condition.	This alternative includes (1) treatment of vadose zone soil contamination via SVE, and (2) treatment of soil and groundwater below the water table via ERD injection. The applicability of ERD at similar DNAPL sites is an emerging technology that has not been proven effective at sites with similar conditions; therefore, the level of confidence associated with this technology is low, which is reflected in the evaluation of this alternative.	This alternative includes treatment of impacted soil and groundwater within the vadose zone, 1st and 2nd WBZs by thermal remediation, followed by ERD injection for treatment of low-level residual contamination following completion of thermal treatment. It is the most permanent of the alternatives.	This alternative includes containment through construction of a low-permeability barrier wall surrounding the facility. The wall will control the on-going source of contamination to the downgradient plume. This alternative will require hydraulic controls (pumping) to maintain an inward groundwater gradient.
Overall Alternative Total Score	**10**	**16**	**22**	**16**
KEY[1] 	**Alternative 1 Relative Scoring Summary** 	**Alternative 2 Relative Scoring Summary** 	**Alternative 3 Relative Scoring Summary** 	**Alternative 4 Relative Scoring Summary** 
Compliance with MTCA Threshold Requirements	No[2]	Yes	Yes	Yes
Estimated Construction Cost [3]	$0.4 Million	$6.4 Million	$9.5 Million	$39.5 Million
Restoration Time Frame (to achieve soil CULs / to achieve groundwater CULs at CPOC)	Indefinite/Indefinite	5–10 years / Indefinite	1–2 years / Approx 50 years	Indefinite / 5 years
MTCA Evaluation of Permanence Using Disproportionate Cost Analysis				
Overall Protectiveness	1	2	5	4
Permanence	1	3	5	3
Long-term Effectiveness	1	3	5	3
Short-term Risk Management (low risk, high score)	5	4	4	4
Implementability	2	4	3	2
Consideration of Public Concerns	Pending Public Comment	Pending Public Comment	Pending Public Comment	Pending Public Comment

Notes:
1. Higher scores equate to a higher level of relative benefit. Fewer short-term risks result in a higher score.
2. The MNA alternative is included for baseline comparison purposes only and is not intended to meet MTCA threshold requirements for alternative evaluation.
3. Specific cost estimate information is provided in Appendix J.

Abbreviations:

CAA	Cleanup Action Area	ERD	Enhanced reductive dechlorination
CPOC	Conditional point of compliance	MNA	Monitored Natural Attenuation
CUL	Cleanup Level	MTCA	Model Toxics Control Act
DNAPL	Dense non-aqueous phase liquid	WBZ	Water Bearing Zone

Table 10.5
Disproportionate Cost Evaluation—Downgradient Groundwater Plume Cleanup Action Area

Alternative	**Alternative 1: Monitored Natural Attenuation**	**Alternative 2: Groundwater Treatment by ERD**	**Alternative 3: Point of Discharge Treatment by Air Sparging**	**Alternative 4: Point of Discharge Treatment by Permeable Reactive Barrier Wall**
Alternative Description	The MNA alternative is included for the purpose of baseline comparison to other alternatives within the Downgradient Groundwater Plume CAA. This alternative relies entirely on natural attenuation processes.	This alternative includes treatment of groundwater in the 1st and 2nd WBZs through ERD injection at multiple points throughout the Downgradient Groundwater Plume to increase the rate of reductive dechlorination. It is the most permanent of the alternatives.	This alternative includes treatment of shallow groundwater at the Myrtle Street Embayment with air sparging immediately before discharge. This alternative provides treatment at the end of plume only.	This alternative includes treatment of shallow groundwater at the Myrtle Street Embayment before discharge with a PRB. This alternative provides treatment at the end of plume only.
Overall Alternative Total Score	**<10**	**22**	**14**	**16**
KEY [1] 				
Compliance with MTCA Threshold Requirements	No[2]	Yes	Yes	Yes
Estimated Construction Cost [3]	$0.3 Million	$1.9 Million	$2.3 Million	$3.2 Million
Restoration Time Frame (to achieve CUL at seeps / throughout downgradient plume)	Indefinite/Indefinite	Approx 10-15 years / Approx 50 years	Approx 1 year / Indefinite	Approx 1 year / Indefinite
MTCA Evaluation of Permanence Using Disproportionate Cost Analysis				
Overall Protectiveness	<1	4	3	3
Permanence	<1	4	1	2
Long-term Effectiveness	1	5	3	3
Short-term Risk Management (low risk, high score)	5	4	4	4
Implementability	2	5	3	4
Consideration of Public Concerns	Pending Public Comment	Pending Public Comment	Pending Public Comment	Pending Public Comment

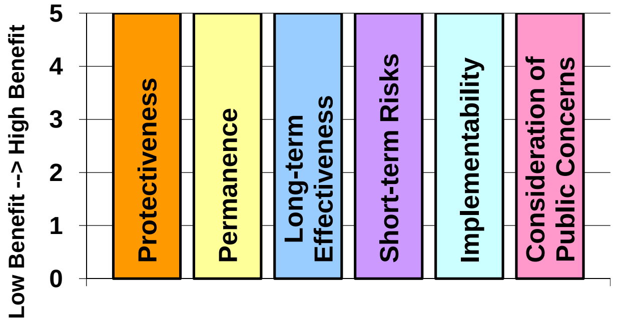
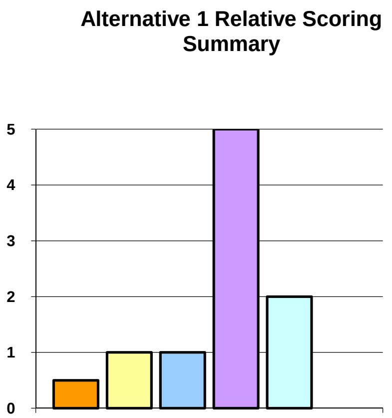
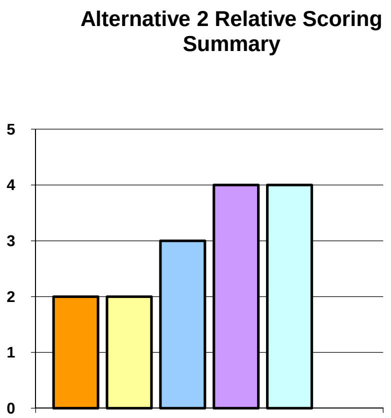
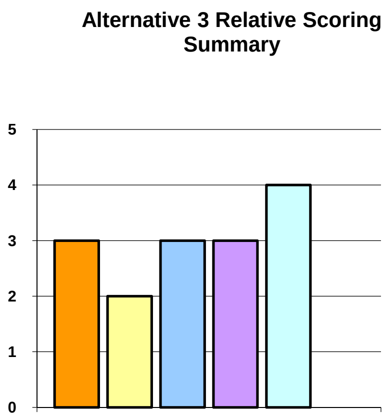
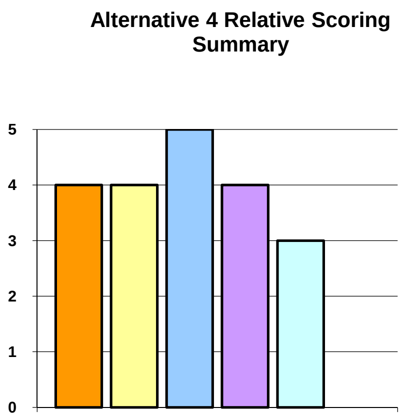
Notes:

1 Higher scores equate to a higher level of relative benefit. Fewer short-term risks result in a higher score.
2 The No Action alternative is included for baseline comparison purposes only.
3 Specific cost estimate information is provided in Appendix J.

Abbreviations:

CAA	Cleanup Action Area
CUL	Cleanup level
ERD	Enhanced reductive dechlorination
MNA	Monitored Natural Attenuation
MTCA	Model Toxics Control Act
PRB	Permeable reactive barrier
WBZ	Water Bearing Zone

Table 10.6
Disproportionate Cost Evaluation—Northwest Corner Plume Cleanup Action Area

Alternative	**Alternative 1: Monitored Natural Attenuation**	**Alternative 2: Groundwater Treatment by ERD**	**Alternative 3: Permeable Reactive Barrier Wall**	**Alternative 4: Shallow Soil Treatment by SVE and Groundwater Treatment by ERD**
Alternative Description	The MNA alternative is included for the purpose of baseline comparison to other alternatives within the Northwest Corner Plume CAA. This alternative will rely entirely on natural attenuation of chlorinated contaminants over time.	This alternative includes treatment of PCE and TCE in the 1^{st} WBZ groundwater via ERD injections. It does not address low-level vadose zone soil contamination.	This alternative includes treatment of contaminated 1^{st} WBZ groundwater through installation of a Permeable Reactive Barrier Wall along Fox Avenue.	This alternative includes treatment of impacted vadose zone soil via implementation of an SVE system and treatment of groundwater in the 1^{st} WBZ via ERD injections. It is the most permanent of the alternatives.
Overall Alternative Total Score	**<10**	**15**	**15**	**20**
KEY[1] 				
Compliance with MTCA Threshold Requirements	No[2]	Yes	Yes	Yes
Estimated Construction Cost [3]	$0.3 Million	$0.7 Million	$2.4 Million	$0.8 Million
Restoration Time Frame (to achieve cleanup level in Groundwater at CPOC)	Indefinite	Indefinite	Approx 5 years	Approx 50 years
MTCA Evaluation of Permanence Using Disproportionate Cost Analysis				
Overall Protectiveness	<1	2	3	4
Permanence	1	2	2	4
Long-term Effectiveness	1	3	3	5
Short-term Risk Management (low risk, high score)	5	4	3	4
Implementability	2	4	4	3
Consideration of Public Concerns	Pending Public Comment	Pending Public Comment	Pending Public Comment	Pending Public Comment

Notes:

1 Higher scores equate to a higher level of relative benefit. Fewer short-term risks result in a higher score.

2 The MNA alternative is included for baseline comparison purposes only and is not intended to meet MTCA threshold requirements for alternative evaluation.

3 Specific cost estimate information is provided in Appendix J.

Abbreviations:

CAA	Cleanup Action Area	PCE	Tetrachloroethene
CPOC	Conditional point of compliance	SVE	Soil vapor extraction
ERD	Enhanced reductive dechlorination	TCE	Trichloroethene
MNA	Monitored Natural Attenuation	WBZ	Water Bearing Zone
MTCA	Model Toxics Control Act		

Table 12.1
Proposed Actions, Testing, and Contingencies

Impacted Media	Pathway/Exposure	Primary Chemicals of Concern	Proposed Media Cleanup Level	Proposed Point of Compliance	Compliance Measured By	Remediation By	Remediation Level	Expected Restoration Time Frame	Contingency Action
Air	Inhalation	PCE, TCE	Method C Air: Cascade Columbia Method B Air[1]: Seattle Boiler Works	Site-wide indoor air at Cascade Columbia and Seattle Boiler Works	Direct sampling of indoor air at each facility[2]	Thermal and post thermal ERD in Main Source Area	None, thermal and ERD expected to result in achievement of applicable cleanup levels in air	Cascade Columbia: 1 year—using thermal Seattle Boiler Works: 10-15 years of post-thermal ERD	Cascade Columbia: Upgraded passive or active ventilation Seattle Boiler Works: Sealing of Floor Cracks, Upgraded passive or active ventilation[3]
Soil	Direct contact by ingestion, industrial worker	PCE	Method C Ingestion (240 mg/kg)	Upper 15 feet site-wide	Sampling in source areas following thermal	Thermal in Main Source Area	None needed, the thermal remediation level is less than the direct contact cleanup level	1 year—thermal	Capping, institutional controls
	Cross Media: Soil vapor in contaminated vadose zone soils causing vapor intrusion to indoor air for industrial worker at Cascade Columbia	PCE, TCE	Empirical demonstration (i.e., no numeric value) that indoor air is in compliance with Method C levels	Indoor air at Cascade Columbia	Compliance in indoor air empirically demonstrates vadose zone soil concentrations are protective site-wide	Thermal in Main Source Area	None needed, indoor air expected to achieve cleanup level using thermal to remediate source soils	1 year—thermal	Cascade Columbia: Upgraded ventilation,
	Cross Media: Soil leaching to groundwater	PCE, TCE, DCE, TPH	Empirical demonstration (i.e., no numeric value) by testing groundwater for chemicals of concern at point of compliance	Groundwater at Fox Avenue	Compliance in groundwater empirically demonstrates soil concentrations throughout the aquifer are protective	**Source Area:** Thermal followed by ERD then by MNA **Downgradient:** ERD followed by MNA	**Soil RL for Thermal:** Average soil concentration in each thermal zone of 10 mg/kg PCE +TCE **Post Thermal and ERD Groundwater RL:** <250 µg/L total CEAs	**Soil RL:** 1 year—thermal **Groundwater RL:** 10-15 years of post-thermal ERD	Continued ERD in Main Source Area, and/or 1st WBZ PRB wall in localized areas of groundwater remediation level exceedance
Surface Water	Aquatic species AND human health through the consumption of contaminated fish/shellfish	PCE, TCE, VC	Lowest of federal/state surface water ARARs	Surface water column	None planned at this time	None planned at this time	None, surface water currently meets cleanup level	S. Myrtle Street Embayment surface water already in compliance	None needed
Groundwater	Direct ingestion, drinking water (NOT APPLICABLE)	The groundwater at this Site is considered non-potable and its maximum beneficial use is discharge into a tidal estuary, which is also non-potable (refer to RI/FS text for details).							
	Cross Media: Groundwater causing vapor intrusion—inhalation	PCE, TCE	Empirical demonstration (i.e., no numeric value) that indoor air is in compliance with proposed indoor air cleanup levels	Indoor air at Cascade Columbia Facility and Seattle Boiler Works	Compliance in indoor air at both facilities demonstrates that 1st WBZ groundwater is in compliance site-wide	Thermal followed by ERD then MNA	**Post Thermal/ERD Groundwater RL:** Less than 250 µg/L (total CEAs) at Fox Avenue and in downgradient wells	10-15 years of post-thermal ERD	Continued ERD in downgradient plume in localized plume hot spot areas that may be contributing to vapor intrusion

Table 12.1
Proposed Actions, Testing, and Contingencies

Impacted Media	Pathway/Exposure	Primary Chemicals of Concern	Proposed Media Cleanup Level	Proposed Point of Compliance	Compliance Measured By	Remediation By	Remediation Level	Expected Restoration Time Frame	Contingency Action
Groundwater	**Cross Media:** Groundwater discharges to surface water via seeps into the S. Myrtle Street Embayment—point of compliance at the seeps	PCE, TCE, VC	Lowest of federal/state surface water ARARs	**Seeps:** Location of groundwater discharge into Lower Duwamish Waterway	Seeps	Thermal followed by ERD then MNA	None, groundwater will meet surface water cleanup level at seeps	15 years to reach cleanup levels in seeps	Re-evaluation of potential exposure pathway that assumes bioconcentration in fish/shellfish (i.e., new science, clam survey/testing, impact of fishing restriction, etc.)
	Cross Media: Groundwater discharges to surface water into the S. Myrtle Street Embayment conditional point of compliance at Fox Avenue	PCE, TCE, VC, DCE, TPH (as mineral spirits), Penta	Lowest of federal/state surface water ARARs, Method A for TPH (as mineral spirits)	Conditional point of compliance at Fox Avenue	Groundwater samples from monitoring wells along the west side of Fox Avenue and on Seattle Boiler Works property	Thermal followed by ERD then MNA	**Post Thermal/ERD Groundwater RL:** Less than 250 µg/L (total CEAs) at Fox Avenue and Downgradient Groundwater Plume wells	10 years to reach remediation levels at Fox Avenue and Downgradient Groundwater Plume wells Approximately 50 years to meet cleanup levels at Fox Avenue and Downgradient Groundwater Plume wells	Continued ERD in downgradient plume in localized areas of groundwater remediation level exceedance Both the groundwater remediation level and the approximate 50-year restoration time frame to reach cleanup levels result in no unacceptable risk and/or exposure

Notes:

1 MTCA Method B CULs are being used for the indoor air at Seattle Boiler Works property because the property owner will not accept institutional controls.

2 Contaminant concentrations in indoor air will be adjusted downwards to account for ambient concentrations of PCE and TCE in accordance with Ecology's 2009 Draft Guidance for Vapor Intrusion (Ecology 2009).

3 The need for contingency actions at Seattle Boiler Works will be evaluated in accordance with Ecology's *Guidance for Evaluating Soil Vapor Intrusion in Washington State: Investigation and Remedial Actions* (Ecology 2009). In accordance with this guidance, indoor air VOC concentrations that are fully protective of the current receptors inside a non-residential building can be calculated by changing the inputs to the default MTCA Method B equations to reflect exposures to adult workers. The resulting protective air CULs will be compared to the measured concentrations following remediation to decide if contingency measures are needed.

Abbreviations:

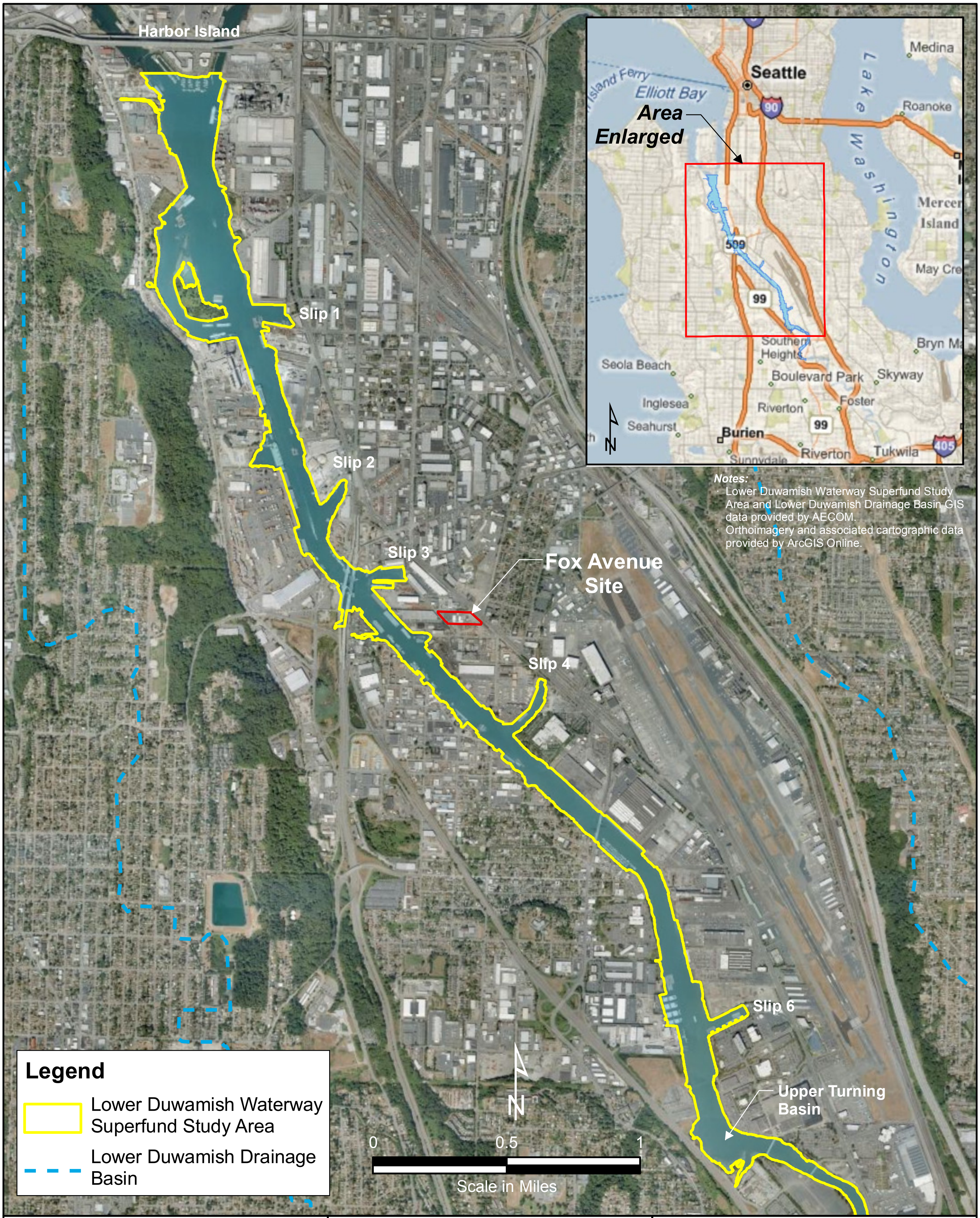
ARAR	Applicable or relevant and appropriate requirement
CEA	Chlorinated ethene and ethane
CUL	Cleanup level
DCE	Dichloroethene
Ecology	Washington State Department of Ecology
ERD	Enhanced reductive dechlorination
MNA	Monitored natural attenuation
MTCA	Model Toxics Control Act
PCE	Tetrachloroethene
Penta	Pentachlorophenol
POC	Point of compliance
PRB	Permeable Reactive Barrier
RL	Remediation level
TBD	To be determined
TCE	Trichloroethene
TPH	Total petroleum hydrocarbons
VC	Vinyl chloride
VOC	Volatile organic compound
WBZ	Water Bearing Zone

Fox Avenue Site
Seattle, Washington

Remedial Investigation/ Feasibility Study

Figures

FINAL



Notes:

- Lower Duwamish Waterway Superfund Study Area and Lower Duwamish Drainage Basin GIS data provided by AECOM.
- Orthoimagery and associated cartographic data provided by ArcGIS Online.

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Fox Avenue Site
Seattle, Washington

Figure 1.1
Lower Duwamish Industrial Corridor

File: F:\projects\FoxAve-RA\GIS\MXD\RIFS\2011 RIFS\Figure 1.1 (Lower Duwamish Industrial Corridor).mxd
Date: 2/8/2011

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Remedial Investigation/Feasibility Study
Fox Avenue Site
Seattle, Washington

Figure 2.1
Area Map

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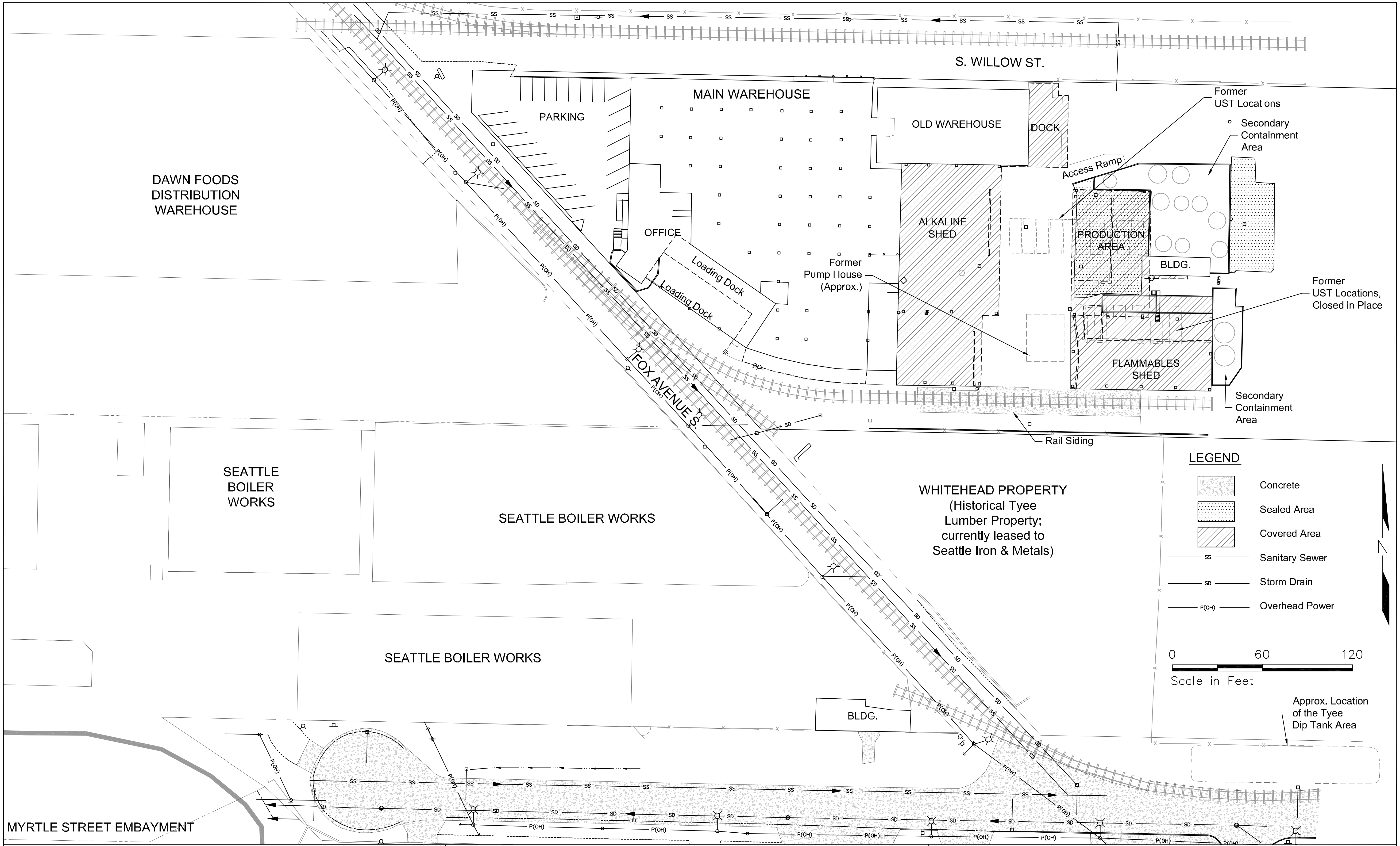
Date: 2/8/2011



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Fox Avenue Site
Seattle, Washington

Figure 2.2
Site Plan

DWG NAME: G:\project\Clients\Floyd and Snider\Fox Ave 2010\CAD\FoxAve2010_001.dwg
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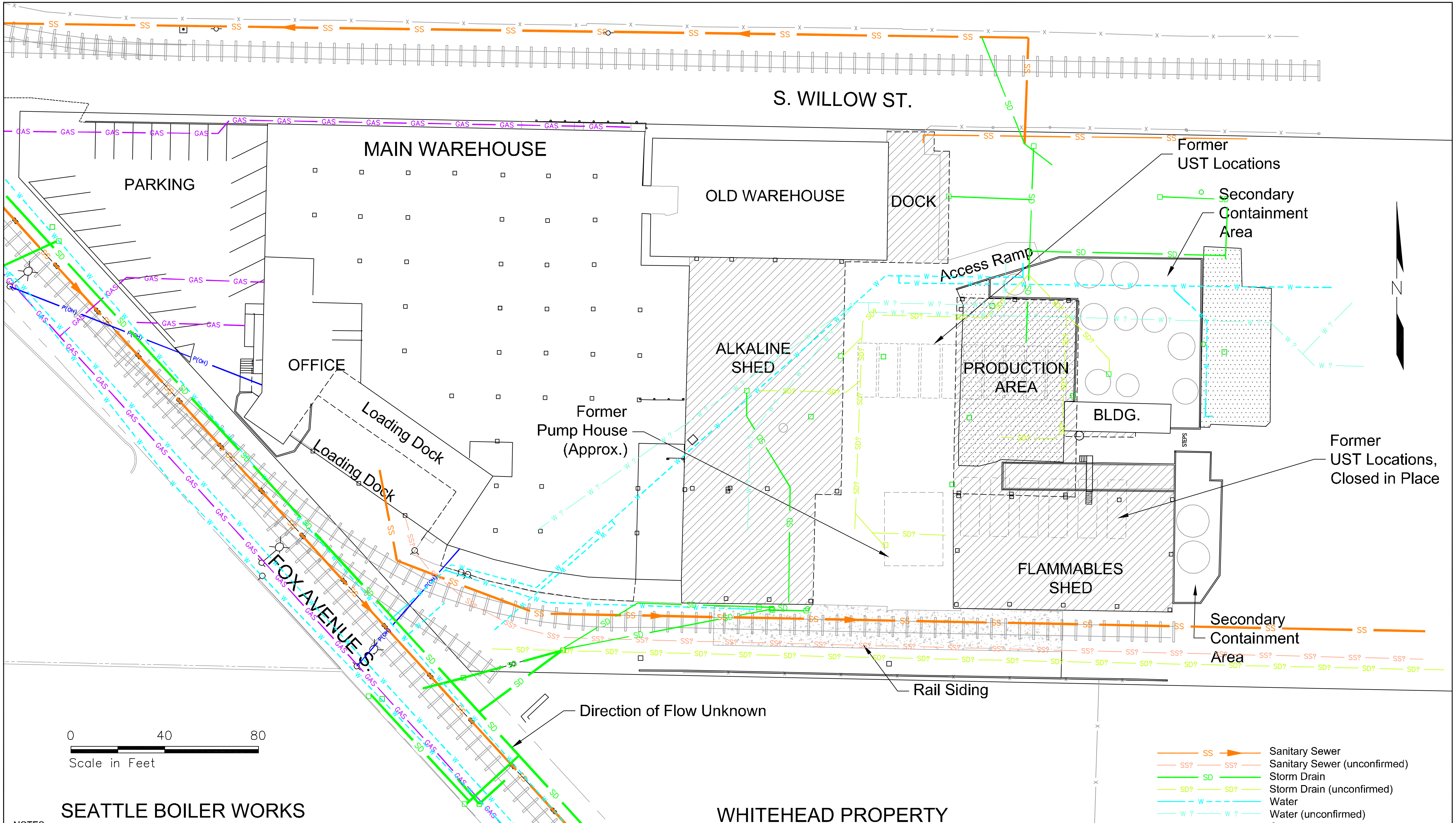

NOTES:

1. Not for use in construction.
2. Sources: Barghausen 2008 Survey; Plate 200, Map Series 2400, City of Seattle Misc. Great Western Chemical Company Plans

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Fox Avenue Site
Seattle, Washington

Figure 2.3
Utility Location Map

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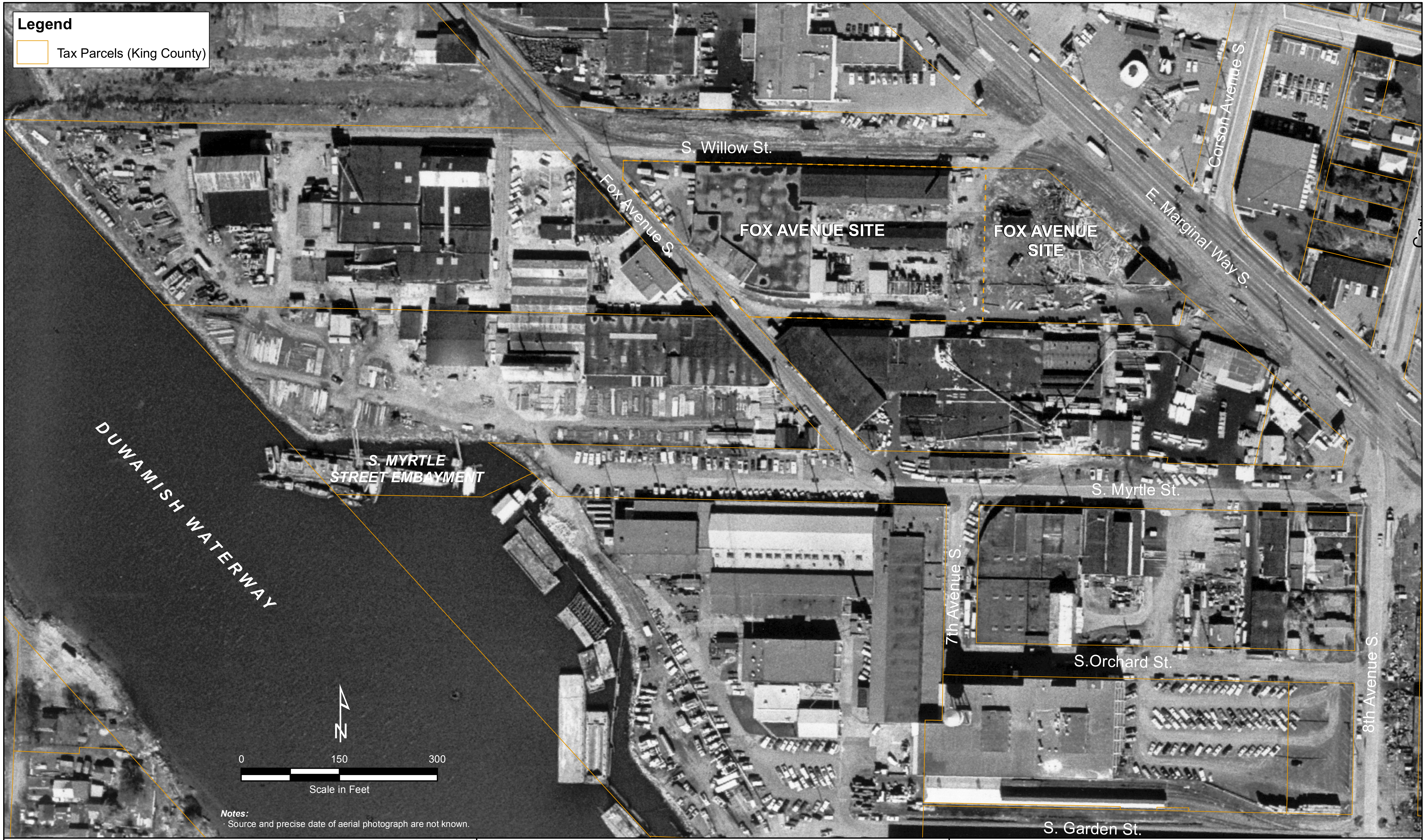

Notes:
· Source and precise date of aerial photograph are not known.

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Fox Avenue Site
Seattle, Washington

Figure 2.4
1960s-era Aerial Photograph

File: F:\projects\FoxAve-RA\GIS\MXD\RIFS\2011 RIFS\Figure 2.4 (1960s-era Historical Aerial Photograph).mxd
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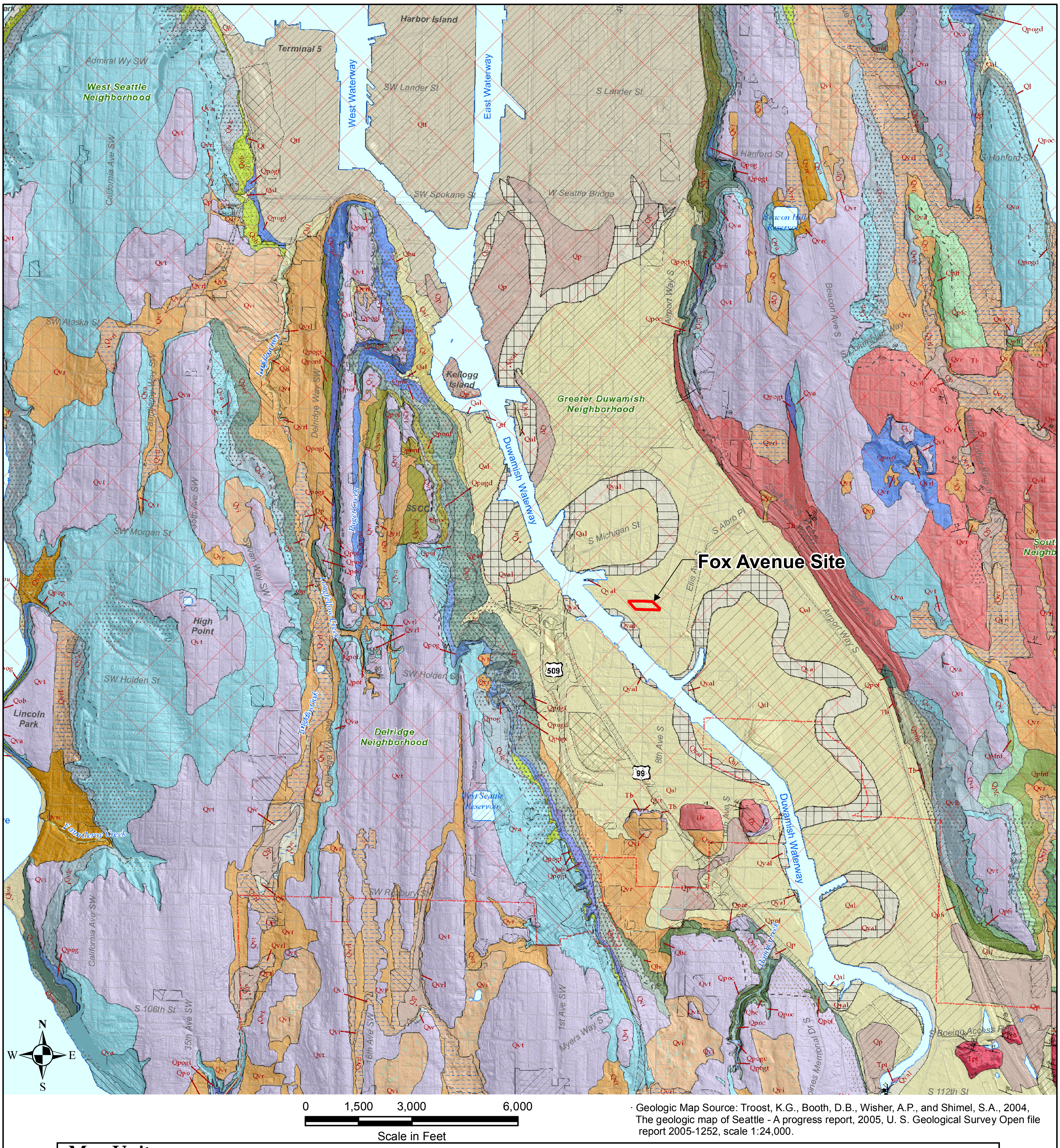

Geologic Map Source: Troost, K.G., Booth, D.B., Wisher, A.P., and Shimel, S.A., 2004, The geologic map of Seattle - A progress report, 2005, U. S. Geological Survey Open file report 2005-1252, scale 1:24,000.

Map Units

Nonglacial Deposits (Holocene)

- water
- Qw - Wetland deposits
- Qp - Peat
- Qb - Beach deposits
- Qbu - Uplifted beach deposits
- Qtf - Tideflat deposits
- Qal - Alluvium
- Qyal - Younger alluvium
- Ql - Lake deposits
- Qf - Fan deposits
- Qt - Terrace deposits

Younger Glacial Deposits (Fraser Glaciation, Pleistocene)

- Qvr - Vashon recessional outwash deposits
- Qvrl - Vashon recessional lacustrine deposits
- Qvrc - Vashon recessional coarse-grained deposits
- Qvi - Vashon ice-contact deposits
- Qvt - Vashon subglacial till
- Qvtm - Vashon subglacial meltout till
- Qva - Vashon advance outwash deposits
- Qvlc - Lawton Clay member of the Vashon Drift

Older Glacial and Nonglacial Deposits (Pleistocene)

- Qpf - Pre-Fraser glaciation age deposits
- Qpfc - Pre-Fraser coarse-grained deposits
- Qpff - Pre-Fraser fine-grained deposits
- Qpfn - Pre-Fraser nonglacial deposits
- Qpfnc - Pre-Fraser coarse-grained nonglacial deposits
- Qpfnf - Pre-Fraser fine-grained nonglacial deposits
- Qob - Olympia beds
- Qpo - Pre-Olympia deposits
- Qpoc - Pre-Olympia coarse-grained deposits
- Qpof - Pre-Olympia fine-grained deposits
- Qpog - Pre-Olympia glacial deposits
- Qpogc - Pre-Olympia coarse-grained glacial deposits
- Qpogf - Pre-Olympia fine-grained glacial deposits
- Qpogt - Pre-Olympia glacial till
- Qpogd - Pre-Olympia glacial diamict
- Qpon - Pre-Olympia nonglacial deposits
- Qponc - Pre-Olympia coarse-grained nonglacial deposits
- Qponf - Pre-Olympia fine-grained nonglacial deposits
- Qpdf - Possession drift fine-grained deposits
- Qhc - Hamm Creek formation
- Qpone - Pre-Olympia estuarine deposits

Bedrock (Tertiary)

- Tb - Blakeley Formation
- Tva - Andesite
- Tpt - Tukwila Formation

Overprints

- Mass wastage deposits
- Landslide deposits
- Modified land
- af - artificial fill
- afl - landfill debris
- afr - filled river channels
- graded land
- regraded land
- anticline, approx. located (McWilliams, 1971)
- fault, approx. located (Waldron and others, 1962; McWilliams, 1971)
- inclined bedding
- vertical bedding
- inclined jointing
- vertical joint
- Contact
- Scarps
- Peat bed
- Till bed
- Seattle Fault Zone
- Seattle City Limit

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Remedial Investigation/Feasibility Study
Fox Avenue Site
Seattle, Washington

Figure 2.5
Regional Geologic Map

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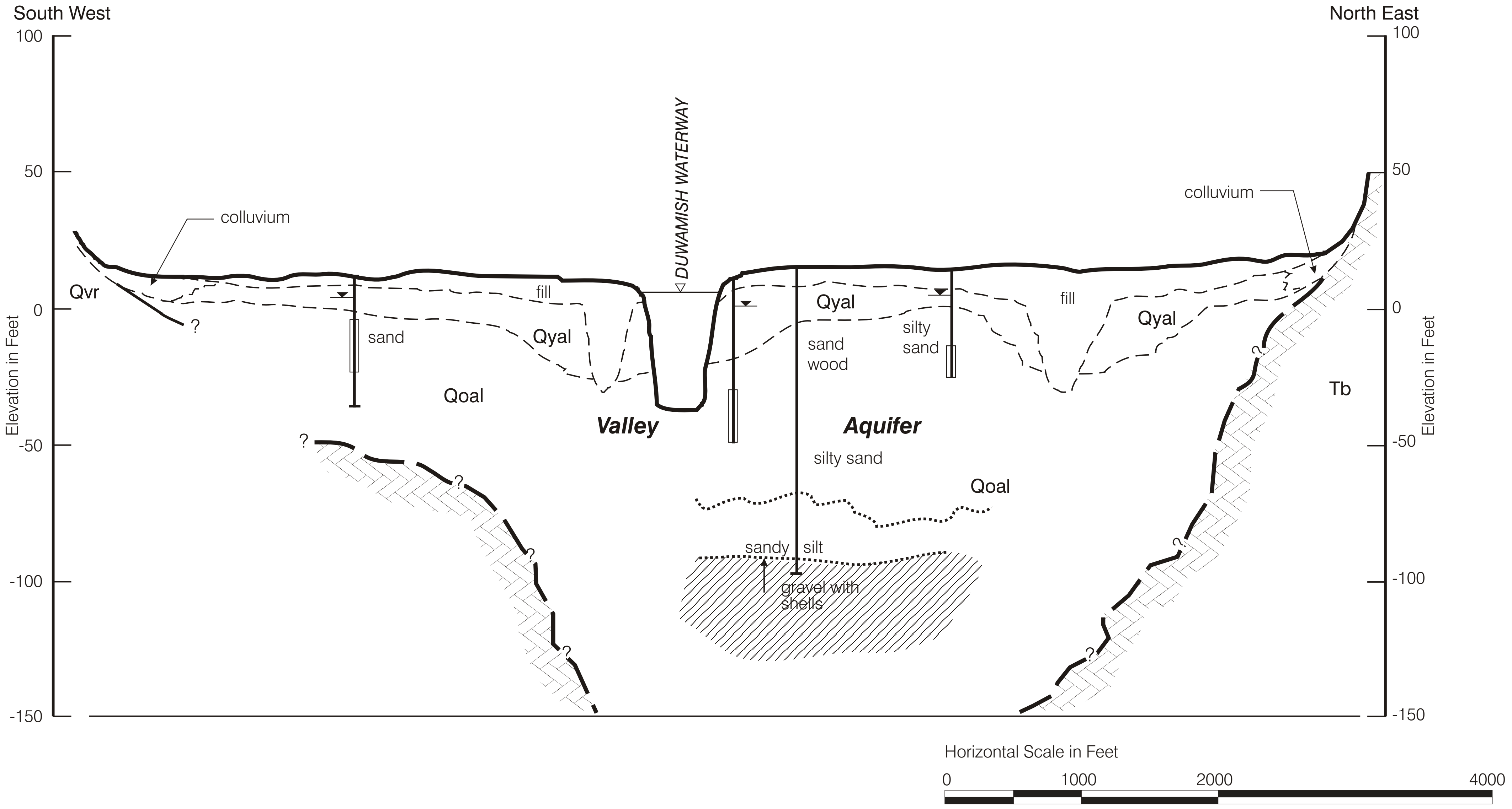

Vertical Exaggeration: 20X

Note: First and second water zones occur with the regional upper water bearing zone.

Well Location

- Water level from original log.
- Screened interval.
- 0.07 Direction and magnitude (where available) of vertical gradient indicated at nested well pairs.

Notes:
1. Contacts between geologic units are based upon interpolation between wells and surface exposures where available. They represent the interpretation of subsurface conditions based upon currently available data.
2. 1st and 2nd water bearing zones occur with the regional upper water bearing zone.
3. Section from Duwamish Industrial Area Hydrogeologic Pathways Project, April 1998. Developed by Lori Herman and Derek Booth.

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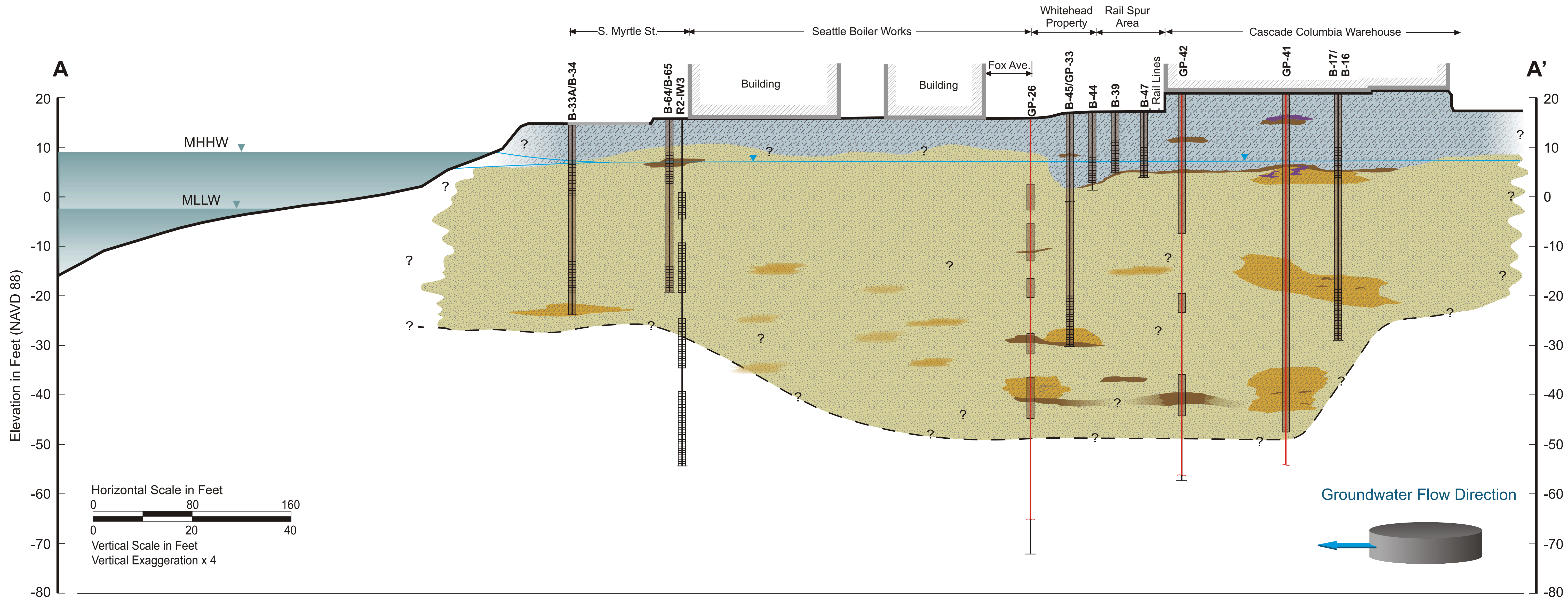
Figure 2.6
Generalized Cross Section
Duwamish Valley

G:Project\Clients\Floyd Snider\Fox Avenue\2010\Cross Sections\Generalized Cross Section



▨ Fine SAND to silty SAND, with occasional Gravel Fill

▨ Silt lense

▨ Silty fine SAND to sandy SILT

▨ SAND, fine to medium trace to some silt

? Geology Unknown or Inferred No Samples Collected

▼ Groundwater Surface

Soil Sample Interval for Geology Control (current and prior borings)

Screen Interval

Base of Boring

Base of MIP Boring

NAPL Indications in Soil Samples - Mixed Petroleum and PCE

NAPL Indications in Soil Samples - Dominantly Petroleum-based

Note: Reproduced from Data Gaps Investigation Technical Memorandum (Floyd|Snider and CALIBRE 2009).

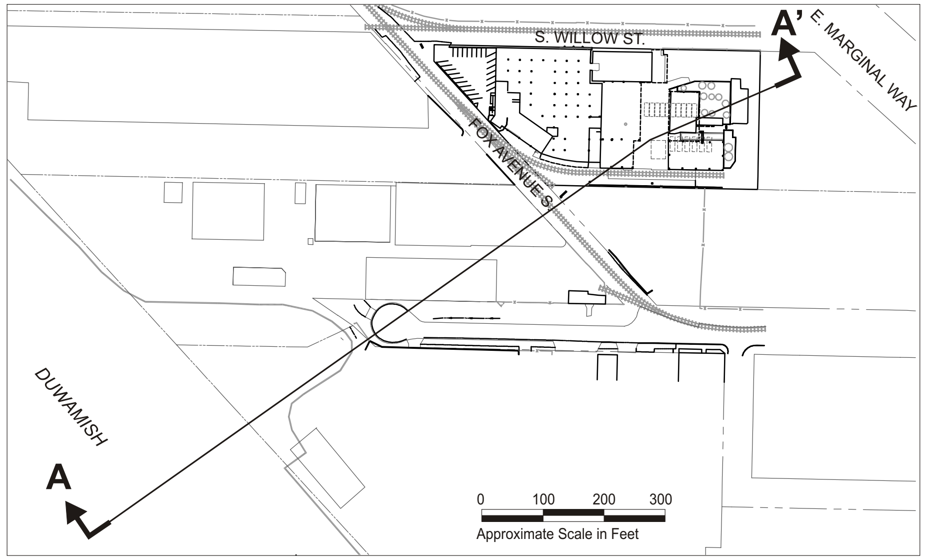


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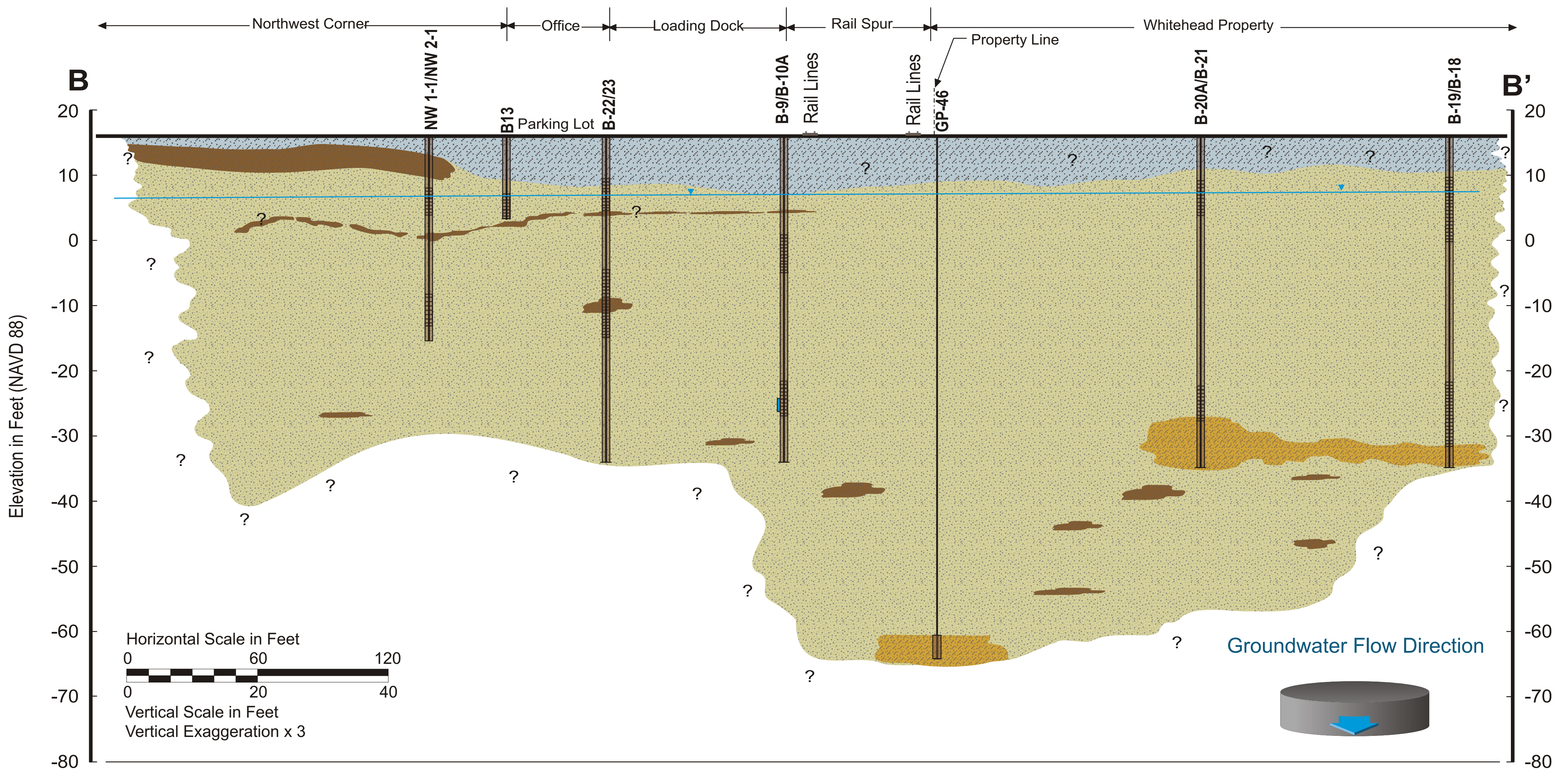
Figure 2.7a
Geologic Cross Section A-A'

G:Project\Clients\Floyd Snider\Fox Avenue\2010\Cross Sections\A-A'



▨ Fine SAND to silty SAND, with occasional Gravel Fill

▨ Silt lense

▨ Silty fine SAND to sandy SILT

▨ SAND, fine to medium trace to some silt

? Geology Unknown or Inferred No Samples Collected

Groundwater Surface

Soil Sample Interval for Geology Control (current and prior borings)

Screen Interval

Ground Water Sample Interval

Base of Boring

Base of MIP Boring

NAPL Indications in Soil Samples - Mixed Petroleum and PCE

NAPL Indications in Soil Samples - Dominantly Petroleum-based

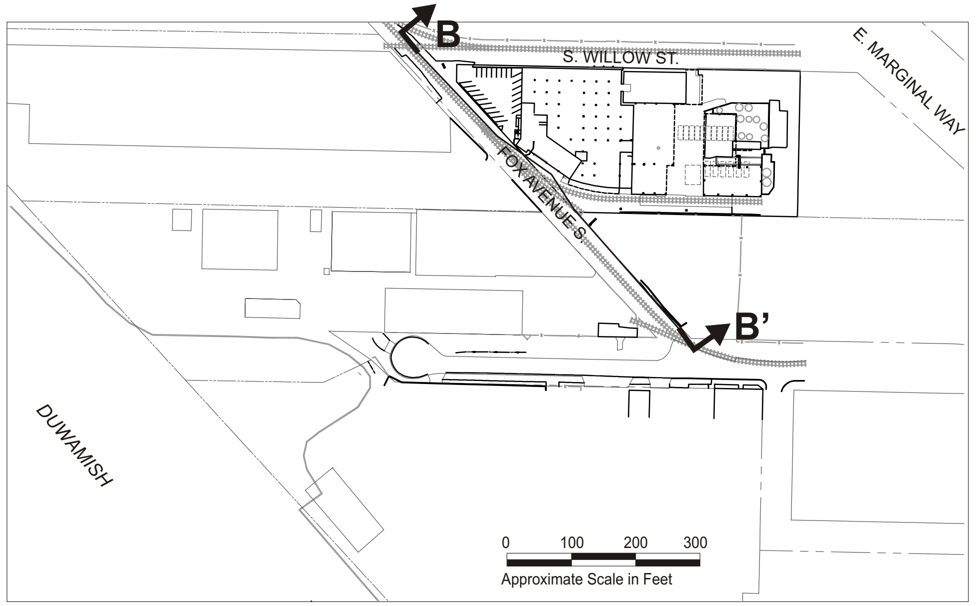


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Figure 2.7b
Geologic Cross Section B-B'

G:Project\Clients\Floyd Snider\Fox Avenue\2010\Geologic Cross Section B-B'

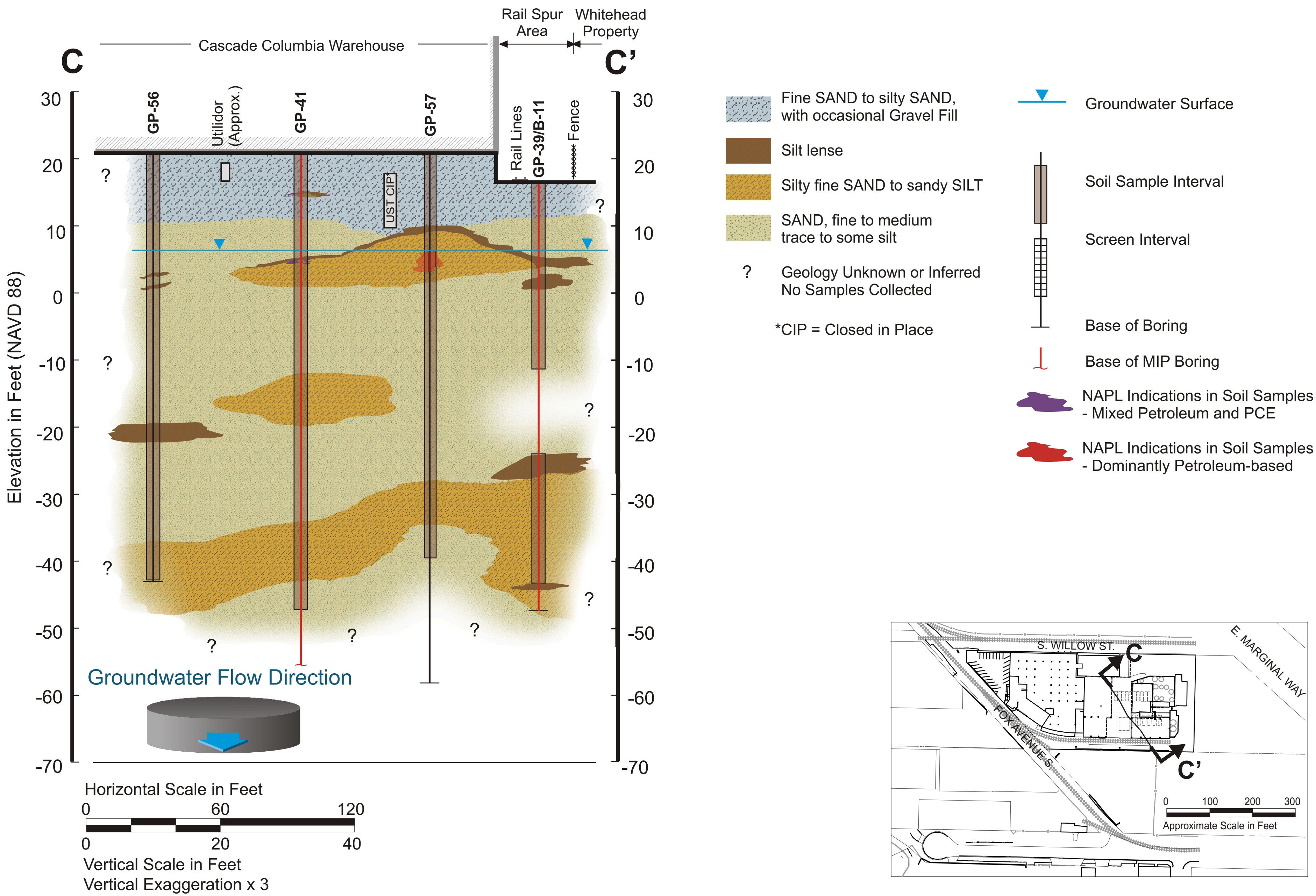

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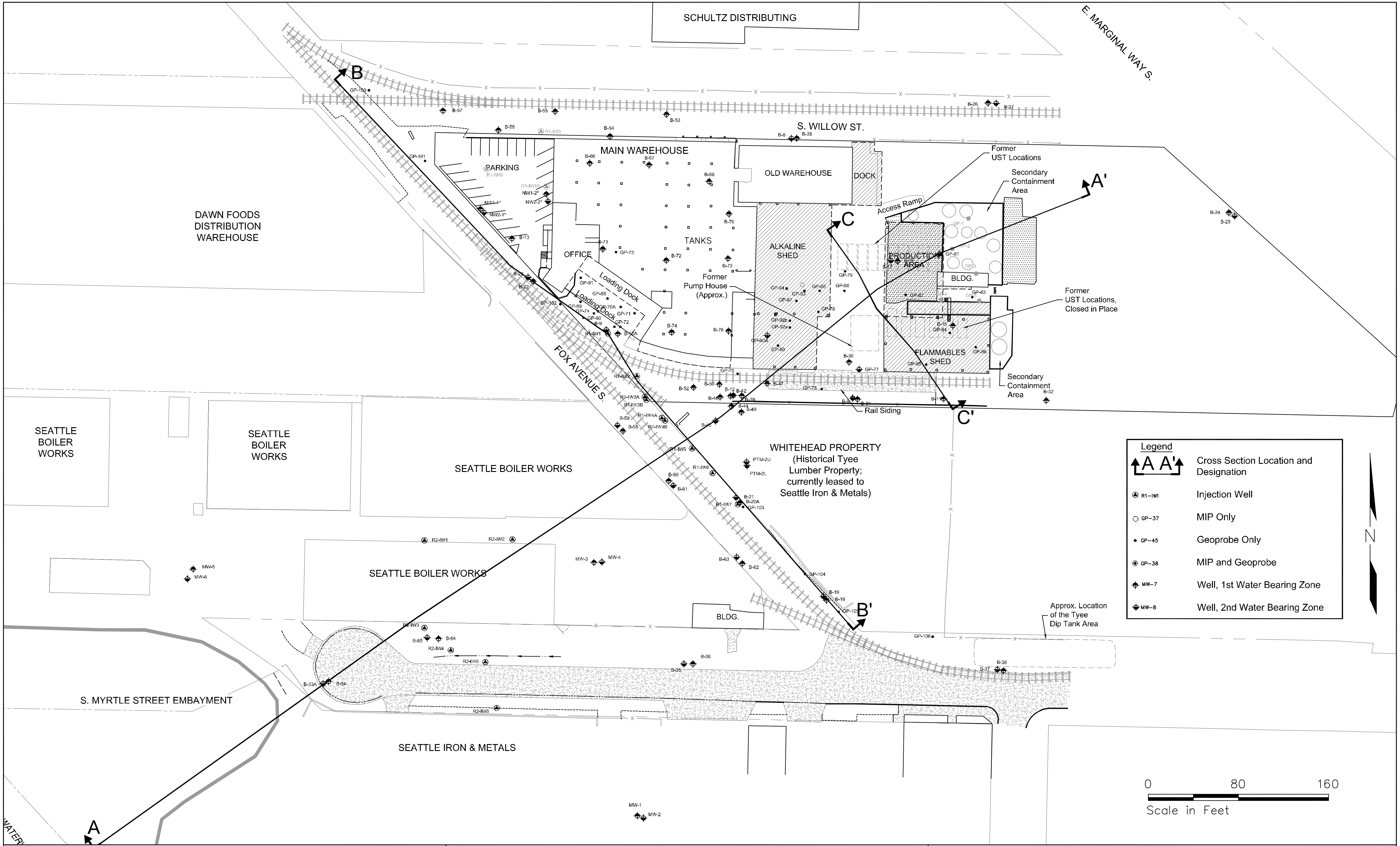
Figure 2.7c
Geologic Cross Section C-C'

G:Project\Clients\Floyd Snider\Fox Avenue\2010\Cross Sections\C-C'



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Fox Avenue Site
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Figure 2.8
Site Cross Section Locations

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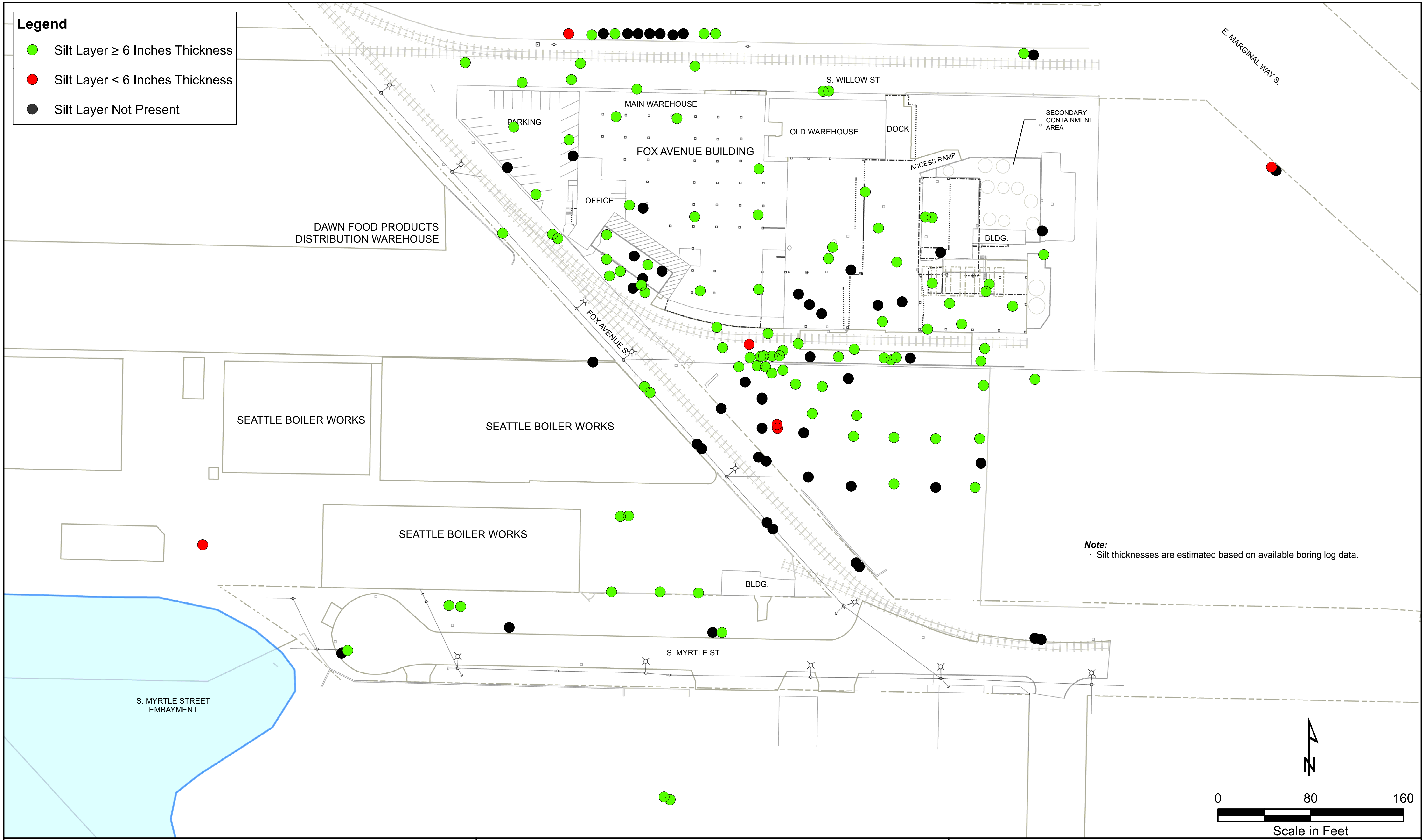

Note:
- Silt thicknesses are estimated based on available boring log data.

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Remedial Investigation/Feasibility Study
Fox Avenue Site
Seattle, Washington

Figure 2.9
1st Silt Horizon Map

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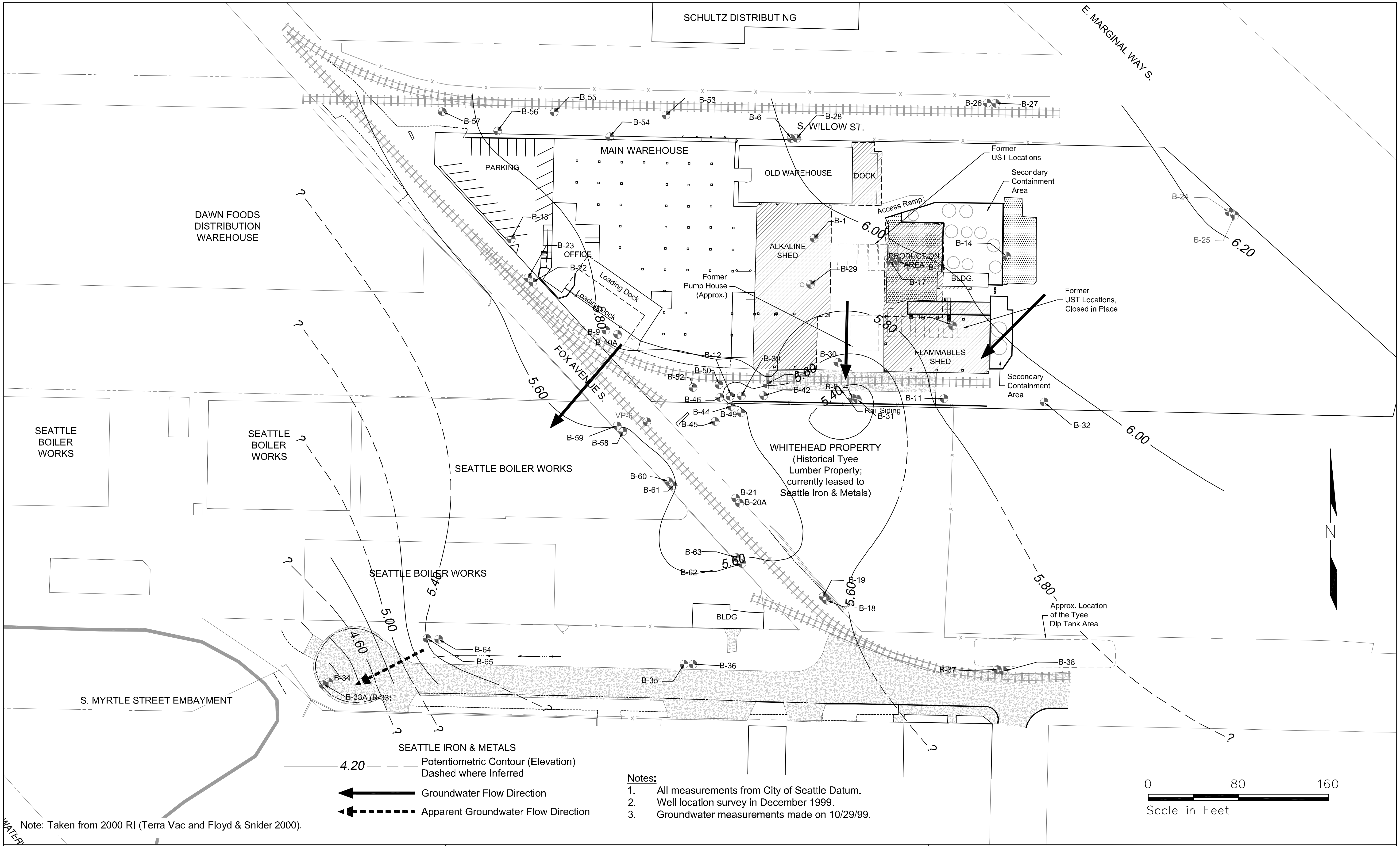

—— 4.20 — — — Potentiometric Contour (Elevation) Dashed where Inferred

Groundwater Flow Direction

Apparent Groundwater Flow Direction

Notes:
1. All measurements from City of Seattle Datum.
2. Well location survey in December 1999.
3. Groundwater measurements made on 10/29/99.

Note: Taken from 2000 RI (Terra Vac and Floyd & Snider 2000).

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Figure 2.10
Potentiometric Map
Low Tide 1st Water Bearing Zone

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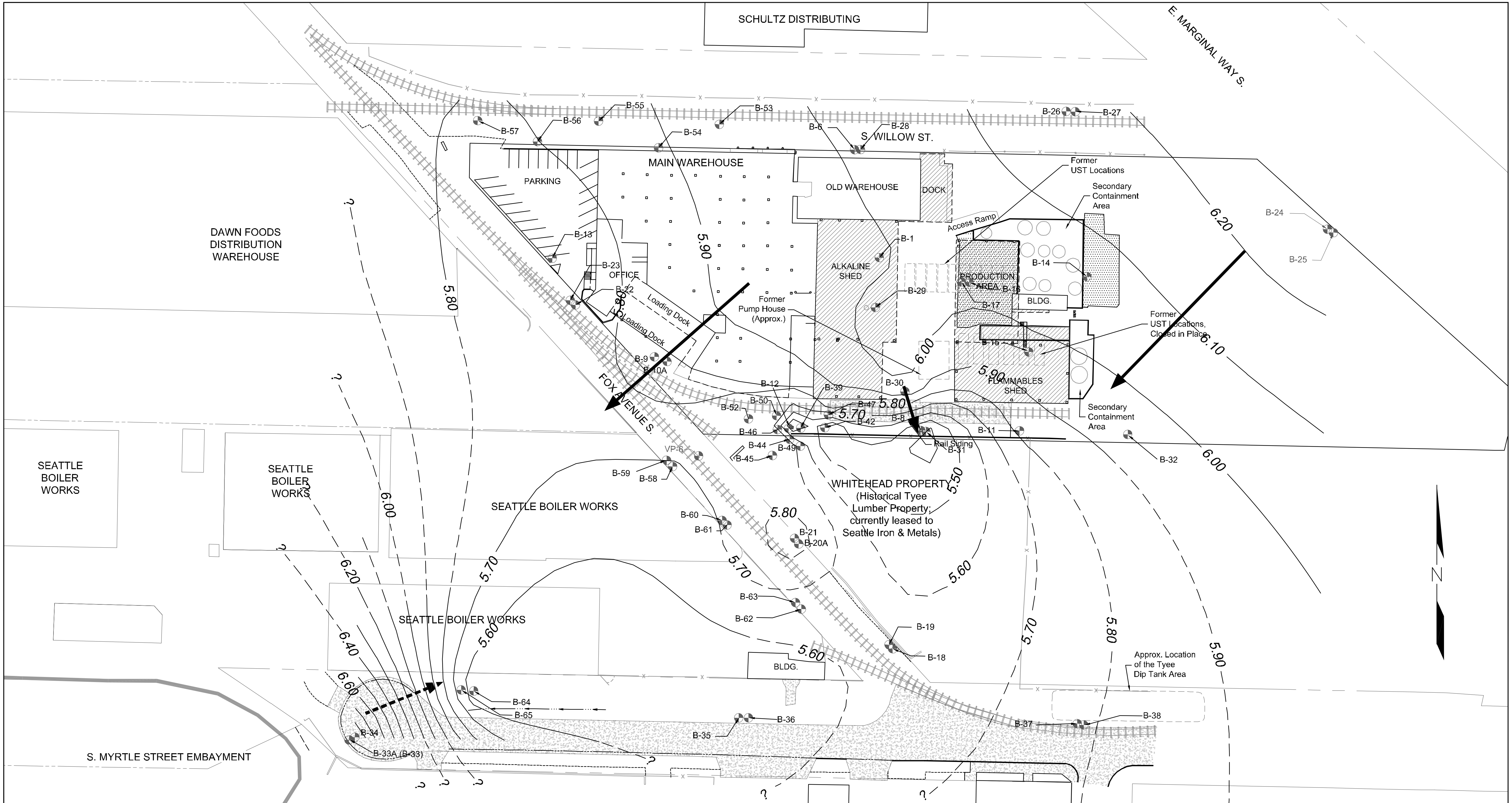
DATE: 2/8/2011 11:09 AM



4.20 — — Potentiometric Contour (Elevation) Dashed where Inferred

Groundwater Flow Direction

Apparent Groundwater Flow Direction

Notes:
1. All measurements from City of Seattle Datum.
2. Well location survey in December 1999.
3. Groundwater measurements made on 10/29/99.

Note: Taken from 2000 RI (Terra Vac and Floyd & Snider 2000).

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Figure 2.11
Potentiometric Map
High Tide 1st Water Bearing Zone

DWG NAME: G:\project\Clients\Floyd and Snider\Fox Ave 2010\CAD\FoxAve2010_005.dwg
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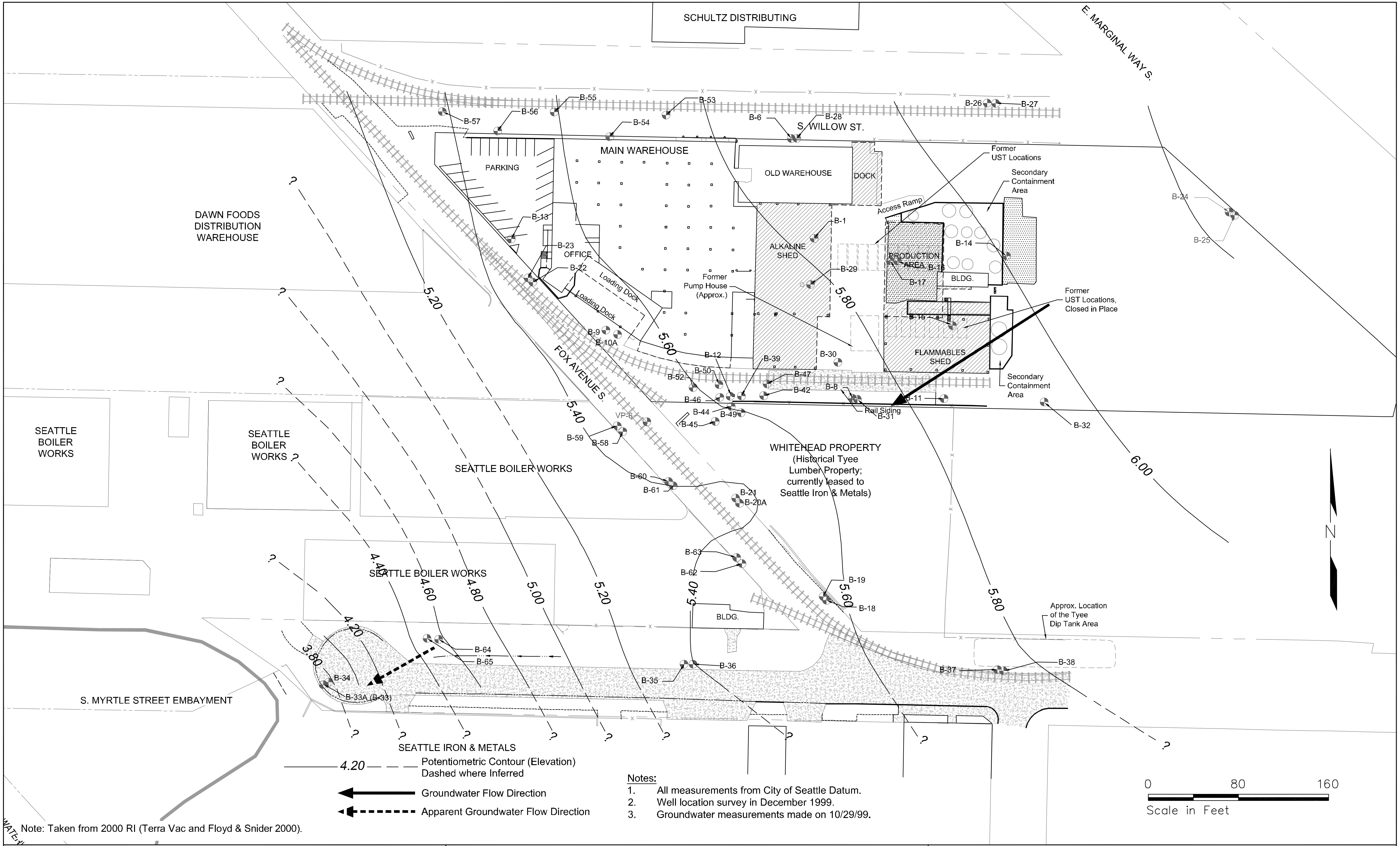

4.20 Potentiometric Contour (Elevation) Dashed where Inferred

Groundwater Flow Direction

Apparent Groundwater Flow Direction

Note: Taken from 2000 RI (Terra Vac and Floyd & Snider 2000).

Notes:

1. All measurements from City of Seattle Datum.
2. Well location survey in December 1999.
3. Groundwater measurements made on 10/29/99.

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Fox Avenue Site
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Figure 2.12
Potentiometric Map
Low Tide 2nd Water Bearing Zone

DWG NAME: G:\project\Clients\Floyd and Snider\Fox Ave 2010\CAD\FoxAve2010_005.dwg
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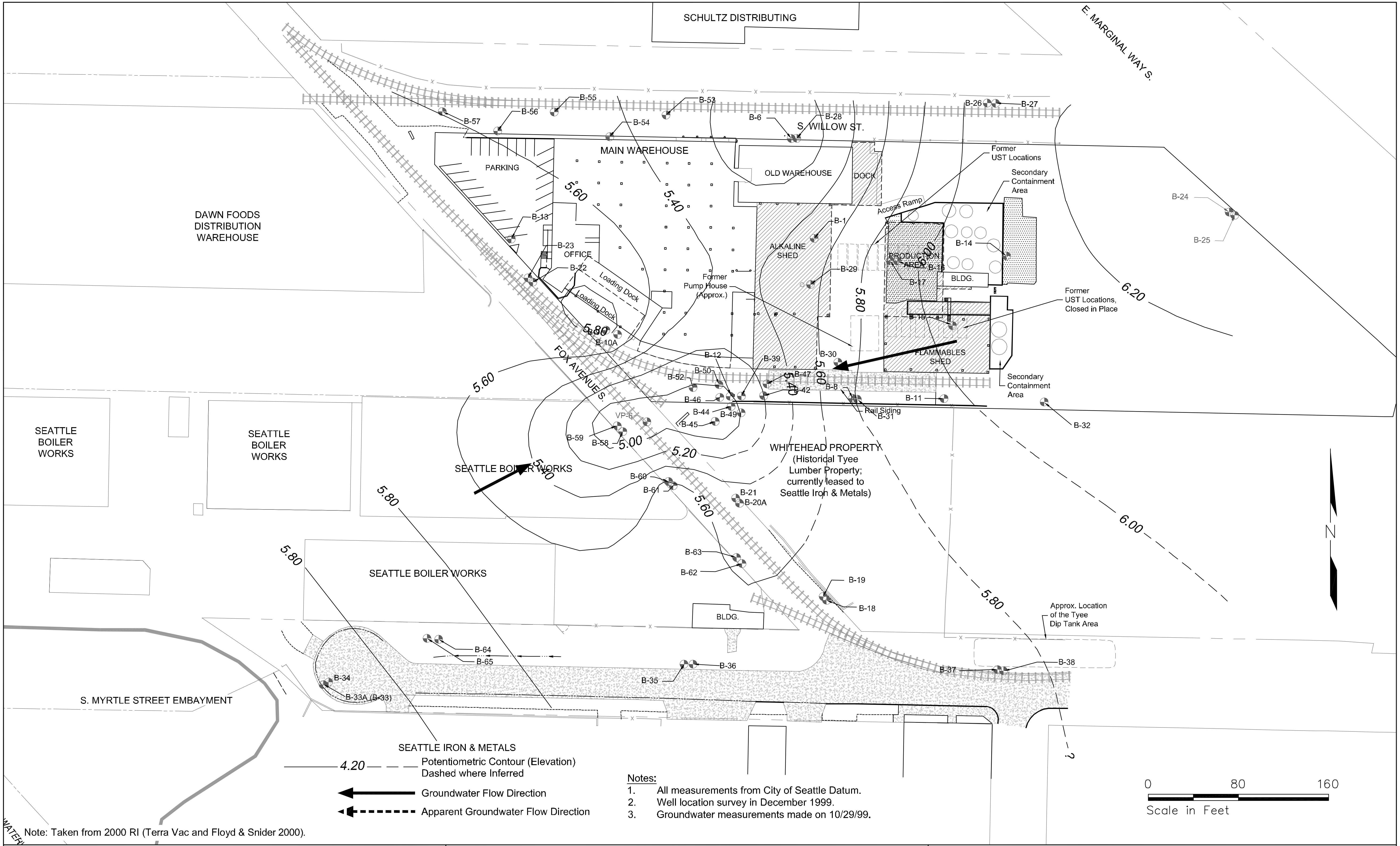

4.20 — — — Potentiometric Contour (Elevation) Dashed where Inferred

Groundwater Flow Direction

Apparent Groundwater Flow Direction

Note: Taken from 2000 RI (Terra Vac and Floyd & Snider 2000).

Notes:

1. All measurements from City of Seattle Datum.
2. Well location survey in December 1999.
3. Groundwater measurements made on 10/29/99.

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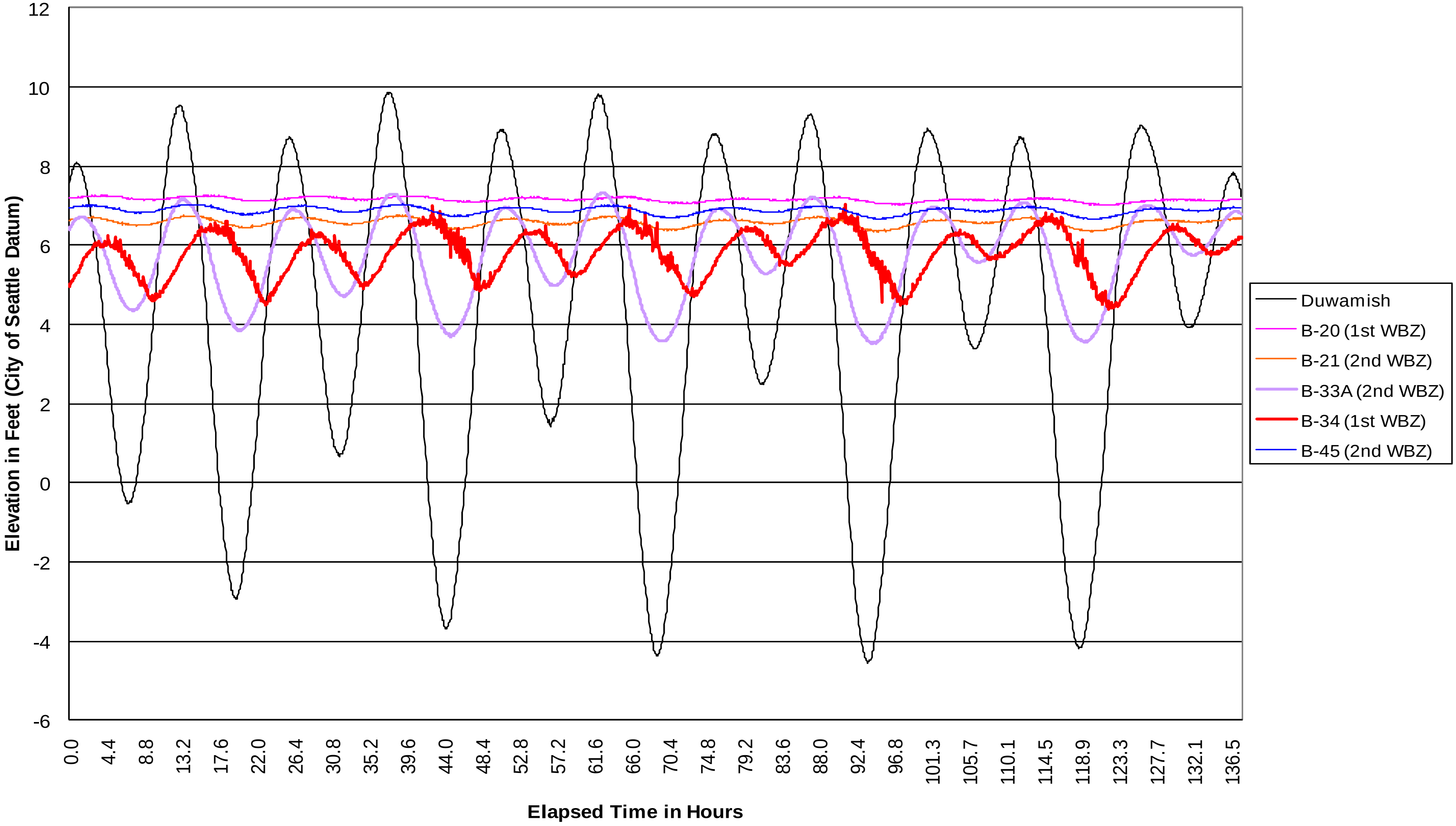
Remedial Investigation/Feasibility Study
Fox Avenue Site
Seattle, Washington

Figure 2.13
Potentiometric Map
High Tide 2nd Water Bearing Zone

DWG NAME: G:\project\Clients\Floyd and Snider\Fox Ave 2010\CAD\FoxAve2010_005.dwg
DATE: 2/8/2011 11:11 AM



Notes:
WBZ = Water Bearing Zone.
Source: 2000 SRI/FS (Terra Vac and Floyd & Snider Inc. 2000).

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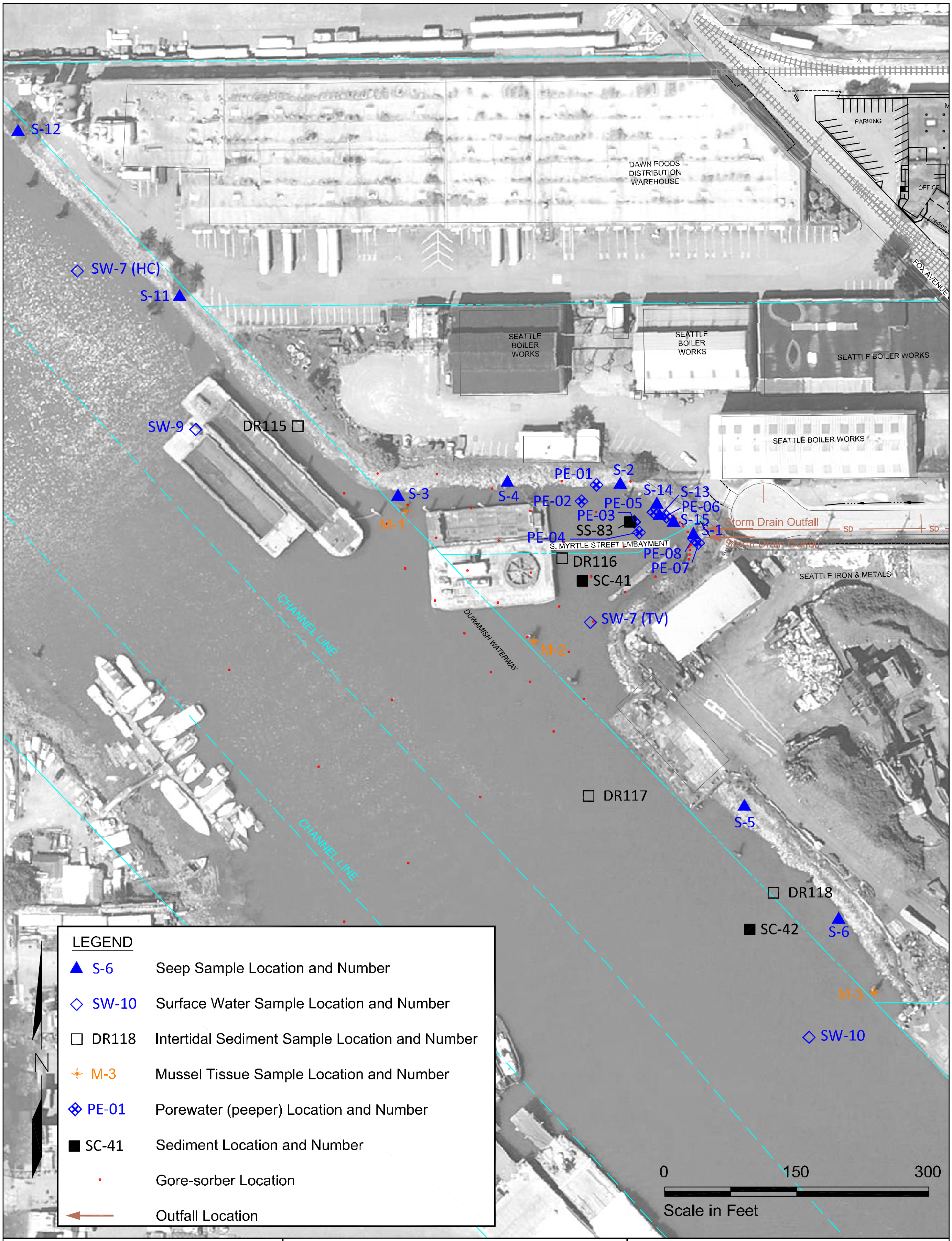
Figure 2.14
Transducer Responses for Monitoring
Wells B-20, B-21, B-33A, B-34, and B-45



DWG NAME: G:\project\Clients\Floyd and Snider\Fox Ave 2010\CAD\FoxAve2010_011.dwg
DATE: 2/8/2011 11:49 AM

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Figure 2.15
Seep, Surface Water,
Sediment, Porewater, and
Mussel Sample Locations

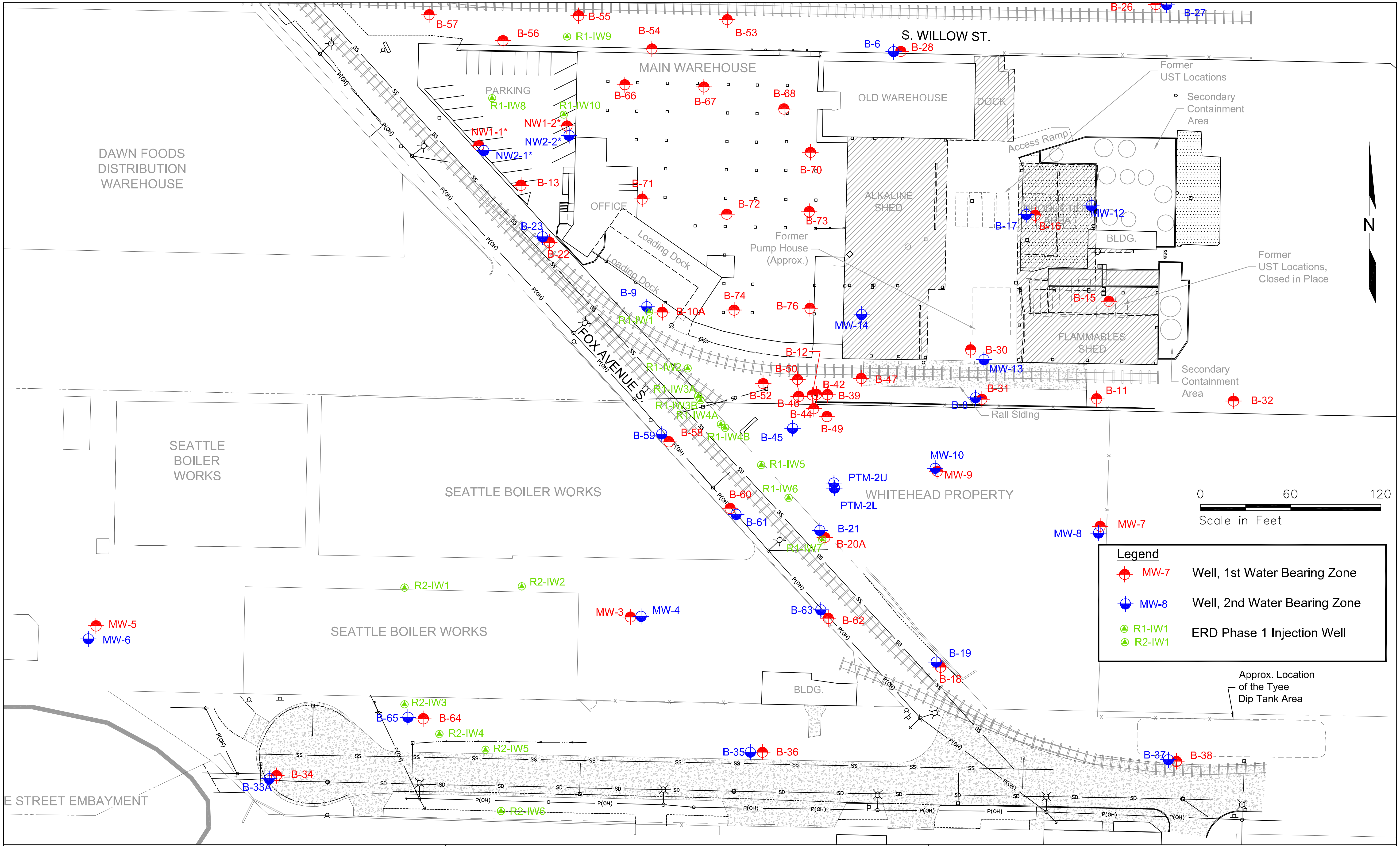

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Figure 3.1
Groundwater Well Locations

DWG NAME: G:\project\Clients\Floyd and Snider\Fox Ave 2010\CAD\FoxAve2010_013.dwg
DATE: 2/8/2011 11:51 AM

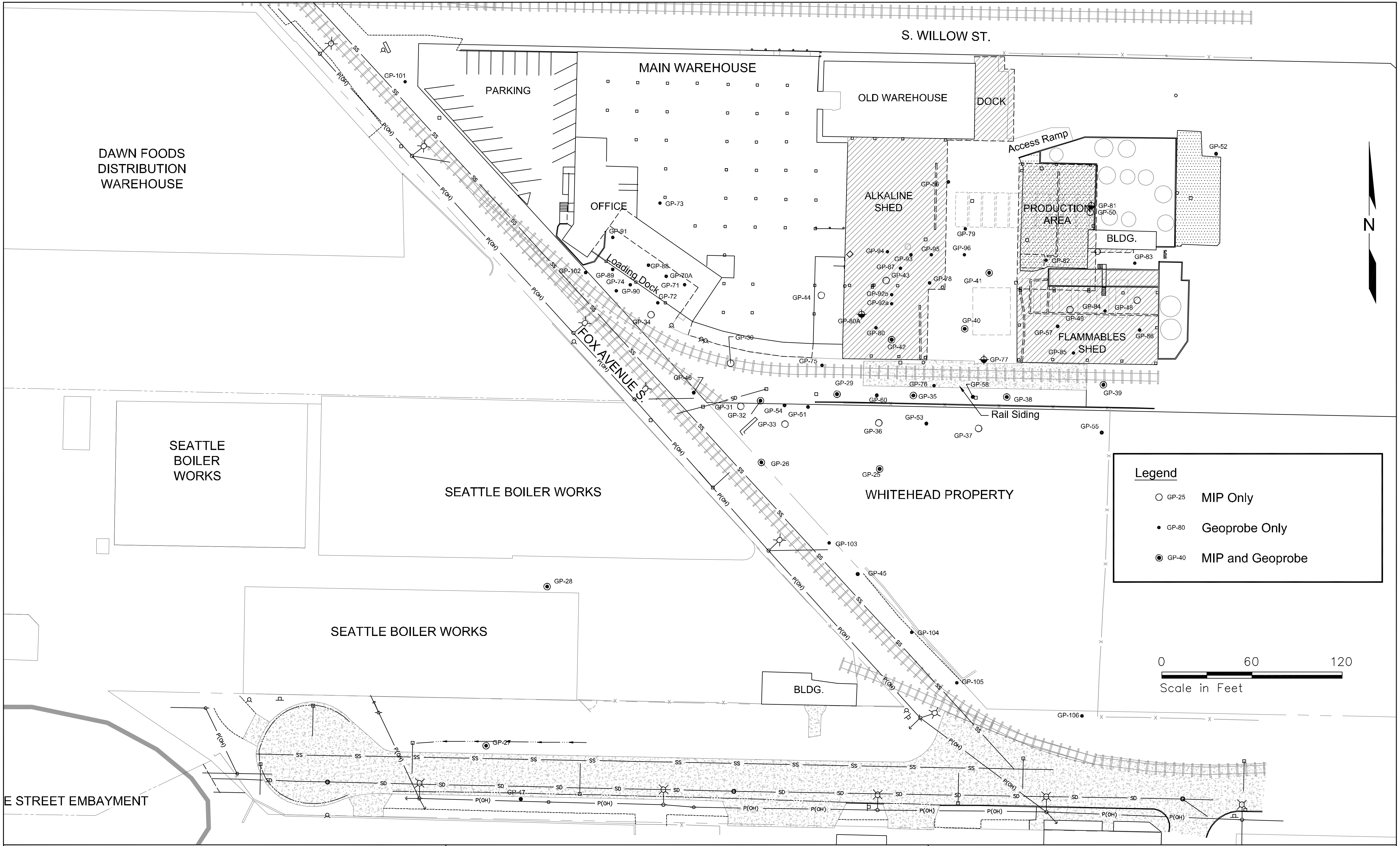

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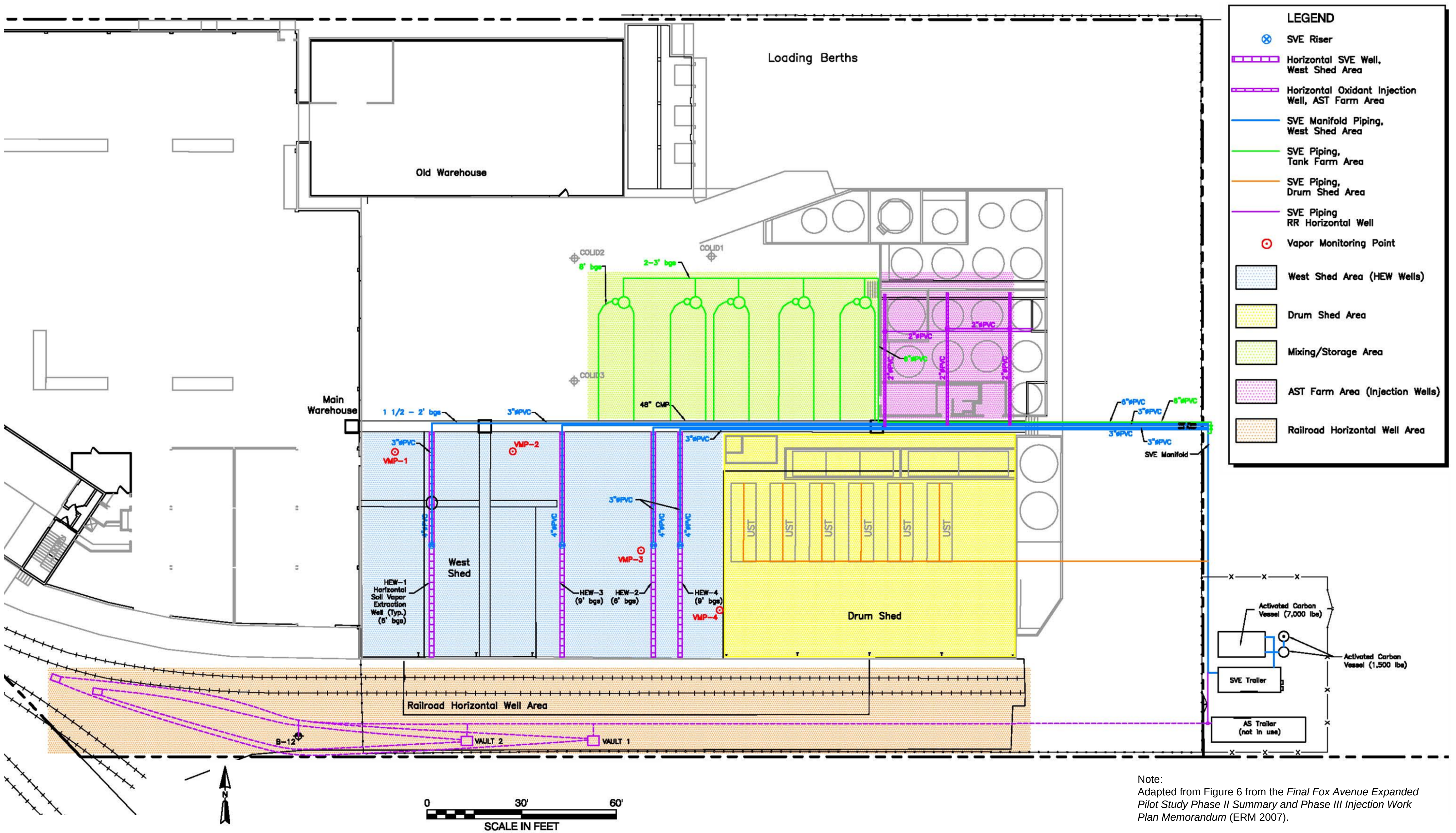
Figure 3.2
Boring Locations
(2008 to 2010)

DWG NAME: G:\project\Clients\Floyd and Snider\Fox Ave 2010\CAD\FoxAve2010_012.dwg
DATE: 2/8/2011 12:11 PM



Note:
Adapted from Figure 6 from the *Final Fox Avenue Expanded Pilot Study Phase II Summary and Phase III Injection Work Plan Memorandum* (ERM 2007).

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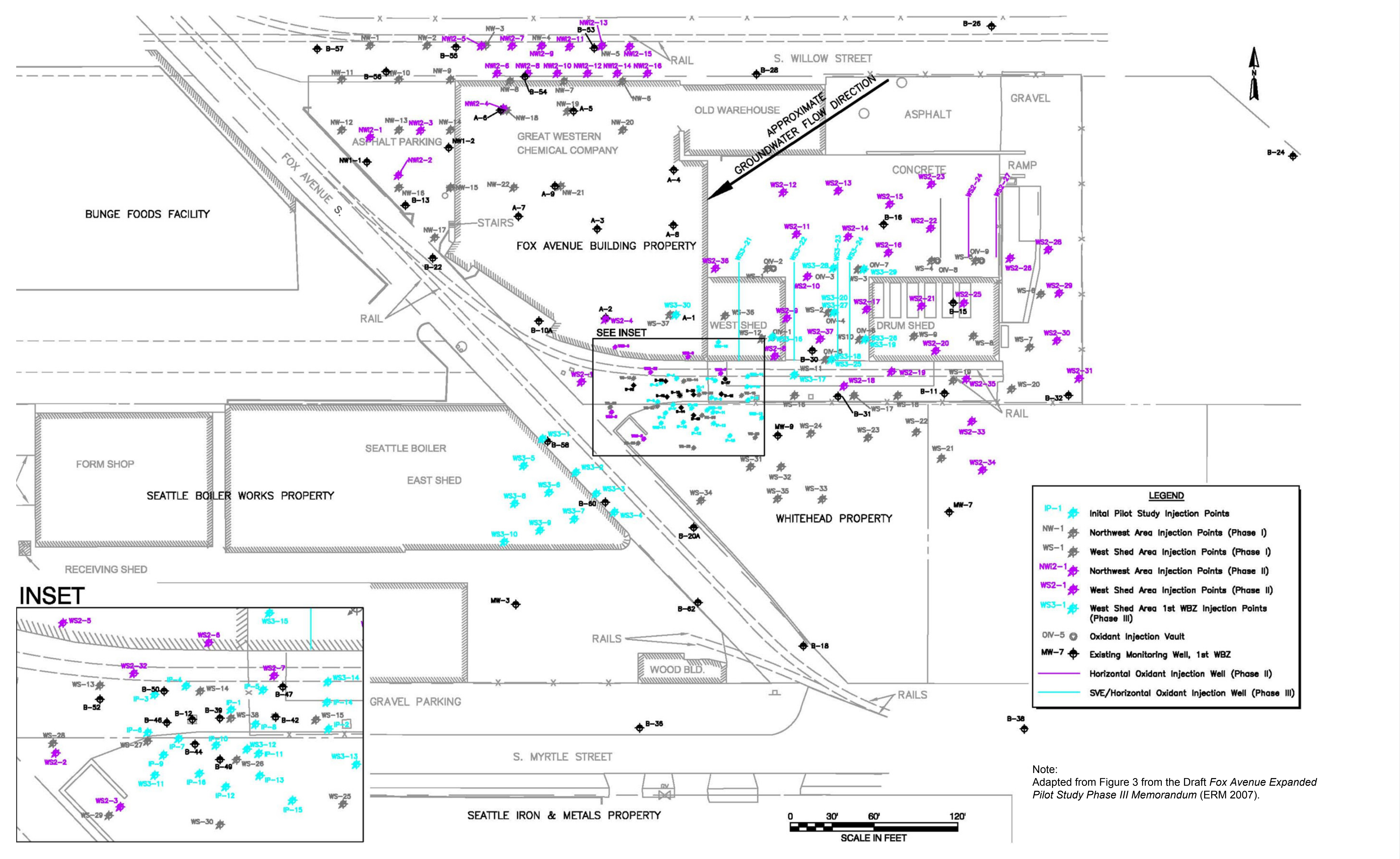
Figure 3.3
Soil Vapor Extraction System Layout

F:\projects\FoxAve-RA\REPORT 2010 Revised RIFS\10 TECH EDIT\Figures\FA RIFS F3.3 020811.vsd



Note:
Adapted from Figure 3 from the Draft *Fox Avenue Expanded Pilot Study Phase III Memorandum* (ERM 2007).

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Figure 3.4
Expanded Pilot Study Phase III
1st Water Bearing Zone Injection Point Locations

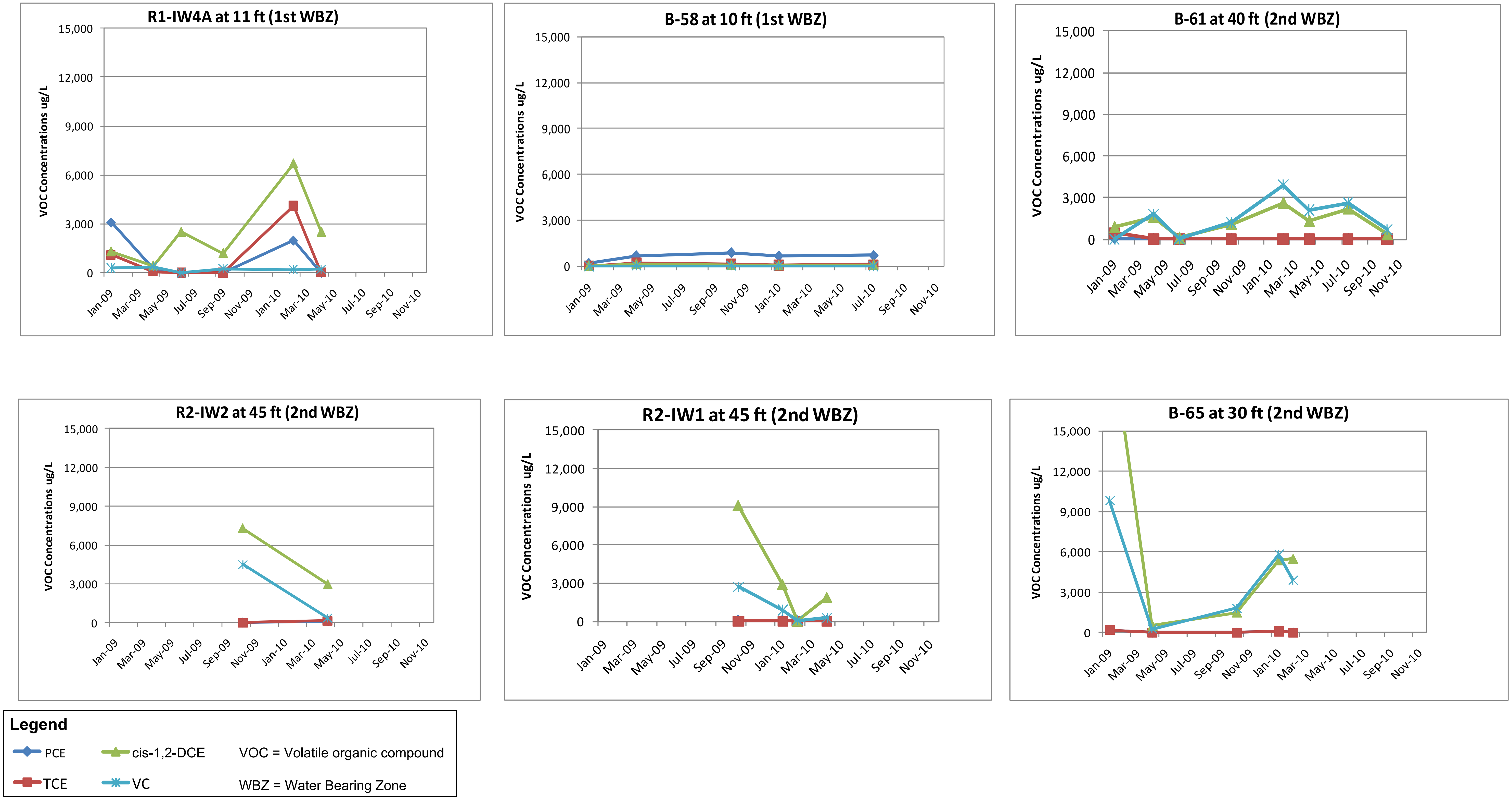

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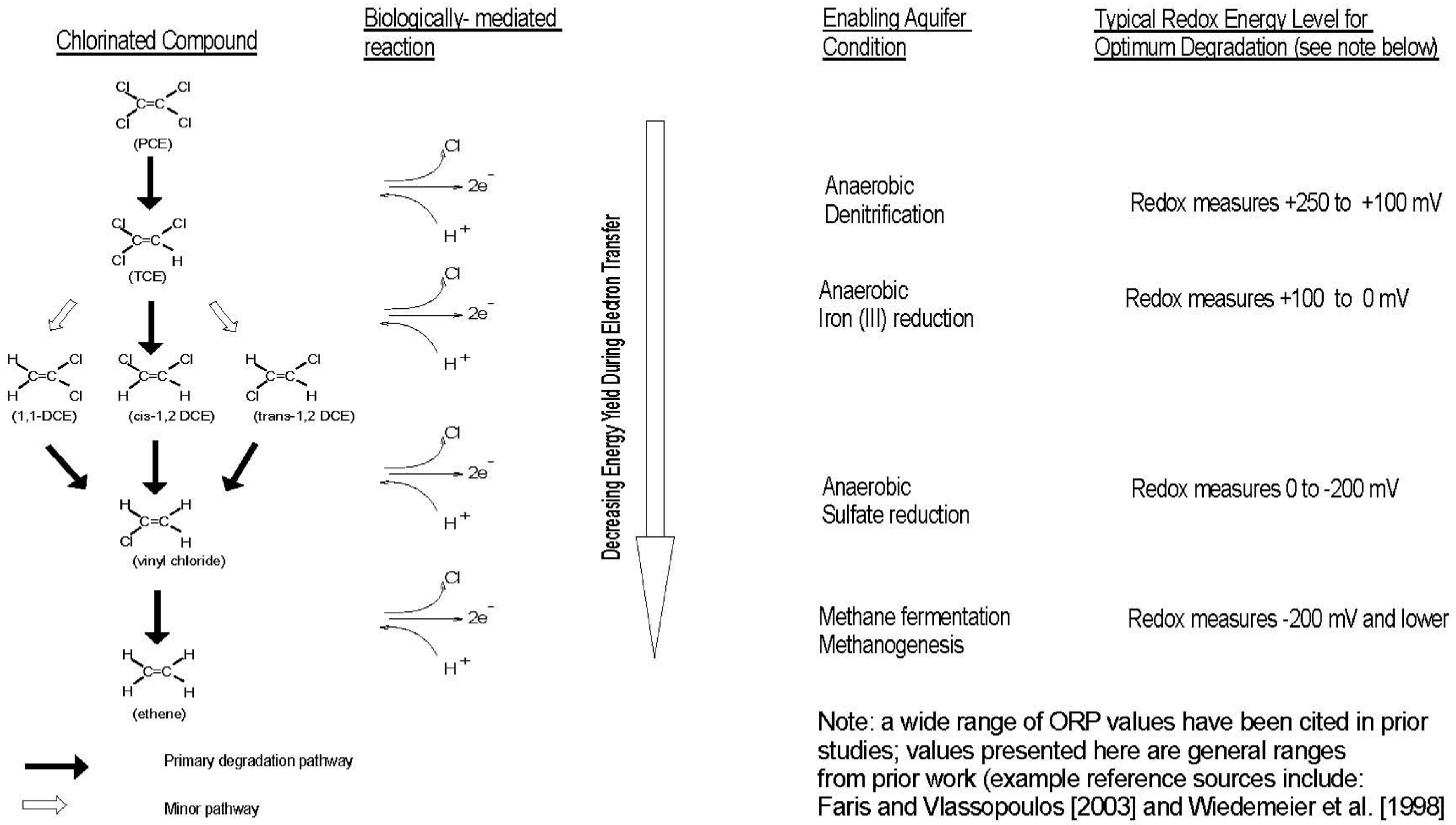
Figure 3.5
Enhanced Reductive Dechlorination Trend Graphs
Baseline to End of the 4th Quarter of the Interim Action



Note: a wide range of ORP values have been cited in prior studies; values presented here are general ranges from prior work (example reference sources include: Faris and Vlassopoulos [2003] and Wiedemeier et al. [1998]

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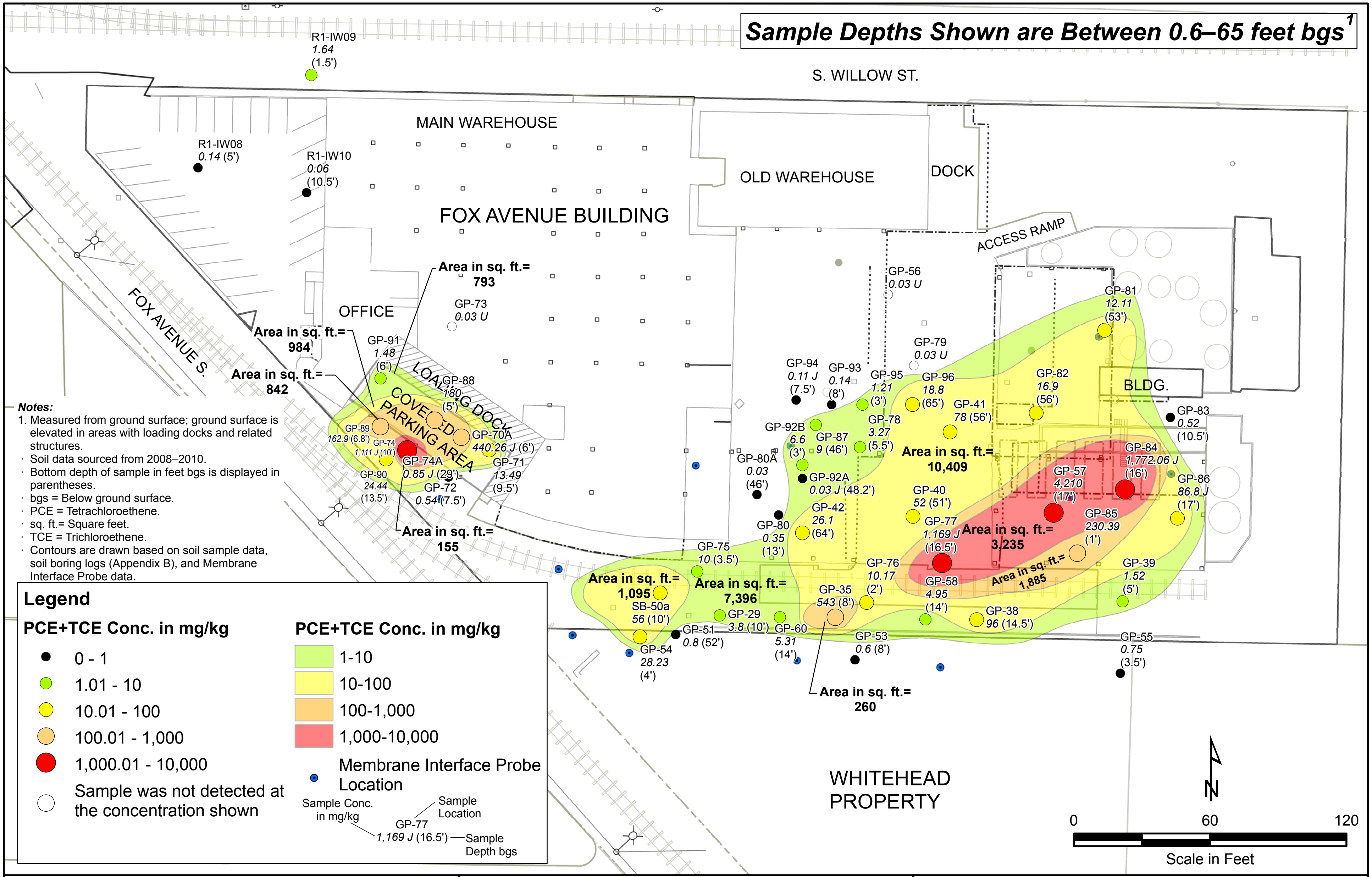
Figure 5.1
Degradation Pathways of Chlorinated Ethenes by Reductive Dechlorination



Notes:

1. Measured from ground surface; ground surface is elevated in areas with loading docks and related structures.

- Soil data sourced from 2008–2010.
- Bottom depth of sample in feet bgs is displayed in parentheses.
- bgs = Below ground surface.
- PCE = Tetrachloroethene.
- sq. ft.= Square feet.
- TCE = Trichloroethene.
- Contours are drawn based on soil sample data, soil boring logs (Appendix B), and Membrane Interface Probe data.

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Figure 5.2
Current Conditions: Maximum PCE+TCE Concentration in Soil at any Depth

File: F:\projects\FoxAve-RA\GIS\MXD\RIFS\2011 RIFS\Figure 5.2 (Max PCE+TCE in Soil Locations Irrespective of Depth).mxd
Date: 2/8/2011

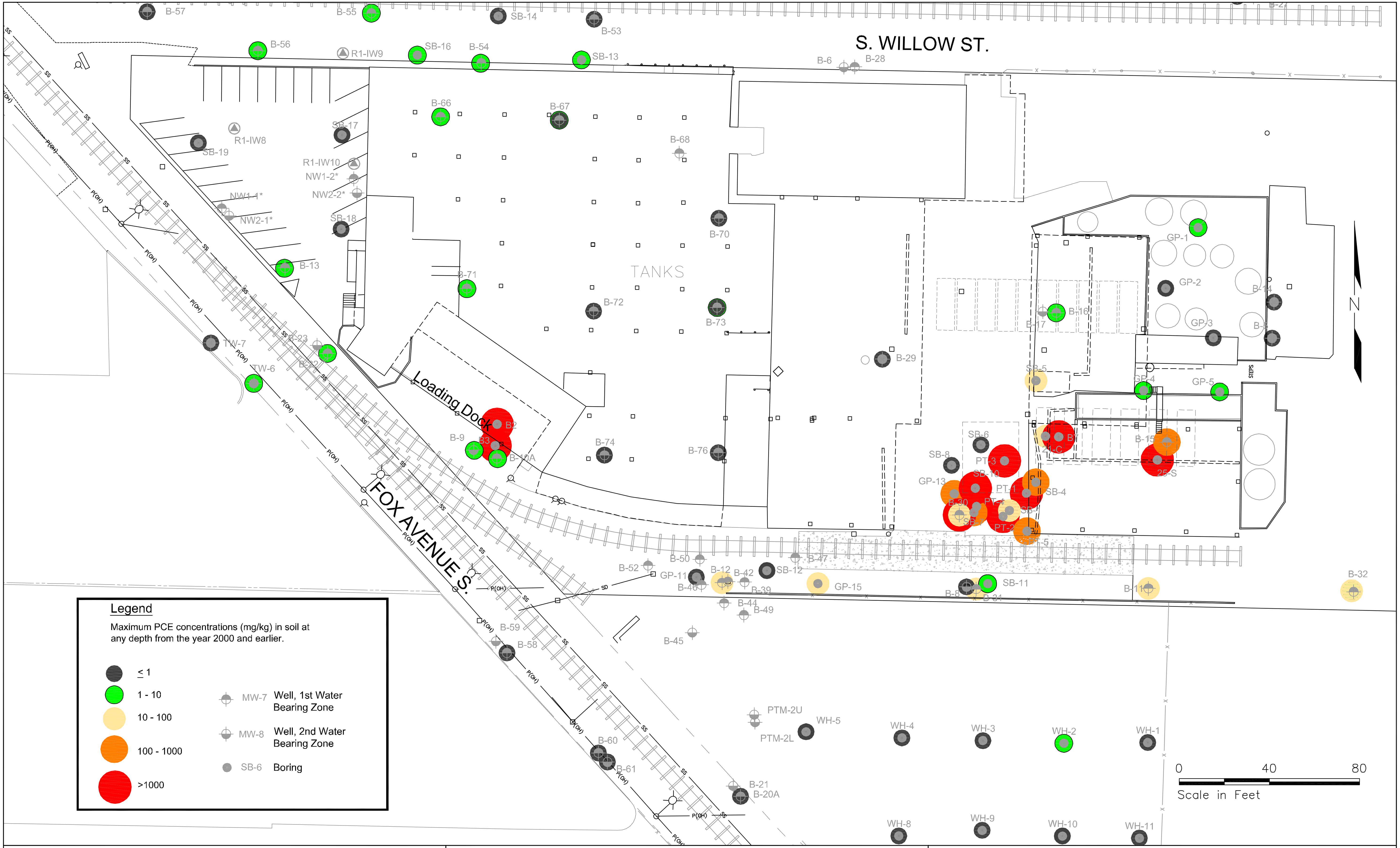

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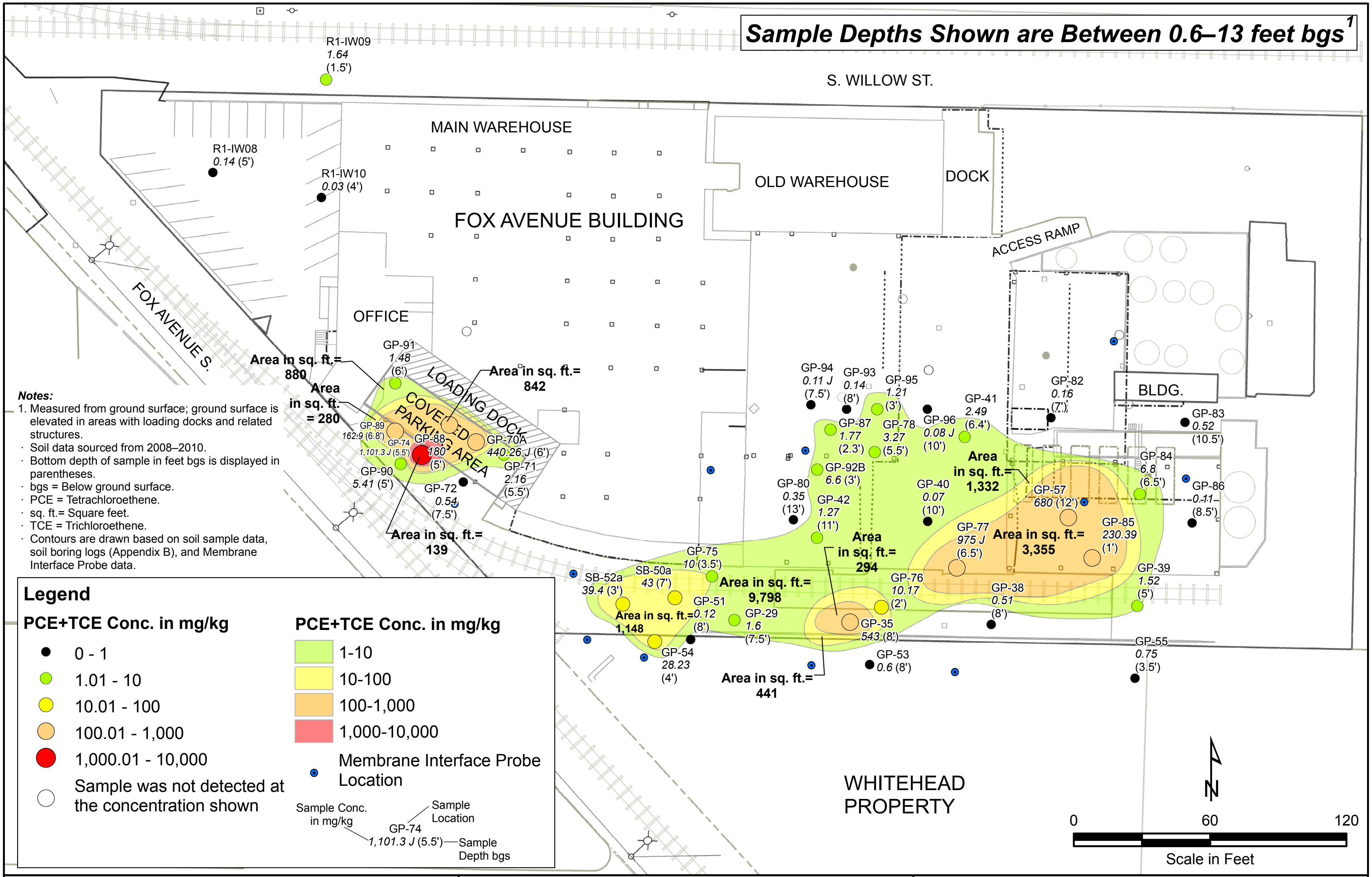
Figure 5.3
Historical Maximum PCE Concentrations in Soil
(2000 and Earlier)

DWG NAME: G:\project\Clients\Floyd and Snider\Fox Ave 2010\CAD\FoxAve2010_009.dwg
DATE: 2/8/2011 12:18 PM



Sample Depths Shown are Between 0.6–13 feet bgs[1]

Notes:

1. Measured from ground surface; ground surface is elevated in areas with loading docks and related structures.

- Soil data sourced from 2008–2010.
- Bottom depth of sample in feet bgs is displayed in parentheses.
- bgs = Below ground surface.
- PCE = Tetrachloroethene.
- sq. ft.= Square feet.
- TCE = Trichloroethene.
- Contours are drawn based on soil sample data, soil boring logs (Appendix B), and Membrane Interface Probe data.

Legend

PCE+TCE Conc. in mg/kg

- ● 0 - 1
- ● 1.01 - 10
- ● 10.01 - 100
- ● 100.01 - 1,000
- ● 1,000.01 - 10,000
- ○ Sample was not detected at the concentration shown

PCE+TCE Conc. in mg/kg

- 🟩 1-10
- 🟨 10-100
- 🟧 100-1,000
- 🟥 1,000-10,000
- ⊙ Membrane Interface Probe Location

Sample Conc. in mg/kg
Sample Location
GP-74
1,101.3 J (5.5')
Sample Depth bgs

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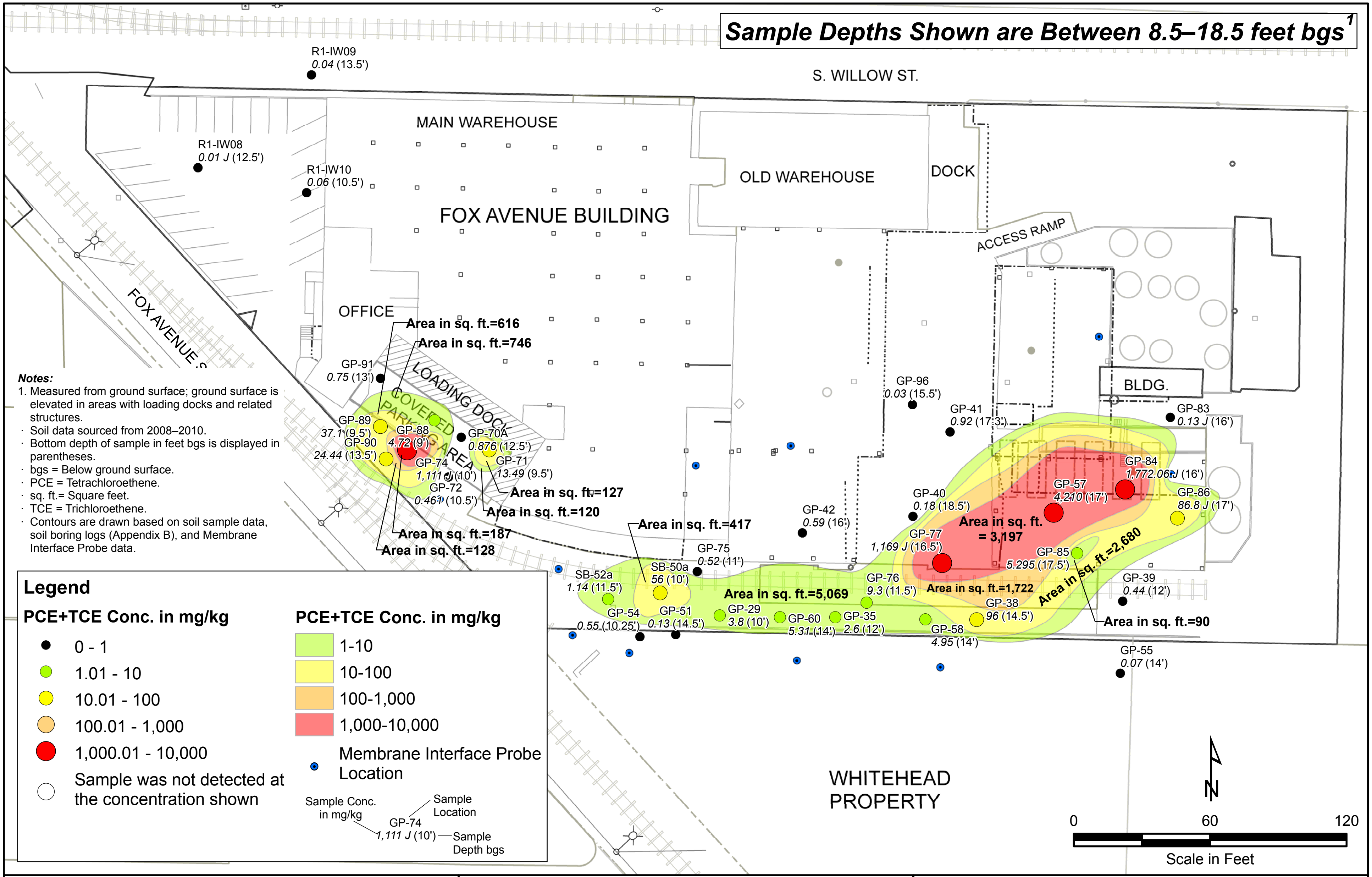
Figure 5.4a
Current Conditions: Maximum PCE+ TCE Concentration in Soil at any Depth in Vadose Zone

File: F:\projects\FoxAve-RA\GIS\MXD\RIFS\2011 RIFS\Figure 5.4a (Max PCE+TCE in Vadose Zone Soil Locations).mxd
Date: 2/8/2011



Notes:

1. Measured from ground surface; ground surface is elevated in areas with loading docks and related structures.

- Soil data sourced from 2008–2010.
- Bottom depth of sample in feet bgs is displayed in parentheses.
- bgs = Below ground surface.
- PCE = Tetrachloroethene.
- sq. ft.= Square feet.
- TCE = Trichloroethene.
- Contours are drawn based on soil sample data, soil boring logs (Appendix B), and Membrane Interface Probe data.

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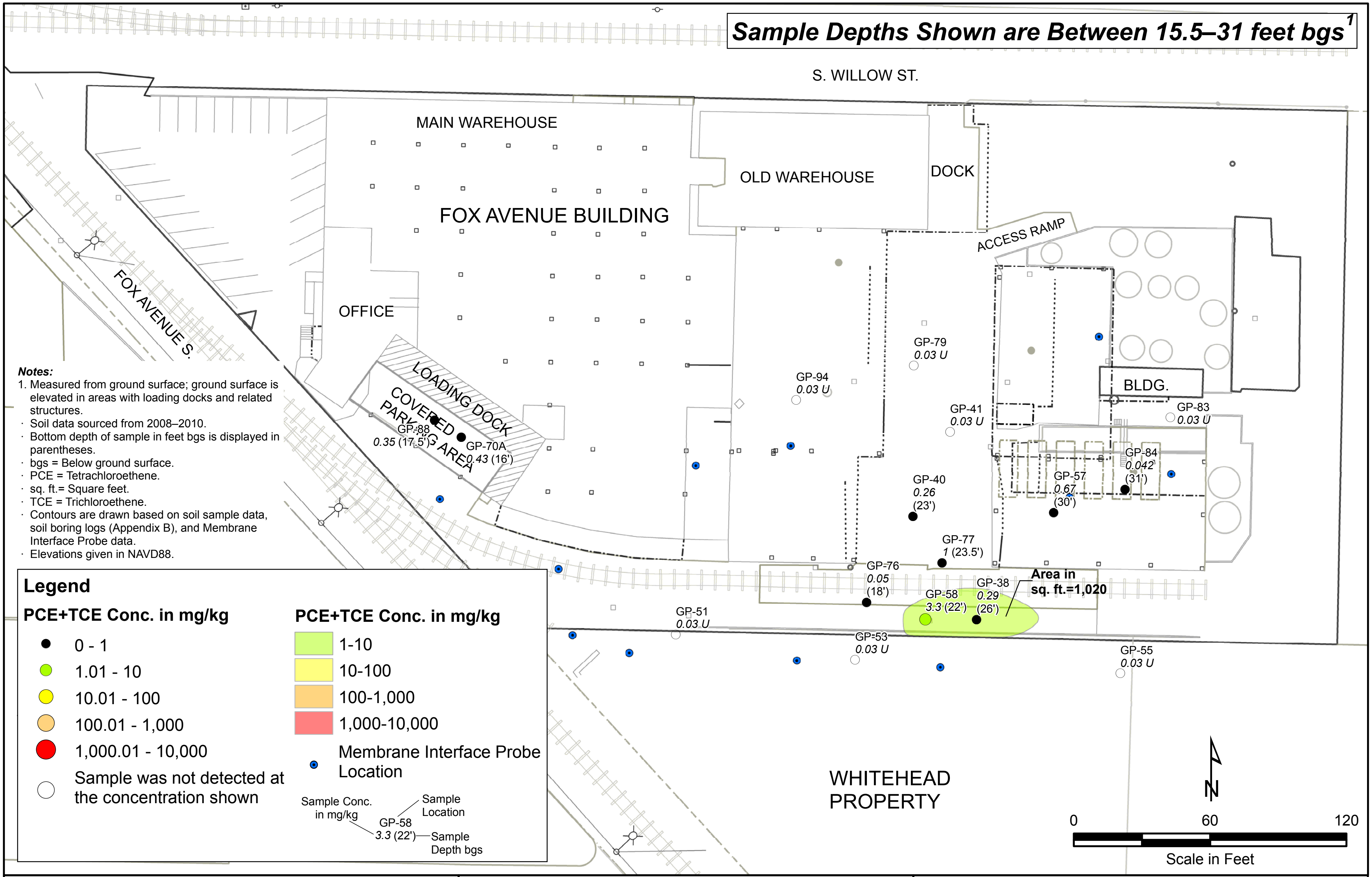
Figure 5.4b
Current Conditions: Maximum PCE+TCE Concentration in Soil within 1st Water Bearing Zone and 1st Silt Horizon

File: F:\projects\FoxAve-RA\GIS\MXD\RIFS\2011 RIFS\Figure 5.4b (Max PCE+TCE in 1st Water Bearing Zone Soil Locations).mxd
Date: 2/8/2011



Notes:

1. Measured from ground surface; ground surface is elevated in areas with loading docks and related structures.

- Soil data sourced from 2008–2010.
- Bottom depth of sample in feet bgs is displayed in parentheses.
- bgs = Below ground surface.
- PCE = Tetrachloroethene.
- sq. ft.= Square feet.
- TCE = Trichloroethene.
- Contours are drawn based on soil sample data, soil boring logs (Appendix B), and Membrane Interface Probe data.
- Elevations given in NAVD88.

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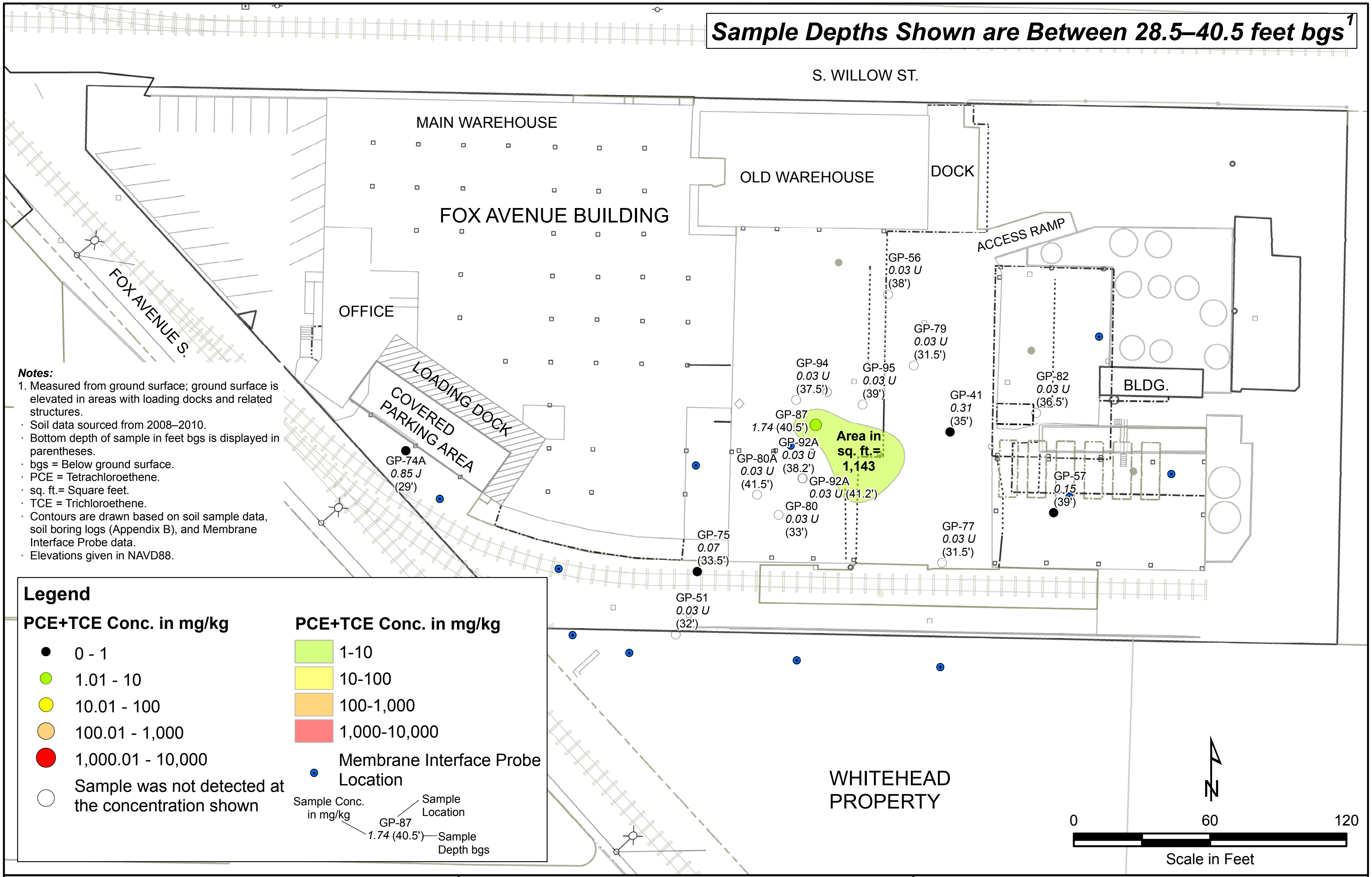
Figure 5.4c
Current Conditions: Maximum PCE+TCE Concentration in Soil within 2nd Water Bearing Zone between Elevation 0 and -10 feet

File: F:\projects\FoxAve-RA\GIS\MXD\RIFS\2011 RIFS\Figure 5.4c (Max PCE+TCE in 2nd Water Bearing Zone Soil Locations NAVD88 Elev 0 to -10).mxd
Date: 2/8/2011



Notes:

1. Measured from ground surface; ground surface is elevated in areas with loading docks and related structures.
- Soil data sourced from 2008–2010.
- Bottom depth of sample in feet bgs is displayed in parentheses.
- bgs = Below ground surface.
- PCE = Tetrachloroethene.
- sq. ft.= Square feet.
- TCE = Trichloroethene.
- Contours are drawn based on soil sample data, soil boring logs (Appendix B), and Membrane Interface Probe data.
- Elevations given in NAVD88.

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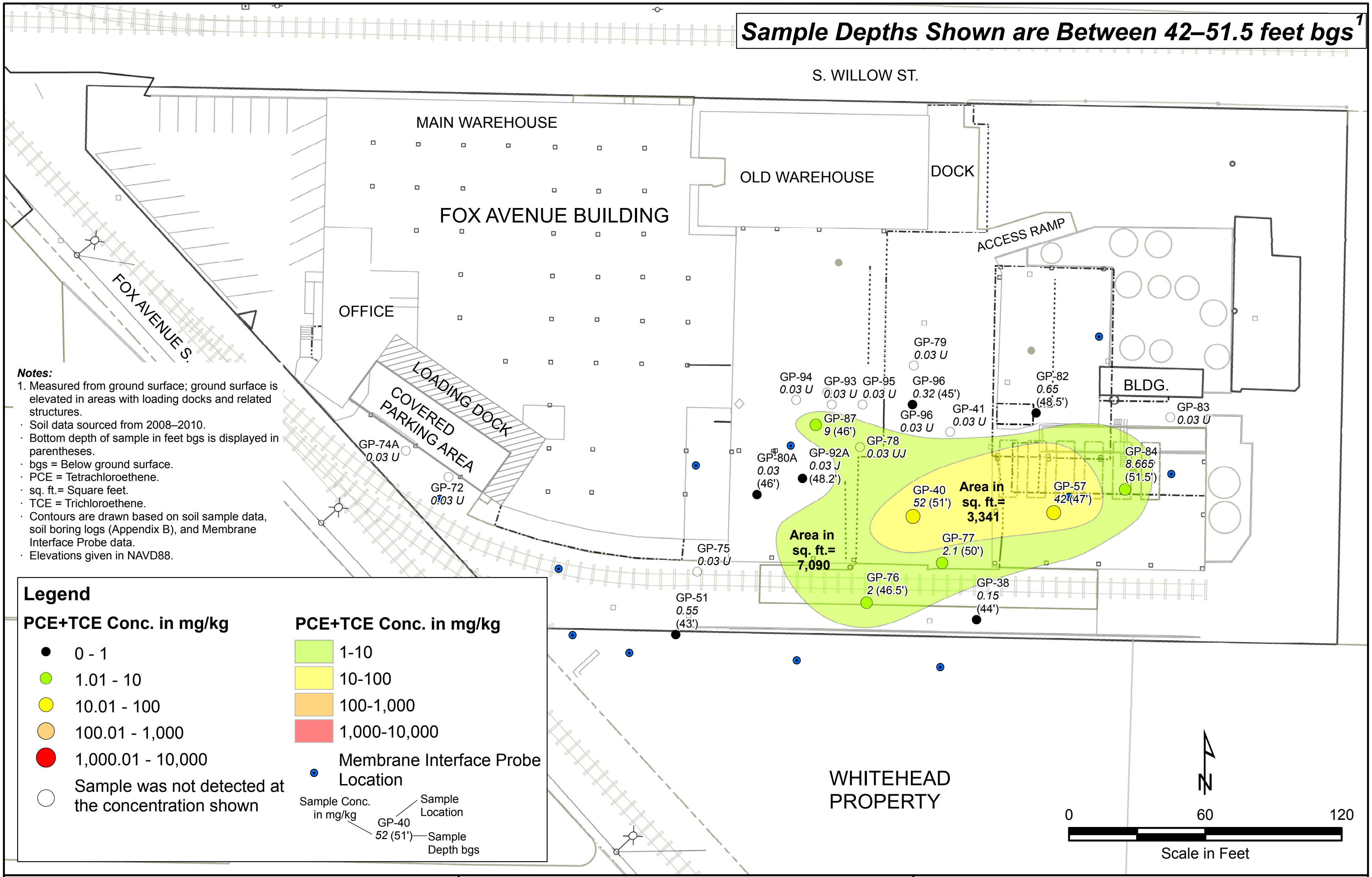
Figure 5.4d
Current Conditions: Maximum PCE+TCE Concentration in Soil within 2nd Water Bearing Zone between Elevation -10 and -20 feet

File: F:\projects\FoxAve-RA\GIS\MXD\RIFS\2011 RIFS\Figure 5.4d (Max PCE+TCE in 2nd Water Bearing Zone Soil Locations NAVD88 Elev -10 to -20).mxd
Date: 2/8/2011

Sample Depths Shown are Between 42–51.5 feet bgs[1]



Notes:

1. Measured from ground surface; ground surface is elevated in areas with loading docks and related structures.

- Soil data sourced from 2008–2010.
- Bottom depth of sample in feet bgs is displayed in parentheses.
- bgs = Below ground surface.
- PCE = Tetrachloroethene.
- sq. ft.= Square feet.
- TCE = Trichloroethene.
- Contours are drawn based on soil sample data, soil boring logs (Appendix B), and Membrane Interface Probe data.
- Elevations given in NAVD88.

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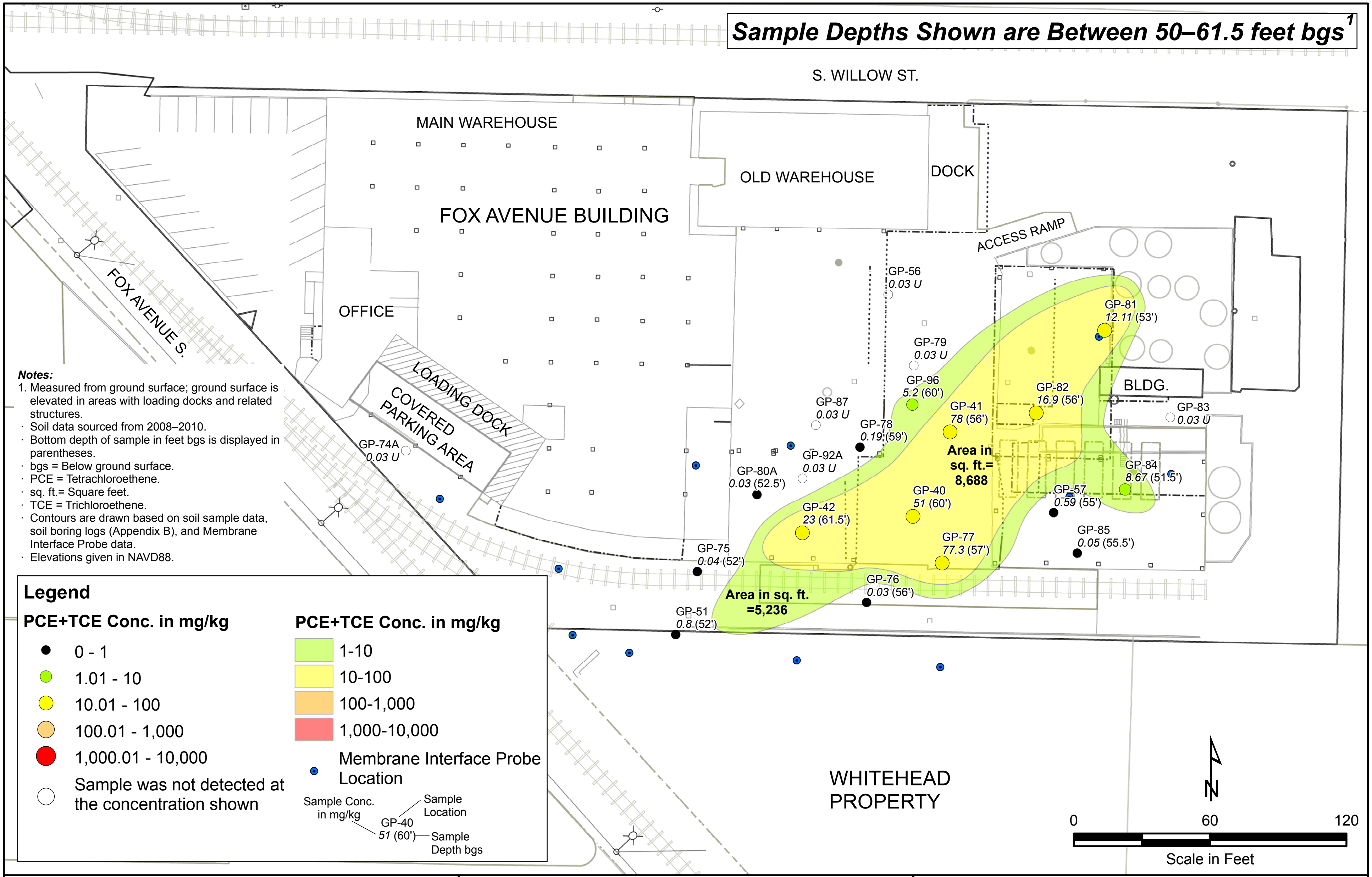
Figure 5.4e
Current Conditions: Maximum PCE+TCE Concentration in Soil within 2nd Water Bearing Zone between Elevation -20 and -30 feet

File: F:\projects\FoxAve-RA\GIS\MXD\RIFS\2011 RIFS\Figure 5.4e (Max PCE+TCE in 2nd Water Bearing Zone Soil Locations NAVD88 Elev -20 to -30).mxd
Date: 2/8/2011



Notes:

1. Measured from ground surface; ground surface is elevated in areas with loading docks and related structures.

- Soil data sourced from 2008–2010.
- Bottom depth of sample in feet bgs is displayed in parentheses.
- bgs = Below ground surface.
- PCE = Tetrachloroethene.
- sq. ft.= Square feet.
- TCE = Trichloroethene.
- Contours are drawn based on soil sample data, soil boring logs (Appendix B), and Membrane Interface Probe data.
- Elevations given in NAVD88.

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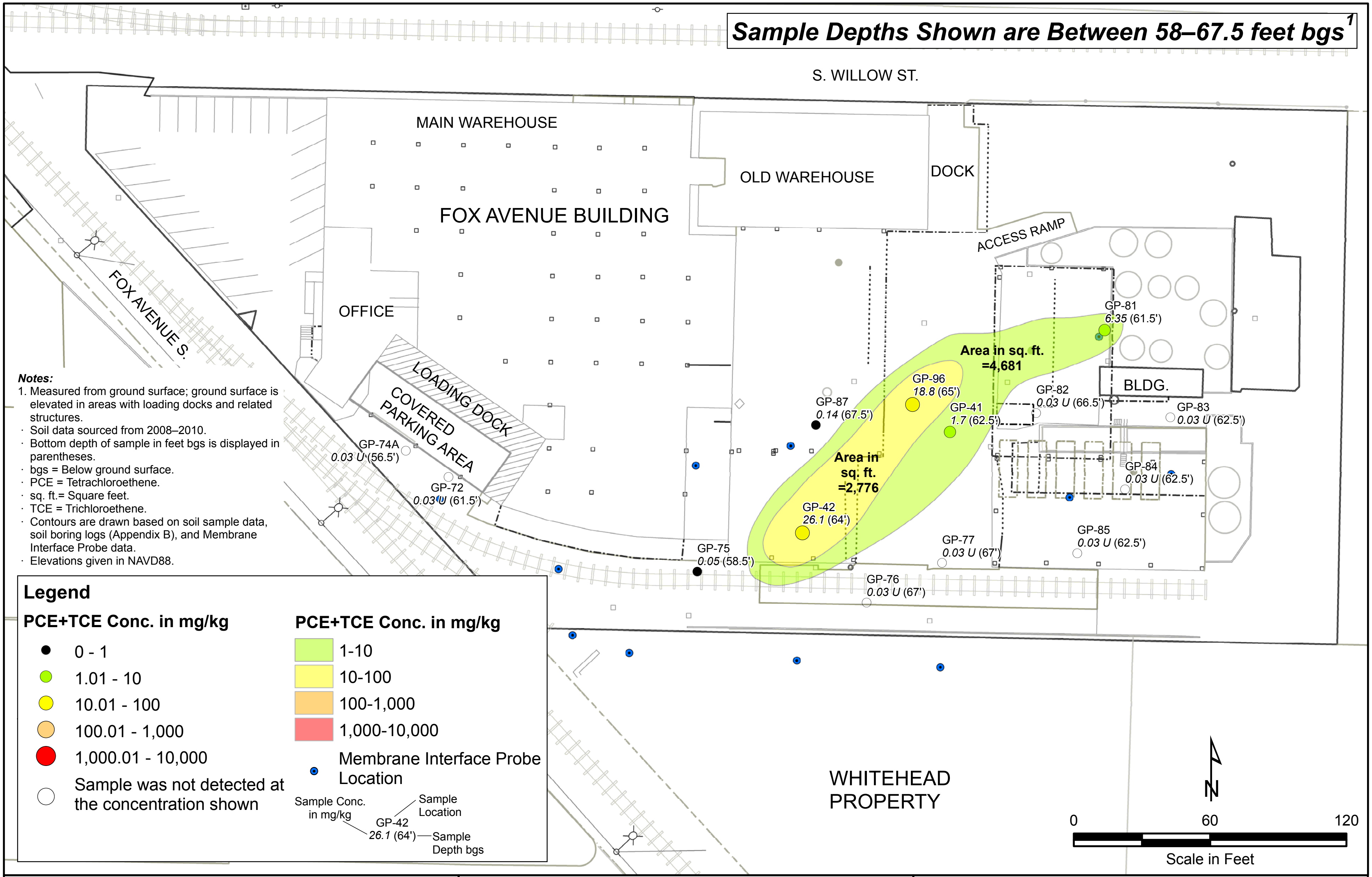
Figure 5.4f
Current Conditions: Maximum PCE+TCE Concentration in Soil within 2nd Water Bearing Zone between Elevation -30 and -40 feet

File: F:\projects\FoxAve-RA\GIS\MXD\RIFS\2011 RIFS\Figure 5.4f (Max PCE+TCE in 2nd Water Bearing Zone Soil Locations NAVD88 Elev -30 to -40).mxd
Date: 2/8/2011



Sample Depths Shown are Between 58–67.5 feet bgs[1]

Notes:

1. Measured from ground surface; ground surface is elevated in areas with loading docks and related structures.

- Soil data sourced from 2008–2010.
- Bottom depth of sample in feet bgs is displayed in parentheses.
- bgs = Below ground surface.
- PCE = Tetrachloroethene.
- sq. ft.= Square feet.
- TCE = Trichloroethene.
- Contours are drawn based on soil sample data, soil boring logs (Appendix B), and Membrane Interface Probe data.
- Elevations given in NAVD88.

Legend

PCE+TCE Conc. in mg/kg

- ● 0 - 1
- ● 1.01 - 10
- ● 10.01 - 100
- ● 100.01 - 1,000
- ● 1,000.01 - 10,000
- ○ Sample was not detected at the concentration shown

PCE+TCE Conc. in mg/kg

- 🟩 1-10
- 🟨 10-100
- 🟧 100-1,000
- 🟥 1,000-10,000
- ● Membrane Interface Probe Location

Sample Conc. in mg/kg
Sample Location
GP-42
26.1 (64')
Sample Depth bgs

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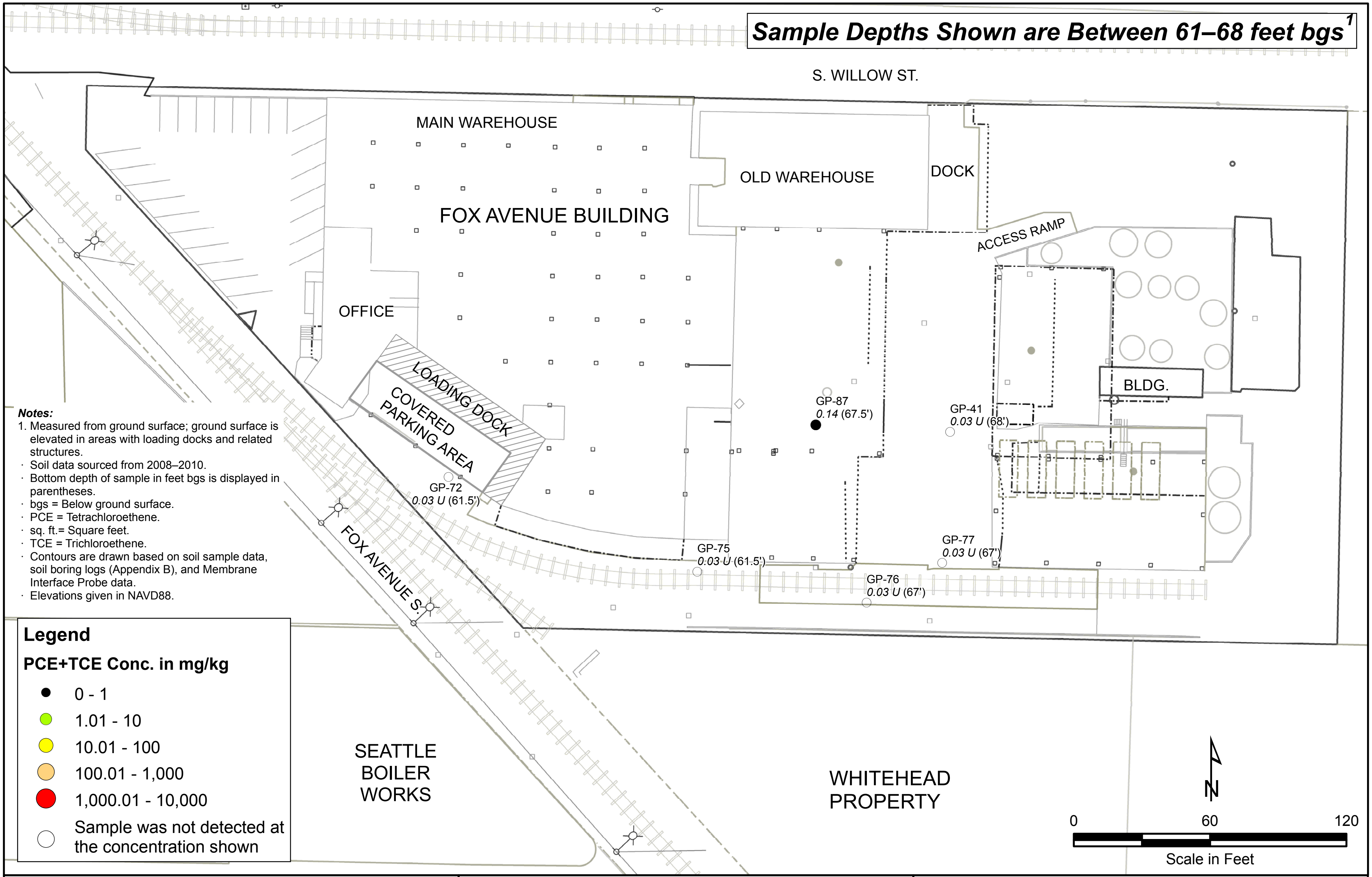
Figure 5.4g
Current Conditions: Maximum PCE+TCE Concentration in Soil within 2nd Water Bearing Zone between Elevation -40 and -50 feet

File: F:\projects\FoxAve-RA\GIS\MXD\RIFS\2011 RIFS\Figure 5.4g (Max PCE+TCE in 2nd Water Bearing Zone Soil Locations NAVD88 Elev -40 to -50).mxd
Date: 2/8/2011



Notes:

1. Measured from ground surface; ground surface is elevated in areas with loading docks and related structures.

- Soil data sourced from 2008–2010.
- Bottom depth of sample in feet bgs is displayed in parentheses.
- bgs = Below ground surface.
- PCE = Tetrachloroethene.
- sq. ft.= Square feet.
- TCE = Trichloroethene.
- Contours are drawn based on soil sample data, soil boring logs (Appendix B), and Membrane Interface Probe data.
- Elevations given in NAVD88.

Legend

PCE+TCE Conc. in mg/kg

●	0 - 1
●	1.01 - 10
●	10.01 - 100
●	100.01 - 1,000
●	1,000.01 - 10,000
○	Sample was not detected at the concentration shown

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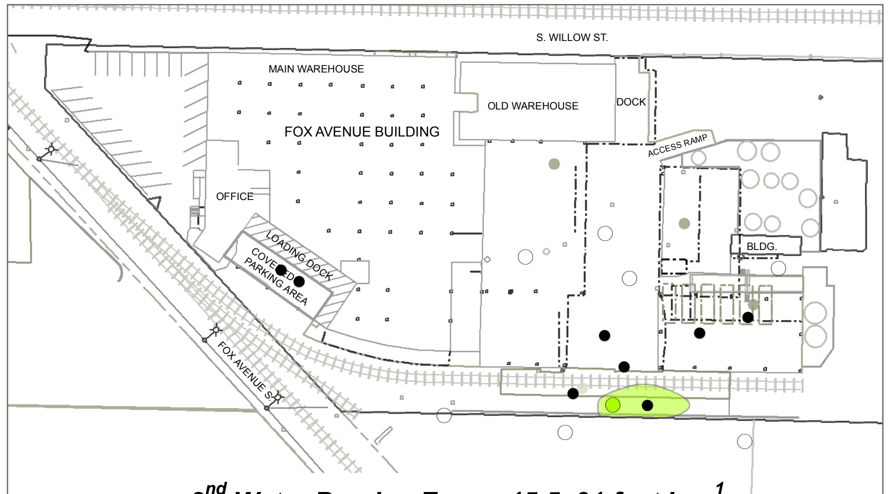
Figure 5.4h
Current Conditions: Maximum PCE+TCE Concentration in Soil within 2nd Water Bearing Zone < -45 feet Elevation

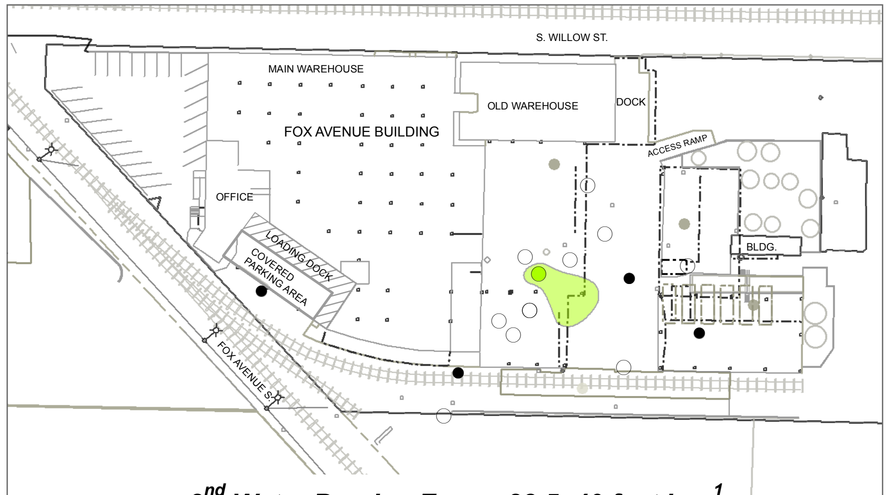
File: F:\projects\FoxAve-RA\GIS\MXD\RIFS\2011 RIFS\Figure 5.4h (Max PCE+TCE in 2nd Water Bearing Zone Soil Locations NAVD88 Elev Less Than -45).mxd
Date: 2/8/2011

Vadose Zone: 0.6–13 feet bgs[1]

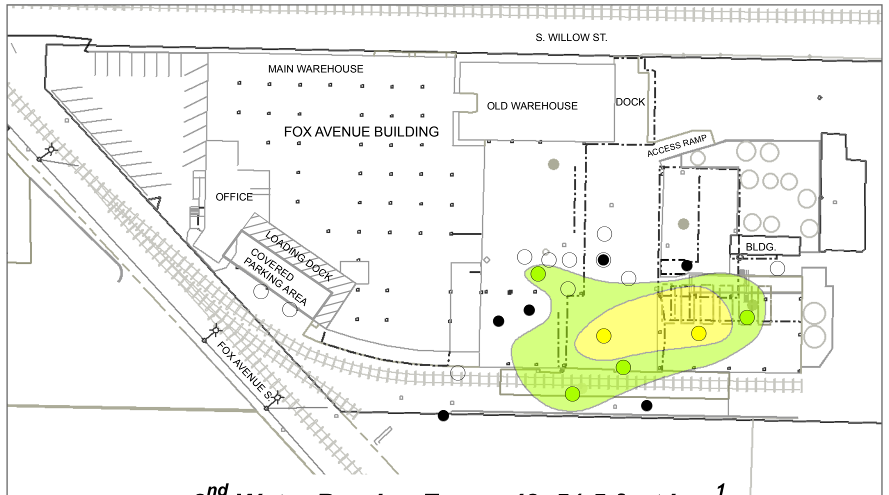
1st Water Bearing Zone: 8.5–18.5 feet bgs[1]



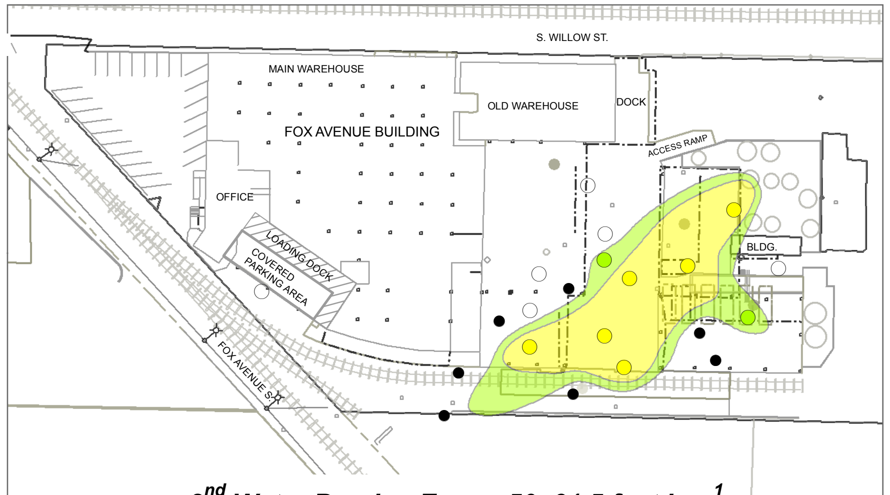
2nd Water Bearing Zone: 15.5–31 feet bgs[1]



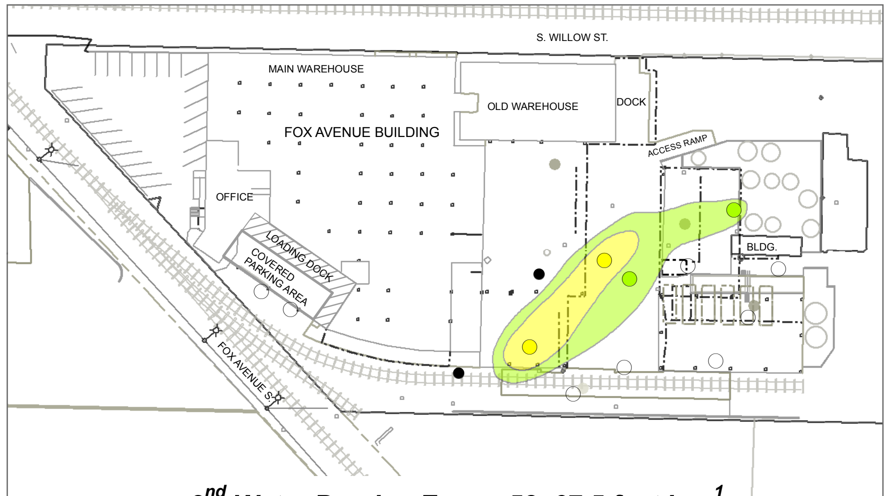
2nd Water Bearing Zone: 28.5–40 feet bgs[1]



2nd Water Bearing Zone: 42–51.5 feet bgs[1]



2nd Water Bearing Zone: 50–61.5 feet bgs[1]



2nd Water Bearing Zone: 58–67.5 feet bgs[1]

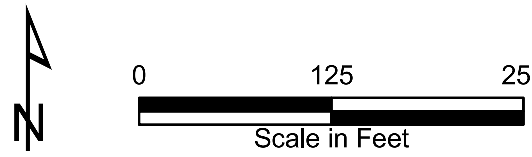
Legend

PCE+TCE Conc. in mg/kg

- ● 0 - 1
- ● 1.01 - 10
- ● 10.01 - 100
- ● 100.01 - 1,000
- ● 1,000.01 - 10,000
- ○ Sample was not detected at the concentration shown

PCE+TCE Conc. in mg/kg

- 🟩 1-10
- 🟨 10-100
- 🟧 100-1,000
- 🟥 1,000-10,000



Notes:

1. Measured from ground surface; ground surface is elevated in areas with loading docks and related structures.

- Soil data sourced from 2008-2010.
- PCE = Tetrachloroethene.
- TCE = Trichloroethene.
- bgs = Below ground surface.

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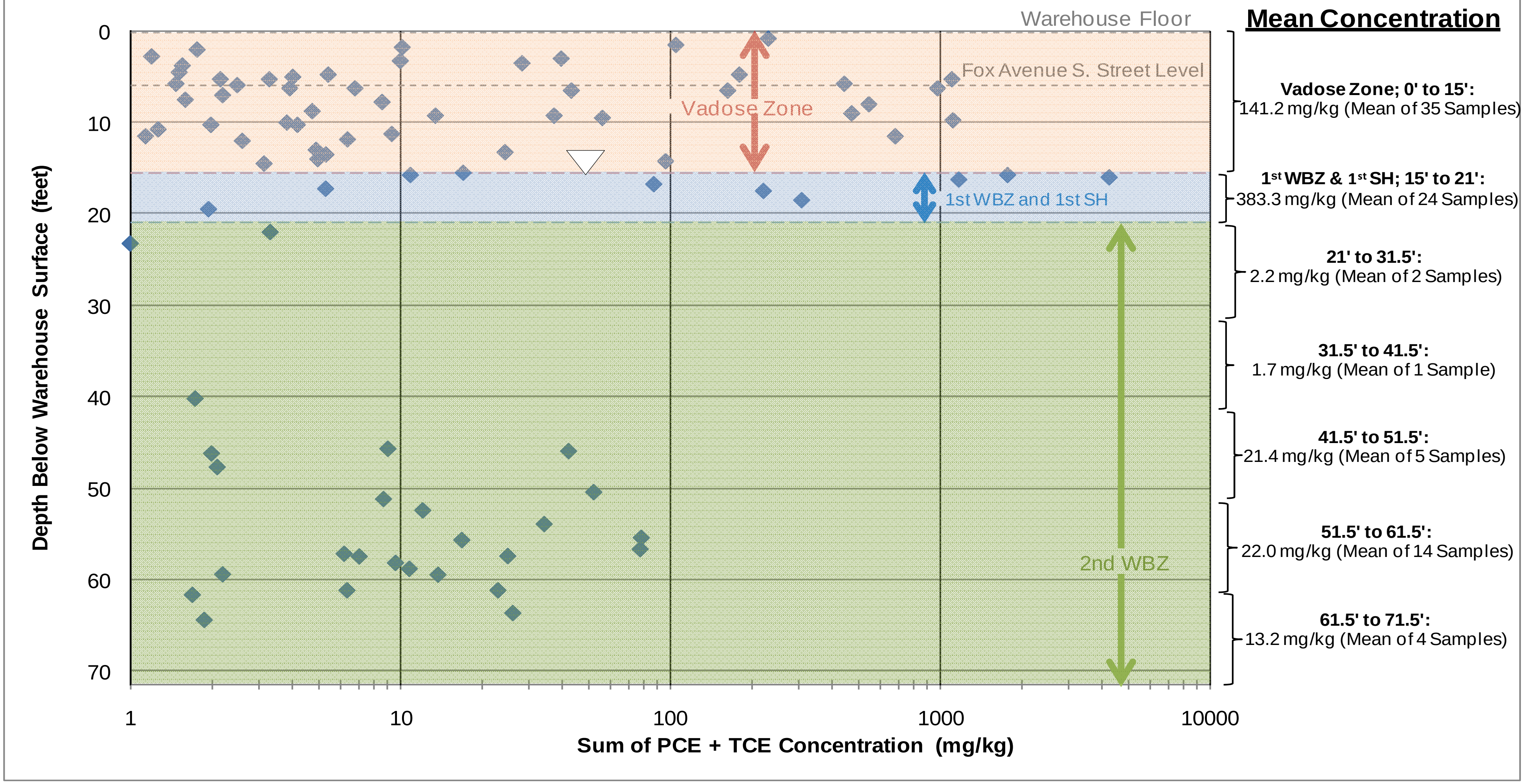
Figure 5.5
Isoconcentration Contours of PCE+TCE in Soil
0.6 to 68 Feet Below Ground Surface

File: F:\projects\FoxAve-RA\GIS\MXD\RIFS\2011 RIFS\Figure 5.5 (PCE plus TCE Variation with Depth - Multiple Frames).mxd
Date: 2/9/2011

Detected PCE and TCE in Soil: Concentration vs. Depth



Notes:

- Geologic horizons and corresponding averages are approximate.
- Only detected concentrations ≥ 1.0 mg/kg were considered.

Abbreviations:
SH = Silt Horizon
WBZ = Water Bearing Zone

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Figure 5.6
Detected PCE and TCE in Soil:
Concentration vs. Sample Depth

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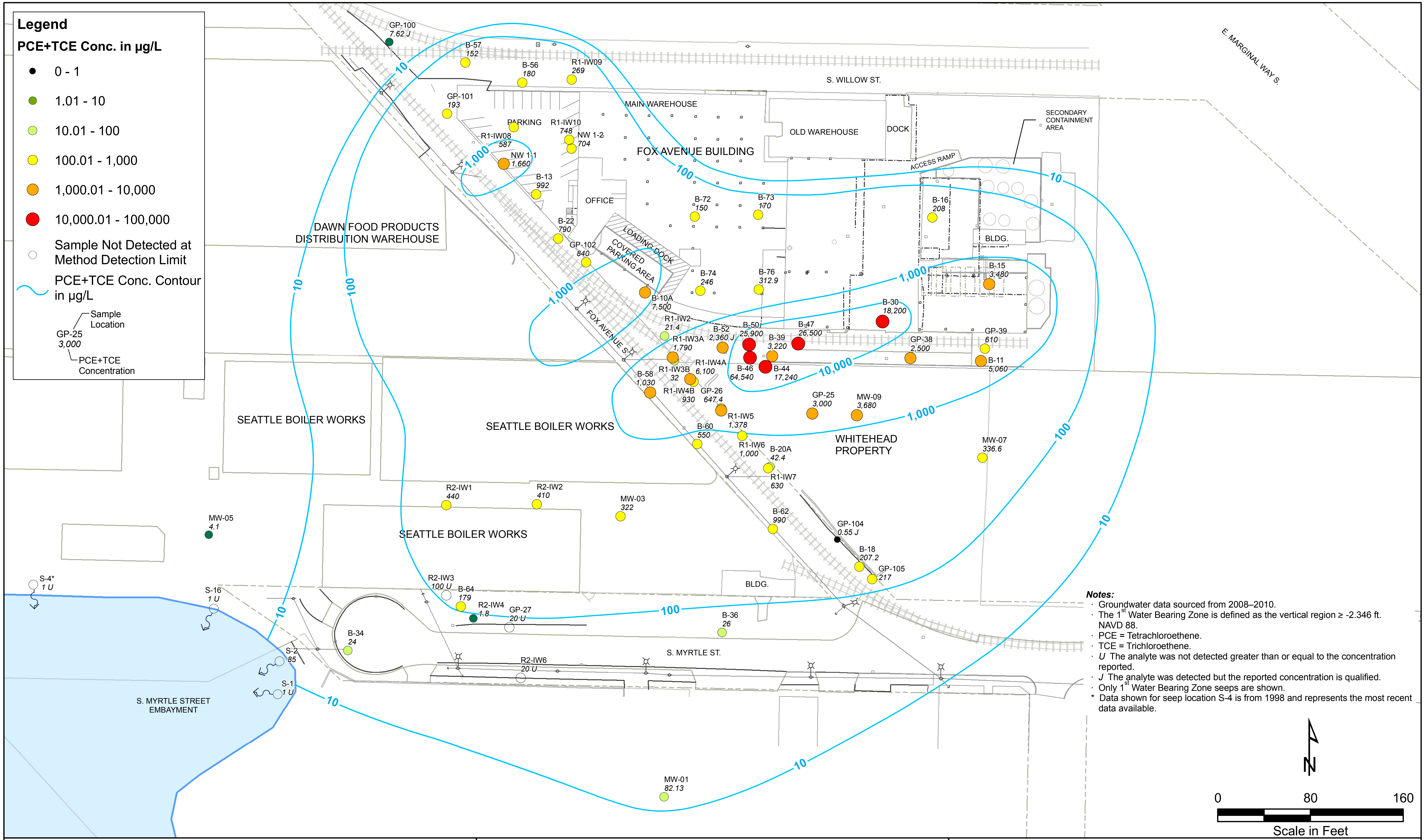

Notes:
- Groundwater data sourced from 2008–2010.
- The 1^{st} Water Bearing Zone is defined as the vertical region ≥ -2.346 ft. NAVD 88.
- PCE = Tetrachloroethene.
- TCE = Trichloroethene.
- *U* The analyte was not detected greater than or equal to the concentration reported.
- *J* The analyte was detected but the reported concentration is qualified.
- Only 1^{st} Water Bearing Zone seeps are shown.

* Data shown for seep location S-4 is from 1998 and represents the most recent data available.

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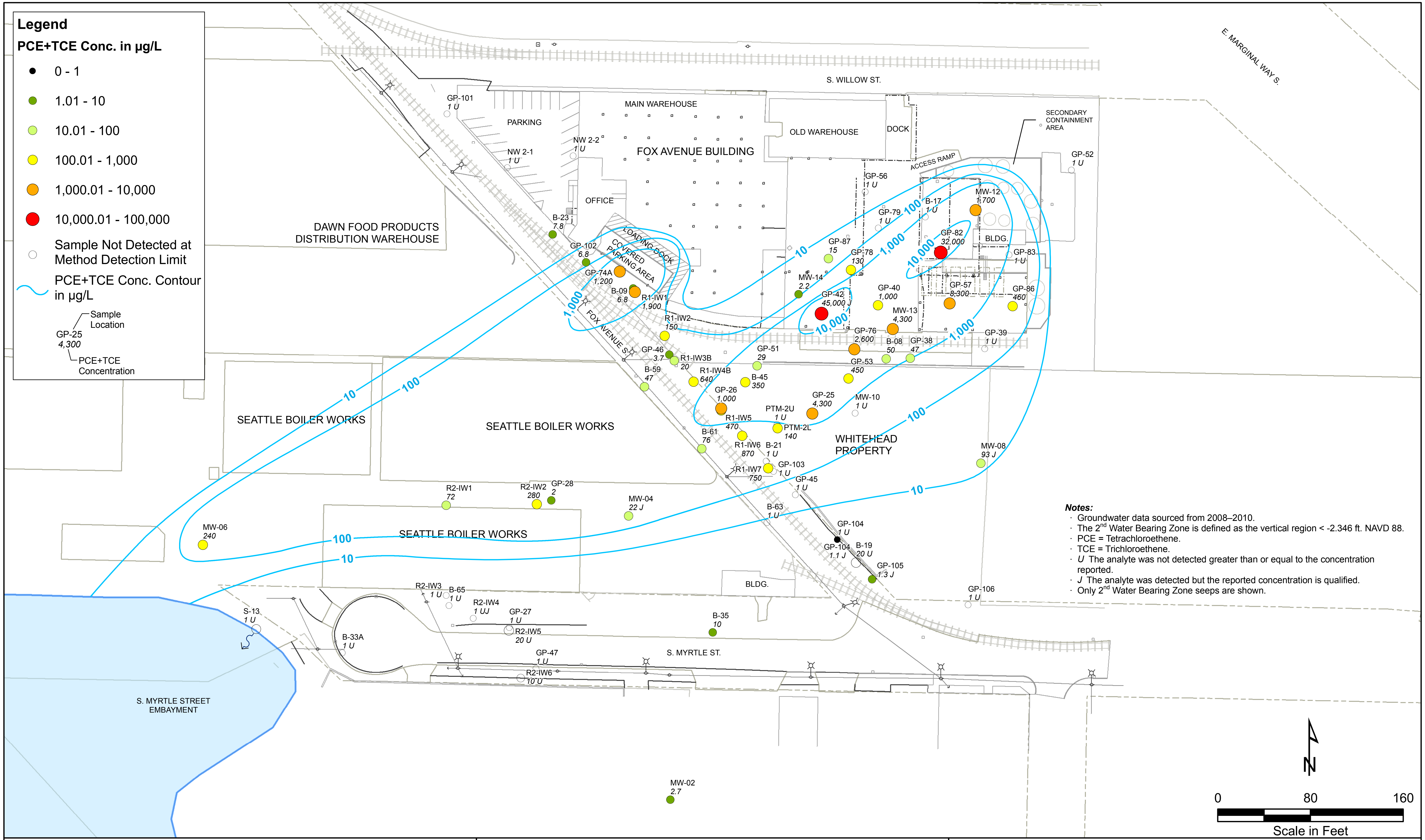
Figure 5.7a
Current Conditions: Maximum PCE + TCE Concentrations in Groundwater in 1^{st} Water Bearing Zone

File: F:\projects\FoxAve-RA\GIS\MXD\RIFS\2011 RIFS\Figure 5.7a (Max PCE plus TCE in GW in 1st Water Bearing Zone 2008-2010 Data).mxd
Date: 2/9/2011



Notes:

- Groundwater data sourced from 2008–2010.
- The 2nd Water Bearing Zone is defined as the vertical region < -2.346 ft. NAVD 88.
- PCE = Tetrachloroethene.
- TCE = Trichloroethene.
- *U* The analyte was not detected greater than or equal to the concentration reported.
- *J* The analyte was detected but the reported concentration is qualified.
- Only 2nd Water Bearing Zone seeps are shown.

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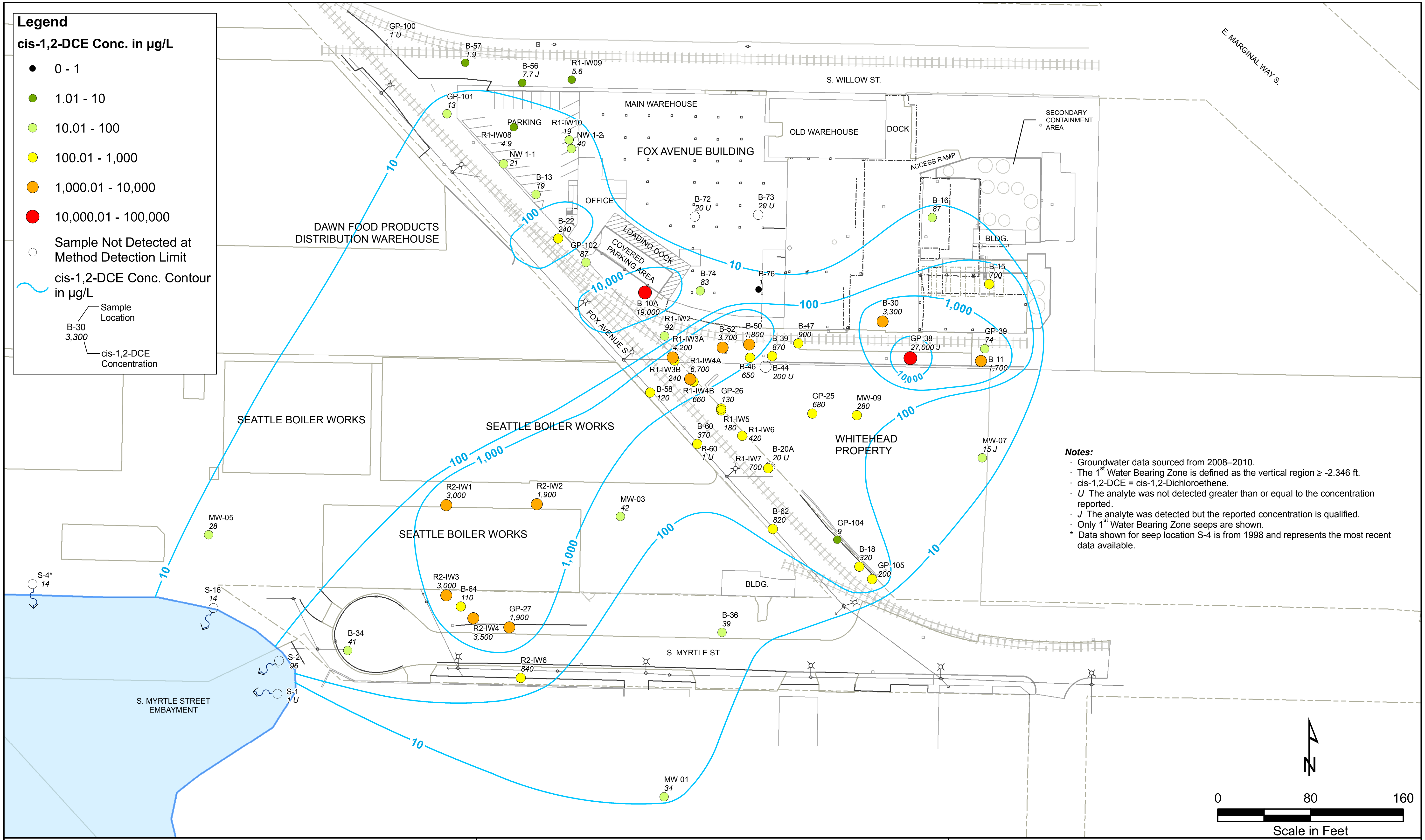
Figure 5.7b
Current Conditions: Maximum PCE + TCE Concentrations in Groundwater in 2nd Water Bearing Zone

File: F:\projects\FoxAve-RA\GIS\MXD\RIFS\2011 RIFS\Figure 5.7b (Max PCE plus TCE in GW in 2nd Water Bearing Zone 2008-2010 Data).mxd
Date: 2/9/2011



Notes:

- Groundwater data sourced from 2008–2010.
- The 1st Water Bearing Zone is defined as the vertical region ≥ -2.346 ft.
- cis-1,2-DCE = cis-1,2-Dichloroethene.
- *U* The analyte was not detected greater than or equal to the concentration reported.
- *J* The analyte was detected but the reported concentration is qualified.
- Only 1st Water Bearing Zone seeps are shown.

* Data shown for seep location S-4 is from 1998 and represents the most recent data available.

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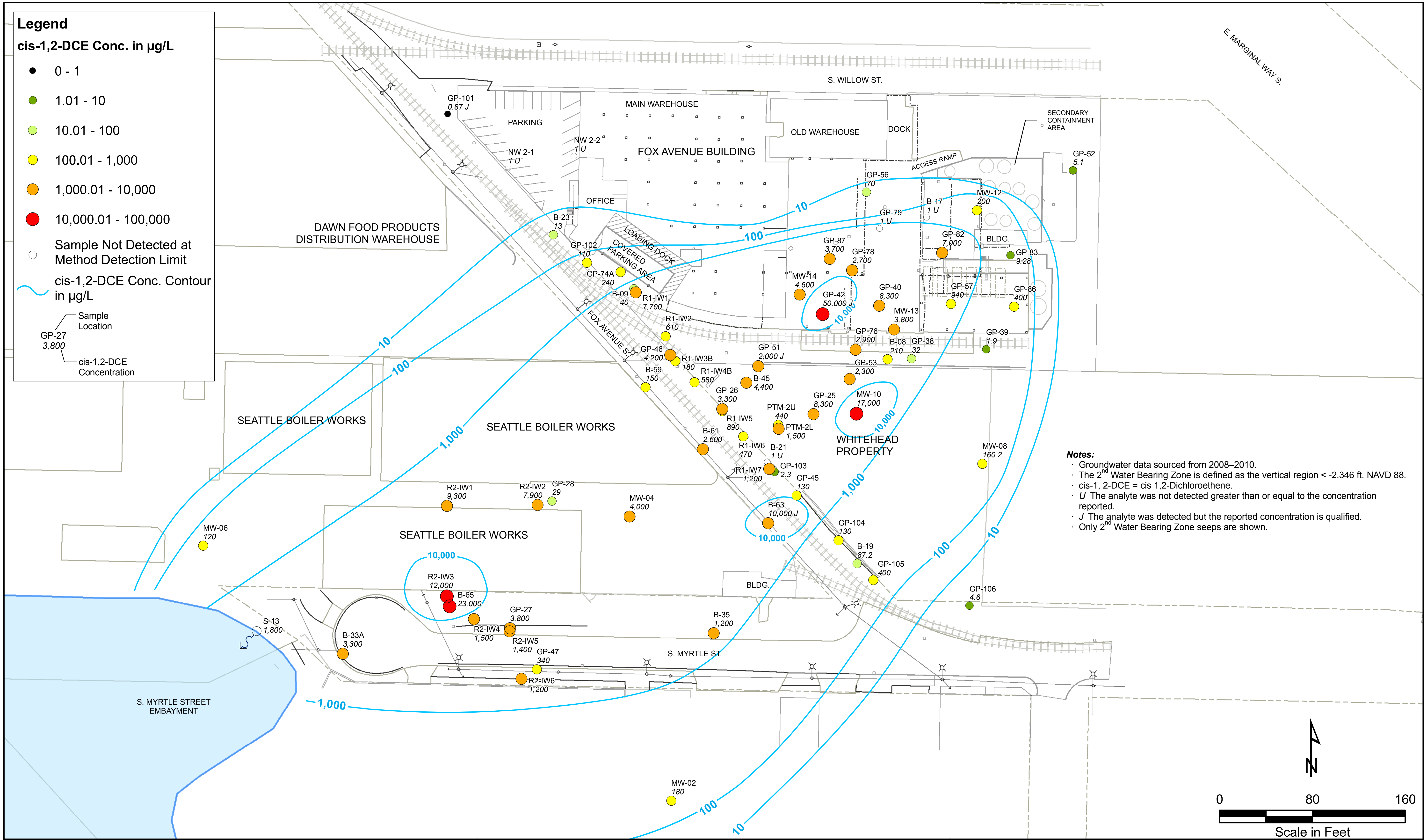
Figure 5.7c
Current Conditions: Maximum cis-1,2-DCE Concentrations in Groundwater in 1st Water Bearing Zone

File: F:\projects\FoxAve-RA\GIS\MXD\RIFS\2011 RIFS\Figure 5.7c (Max cis-1,2-DCE in GW in 1st Water Bearing Zone 2008-2010 Data).mxd
Date: 2/9/2011



Notes:

- Groundwater data sourced from 2008–2010.
- The 2^{nd} Water Bearing Zone is defined as the vertical region < -2.346 ft. NAVD 88.
- cis-1, 2-DCE = cis 1,2-Dichloroethene.
- *U* The analyte was not detected greater than or equal to the concentration reported.
- *J* The analyte was detected but the reported concentration is qualified.
- Only 2^{nd} Water Bearing Zone seeps are shown.

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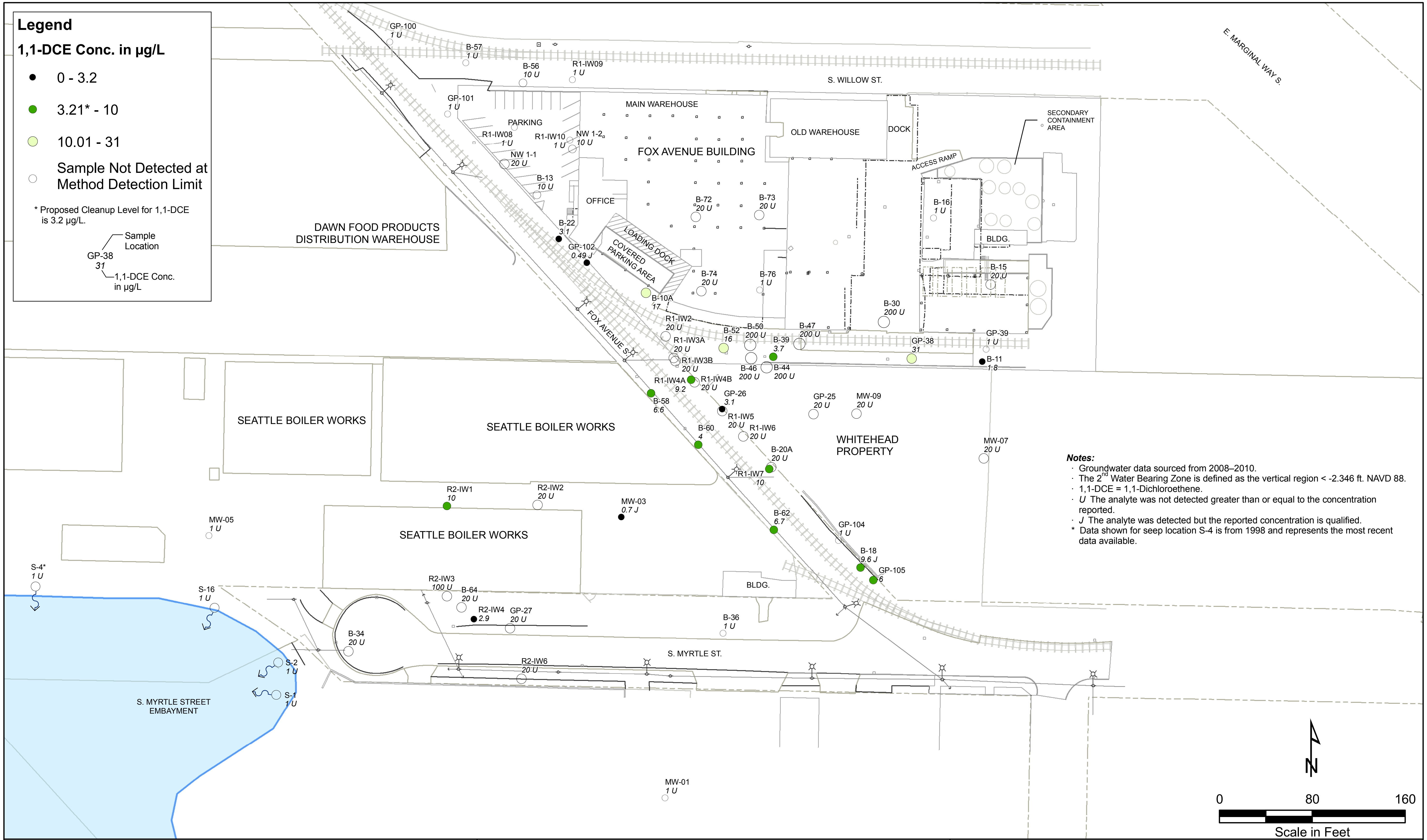
Figure 5.7d
Current Conditions: Maximum cis-1,2-DCE Concentrations in Groundwater in 2^{nd} Water Bearing Zone

File: F:\projects\FoxAve-RA\GIS\MXD\RIFS\2011 RIFS\Figure 5.7d (Max cis-1,2-DCE in GW in 2nd Water Bearing Zone 2008-2010 Data).mxd
Date: 2/9/2011



Notes:

- Groundwater data sourced from 2008–2010.
- The 2nd Water Bearing Zone is defined as the vertical region < -2.346 ft. NAVD 88.
- 1,1-DCE = 1,1-Dichloroethene.
- *U* The analyte was not detected greater than or equal to the concentration reported.
- *J* The analyte was detected but the reported concentration is qualified.
- * Data shown for seep location S-4 is from 1998 and represents the most recent data available.

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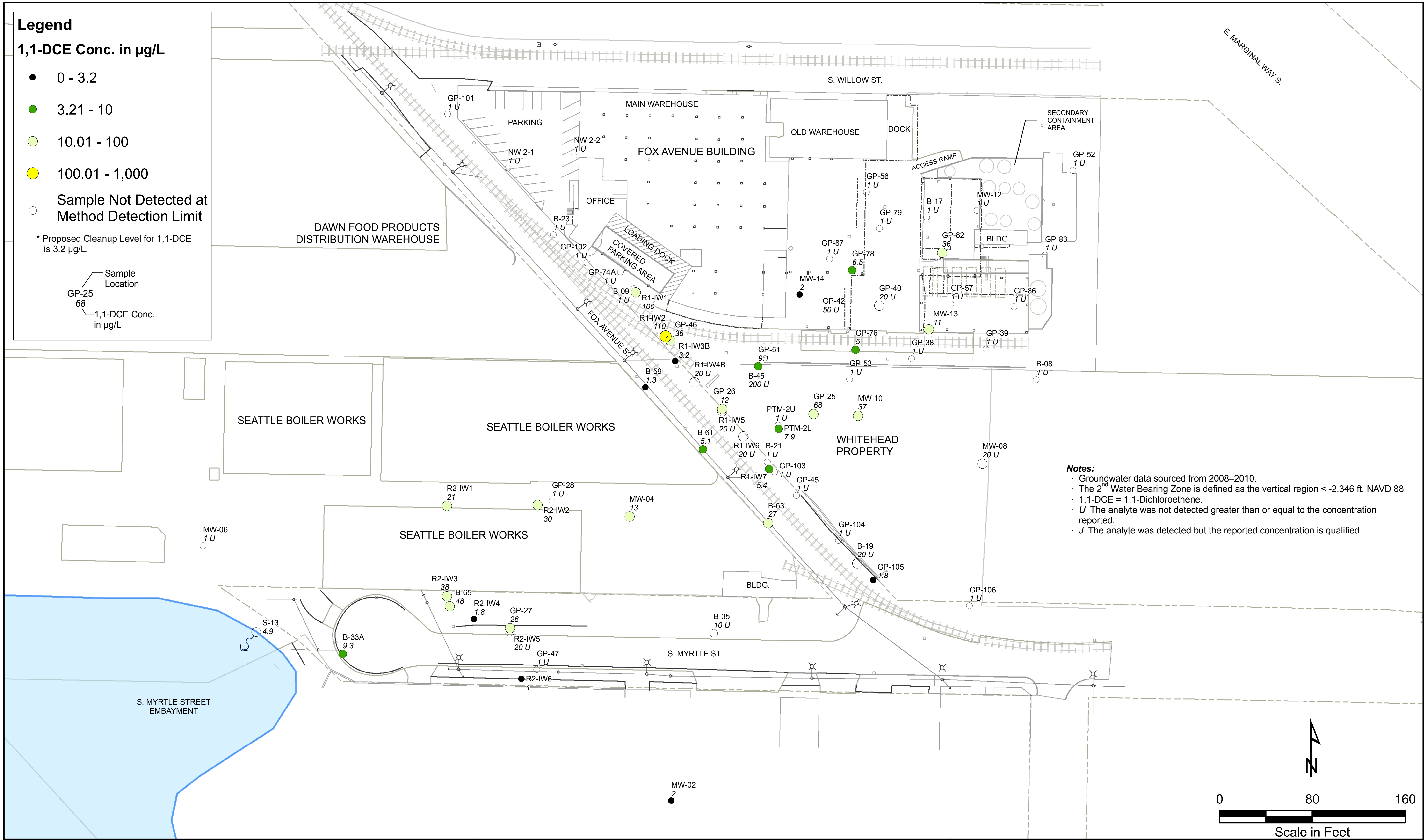
Figure 5.7e
Current Conditions: Maximum 1,1-DCE Concentrations in Groundwater in 1st Water Bearing Zone

File: F:\projects\FoxAve-RA\GIS\MXD\RIFS\2011 RIFS\Figure 5.7e (Max 1,1-DCE in GW in 1st Water Bearing Zone 2008-2010 Data).mxd
Date: 2/9/2011



Notes:

- Groundwater data sourced from 2008–2010.
- The 2nd Water Bearing Zone is defined as the vertical region < -2.346 ft. NAVD 88.
- 1,1-DCE = 1,1-Dichloroethene.
- *U* The analyte was not detected greater than or equal to the concentration reported.
- *J* The analyte was detected but the reported concentration is qualified.

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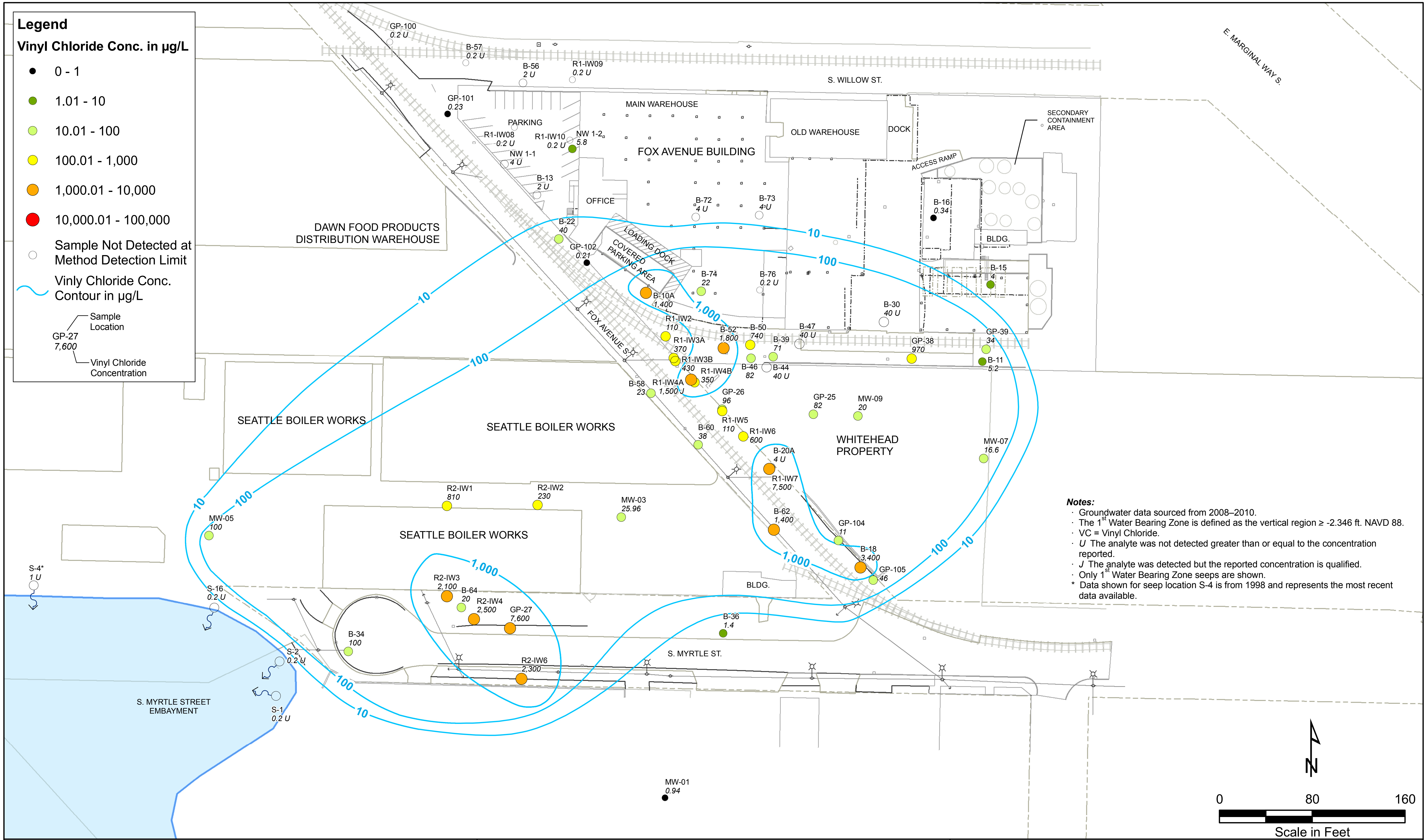
Figure 5.7f
Current Conditions: Maximum 1,1-DCE Concentrations in Groundwater in 2nd Water Bearing Zone

File: F:\projects\FoxAve-RA\GIS\MXD\RIFS\2011 RIFS\Figure 5.7f (Max 1,1-DCE in GW in 2nd Water Bearing Zone 2008-2010 Data).mxd
Date: 2/9/2011



Notes:

- Groundwater data sourced from 2008–2010.
- The 1st Water Bearing Zone is defined as the vertical region ≥ -2.346 ft. NAVD 88.
- VC = Vinyl Chloride.
- *U* The analyte was not detected greater than or equal to the concentration reported.
- *J* The analyte was detected but the reported concentration is qualified.
- Only 1st Water Bearing Zone seeps are shown.

* Data shown for seep location S-4 is from 1998 and represents the most recent data available.

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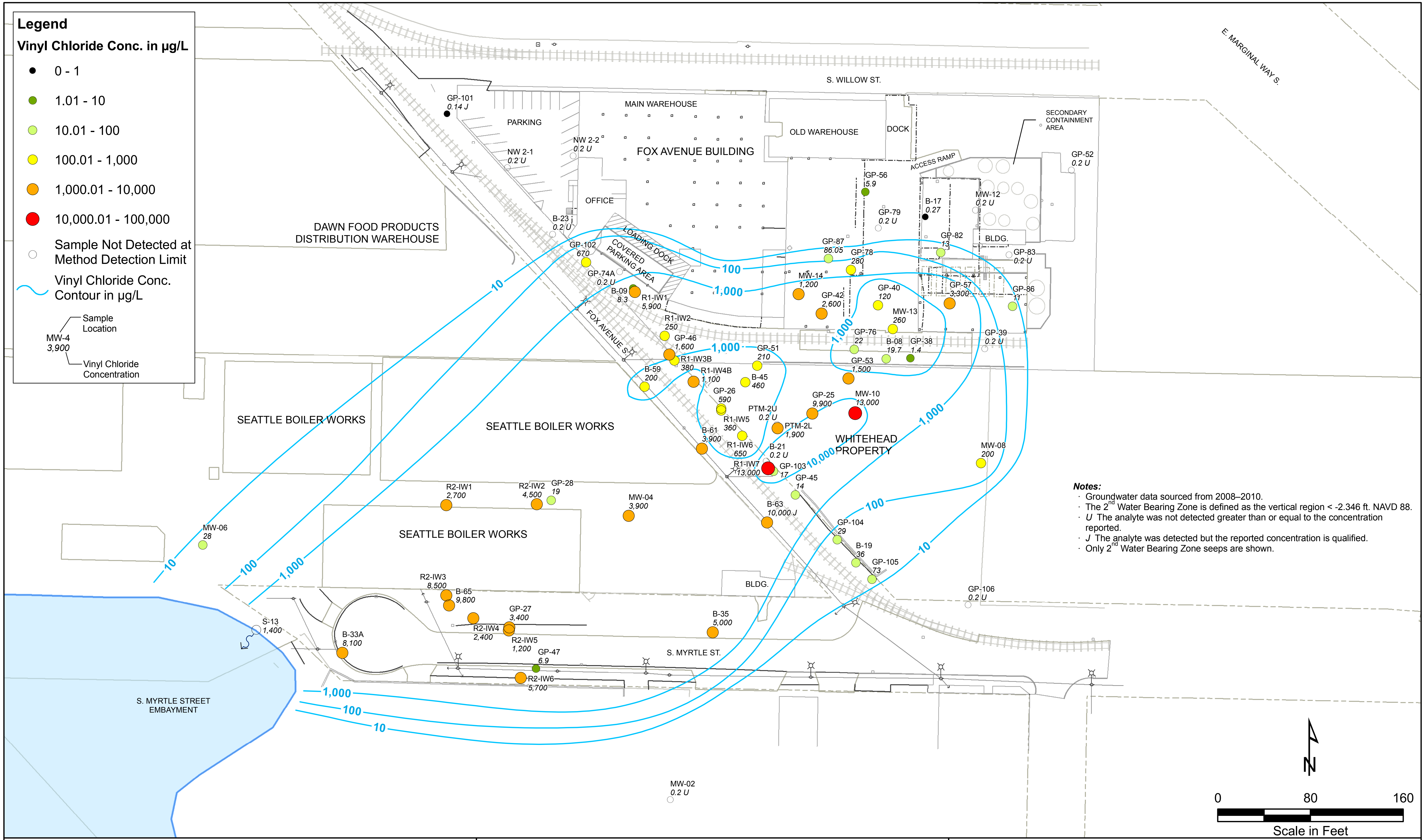
Figure 5.7g
Current Conditions: Maximum Vinyl Chloride Concentrations in Groundwater in 1st Water Bearing Zone

File: F:\projects\FoxAve-RA\GIS\MXD\RIFS\2011 RIFS\Figure 5.7g (Max Vinly Chloride in GW in 1st Water Bearing Zone 2008-2010 Data).mxd
Date: 2/9/2011



Notes:

- Groundwater data sourced from 2008–2010.
- The 2nd Water Bearing Zone is defined as the vertical region < -2.346 ft. NAVD 88.
- *U* The analyte was not detected greater than or equal to the concentration reported.
- *J* The analyte was detected but the reported concentration is qualified.
- Only 2nd Water Bearing Zone seeps are shown.

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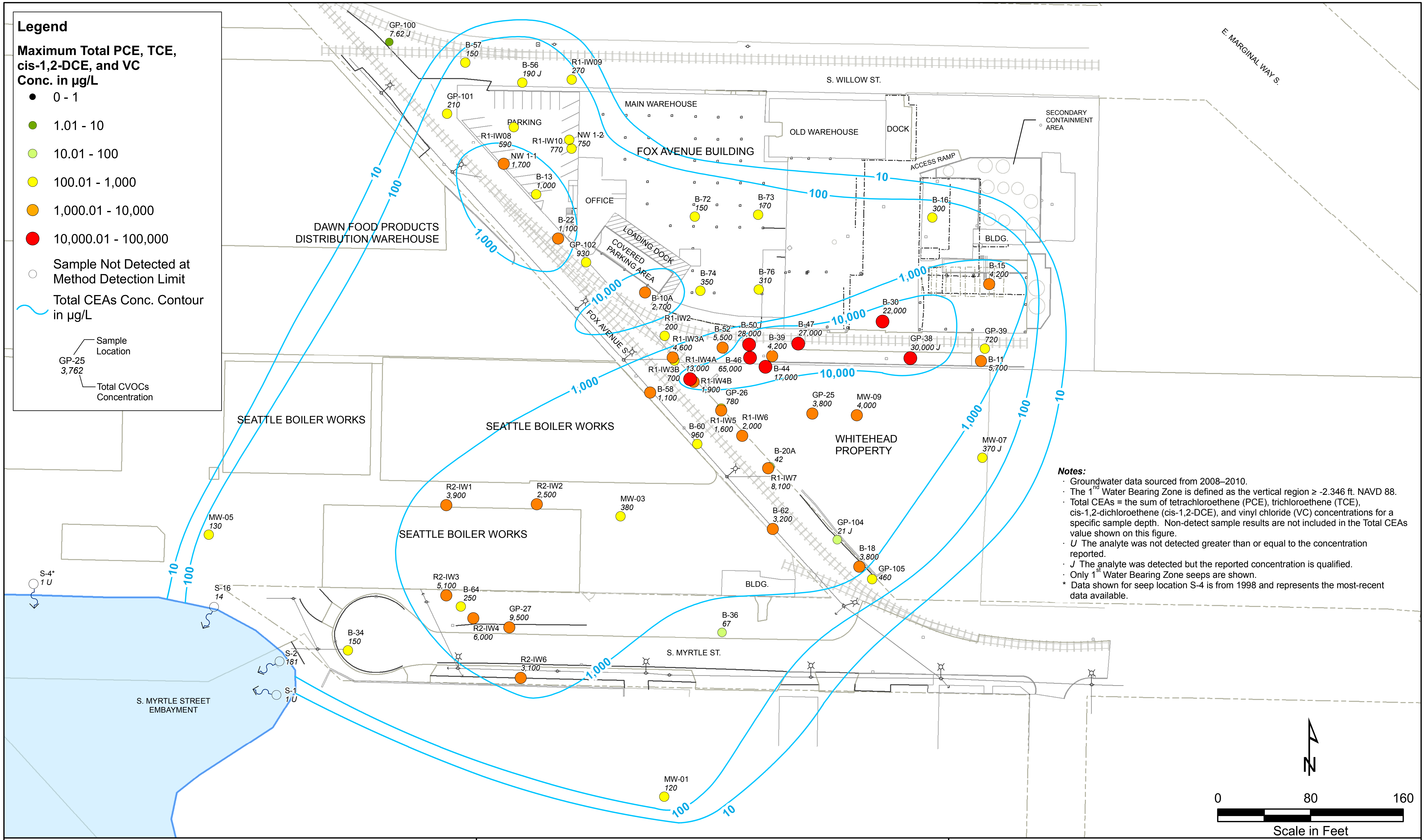
Figure 5.7h
Current Conditions: Maximum Vinyl Chloride Concentrations in Groundwater in 2nd Water Bearing Zone

File: F:\projects\FoxAve-RA\GIS\MXD\RIFS\2011 RIFS\Figure 5.7h (Max Vinly Chloride in GW in 2nd Water Bearing Zone 2008-2010 Data).mxd
Date: 2/9/2011



Notes:

- Groundwater data sourced from 2008–2010.
- The 1nd Water Bearing Zone is defined as the vertical region ≥ -2.346 ft. NAVD 88.
- Total CEAs = the sum of tetrachloroethene (PCE), trichloroethene (TCE), cis-1,2-dichloroethene (cis-1,2-DCE), and vinyl chloride (VC) concentrations for a specific sample depth. Non-detect sample results are not included in the Total CEAs value shown on this figure.
- *U* The analyte was not detected greater than or equal to the concentration reported.
- *J* The analyte was detected but the reported concentration is qualified.
- Only 1st Water Bearing Zone seeps are shown.
- * Data shown for seep location S-4 is from 1998 and represents the most-recent data available.

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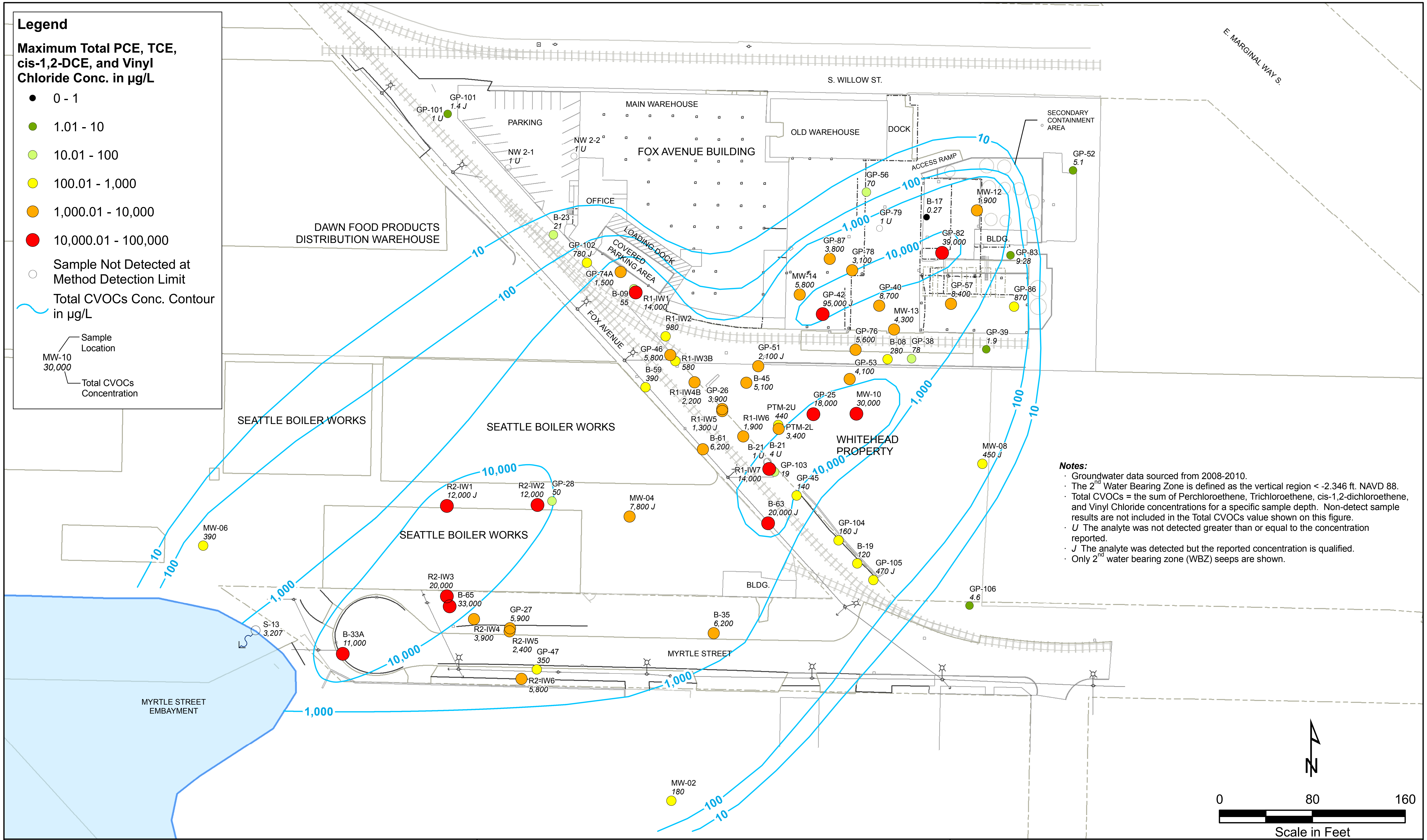
Figure 5.8a
Current Conditions: Maximum Total PCE, TCE, cis-1,2-DCE, and VC Concentrations in Groundwater in 1st Water Bearing Zone

File: F:\projects\FoxAve-RA\GIS\MXD\RIFS\2011 RIFS\Figure 5.8a (Max Total CVOCs in GW in 1st Water Bearing Zone 2008-2010 Data).mxd
Date: 2/9/2011



Notes:

- Groundwater data sourced from 2008-2010.
- The 2nd Water Bearing Zone is defined as the vertical region < -2.346 ft. NAVD 88.
- Total CVOCs = the sum of Perchloroethene, Trichloroethene, cis-1,2-dichloroethene, and Vinyl Chloride concentrations for a specific sample depth. Non-detect sample results are not included in the Total CVOCs value shown on this figure.
- *U* The analyte was not detected greater than or equal to the concentration reported.
- *J* The analyte was detected but the reported concentration is qualified.
- Only 2nd water bearing zone (WBZ) seeps are shown.

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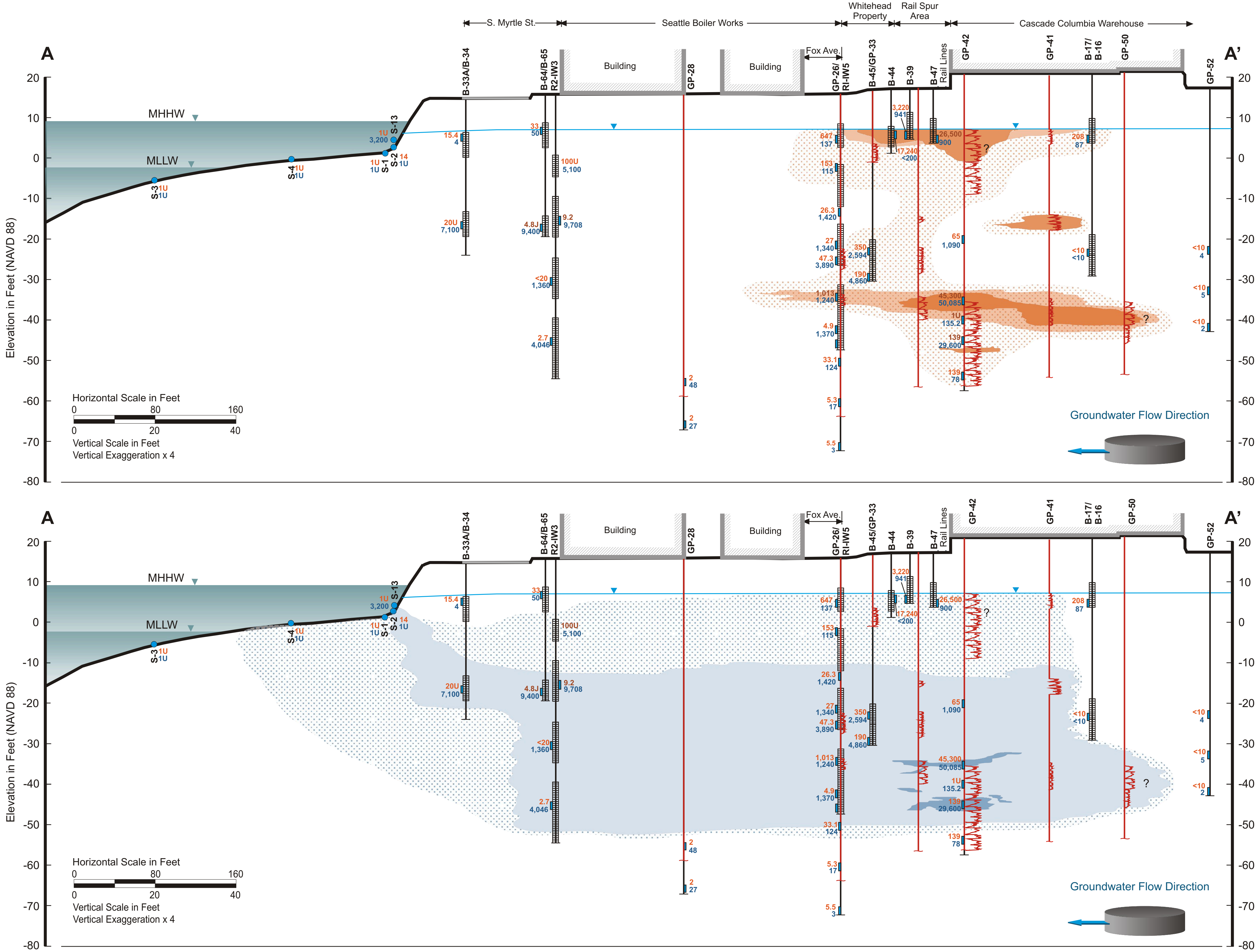
Figure 5.8b
Current Conditions: Maximum Total PCE, TCE, cis-1,2-DCE, and VC Concentrations in Groundwater in 2nd Water Bearing Zone

F:\projects\FoxAve-RA\GIS\MXD\RIFS\2011 RIFS\Figure 5.8b (Max Total CVOCs in GW in 2nd Water Bearing Zone 2008-2010 Data).mxd
Date: 1/10/2011 3:12 PM



PCE and TCE

> 100 μgL

> 1,000 μgL

> 10,000 μgL

DCE and VC

> 100 μgL

> 1,000 μgL

> 10,000 μgL

MIP Response

Slight

Medium

Strong

647	PCE & TCE in Groundwater μgL
137	DCE & VC in Groundwater μgL
<10	Undetected at the Concentration Shown
J	Estimated
U	Non-Detect

Notes:
1. Data collected December 2008 through January 2009.
2. When data for multiple dates were available, the most recent data were used.
3. Data collected November 2008 through October 2010.

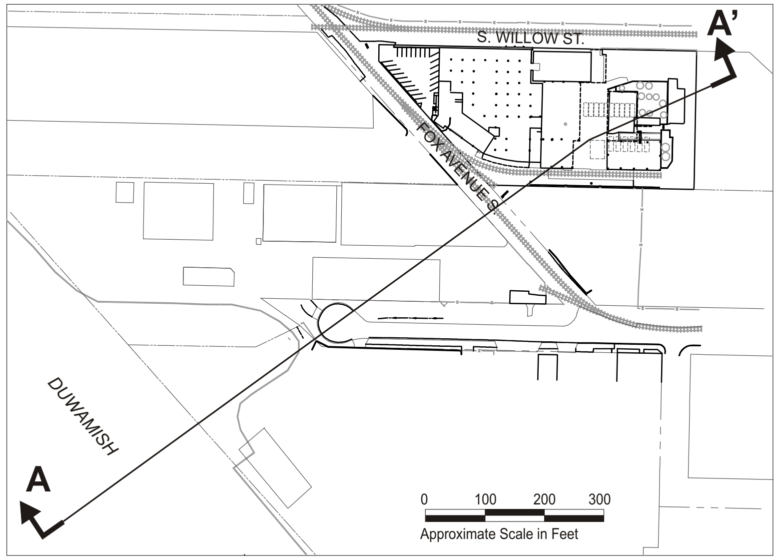


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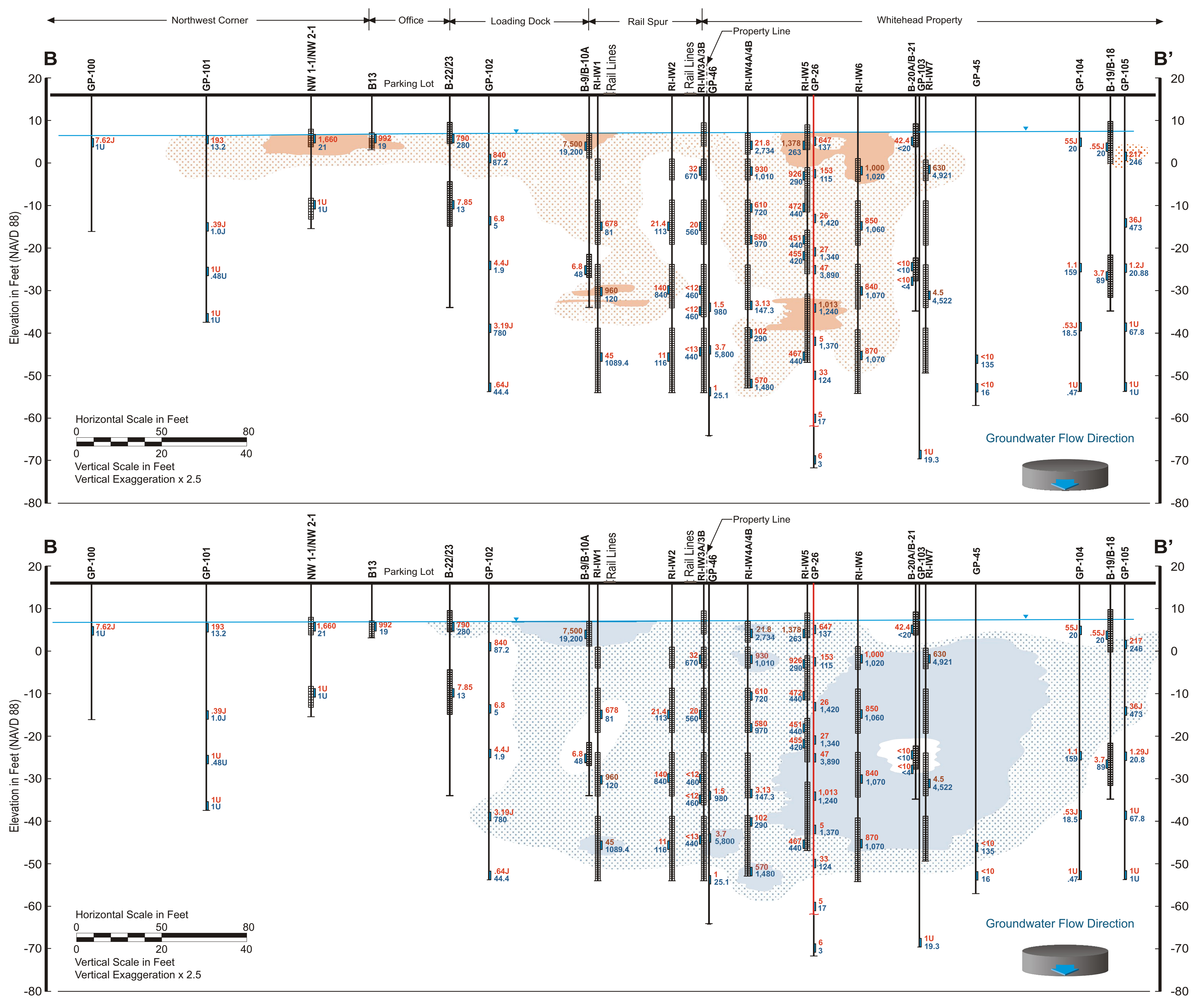
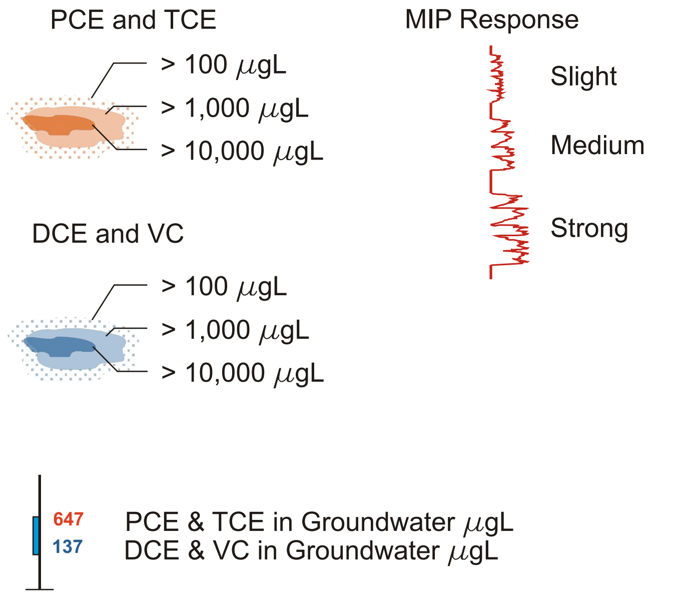
Figure 5.9a
Chemical Concentration in Groundwater
PCE,TCE, DCE, and VC

G:Project\Clients\Floyd Snider\Fox Avenue\2010\Geologic Cross Section A-A' Concentrations'





PCE and TCE

> 100 μgL
> 1,000 μgL
> 10,000 μgL

MIP Response

Slight
Medium
Strong

DCE and VC

> 100 μgL
> 1,000 μgL
> 10,000 μgL

647 PCE & TCE in Groundwater μgL
137 DCE & VC in Groundwater μgL

<10	Undetected at the Concentration Shown
J	Estimated
U	Non-Detect

Notes:
1. Data collected December 2008 through January 2009.
2. When data for multiple dates were available, the most recent data were used.
3. Data collected November 2008 through October 2010.

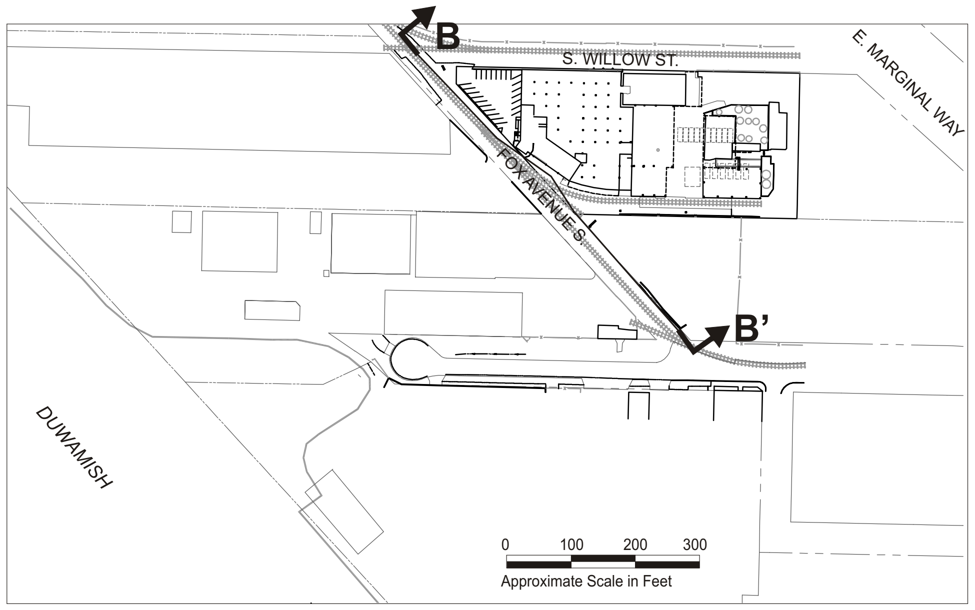


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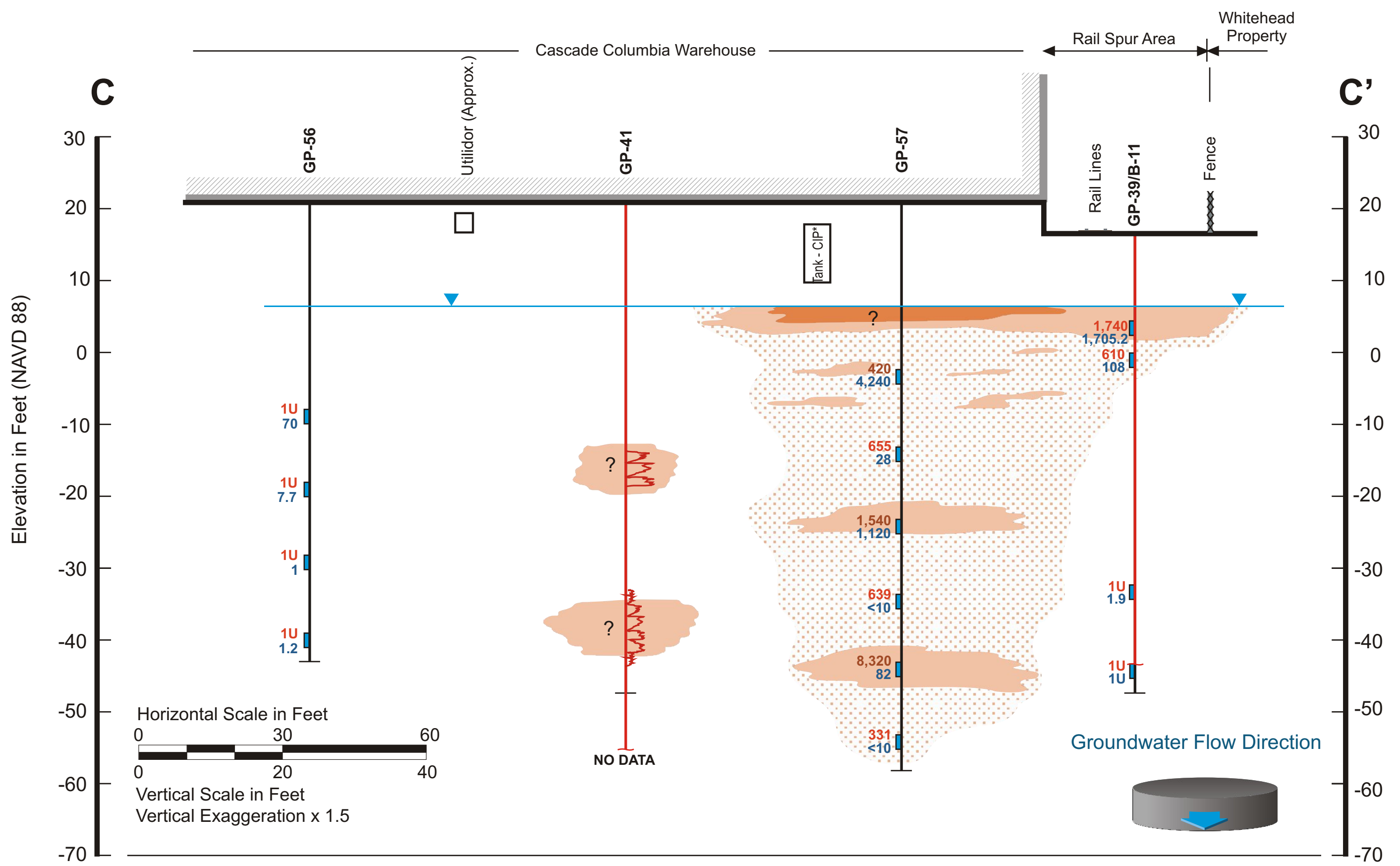
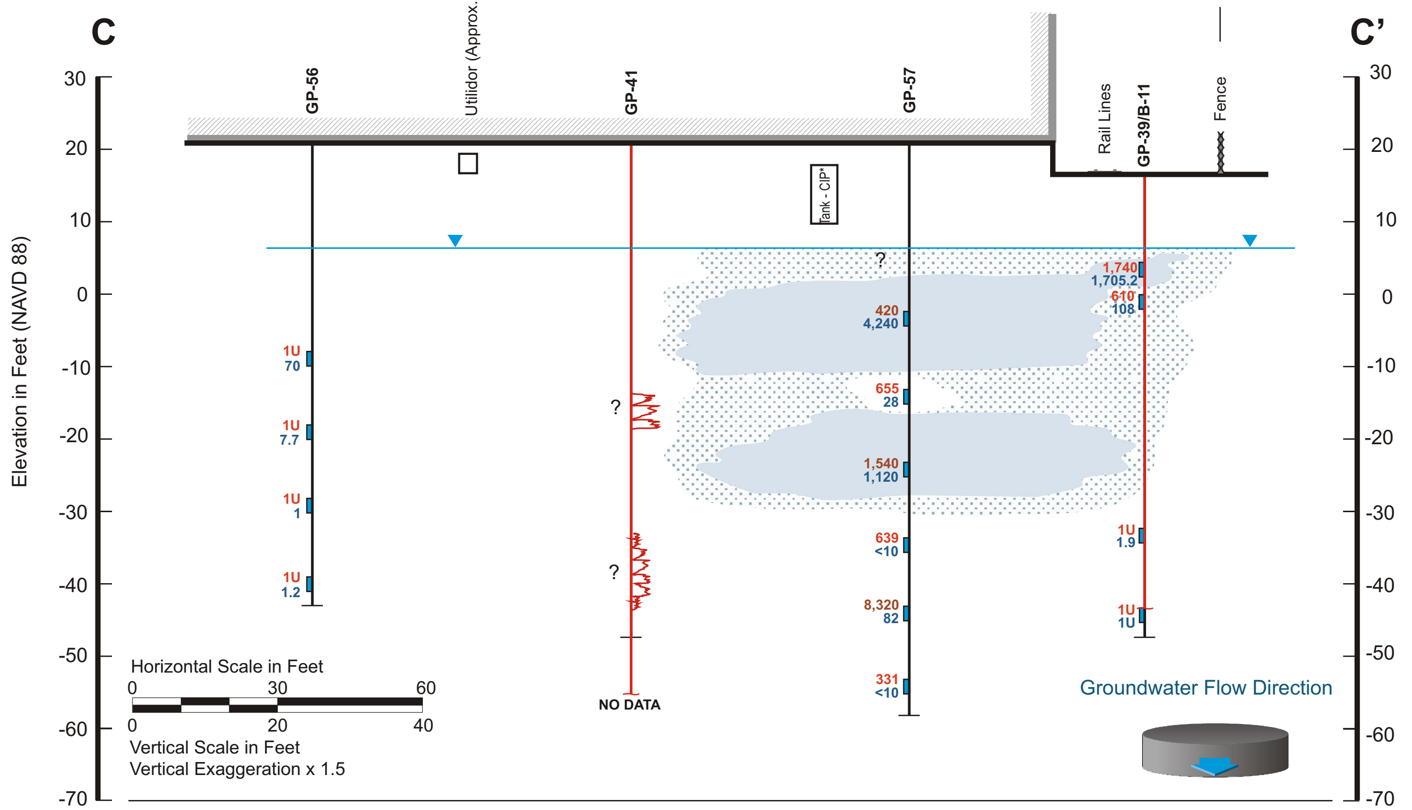
Figure 5.9b
Chemical Concentration in Groundwater
PCE,TCE, DCE, and VC

G:Project\Clients\Floyd Snider\Fox Avenue\2010\Geologic Cross Section B-B Concentrations'





PCE and TCE

- > 100 μgL
- > 1,000 μgL
- > 10,000 μgL

MIP Response

- Slight
- Medium
- Strong

DCE and VC

- > 100 μgL
- > 1,000 μgL
- > 10,000 μgL

647 PCE & TCE in Groundwater μgL
137 DCE & VC in Groundwater μgL

<10 Undetected at the Concentration Shown
J Estimated
U Non-Detect

*CIP = Closed in Place

Notes:
1. Data collected December 2008 through January 2009.
2. When data for multiple dates were available, the most recent data were used.
3. Data collected November 2008 through October 2010.

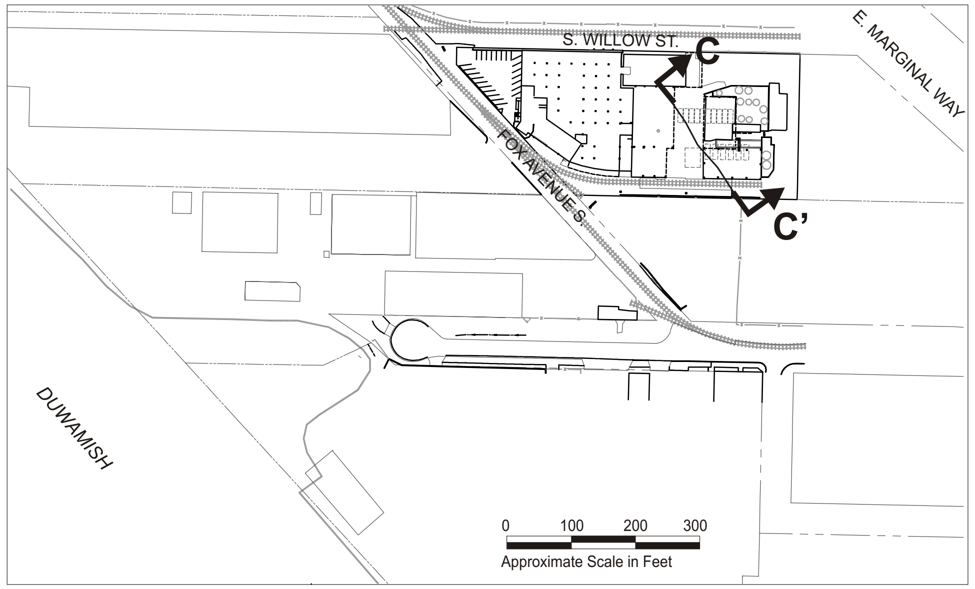


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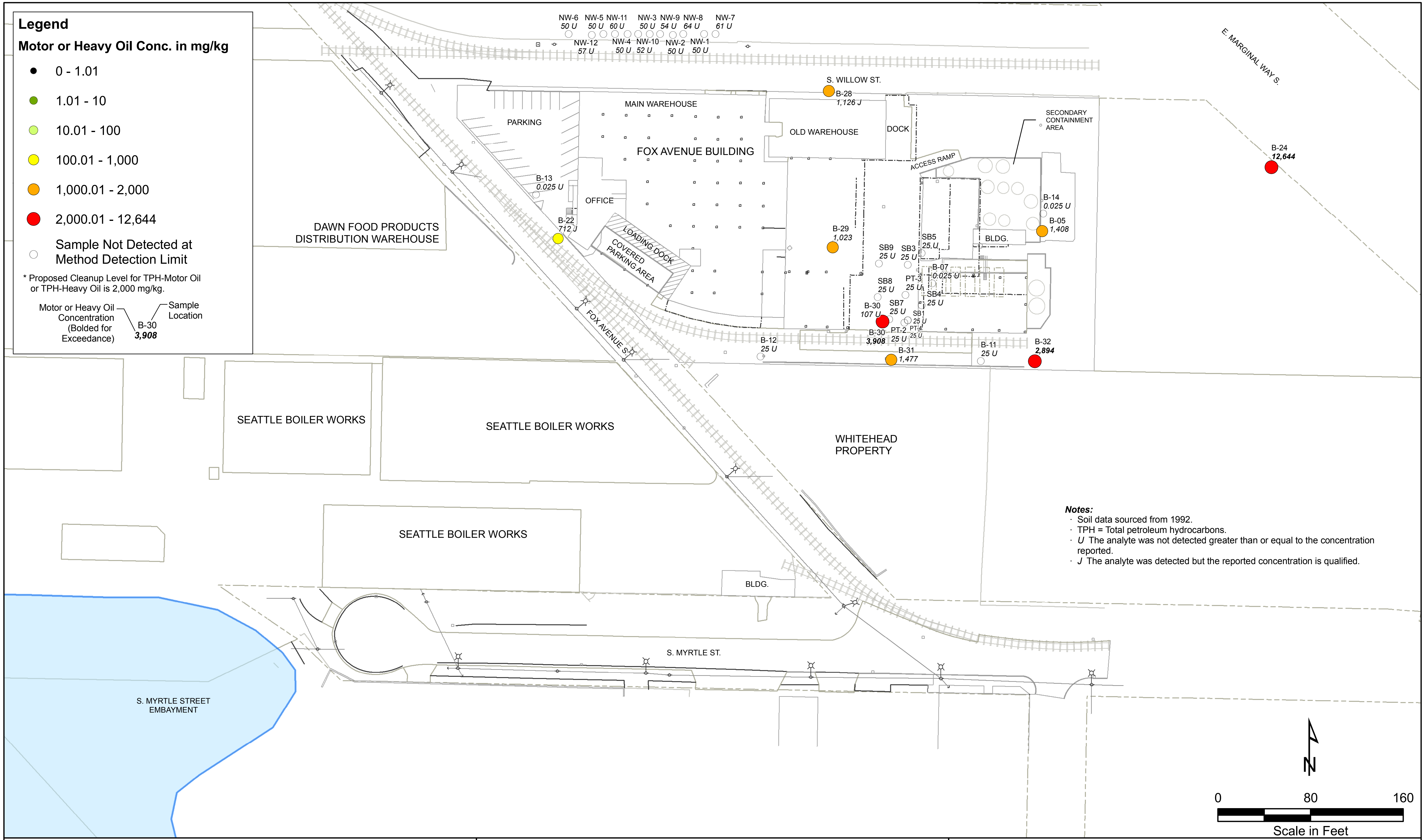
Figure 5.9c
Chemical Concentration in Groundwater
PCE,TCE, DCE, and VC

G:Project\Clients\Floyd Snider\Fox Avenue\2010\Geologic Cross Section B-B Concentrations'



Notes:
- Soil data sourced from 1992.
- TPH = Total petroleum hydrocarbons.
- *U* The analyte was not detected greater than or equal to the concentration reported.
- *J* The analyte was detected but the reported concentration is qualified.

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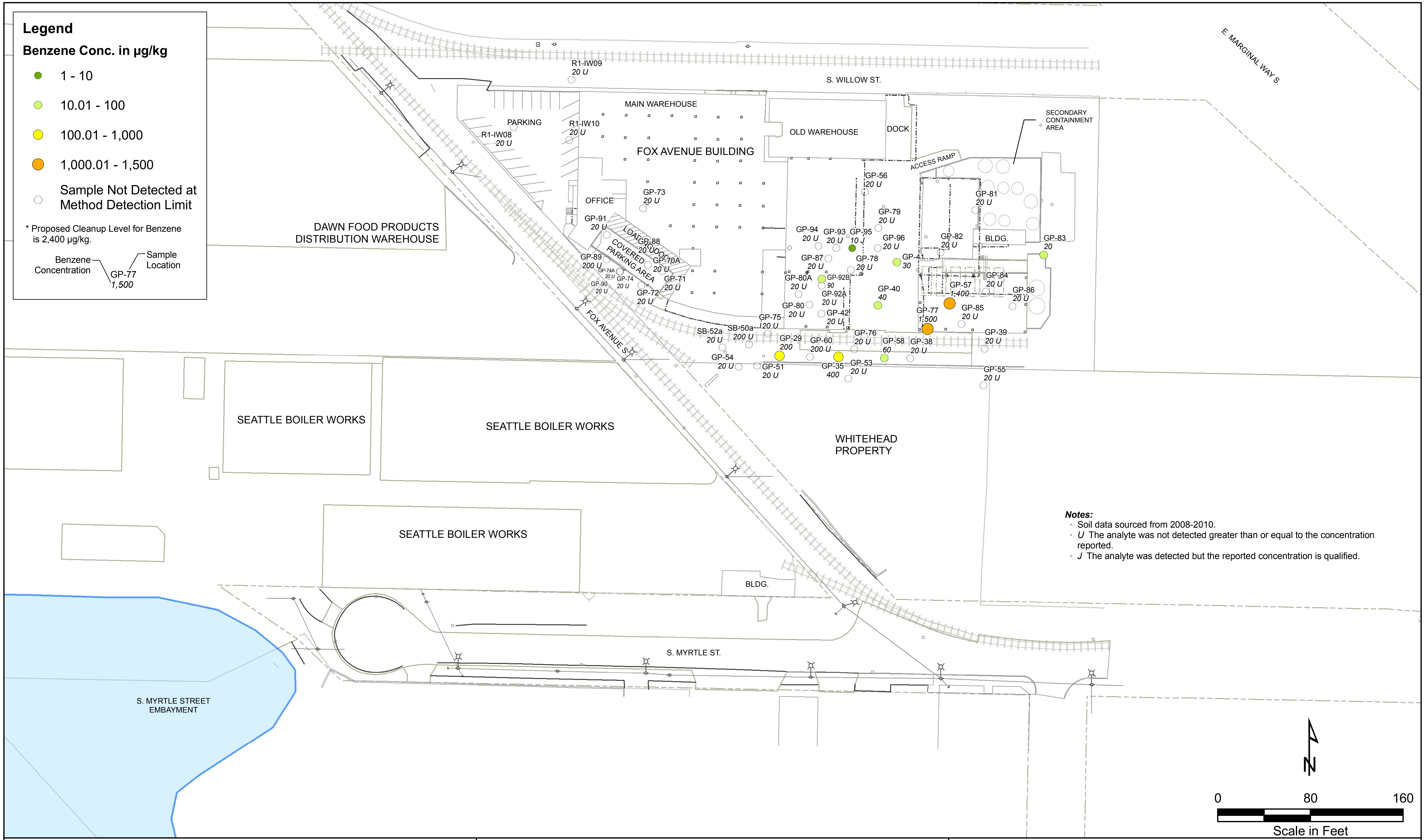
Figure 5.10
Maximum TPH-Motor Oil or TPH-Heavy Oil Concentrations in Soil at any Depth

File: F:\projects\FoxAve-RA\GIS\MXD\RIFS\2011 RIFS\Figure 5.10 (Max Motor and Heavy Oil Concentrations in Soil at Any Depth).mxd
Date: 2/9/2011



Notes:

- Soil data sourced from 2008-2010.
- *U* The analyte was not detected greater than or equal to the concentration reported.
- *J* The analyte was detected but the reported concentration is qualified.

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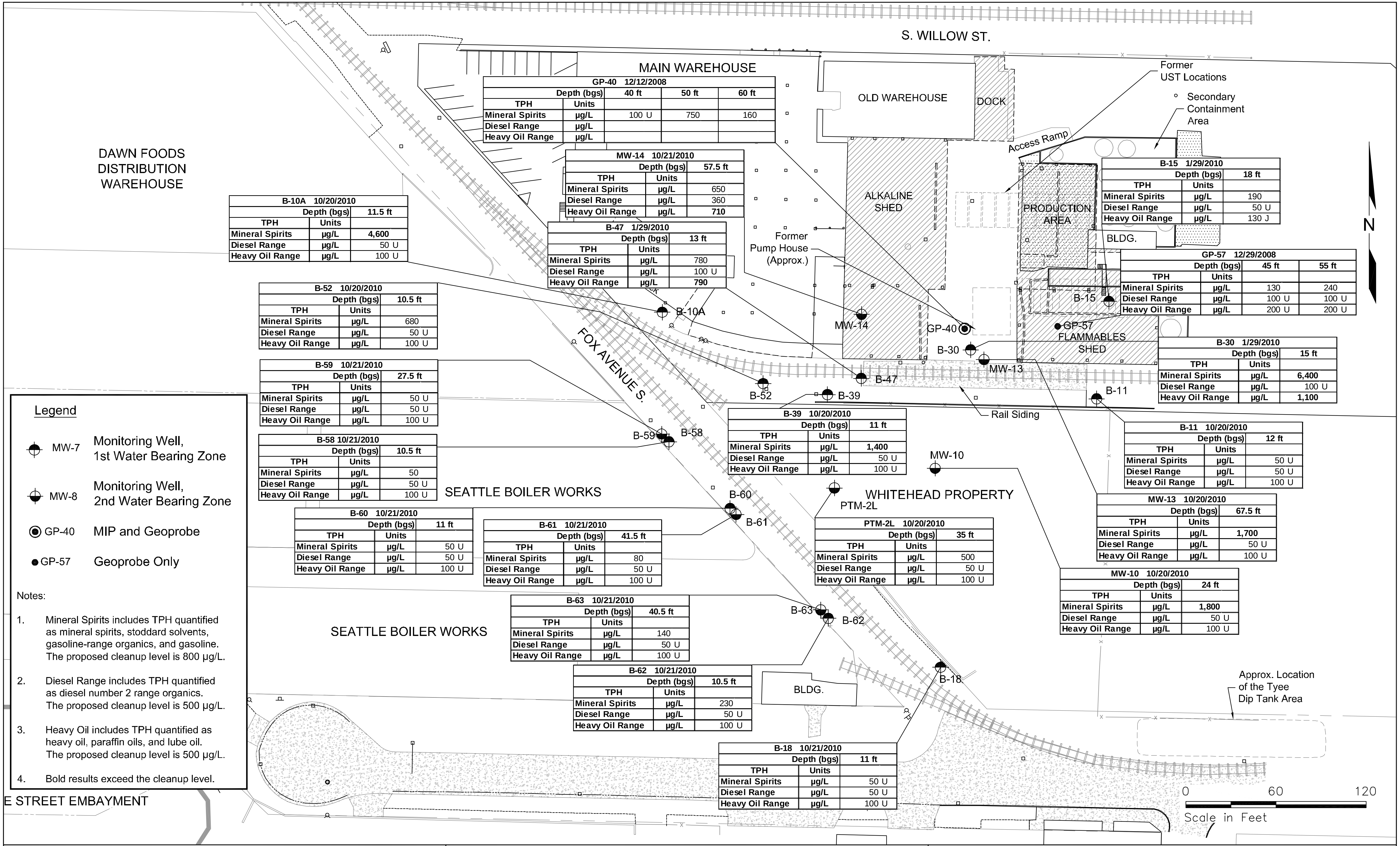
Figure 5.11
Maximum Benzene Concentrations
in Soil at any Depth

File: F:\projects\FoxAve-RA\GIS\MXD\RIFS\2011 RIFS\Figure 5.11 (Max Benzene in Soil at Any Depth).mxd
Date: 2/9/2011



GP-40 12/12/2008				
Depth (bgs)		40 ft	50 ft	60 ft
TPH	Units			
Mineral Spirits	µg/L	100 U	750	160
Diesel Range	µg/L			
Heavy Oil Range	µg/L			

MW-14 10/21/2010		
Depth (bgs)		57.5 ft
TPH	Units	
Mineral Spirits	µg/L	650
Diesel Range	µg/L	360
Heavy Oil Range	µg/L	**710**

B-10A 10/20/2010		
Depth (bgs)		11.5 ft
TPH	Units	
Mineral Spirits	µg/L	**4,600**
Diesel Range	µg/L	50 U
Heavy Oil Range	µg/L	100 U

B-47 1/29/2010		
Depth (bgs)		13 ft
TPH	Units	
Mineral Spirits	µg/L	780
Diesel Range	µg/L	100 U
Heavy Oil Range	µg/L	**790**

B-15 1/29/2010		
Depth (bgs)		18 ft
TPH	Units	
Mineral Spirits	µg/L	190
Diesel Range	µg/L	50 U
Heavy Oil Range	µg/L	130 J

GP-57 12/29/2008			
Depth (bgs)		45 ft	55 ft
TPH	Units		
Mineral Spirits	µg/L	130	240
Diesel Range	µg/L	100 U	100 U
Heavy Oil Range	µg/L	200 U	200 U

B-52 10/20/2010		
Depth (bgs)		10.5 ft
TPH	Units	
Mineral Spirits	µg/L	680
Diesel Range	µg/L	50 U
Heavy Oil Range	µg/L	100 U

B-30 1/29/2010		
Depth (bgs)		15 ft
TPH	Units	
Mineral Spirits	µg/L	**6,400**
Diesel Range	µg/L	100 U
Heavy Oil Range	µg/L	**1,100**

B-59 10/21/2010		
Depth (bgs)		27.5 ft
TPH	Units	
Mineral Spirits	µg/L	50 U
Diesel Range	µg/L	50 U
Heavy Oil Range	µg/L	100 U

B-39 10/20/2010		
Depth (bgs)		11 ft
TPH	Units	
Mineral Spirits	µg/L	**1,400**
Diesel Range	µg/L	50 U
Heavy Oil Range	µg/L	100 U

B-11 10/20/2010		
Depth (bgs)		12 ft
TPH	Units	
Mineral Spirits	µg/L	50 U
Diesel Range	µg/L	50 U
Heavy Oil Range	µg/L	100 U

B-58 10/21/2010		
Depth (bgs)		10.5 ft
TPH	Units	
Mineral Spirits	µg/L	50
Diesel Range	µg/L	50 U
Heavy Oil Range	µg/L	100 U

MW-13 10/20/2010		
Depth (bgs)		67.5 ft
TPH	Units	
Mineral Spirits	µg/L	**1,700**
Diesel Range	µg/L	50 U
Heavy Oil Range	µg/L	100 U

B-60 10/21/2010		
Depth (bgs)		11 ft
TPH	Units	
Mineral Spirits	µg/L	50 U
Diesel Range	µg/L	50 U
Heavy Oil Range	µg/L	100 U

B-61 10/21/2010		
Depth (bgs)		41.5 ft
TPH	Units	
Mineral Spirits	µg/L	80
Diesel Range	µg/L	50 U
Heavy Oil Range	µg/L	100 U

PTM-2L 10/20/2010		
Depth (bgs)		35 ft
TPH	Units	
Mineral Spirits	µg/L	500
Diesel Range	µg/L	50 U
Heavy Oil Range	µg/L	100 U

MW-10 10/20/2010		
Depth (bgs)		24 ft
TPH	Units	
Mineral Spirits	µg/L	**1,800**
Diesel Range	µg/L	50 U
Heavy Oil Range	µg/L	100 U

B-63 10/21/2010		
Depth (bgs)		40.5 ft
TPH	Units	
Mineral Spirits	µg/L	140
Diesel Range	µg/L	50 U
Heavy Oil Range	µg/L	100 U

B-62 10/21/2010		
Depth (bgs)		10.5 ft
TPH	Units	
Mineral Spirits	µg/L	230
Diesel Range	µg/L	50 U
Heavy Oil Range	µg/L	100 U

B-18 10/21/2010		
Depth (bgs)		11 ft
TPH	Units	
Mineral Spirits	µg/L	50 U
Diesel Range	µg/L	50 U
Heavy Oil Range	µg/L	100 U

Legend

MW-7	Monitoring Well, 1st Water Bearing Zone
MW-8	Monitoring Well, 2nd Water Bearing Zone
◉ GP-40	MIP and Geoprobe
● GP-57	Geoprobe Only

Notes:

1. Mineral Spirits includes TPH quantified as mineral spirits, stoddard solvents, gasoline-range organics, and gasoline. The proposed cleanup level is 800 µg/L.
2. Diesel Range includes TPH quantified as diesel number 2 range organics. The proposed cleanup level is 500 µg/L.
3. Heavy Oil includes TPH quantified as heavy oil, paraffin oils, and lube oil. The proposed cleanup level is 500 µg/L.
4. Bold results exceed the cleanup level.

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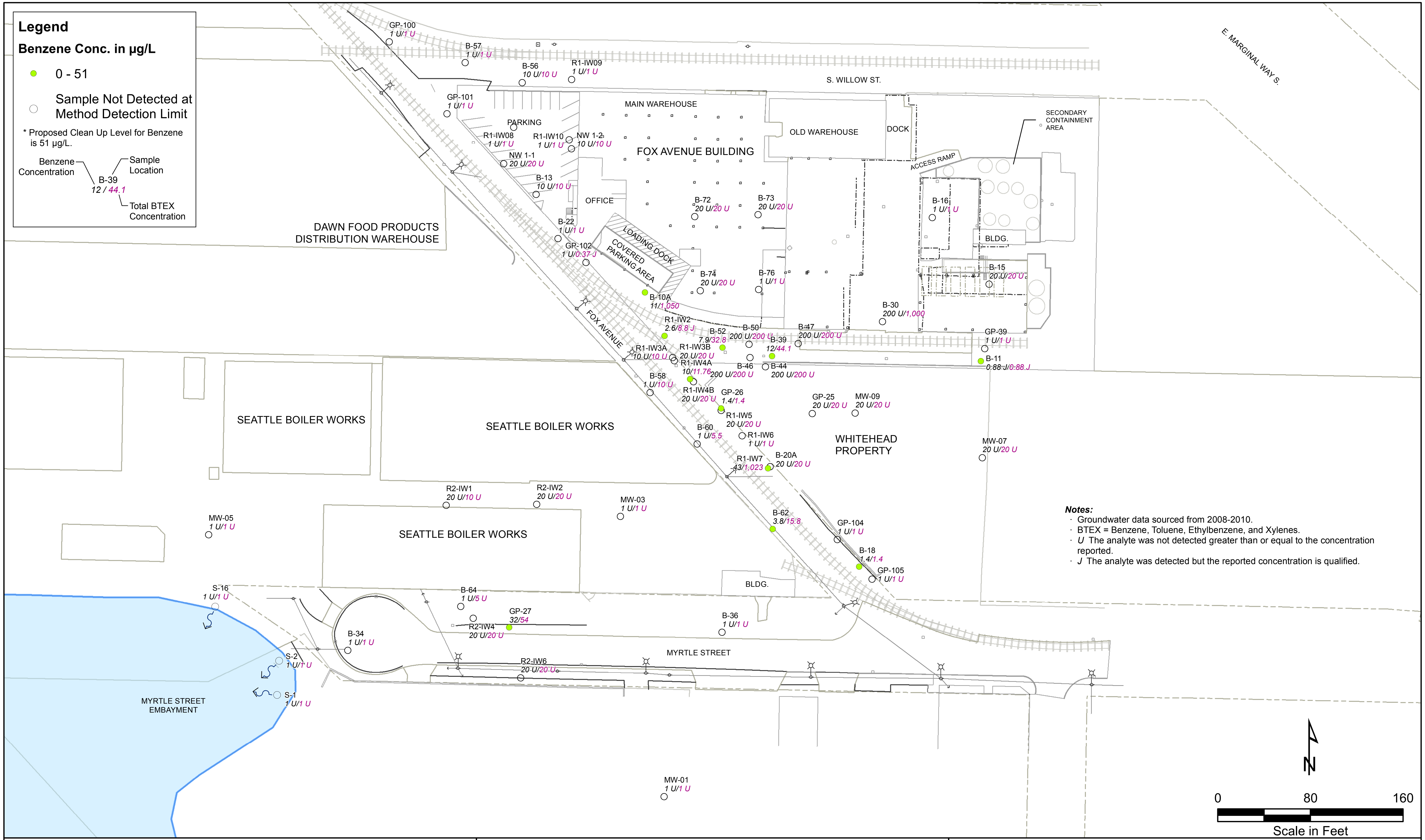
Figure 5.12
TPH Concentration in Groundwater
(2007 to 2010)

DWG NAME: G:\project\Clients\Floyd and Snider\Fox Ave 2010\CAD\FoxAve2010_016.dwg
DATE: 2/9/2011 10:15 AM



Notes:

- Groundwater data sourced from 2008-2010.
- BTEX = Benzene, Toluene, Ethylbenzene, and Xylenes.
- *U* The analyte was not detected greater than or equal to the concentration reported.
- *J* The analyte was detected but the reported concentration is qualified.

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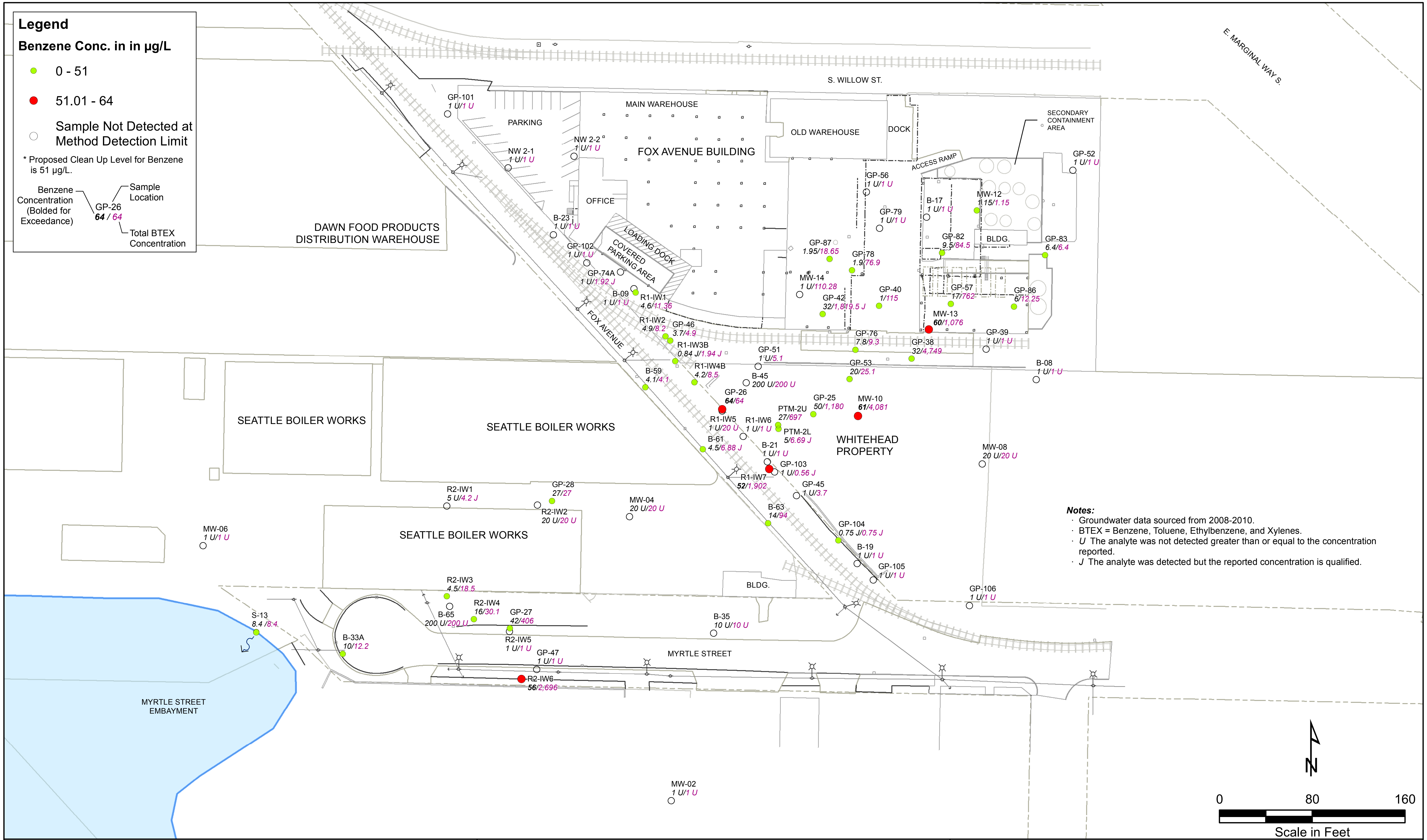
Figure 5.13a
Current Conditions: Maximum Benzene and Total BTEX Concentrations in Groundwater in 1st Water Bearing Zone

Path: F:\projects\FoxAve-RA\GIS\MXD\RIFS\2011 RIFS\Figure 5.13a (Max Benzene and Total BTEX Concentrations in GW in 1st WBZ).mxd
Date: 2/8/2011



Notes:
- Groundwater data sourced from 2008-2010.
- BTEX = Benzene, Toluene, Ethylbenzene, and Xylenes.
- *U* The analyte was not detected greater than or equal to the concentration reported.
- *J* The analyte was detected but the reported concentration is qualified.

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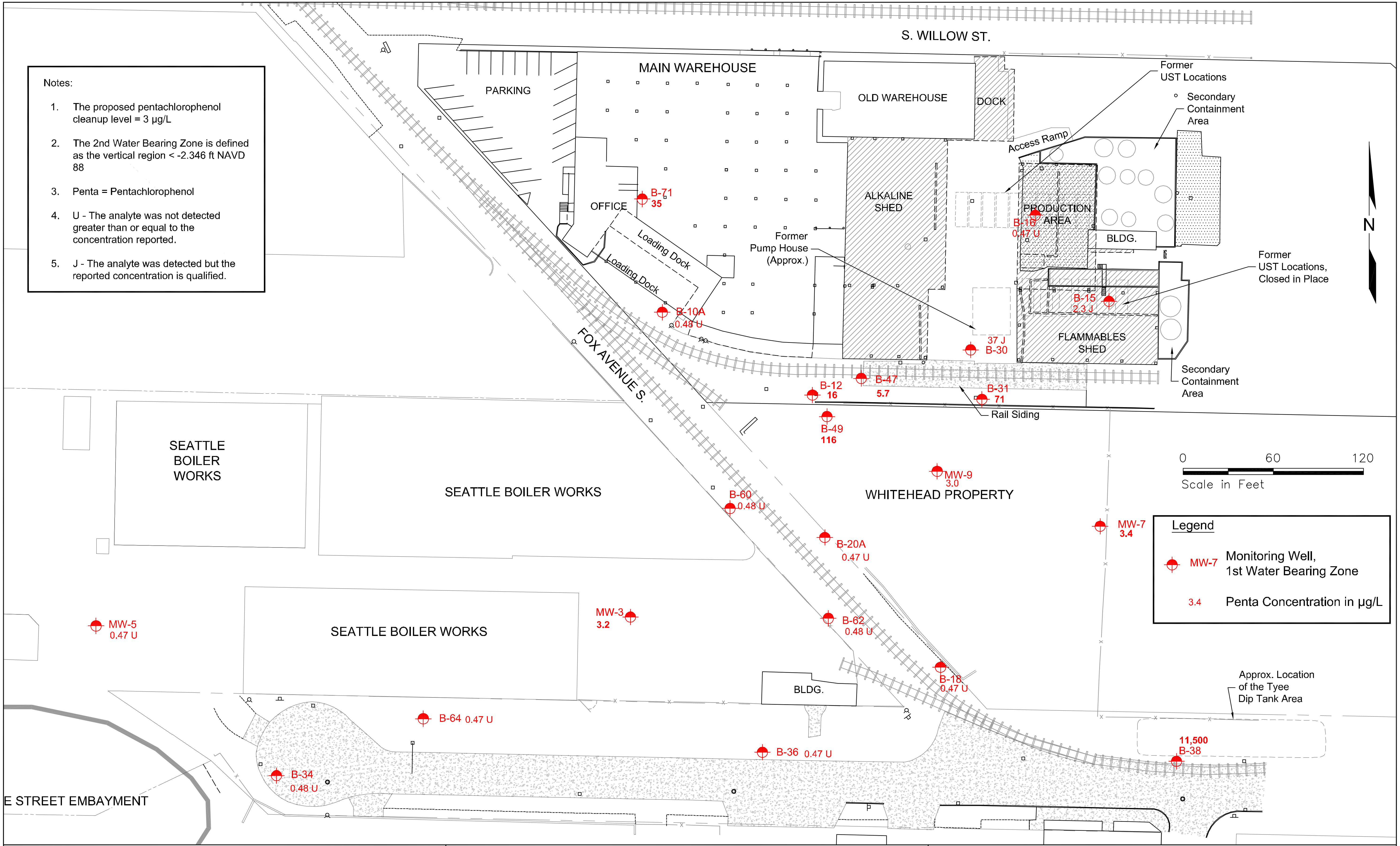
Figure 5.13b
Current Conditions: Maximum Benzene and Total BTEX Concentrations in Groundwater in 2nd Water Bearing Zone

Path: F:\projects\FoxAve-RA\GIS\MXD\RIFS\2011 RIFS\Figure 5.13b (Max Benzene and Total BTEX Concentrations in GW in 2nd WBZ).mxd
Date: 2/8/2011



Notes:

1. The proposed pentachlorophenol cleanup level = 3 μg/L
2. The 2nd Water Bearing Zone is defined as the vertical region < -2.346 ft NAVD 88
3. Penta = Pentachlorophenol
4. U - The analyte was not detected greater than or equal to the concentration reported.
5. J - The analyte was detected but the reported concentration is qualified.

Legend

MW-7	Monitoring Well, 1st Water Bearing Zone
3.4	Penta Concentration in μg/L

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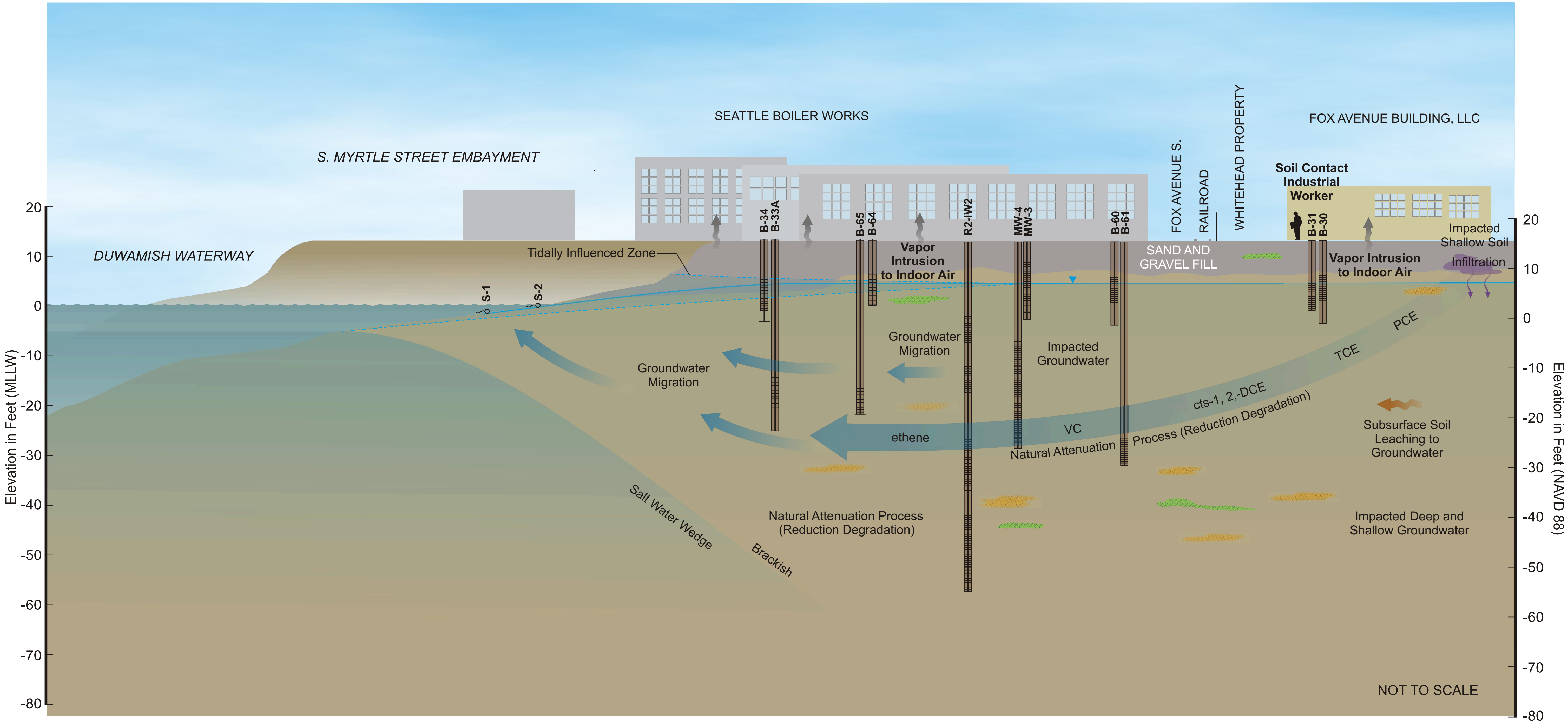
Seattle, Washington

Figure 5.14
Pentachlorophenol Concentrations in Groundwater
in the 1st WBZ (2007)

DWG NAME: G:\project\Clients\Floyd and Snider\Fox Ave 2010\CAD\FoxAve2010_015.dwg
DATE: 2/8/2011 12:26 PM



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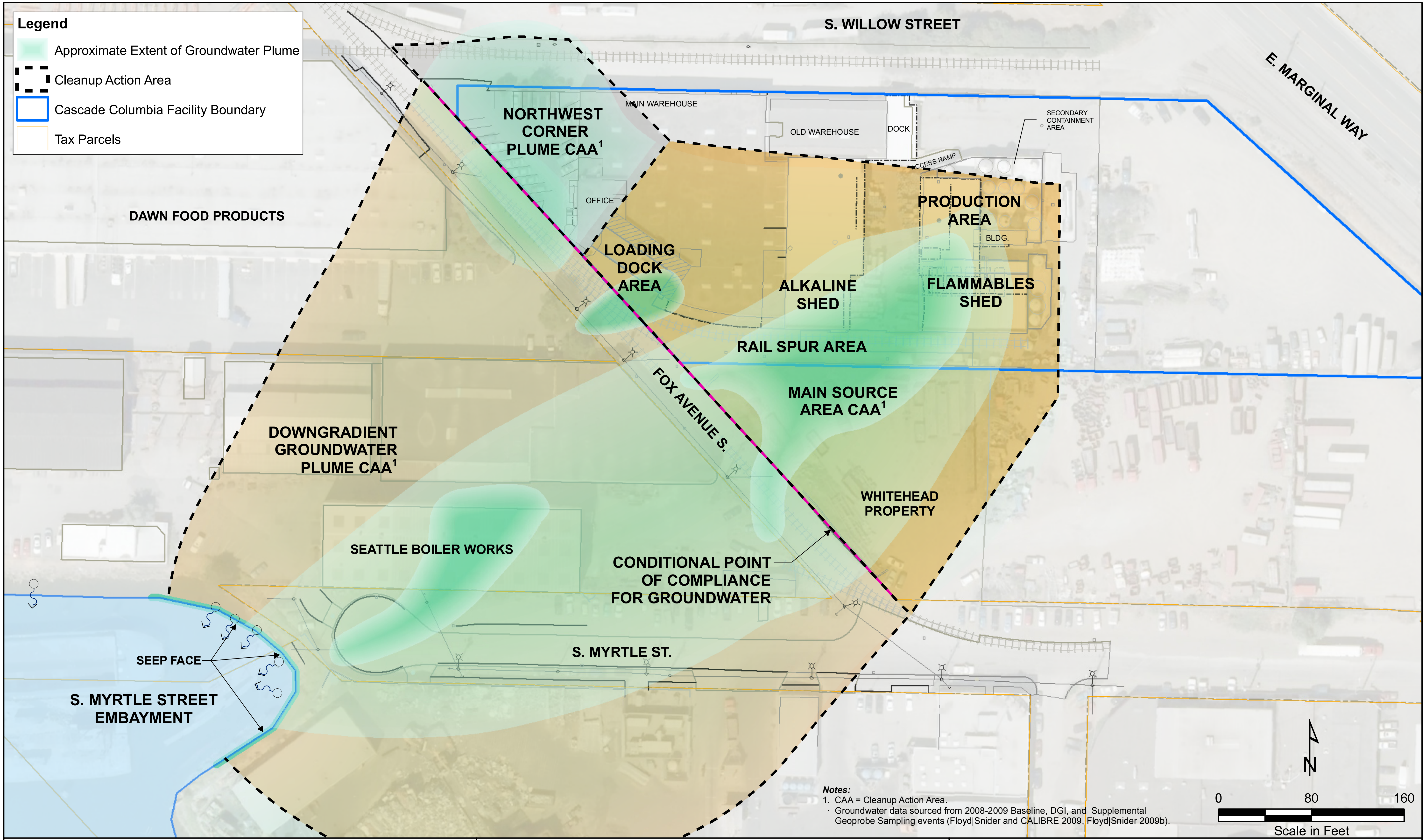
Fox Avenue Site
Seattle, Washington

Figure 6.1
Conceptual Site Model

G:Project\Clients\Floyd Snider\Fox Avenue\2010\Geologic Cross Section B-B'



Notes:
1. CAA = Cleanup Action Area.
· Groundwater data sourced from 2008-2009 Baseline, DGI, and Supplemental Geoprobe Sampling events (Floyd|Snider and CALIBRE 2009, Floyd|Snider 2009b).

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Figure 7.1
Cleanup Action Areas

File: F:\projects\FoxAve-RA\GIS\MXD\RIFS\2011 RIFS\Figure 7.1 (Cleanup Action Areas).mxd
Date: 2/9/2011

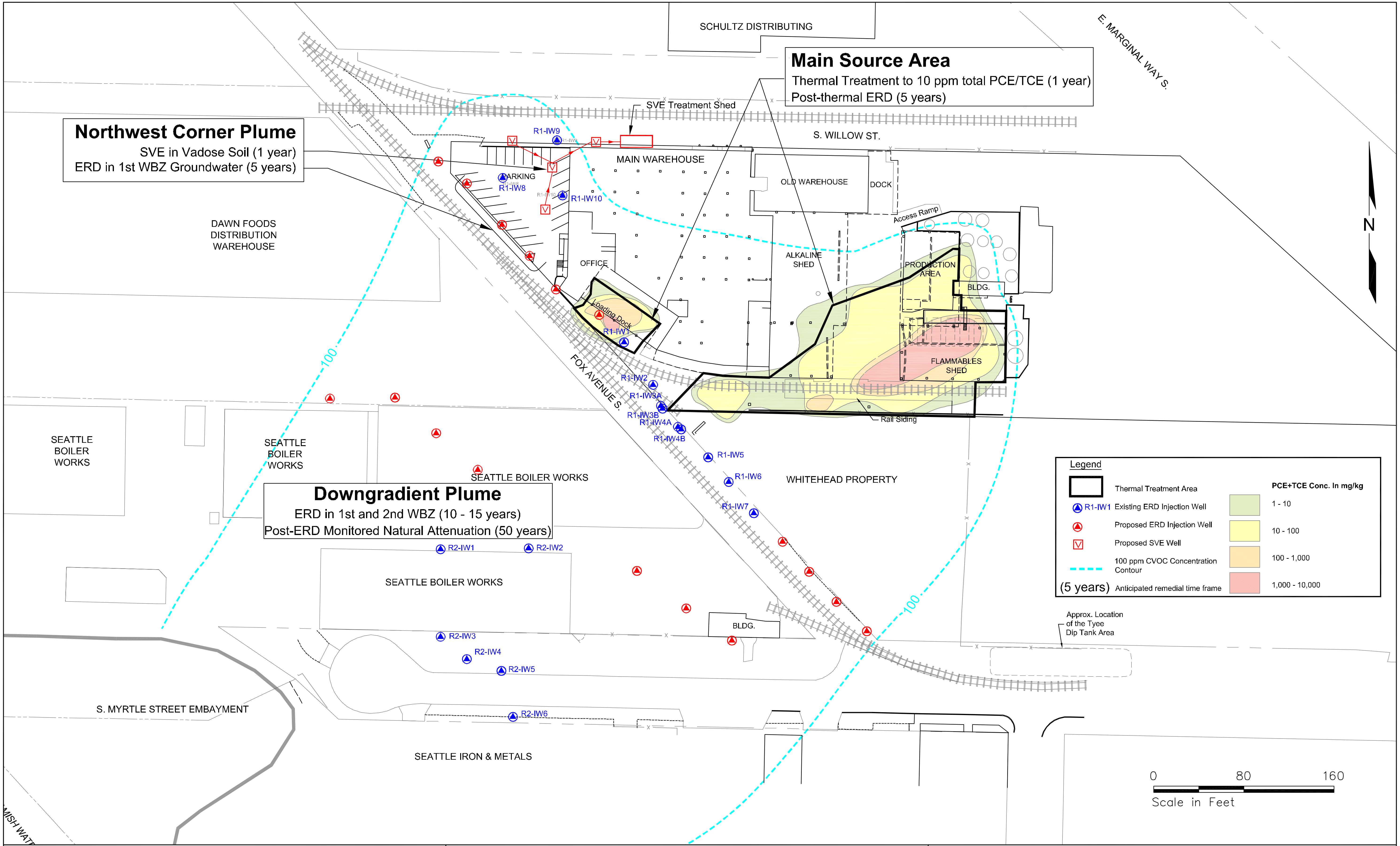

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Figure 11.1
Preferred Remedy Elements

DWG NAME: G:\project\Clients\Floyd and Snider\Fox Ave 2010\CAD\FoxAve2010_018.dwg
DATE: 2/8/2011 12:34 PM

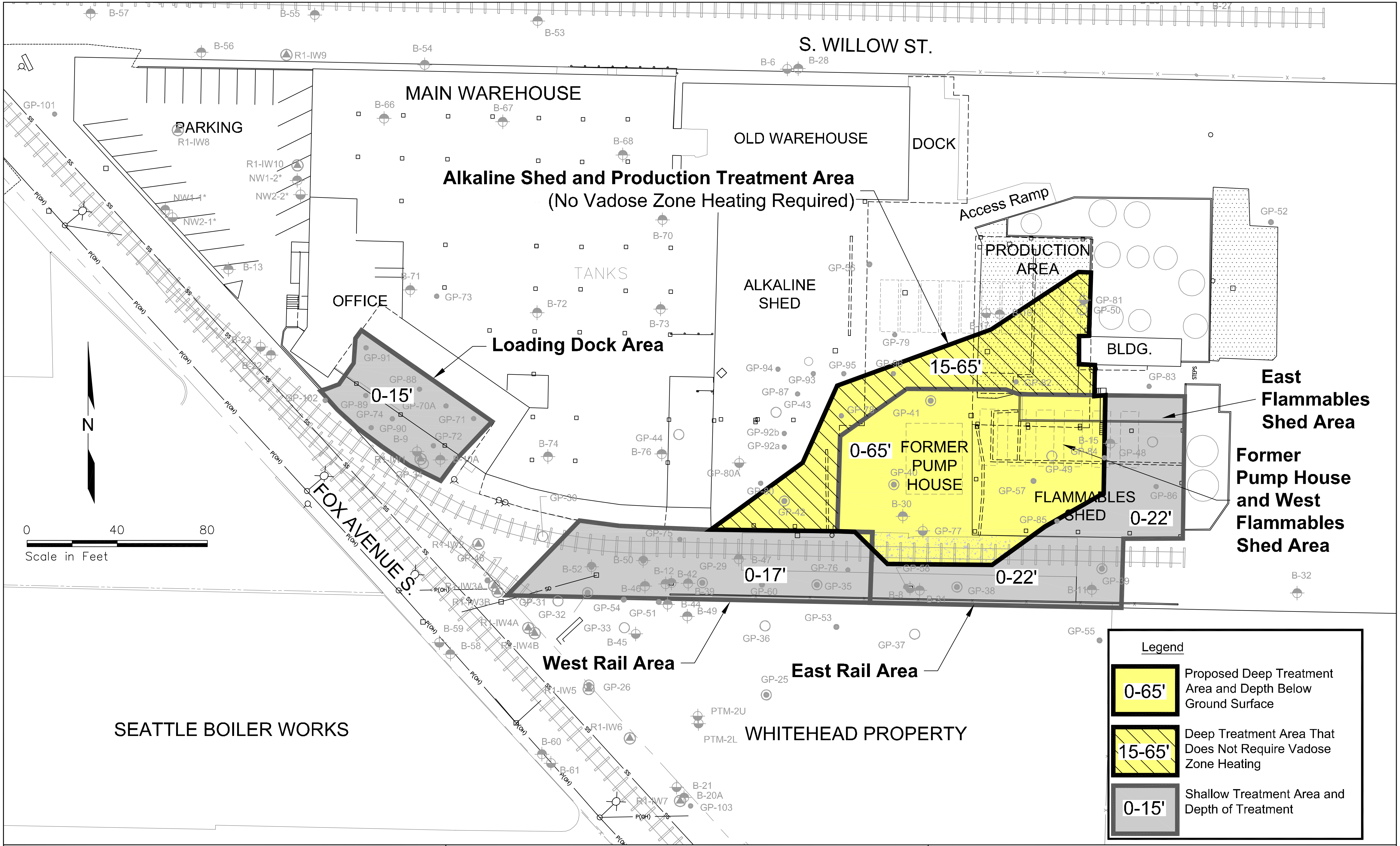

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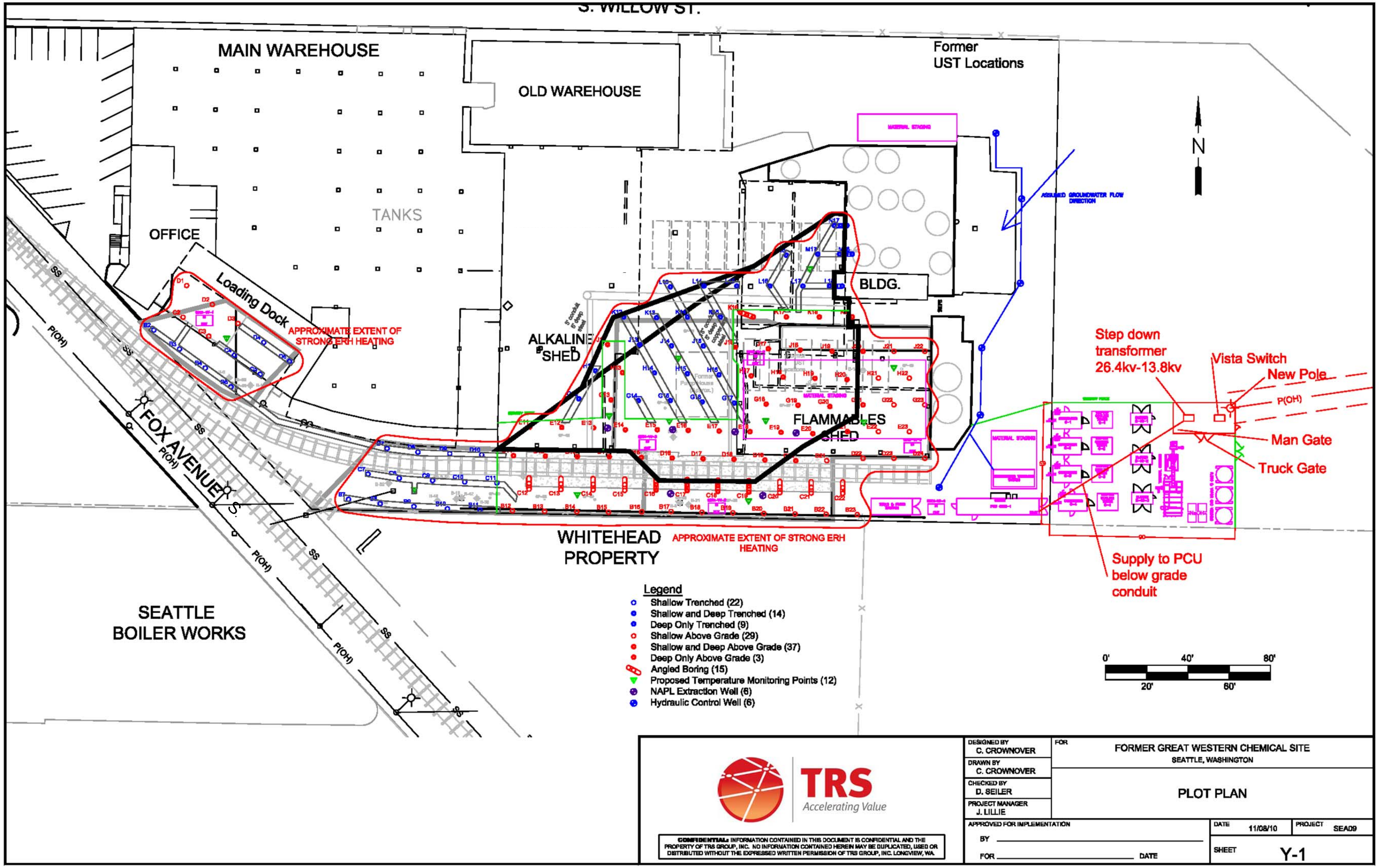
Figure 11.2
Proposed Thermal Treatment Areas

DWG NAME: G:\project\Clients\Floyd and Snider\Fox Ave 2010\CAD\FoxAve2010_008.dwg
DATE: 2/9/2011 10:19 AM



Note: Provided by TRS as part of initial planning.

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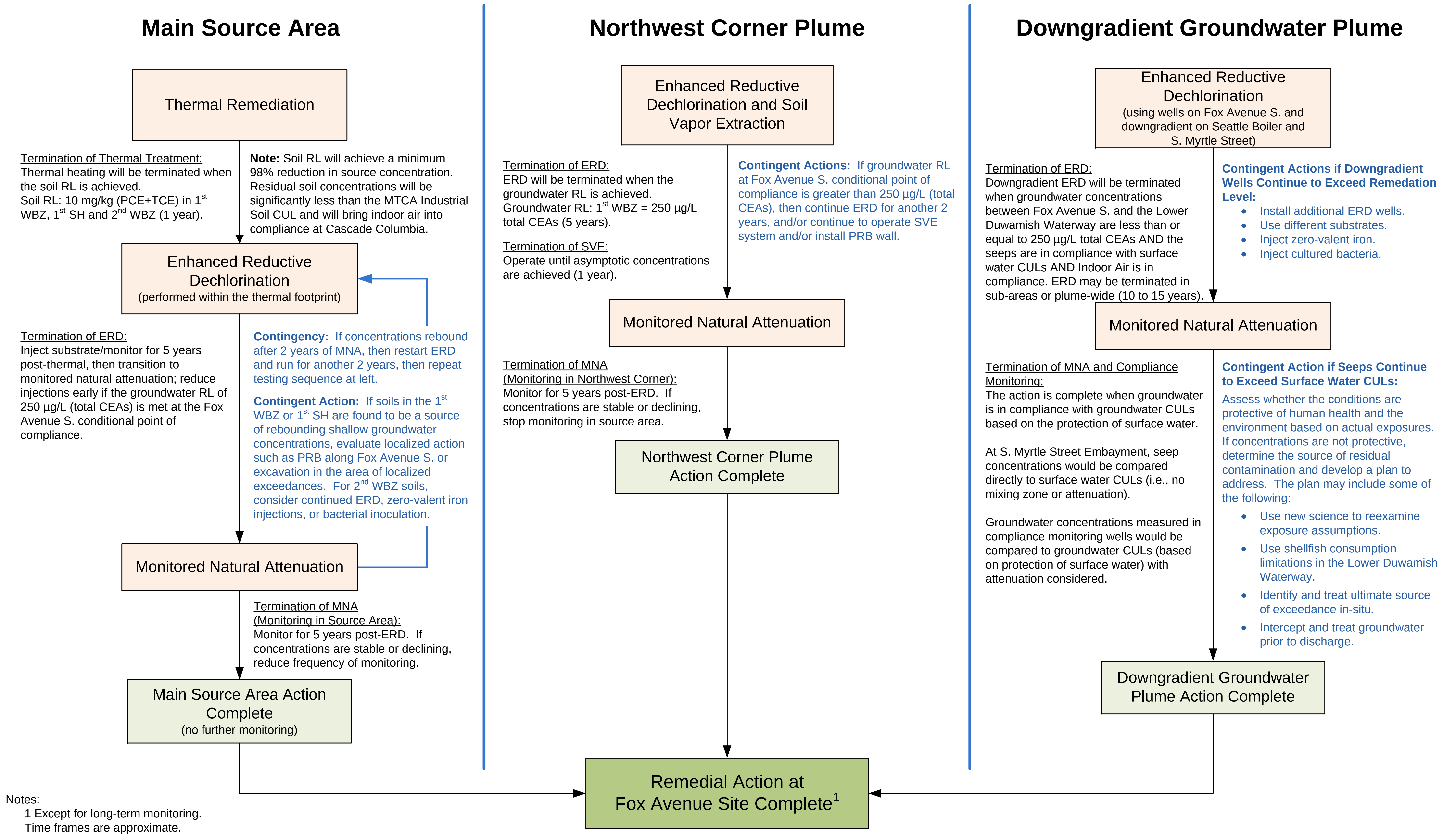
Figure 11.3
Layout of Thermal Electrodes and Support Equipment



Main Source Area

Thermal Remediation

Termination of Thermal Treatment:
Thermal heating will be terminated when the soil RL is achieved.
Soil RL: 10 mg/kg (PCE+TCE) in 1st WBZ, 1st SH and 2nd WBZ (1 year).

Note: Soil RL will achieve a minimum 98% reduction in source concentration. Residual soil concentrations will be significantly less than the MTCA Industrial Soil CUL and will bring indoor air into compliance at Cascade Columbia.

Enhanced Reductive Dechlorination
(performed within the thermal footprint)

Termination of ERD:
Inject substrate/monitor for 5 years post-thermal, then transition to monitored natural attenuation; reduce injections early if the groundwater RL of 250 µg/L (total CEAs) is met at the Fox Avenue S. conditional point of compliance.

Contingency: If concentrations rebound after 2 years of MNA, then restart ERD and run for another 2 years, then repeat testing sequence at left.

Contingent Action: If soils in the 1st WBZ or 1st SH are found to be a source of rebounding shallow groundwater concentrations, evaluate localized action such as PRB along Fox Avenue S. or excavation in the area of localized exceedances. For 2nd WBZ soils, consider continued ERD, zero-valent iron injections, or bacterial inoculation.

Monitored Natural Attenuation

Termination of MNA
(Monitoring in Source Area):
Monitor for 5 years post-ERD. If concentrations are stable or declining, reduce frequency of monitoring.

Main Source Area Action Complete
(no further monitoring)

Northwest Corner Plume

Enhanced Reductive Dechlorination and Soil Vapor Extraction

Termination of ERD:
ERD will be terminated when the groundwater RL is achieved.
Groundwater RL: 1st WBZ = 250 µg/L total CEAs (5 years).

Termination of SVE:
Operate until asymptotic concentrations are achieved (1 year).

Contingent Actions: If groundwater RL at Fox Avenue S. conditional point of compliance is greater than 250 µg/L (total CEAs), then continue ERD for another 2 years, and/or continue to operate SVE system and/or install PRB wall.

Monitored Natural Attenuation

Termination of MNA
(Monitoring in Northwest Corner):
Monitor for 5 years post-ERD. If concentrations are stable or declining, stop monitoring in source area.

Northwest Corner Plume Action Complete

Downgradient Groundwater Plume

Enhanced Reductive Dechlorination
(using wells on Fox Avenue S. and downgradient on Seattle Boiler and S. Myrtle Street)

Termination of ERD:
Downgradient ERD will be terminated when groundwater concentrations between Fox Avenue S. and the Lower Duwamish Waterway are less than or equal to 250 µg/L total CEAs AND the seeps are in compliance with surface water CULs AND Indoor Air is in compliance. ERD may be terminated in sub-areas or plume-wide (10 to 15 years).

Contingent Actions if Downgradient Wells Continue to Exceed Remedation Level:

- Install additional ERD wells.
- Use different substrates.
- Inject zero-valent iron.
- Inject cultured bacteria.

Monitored Natural Attenuation

Termination of MNA and Compliance Monitoring:
The action is complete when groundwater is in compliance with groundwater CULs based on the protection of surface water.

At S. Myrtle Street Embayment, seep concentrations would be compared directly to surface water CULs (i.e., no mixing zone or attenuation).

Groundwater concentrations measured in compliance monitoring wells would be compared to groundwater CULs (based on protection of surface water) with attenuation considered.

Contingent Action if Seeps Continue to Exceed Surface Water CULs:

Assess whether the conditions are protective of human health and the environment based on actual exposures. If concentrations are not protective, determine the source of residual contamination and develop a plan to address. The plan may include some of the following:

- Use new science to reexamine exposure assumptions.
- Use shellfish consumption limitations in the Lower Duwamish Waterway.
- Identify and treat ultimate source of exceedance in-situ.
- Intercept and treat groundwater prior to discharge.

Downgradient Groundwater Plume Action Complete

Remedial Action at Fox Avenue Site Complete[1]

Notes:
1 Except for long-term monitoring.
Time frames are approximate.

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Figure 12.1
Proposed Remedial and Contingency Actions for Soil and Groundwater

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Fox Avenue Site
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Remedial Investigation/ Feasibility Study

Appendix A
Aquifer Non-potability Determination

FINAL

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1.0 INTRODUCTION

The alluvial aquifer at the Site is considered non-potable based on site conditions that are consistent with the Model Toxics Control Act (MTCA) definitions (Washington Administrative Code [WAC] 173-340-720) specifically related to evaluating highest beneficial use (i.e., groundwater potability) and corresponding groundwater cleanup requirements. This appendix augments the discussion on non-potability in Section 2.4 of the Remedial Investigation (RI) by providing additional detail on past Washington State Department of Ecology (Ecology) decisions regarding potability in the Duwamish Valley, as well as referencing other relevant applicable or relevant and appropriate requirements (ARARs) that restrict potable groundwater use in the area.

2.0 AREA-WIDE CONSIDERATIONS

Since the advent of the MTCA regulation and because of the proximity of this Site to the Lower Duwamish Waterway (a saline portion of the Duwamish estuary), groundwater at this Site has typically been considered non-potable by Ecology with the highest beneficial use of groundwater designated as protection of the adjacent surface water body. In part, this determination was a result of the Duwamish Industrial Area Hydrogeologic Pathways Project discussed in detail below.

2.1 Duwamish Industrial Area Hydrogeologic Pathways Project

The Duwamish Industrial Area Hydrogeologic Pathways Project was jointly funded in 1998 to 2000 by the City of Seattle (City) and King County. The University of Washington’s Center for Urban Water Resources Management, Ecology, and the U. S. Environmental Protection Agency (USEPA) were active participants in the scoping and execution of the project.

The goal of the project was to facilitate the redevelopment of brownfields in the Duwamish Industrial Corridor by improving the quality and pace of cleanup-related decision-making for the area. “Duwamish Basin Groundwater Pathways Guidance Documents” were produced and accepted by Ecology as suitable for use by consultants, property owners, and site managers who will make site-specific cleanup decisions under MTCA for sites within the Duwamish Industrial Valley. The guidance documents provide necessary information for making site-specific arguments that within the studied area, groundwater is non-potable per MTCA criteria, and the highest beneficial use of shallow groundwater is the protection of beneficial uses of adjacent surface waters.

The Ecology-approved “User’s Guide” for the guidance documents states that

> “The guidance documents provide the regional setting for evaluating hydrogeologic information for individual properties within the study area. The material is meant to streamline the process for determining, on a site-specific basis, the highest beneficial use of groundwater in the shallow aquifer within the study area and setting the appropriate cleanup standards…Provision of this material should streamline the evaluation and regulatory process for individual sites by reducing the expenditures of individual property owners to replicate this information, and by eliminating redundant and sometimes conflicting interpretation of regional information by multiple consultants and site managers” (Floyd & Snider Team 1999).

Formal acceptance of the guidance by Ecology was documented in a May 1, 2000 letter from Jim Pendowski to King County and City officials. The letter states:

> "The…products of this project…*Duwamish Industrial Area Technical Memorandum – Shallow Groundwater Use Designation*…have been reviewed by Ecology and found to be suitable for use by site managers and others in making site-specific cleanup decisions under the Model Toxics Control Act (MTCA) for sites within the Duwamish Industrial area." (Pendowski 2000).

The Shallow Groundwater Use Designation technical memorandum summarizes why shallow groundwater in the Duwamish Valley will never be used as a source of potable water, and proposes that the highest beneficial use of shallow groundwater should be classified as discharge to surface water. The memo lays out the rationale relative to the designation criteria in WAC 173-340-720 (Herman and Snider 1998).

2.2 Duwamish Industrial Area Non-potable Designation

The Shallow Groundwater Use Designation Memorandum addresses all of the potable groundwater definition provisions: 720 (a), (b), (c), and (d). Importantly, Ecology confirmed in this process that the criteria defined for designation are not required to be met inclusively. Not all of the criteria need to be met to support designation. The primary criteria for non-potable designation that are met in the Duwamish Industrial Corridor are discussed below with emphasis on the Fox Avenue Site (Site).

- The groundwater does not serve as a current source of drinking water. There are no known uses of shallow groundwater for drinking water purposes within the Duwamish Valley north of the turning basin (173-340-720(2)(a)).
- The groundwater is not a reasonable potential future source of drinking water given the industrial nature of the Site and surrounding land use. In addition, Ecology has historically considered groundwater in the Lower Duwamish Waterway and Duwamish Valley as non-potable. The Site is hydraulically connected to the Lower Duwamish Waterway, which is a saline surface water body tidally influenced by salt water that is not suitable as a domestic water supply (173-340-720(2)(b)).
- The groundwater at the Site contains natural background concentrations of organic or inorganic constituents that make use of the groundwater as a drinking water source not practicable.
- Distinct hydrogeologic boundary conditions exist that hydraulically separate the shallow aquifer systems from adjacent or underlying water bearing units. Additionally, it is unlikely that hazardous substances will be transported from the contaminated groundwater to groundwater that is a current or potential future source of drinking water because there are no drinking water wells located in the vicinity of the Site, or that are hydraulically connected to the Site (173-340-720(2)(c)).
- The Site has an extremely low probability that the groundwater could ever be used as a source of potable water. In these cases Ecology has allowed groundwater to be classified as non-potable if the conditions of Section (2)(a) and (2)(c) are met. The conditions of (2)(a) are met because site groundwater is not currently used as a source of drinking water and the conditions in (2)(c) are met because of the existing hydrogeologic boundary that separates the shallow aquifer system from any adjacent water bearing units (173-340-720(2)(d)(i)).

- Conditions under sections (2)(d)(ii)(iii)(iv) are met because there are known and projected points of entry of the groundwater into the surface water (e.g., the Duwamish Waterway). Secondly, the surface water (Lower Duwamish Waterway) is saline; therefore, it is not classified as a suitable domestic water supply source. Finally, the groundwater is sufficiently hydraulically connected to the surface water that the groundwater is not practicable to use as a drinking water source (173-340-720(2)(d)(ii)(iii)(iv)).

3.0 APPLICABLE DRINKING WATER REGULATORY CONSIDERATIONS

A number of additional rules and regulations are in place that prohibit the use of groundwater as a potable supply in the area that includes the Site:

- King County Board of Health Title 12, Section 12.32
- WAC 246-290 & 246-291 Public Water Systems
- Ecology Seawater Intrusion Policy
- WAC 173-160 Well Construction Standards
- King County Coordinated Water Supply Plan

These regulations prohibit the installation and operation of new drinking water wells in the vicinity of the Site, as discussed below. The nearest public water supply wells are located approximately 4 miles southwest of the Site and are operated by the City only during the summer.

3.1 Drinking Water Supply

Public and private water systems are used throughout Washington State. The design, construction, operation, and monitoring of all public systems are regulated by the Washington State Department of Health (WDOH) Office of Drinking Water and/or Seattle-King County Department of Public Health. The regulations governing public water systems are WAC 246-290 for Group A systems and WAC 246-291 for Group B systems. Pursuant to the requirements of the WAC, new water sources require approval from the WDOH and <u>the source must meet both primary and secondary maximum contaminant levels (MCLs).</u> The specific secondary MCLs of concern (i.e., those that are routinely exceeded at the Site due to natural conditions) in the area include chloride, iron, manganese, electrical conductivity, and total dissolved solids). WDOH requires that these secondary MCLs must be met for a new water source.

The Duwamish aquifer is not listed as one of the City's long range water supply options. In addition, the City has noted that given the widely accepted assumption that the shallow groundwater is under the influence of surface water, the City would not be interested in using the shallow aquifer for drinking water because of required treatment (i.e., it would not be practicable per the MTCA definitions).

Under the requirements of WAC 246-290-106, a water supplier has a duty to provide retail water service to all new service connections within its service area. Similarly, under King County Board of Health Title 12.32, an owner or occupant of lands undertaking new construction or other new development must connect to an approved public water system (when available). Neither of these conditions is optional. Regarding private water systems, there is no currently known use of shallow groundwater for drinking water purposes in the area. Municipal water supply has been available to all of the properties in the area for many years.

Within the Duwamish Valley area, any new water user is required to connect to the potable water supply systems supplied by the Seattle Water Department and other water districts. As part of the Duwamish Industrial Area Hydrogeologic Pathways Project, letters were requested and received from both Seattle Public Utilities and the Seattle-King County Department of Public Health documenting that the aquifer(s) in the Duwamish Valley would not be considered for drinking water supply. In response, the Seattle-King County Department of Public Health noted they “could not imagine any circumstance where a request to drill a drinking water well in the area would be approved.” These King County and City rules prohibit use of the shallow aquifer in the Duwamish Valley for drinking water.

The creation of a new water supply utility in the area is unlikely, given the Public Water System Coordination Act (RCW 70.116), WAC 246-290, and the adopted King County Coordinated Water Supply Plan. RCW 70.116.040(1) states: “After establishment of the external boundaries of the critical water supply service area, no new public water supply may be approved with the boundary area unless an existing water purveyor is unable to provide water service.”

If the existing utility could not provide water service in the area, any new service would require source approval from WDOH (demonstrating that the source meets primary and secondary MCLs) and also meet the requirements of WAC 173-160. Under WAC 173-160-171, all supply wells are to be located not less than minimum distances from known or potential sources of contamination and sea/salt water intrusion areas are specifically noted. The potential for seawater intrusion has been documented in all coastal areas of western Washington State (e.g., Ecology and USGS 1971, Ecology and USGS 1984, and USEPA 1992) and is a well known problem in many island/peninsula communities. Early samples taken from two wells in the Duwamish Valley area contained chloride at 348 and 990 mg/L (Ecology and USGS 1971); the wells were subsequently closed (prior to 1968). Further water development in the area has been primarily surface water sources, which has limited continued intrusion in the mainland areas; however, the potential for saltwater intrusion remains and “problems with saltwater intrusion are likely to occur if groundwater pumpage in the area is increased” (Ecology and USGS 1971).

3.2 Salt Water Intrusion to Water Systems

WDOH guidelines for water systems consider wells within ½ mile of the shoreline and with the pumped water level below sea level, or within ½ mile of a groundwater source with chloride concentrations over 100 mg/L, to be at risk for potential seawater intrusion (WDOH 2001). In addition, the subject area has previously been identified to be at risk for saltwater intrusion (Ecology and USGS 1971, USEPA 1992). Any theoretical future supply well in the Duwamish Valley would necessarily have a pump intake at a level below sea level and multiple locations have indicated chloride concentrations in excess of 800 mg/L in the immediate area. The Ecology Seawater Intrusion Policy establishes risk categories as a basis for controlling intrusion and sets forth actions to be taken by Ecology, as deemed by the existing risk level.

Risk Categories:

- **Low:** 25 mg/L > Chloride < 100 mg/L. Based on data from an existing well, a test well or general groundwater basin conditions. If the basin is not geologically delineated, a half-mile radius from a well with these chloride levels is used.

- **Medium:** 100 mg/L > Chloride < 200 mg/L. Based on data from sources outlined in low risk areas. In addition, an area with chloride levels classified as low, but where data show a trend towards increasing levels falls in the medium risk category.
- **High:** Chloride > 200 mg/L. Based on data from sources outlined in low risk areas. In addition, an area with chloride levels classified as medium risk, but where data show a trend towards increasing levels falls in the high risk category.

Responses vary depending on the level of risk and whether it is a new or existing well. In low risk areas Ecology can require design, operation, and monitoring controls for new wells. Ecology will deny a water permit in a medium or high risk area unless the applicant can show that further intrusion would not result from the proposed withdrawal.

Based on the WAC requirements, WDOH guidelines, and the Ecology Seawater Intrusion Policy, a new supply well in the area would not be allowed (even with treatment to meet the secondary MCLs).

4.0 SUMMARY

The key characteristics that identify groundwater at the Site as non-potable, in accordance with the requirements of WAC 173-340-720 2(d), are described below:

- **The Regional Aquifer is saline at depth.** Groundwater at the Site is part of the Lower Duwamish Valley aquifer, which is saline (greater than 10,000 parts per thousand [ppt]) at depth throughout the area. Surficial groundwater at the Site is located within the Upper Groundwater Zone (UGZ) of the valley aquifer, which tends to be fresh water down to 60 to 80 feet, except near the waterway where the permanent saltwater zone within the dredged waterway extends into the aquifer.
- **The Site is adjacent to and discharges to marine waters.** The Lower Duwamish Waterway, an extension of Puget Sound, is saline and not appropriate for drinking water use (WAC 173-201A-602). The Site's source area is approximately 500 feet from the waterway and the Site extends to the waterway.
- **There are known or projected points of entry of the groundwater into the surface water.** As discussed in detail in Section 2.5 of the RI, groundwater at the Site discharges into surface water via a series of discrete seeps along the S. Myrtle Street Embayment.
- **The site groundwater is sufficiently connected hydraulically to the surface water that it is not practicable to use as a drinking water source.** Section 2.5 of the RI discusses the influence of tides upon groundwater elevations. The clearly demonstrated tidal influence upon groundwater at the Site provides direct evidence that the groundwater is hydraulically connected to the surface water body.
- **The surface water is not classified as a suitable domestic water supply source.** Per Chapter 173-201A WAC, the Duwamish Waterway, part of Water Resource Inventory Area (WRIA) 9, from the mouth south to the River Mile 11 is not listed as a domestic water supply.
- **The groundwater at the Site does not serve as a current source of drinking water.** Section 2.0 of the RI discusses the absence of drinking water wells in the vicinity of the Site and the regulations prohibiting installation of new wells.

Based on the existing site conditions, reasonable future site uses (i.e., industrial activity), and existing state and local regulations that prohibit installation of groundwater supply wells, it is recommended that the site groundwater continue to be classified as non-potable groundwater. The site remediation goals for groundwater are still required and would be developed to be protective of the receiving surface water body, as required under MTCA.

5.0 REFERENCES

Floyd & Snider Team. 1999. *Duwamish Industrial Area Hydrogeologic Pathways Project User's Guide*. Prepared for City of Seattle Office of Economic Development and King County Office of Regional Policy and Planning. October.

Herman, L. and K. Snider. 1998. *Duwamish Basin Shallow Groundwater Use Designation.* Duwamish Industrial Area Hydrogeologic Pathways Project. Prepared for City of Seattle Office of Economic Development and King County Office of Budget and Strategic Planning. April.

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———. 1984. *Seawater Intrusion into Coastal Aquifers in Washington 1978*. Water-Supply Bulletin No. 56.

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Appendix B

Hydrogeological and Well Completion Information

FINAL

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Figure B.2 Boring Locations (2008 to 2010)

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Attachment B.1 Boring Logs (PDF Only)

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Seattle, Washington

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Appendix B
Hydrogeological and Well Completion Information

Tables

FINAL

Table B.1
Well Status Information

Well ID	Water Bearing Zone	Purpose of Well	Completion Date	Consultant	Northing (ft. NAD 83/98)	Easting (ft. NAD 83/98)	Measuring Point Elevation (NAVD88)	Boring Depth (ft)	Well Depth (ft)	Screen Interval (ft)	PVC Diameter (in)	Well Status	Location	Well Log Available
B-1	1st	Monitoring	30-May-89	Hart Crowser	Abandoned	Abandoned	Abandoned	24.50	16.50	6.5–16.5	2	Abandoned	Production Area	Yes
B-2	1st	Monitoring	11-May-90	Hart Crowser	Abandoned	Abandoned	Abandoned	11.50	**Wells Not Installed**			Abandoned		NA
B-3	1st	Monitoring	11-May-90	Hart Crowser	Abandoned	Abandoned	Abandoned	11.50				Abandoned		NA
B-4	1st	Monitoring	11-May-90	Hart Crowser	Abandoned	Abandoned	Abandoned	11.50				Abandoned		NA
B-5	1st	Monitoring	28-Sep-90	Hart Crowser	Abandoned	Abandoned	Abandoned	46.50	45.00	40–45	2	Abandoned		Yes
B-6	2nd	Monitoring	27-Sep-90	Hart Crowser	200821.50	1271754.78	NS	51.75	45.15	40.5–45.5	2	Unknown	S. Willow Street	Yes
B-7	2nd	Monitoring	10-Apr-90	Hart Crowser	Abandoned	Abandoned	Abandoned	19.00	**Well Not Installed**			Abandoned		NA
B-8	2nd	Monitoring	29-Sep-90	Hart Crowser	200591.01	1271809.26	16.321	46.50	43.06	39.5–44.5	2	Active	Railroad Spur	Yes
B-9	2nd	Monitoring	30-Sep-90	Hart Crowser	200651.69	1271590.57	15.743	49.00	41.55	38.5–43.5	2	Active	Fox Avenue/Railroad Spur	Yes
B-10A	1st	Monitoring	9-Oct-90	Hart Crowser	200648.02	1271600.88	16.404	17.50	13.75	9.5–14.5	2	Active	Fox Avenue/Railroad Spur	Yes
B-11	1st	Monitoring	5-Oct-90	Hart Crowser	200589.00	1271891.00	NS	14.50	12.52	11–13	2	Active	Railroad Spur	Yes
B-12	1st	Monitoring	8-Oct-90	Hart Crowser	200592.90	1271700.79	16.640	13.00	11.43	10.5–13	2	Active	Railroad Spur	Yes
B-13	1st	Monitoring	9-Oct-90	Hart Crowser	200732.55	1271506.88	16.491	13.00	11.80	7.5–12.5	2	Active	Northwest Corner	Yes
B-14	1st	Monitoring	10-Oct-90	Hart Crowser	Abandoned	Abandoned	Abandoned	14.50	14.10	8.5–13.5	2	Abandoned	Production Area	Yes
B-15	1st	Monitoring	23-Jan-91	Hart Crowser	200655.28	1271898.08	21.240	18.00	16.18	12–17	2	Abandoned	Production Area	Yes
B-16	1st	Monitoring	16-Aug-91	Hart Crowser	200712.59	1271849.03	21.376	16.00	17.92	11–16	2	Active	Production Area	Yes
B-17	2nd	Monitoring	19-Aug-91	Hart Crowser	200713.11	1271843.04	21.450	49.43	51.80	40–50	4	Active	Production Area	Yes
B-18	1st	Monitoring	29-Mar-92	Hart Crowser	200411.63	1271786.00	16.564	16.50	15.70	6–16	2	Active	Fox Avenue	Yes
B-19	2nd	Monitoring	7-Apr-92	Hart Crowser	200415.05	1271783.17	16.536	50.50	46.60	37.5–47.5	2	Active	Fox Avenue	Yes
B-20	1st	Monitoring	28-Mar-92	Hart Crowser	Abandoned	Abandoned	Abandoned	21.00	22.00	11–22	2	Abandoned		Yes
B-20A	1st	Monitoring	10-Sep-99	Terra Vac	200498.09	1271709.03	15.611	21.00	12.25	6–16	2	Active	Fox Avenue	Yes
B-21	2nd	Monitoring	8-Apr-92	Hart Crowser	200502.71	1271705.71	16.042	51.00	40.10	38–43	2	Active	Fox Avenue	Yes
B-22	1st	Monitoring	27-Mar-92	Hart Crowser	200694.55	1271525.78	16.219	12.00	10.32	6–11	2	Active	Fox Avenue	Yes
B-23	2nd	Monitoring	3-Apr-92	Hart Crowser	200698.18	1271521.19	16.268	50.50	28.77	20.5–30.5	2	Active	Fox Avenue	Yes
B-24	1st	Monitoring	30-Mar-92	Hart Crowser	NS—Off-site	NS—Off-site	NS—Off-site	18.00	16.30	6–16	2	Unknown	E. Marginal Way S.	Yes
B-25	2nd	Monitoring	31-Mar-92	Hart Crowser	NS—Off-site	NS—Off-site	NS—Off-site	47.50	37.05	27–37	2	Unknown	E. Marginal Way S.	Yes
B-26	1st	Monitoring	29-Mar-92	Hart Crowser	NS	NS	NS	13.50	12.70	8.5–13.25	2	Active	S. Willow Street	Yes
B-27	2nd	Monitoring	6-Apr-92	Hart Crowser	200852.68	1271936.50	17.233	50.50	46.31	42.5–47.5	2	Active	S. Willow Street	Yes
B-28	1st	Monitoring	30-Mar-92	Hart Crowser	200821.69	1271759.63	NS	15.00	13.29	9–14	2	Unknown	S. Willow Street	Yes
B-29	1st	Monitoring	8-Apr-92	Hart Crowser	Abandoned	Abandoned	Abandoned	15.00	13.45	9–14	2	Abandoned		Yes
B-30	1st	Monitoring	2-Apr-92	Hart Crowser	200622.95	1271806.06	21.079	16.00	14.45	8–15	4	Active	Production Area	Yes
B-31	1st	Monitoring	2-Apr-92	Hart Crowser	200590.05	1271813.53	NS	13.50	10.66	6.5–11.5	4	Active	Railroad Spur	Yes
B-32	1st	Monitoring	28-Aug-92	Hart Crowser	200588.86	1271980.94	17.965	13.00	11.00	6.5–11.5	2	Active	Railroad Spur	Yes
B-33	NA	Monitoring	25-Aug-90	Hart Crowser	Abandoned	Abandoned	Abandoned	NA	NA	NA	NA	Abandoned		Yes
B-33A	2nd	Monitoring	17-Sep-92	Hart Crowser	200337.40	1271339.38	13.465	38.00	34.22	28–34	2	Active	S. Myrtle Street	Yes
B-34	1st	Monitoring	25-Aug-92	Hart Crowser	200339.48	1271344.17	14.348	14.50	11.72	7.5–12.5	2	Active	S. Myrtle Street	Yes
B-35	2nd	Monitoring	26-Aug-92	Hart Crowser	200355.07	1271659.47	16.509	50.00	27.95	19.5–29.5	2	Active	S. Myrtle Street	Yes
B-36	1st	Monitoring	26-Aug-92	Hart Crowser	200355.05	1271667.50	16.558	13.00	10.60	6–11	2	Active	S. Myrtle Street	Yes
B-37	2nd	Monitoring	27-Aug-92	Hart Crowser	200350.01	1271937.65	15.353	32.00	27.80	23–28	2	Unknown	S. Myrtle Street	Yes
B-38	1st	Monitoring	27-Aug-92	Hart Crowser	200348.99	1271943.01	16.151	19.00	15.69	6–16	2	Unknown	S. Myrtle Street	Yes
B-39	1st	Monitoring	11-Nov-92	Hart Crowser	200593.16	1271710.80	16.682	12.00	11.82	5.5–11.82	2	Active	Railroad Spur	Yes
B-40	1st	Monitoring	28-Dec-99	Hart Crowser	Abandoned	Abandoned	Abandoned	14.00	12.50	6.5–12.5	2	Abandoned		Yes
B-41	1st	Monitoring	11-Nov-92	Hart Crowser	Abandoned	Abandoned	Abandoned	12.00	11.00	5.0–11.00	2	Abandoned		Yes
B-42	1st	Monitoring	12-Nov-92	Hart Crowser	200593.40	1271703.41	NS	12.00	10.74	5.75–11.75	2	Active	Railroad Spur	Yes
B-43	1st	Monitoring	24-Jun-93	Hart Crowser	Abandoned	Abandoned	Abandoned	16.00	15.00	7.0–15.0	2	Abandoned		Yes
B-44	1st	Monitoring	25-Jun-93	Hart Crowser	200584.00	1271705.00	NS	16.00	15.12	9.5–15.5	2	Active	Whitehead Property	Yes
B-45	2nd	Monitoring	25-Jun-93	Hart Crowser	200570.73	1271687.58	17.298	48.00	46.18	37–47	2	Active	Whitehead Property	Yes
B-46	1st	Monitoring	25-Jun-93	Hart Crowser	200591.96	1271691.64	16.347	14.00	12.95	7.3–13.3	2	Active	Railroad Spur	Yes
B-47	1st	Monitoring	7-Jul-93	Hart Crowser	200603.97	1271733.27	16.619	14.00	12.52	6.8–12.8	2	Active	Railroad Spur	Yes
B-48	1st	Monitoring	6-Jul-93	Hart Crowser	Abandoned	Abandoned	Abandoned	16.00	14.50	6.5–14.5	2	Abandoned		Yes
B-49	1st	Monitoring	6-Jul-93	Hart Crowser	200578.55	1271710.46	17.816	16.00	14.52	9.5–15.5	2	Active	Whitehead Property	Yes
B-50	1st	Monitoring	7-Jul-93	Hart Crowser	200603.27	1271690.92	16.469	12.00	10.39	5–11	2	Active	Railroad Spur	Yes

Table B.1
Well Status Information

Well ID	Water Bearing Zone	Purpose of Well	Completion Date	Consultant	Northing (ft. NAD 83/98)	Easting (ft. NAD 83/98)	Measuring Point Elevation (NAVD88)	Boring Depth (ft)	Well Depth (ft)	Screen Interval (ft)	PVC Diameter (in)	Well Status	Location	Well Log Available
B-51	1st	Monitoring	29-Jul-93	Hart Crowser	Abandoned	Abandoned	Abandoned	14.00	13.50	7.5–13.5	2	Abandoned		Yes
B-52	1st	Monitoring	29-Jul-93	Hart Crowser	200600.53	1271667.97	16.131	14.00	12.73	6.75–12.75	2	Active	Railroad Spur	Yes
B-53	1st	Monitoring	3-Feb-99	Terra Vac	Abandoned	Abandoned	Abandoned	15.00	14.20	7–14	2	Abandoned		Yes
B-54	1st	Monitoring	3-Feb-99	Terra Vac	200823.33	1271593.97	17.337	14.50	13.42	9–14	2	Active	S. Willow Street	Yes
B-55	1st	Monitoring	3-Feb-99	Terra Vac	200845.51	1271545.21	NS	15.00	13.75	9–14	2	Unknown	S. Willow Street	Yes
B-56	1st	Monitoring	3-Feb-99	Terra Vac	200828.86	1271494.85	17.171	15.00	13.60	9–14	2	Active	S. Willow Street	Yes
B-57	1st	Monitoring	3-Feb-99	Terra Vac	200846.14	1271445.76	NS	15.00	13.82	10–15	2	Unknown	S. Willow Street	Yes
B-58	1st	Monitoring	7-Jul-99	Terra Vac	200561.75	1271605.34	16.524	14.00	11.66	7–12	2	Active	Fox Avenue	Yes
B-59	2nd	Monitoring	9-Jul-99	Terra Vac	200566.89	1271600.48	16.478	35.00	29.02	25–30	2	Active	Fox Avenue	Yes
B-60	1st	Monitoring	7-Jul-99	Terra Vac	200517.37	1271645.98	16.341	16.50	11.92	7–12	2	Active	Fox Avenue	Yes
B-61	2nd	Monitoring	9-Jul-99	Terra Vac	200513.36	1271649.97	16.314	45.00	44.40	39–44	2	Active	Fox Avenue	Yes
B-62	1st	Monitoring	9-Jul-99	Terra Vac	200444.20	1271711.33	16.286	16.50	13.00	8–13	2	Active	Fox Avenue	Yes
B-63	2nd	Monitoring	8-Jul-99	Terra Vac	200449.78	1271706.34	16.473	45.00	43.20	39–44	2	Active	Fox Avenue	Yes
B-64	1st	Monitoring	6-Jul-99	Terra Vac	200377.36	1271441.84	16.079	13.00	11.62	7–12	2	Active	S. Myrtle Street	Yes
B-65	2nd	Monitoring	6-Jul-99	Terra Vac	200378.30	1271431.65	16.007	35.50	33.95	30–35	2	Active	S. Myrtle Street	Yes
MW-1	1st	Monitoring	27-Oct-03	ERM	200213.32	1271617.40	NS	14.00	12.00	7–12	2	Active	Seattle Iron and Metals	Yes
MW-2	2nd	Monitoring	27-Oct-03	ERM	200210.95	1271622.71	NS	40.00	40.00	20–40	2	Active	Seattle Iron and Metals	Yes
MW-3	1st	Monitoring	28-Oct-03	ERM	200455.09	1271579.70	NS	15.00	14.00	4–14	2	Active	Seattle Boiler Works	Yes
MW-4	2	Monitoring	28-Oct-03	ERM	200455.50	1271586.76	NS	41.50	40.00	20–40	2	Active	Seattle Boiler Works	Yes
MW-5	1st	Monitoring	29-Oct-03	ERM	200439.18	1271224.08	NS	15.00	15.00	5–15	2	Active	Seattle Boiler Works	Yes
MW-6	2nd	Monitoring	29-Oct-03	ERM	200430.48	1271219.01	NS	41.50	40.00	20–40	2	Active	Seattle Boiler Works	Yes
MW-7	1st	Monitoring	2-Dec-03	ERM	200505.51	1271892.20	17.738	14.00	13.80	4–14	2	Active		Yes
MW-8	2nd	Monitoring	3-Dec-03	ERM	200500.95	1271891.09	17.719	30.00	28.92	20–30	2	Active		Yes
MW-9	1st	Monitoring	15-Aug-05	ERM	200542.12	1271783.78	17.522	13.00	12.62	8–13	2	Active	Whitehead Property	Yes
MW-10	2nd	Monitoring	16-Aug-05	ERM	200544.07	1271782.43	17.010	30.00	29.13	20–30	2	Active	Whitehead Property	Yes
PTM1L	2nd	Monitoring	2-Dec-03	ERM	Destroyed	Destroyed	Destroyed	55.00	55.00	45–55	2	Destroyed	Whitehead Property	Yes
PTM1U	1st	Monitoring	2-Dec-03	ERM	Destroyed	Destroyed	Destroyed	30.00	30.00	20–30	2	Destroyed	Whitehead Property	Yes
PTM2U	1st	Monitoring	3-Dec-03	ERM	200534.30	1271715.05	17.460	30.00	30.00	20–30	2	Active	Whitehead Property	Yes
PTM2L	2nd	Monitoring	3-Dec-03	ERM	200530.97	1271715.43	17.325	48.00	38.65	35–45	2	Active	Whitehead Property	Yes
B-76/A1	1st	Monitoring	21-Dec-00	Terra Vac	200650.60	1271699.11	20.271	19.50	15.04	5.5–15.5	2	Active	Warehouse	Yes
B-74/A2	1st	Monitoring	22-Dec-00	Terra Vac	200649.45	1271648.64	20.269	19.50	16.00	6–16	2	Active	Warehouse	Yes
B-72/A3	1st	Monitoring	21-Dec-00	Terra Vac	200713.31	1271643.85	20.203	16.50	15.50	5.5–15.5	2	Active	Warehouse	Yes
B-70/A4	1st	Monitoring	18-Dec-00	Terra Vac	200754.54	1271699.42	20.255	18.50	18.00	8–18	2	Active	Warehouse	Yes
B-67/A5	1st	Monitoring	19-Dec-00	Terra Vac	200798.05	1271628.57	20.311	19.50	18.50	8.5–18.5	2	Active	Warehouse	Yes
B-66/A6	1st	Monitoring	20-Dec-00	Terra Vac	200799.52	1271575.95	20.331	20.50	16.00	6–16	2	Active	Warehouse	Yes
B-71/A7	1st	Monitoring	20-Dec-00	Terra Vac	200723.39	1271587.51	20.309	20.50	17.00	7–17	2	Active	Warehouse	Yes
B-73/A8	1st	Monitoring	18-Dec-00	Terra Vac	200714.94	1271698.62	20.279	20.50	16.68	7–17	2	Active	Warehouse	Yes
B-69/A9	1st	Monitoring	20-Dec-00	Terra Vac	200725.28	1271937.65	19.954	22.00	16.50	6–16.5	2	Unknown	Warehouse	Yes
B-68	1st	Monitoring	19-Dec-00	Terra Vac	200783.34	1271681.83	20.305	19.00	18.00	8–18	2	Active	Warehouse	Yes
NW1-1	1st	Monitoring	8-Nov-04	ERM	200758.93	1271478.86	15.922	14.00	13.00	8–13	2	Active	Northwest Corner	Yes
NW1-2	1st	Monitoring	8-Nov-04	ERM	200772.03	1271537.44	16.862	14.00	13.00	8–13	2	Active	Northwest Corner	Yes
NW2-1	2nd	Monitoring	8-Nov-04	ERM	200755.64	1271482.11	15.860	32.00	30.00	25–30	2	Active	Northwest Corner	Yes
NW2-2	2nd	Monitoring	8-Nov-04	ERM	200765.71	1271538.87	16.923	32.00	30.00	23–30	2	Active	Northwest Corner	Yes
R1-IW1	Multiple	Remediation	10-Dec-08	Calibre	200648.39	1271592.14	16.068	75.00	70.00	15–20, 25–35, 40–50, 55–70	4	Active	Fox Avenue	Yes
R1-IW2	Multiple	Remediation	30-Dec-08	Calibre	200610.61	1271617.80	15.850	75.00	70.00	15–20, 25–35, 40–50, 55–70	4	Active	Fox Avenue	Yes
R1-IW3a	1st	Remediation	2-Dec-08	Calibre	200592.02	1271624.76	15.527	12.00	12.00	7–12	4	Active	Fox Avenue	Yes
R1-IW3b	Multiple	Remediation	8-Dec-08	Calibre	200589.43	1271626.28	15.521	75.00	70.00	15–20, 25–35, 40–50, 55–70	4	Active	Fox Avenue	Yes
R1-IW4a	1st	Remediation	2-Dec-08	Calibre	200573.37	1271639.89	15.491	14.00	14.00	9–14	4	Active	Fox Avenue	Yes

Table B.1
Well Status Information

Well ID	Water Bearing Zone	Purpose of Well	Completion Date	Consultant	Northing (ft. NAD 83/98)	Easting (ft. NAD 83/98)	Measuring Point Elevation (NAVD88)	Boring Depth (ft)	Well Depth (ft)	Screen Interval (ft)	PVC Diameter (in)	Well Status	Location	Well Log Available
R1-IW4b	Multiple	Remediation	5-Dec-08	Calibre	200571.04	1271642.75	15.376	75.00	70.00	15–20, 25–35, 40–50, 55–70	4	Active	Fox Avenue	Yes
R1-IW5	Multiple	Remediation	2-Dec-08	Calibre	200546.28	1271666.69	15.687	63.00	63.00	7–12, 17–27, 32–42, 47–57, 57–63	4	Active	Fox Avenue	Yes
R1-IW6	Multiple	Remediation	5-Dec-08	Calibre	200524.38	1271684.95	15.726	75.00	70.00	15–20, 25–35, 40–50, 55–70	4	Active	Fox Avenue	Yes
R1-IW7	Multiple	Remediation	8-Dec-08	Calibre	200496.62	1271707.26	15.704	70.00	65.00	15–20, 25–35, 40–50, 55–65	4	Active	Fox Avenue	Yes
R1-IW8	1st	Remediation	28-Oct-10	Calibre	200790.60	1271487.60	NA	16.00	13.00	8–13	4	Active	Fox Avenue	Yes
R1-IW9	1st	Remediation	28-Oct-10	Calibre	200831.50	1271537.50	NA	16.00	13.00	8–13	4	Active	Fox Avenue	Yes
R1-IW10	1st	Remediation	28-Oct-10	Calibre	200779.60	1271535.40	NA	16.00	12.50	7.5–12.5	4	Active	Fox Avenue	Yes
R2-IW1	Multiple	Remediation	10-Dec-08	Calibre	200464.66	1271429.32	NS—Off-site	75.00	70.00	15–20, 25–35, 40–50, 55–70	4	Active	S. Myrtle Street	Yes
R2-IW2	Multiple	Remediation	3-Dec-08	Calibre	200465.45	1271507.43	NS—Off-site	75.00	70.00	15–20, 25–35, 40–50, 55–70	4	Active	S. Myrtle Street	Yes
R2-IW3	Multiple	Remediation	3-Dec-08	Calibre	200386.96	1271429.32	15.44	75.00	70.00	15–20, 25–35, 40–50, 55–70	4	Active	S. Myrtle Street	Yes
R2-IW4	Multiple	Remediation	4-Dec-08	Calibre	200367.18	1271452.59	14.78	75.00	70.00	15–20, 25–35, 40–50, 55–70	4	Active	S. Myrtle Street	Yes
R2-IW5	Multiple	Remediation	9-Dec-08	Calibre	200356.67	1271483.26	15.373	75.00	70.00	15–20, 25–35, 40–50, 55–70	4	Active	S. Myrtle Street	Yes
R2-IW6	Multiple	Remediation	5-Dec-08	Calibre	200315.83	1271493.55	15.983	75.00	70.00	15–20, 25–35, 40–50, 55–70	4	Active	S. Myrtle Street	Yes
MW-12	2nd-D	Monitoring	17-Jun-09	Floyd|Snider	200719.00	1271886.40	21.510	64.00	60.00	55–60	0.75	Active	Production Area	Yes
MW-13	2nd-D	Monitoring	18-Jun-09	Floyd|Snider	200616.48	1271814.91	21.08	70.00	70.00	65–70	0.75	Active	Production Area	Yes
MW-14	2nd-D	Monitoring	23-Jun-09	Floyd|Snider	200646.6	1271733.5	21.10	60.00	60.00	55–60	0.75	Active	Alkaline Shed	Yes

Abbreviations:
D Duplicate
ft Feet
in Inches
NA Not applicable

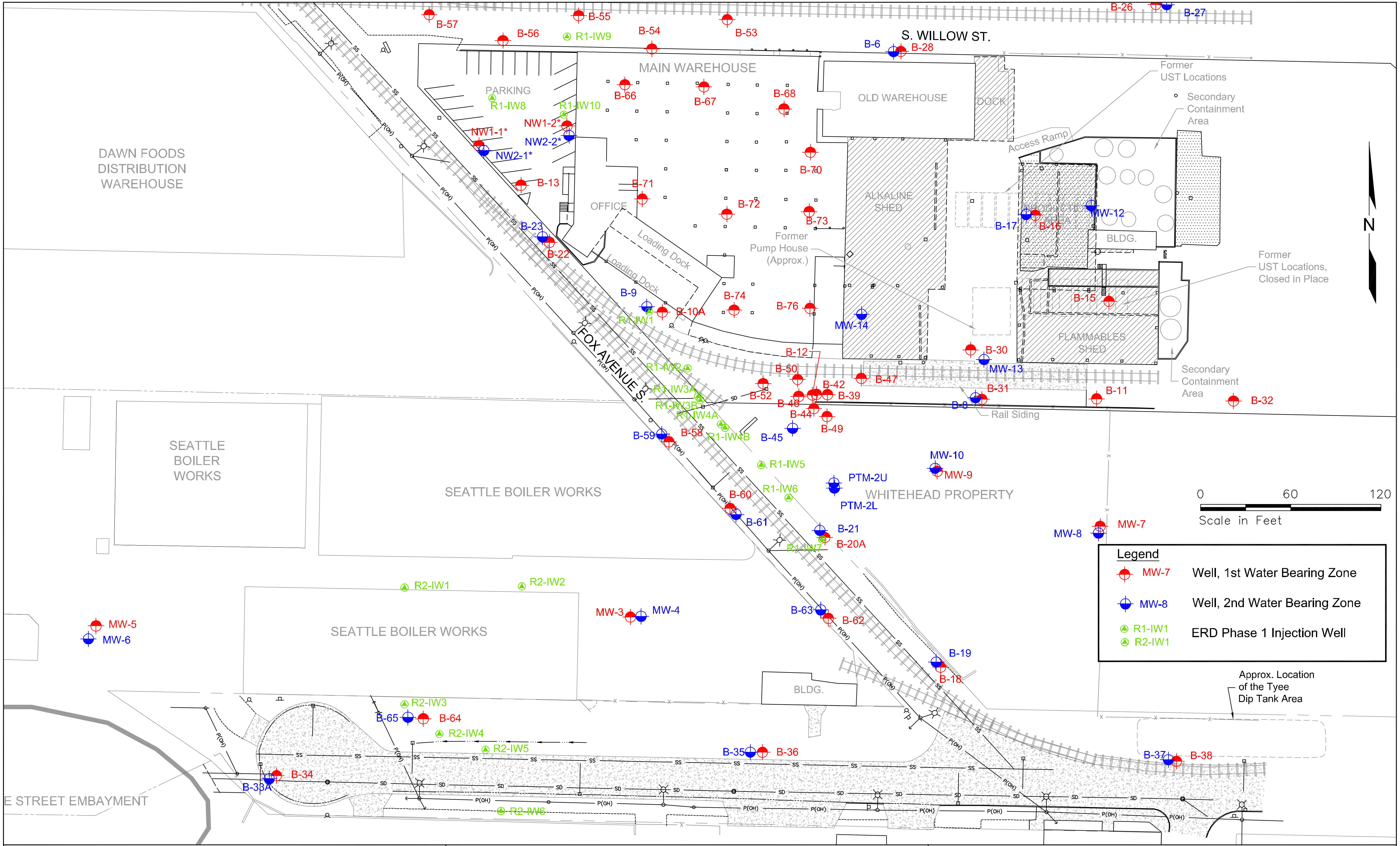
Fox Avenue Site
Seattle, Washington

Remedial Investigation/ Feasibility Study

Appendix B
Hydrogeological and Well Completion Information

Figures

FINAL



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strategy ▪ science ▪ engineering

Remedial Investigation/Feasibility Study
Fox Avenue Site
Seattle, Washington

Figure B.1
Groundwater Well Locations

DWG NAME: G:\project\Clients\Floyd and Snider\Fox Ave 2010\CAD\FoxAve2010_013.dwg
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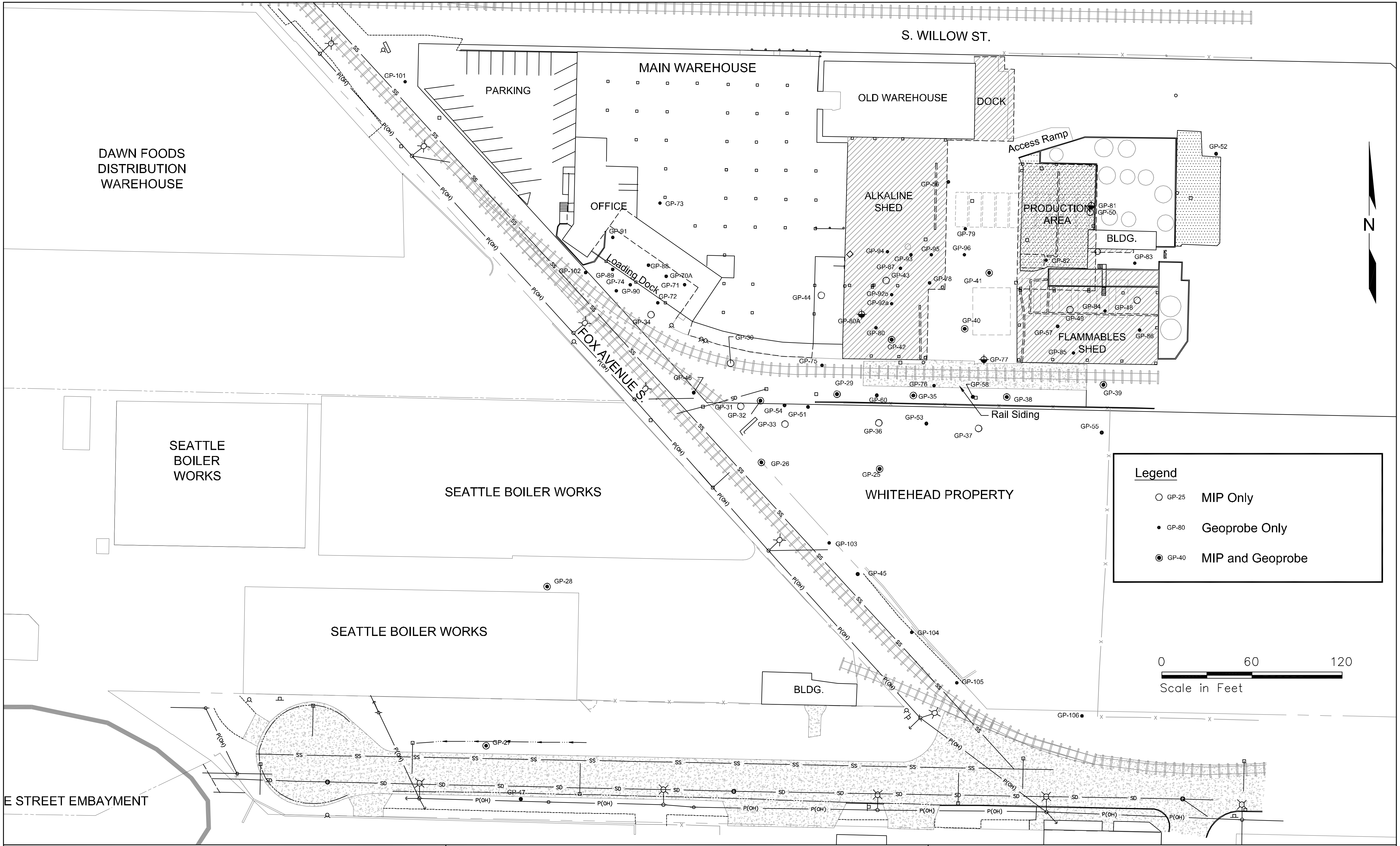

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Remedial Investigation/Feasibility Study
Fox Avenue Site
Seattle, Washington

Figure B.2
Boring Locations
(2008 to 2010)

DWG NAME: G:\project\Clients\Floyd and Snider\Fox Ave 2010\CAD\FoxAve2010_012.dwg
DATE: 2/9/2011 10:23 AM

Fox Avenue Site
Seattle, Washington

Remedial Investigation/ Feasibility Study

Appendix B
Hydrogeological and Well Completion Information

Attachment B.1
Boring Logs

FINAL

ERM
915 118th Avenue S.E.
Suite 130
Bellevue, Washington 98005
(425) 462-8591

BOREHOLE LOG

Site Id: B-1
Page 1 of 1

Project Number: 0025758.0001

Project Name: Phase II ESA

Location: Seattle, Washington

Contractor: Cascade Drilling

Drilling Method: GeoProbe

Date(s): 12/22/04

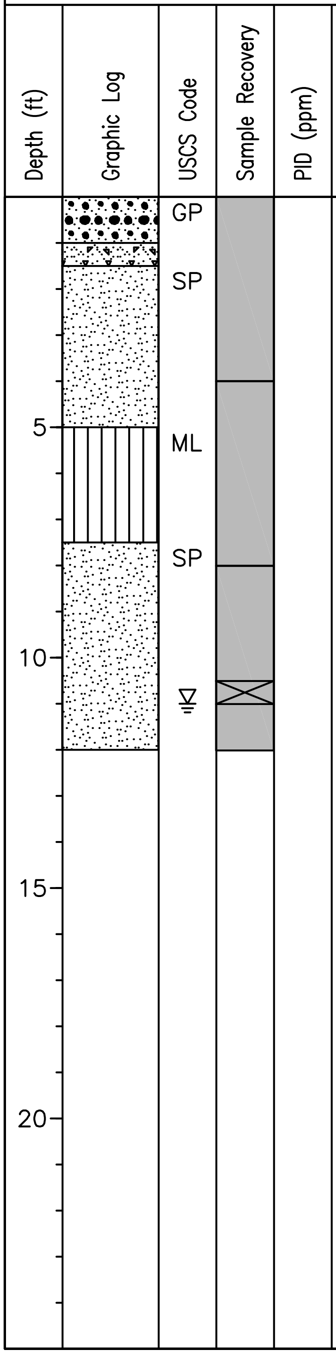
Total Depth: 12.00'

Borehole Dia.: 2.25in

Logged By: A. Musselman

Initial Water Level: 11.00'

Groundwater Screen Interval: 10.0–14.0'



Description/Soil Classificiation

GRAVEL (GP): brown, sandy, slightly silty.

Concrete.
SAND (SP): brown, fine to medium grained.

SANDY SILT (ML): brown with slight mottling, massive, moist (fill).

SANDY SILT (ML): grading to gray, massive with pockets of sand.
SAND (SP): gray, fine to medium grained, with layers and pockets of brown and gray silt, with scattered angular gravel, moist.

Soil sample collected at 10.5'.
SAND (SP): gray, fine to medium grained, wet.
Total Depth – 12.0' bgs.

Boring Log B-1

Soil Descriptions

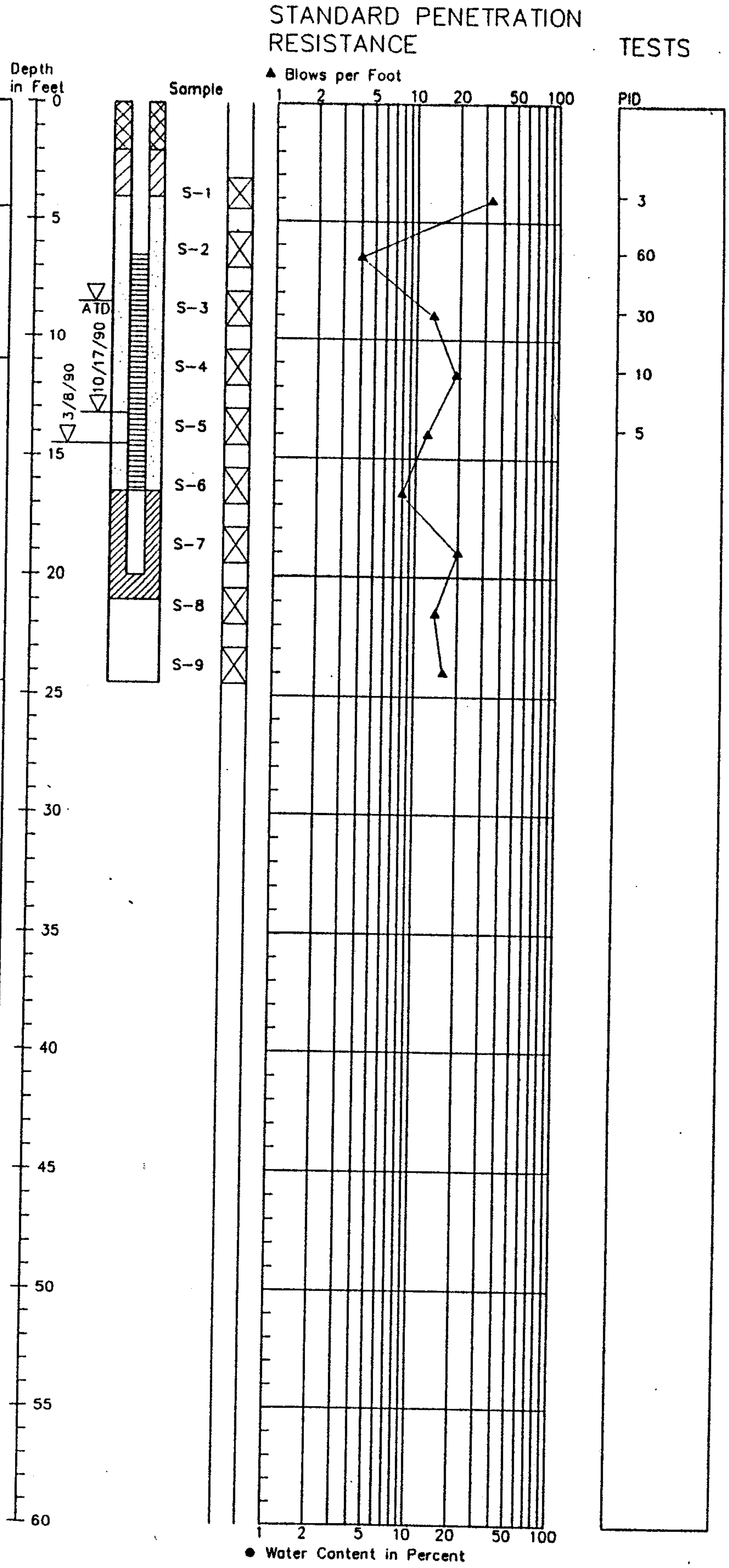
Top of Casing Elevation in Feet 11.05
Ground Surface Elevation in Feet 11.63

6 inches CONCRETE over dense, damp, gray to brown and black, silty SAND and sandy SILT with scattered cobbles, concrete rubble, and debris. (FILL)

Medium stiff, moist to wet, gray and brown, slightly fine sandy SILT and very silty to silty, fine SAND. (POSSIBLE FILL)

Loose to medium dense, wet, black to brown SAND with interbedded gray, silty, fine SAND.

Bottom of Boring at 24.5 Feet.
Completed 5/30/89



1. Refer to Figure A-1 for explanation of descriptions and symbols.
2. Soil descriptions and stratum lines are interpretive and actual changes may be gradual.
3. Groundwater level, if indicated, is at time of drilling (ATD) or for date specified. Level may vary with time.
4. Hole cored below 21'8", backfilled with bentonite pellets to 16.5' around tail pipe. Silica sand around screen extended to surface seal.

HARTCROWSER
J-2489-04 10/90
J-2489 6/89
Figure A-3 1/1

Boring Log B-2

Soil Descriptions

Approximate Ground Surface Elevation 7 Feet

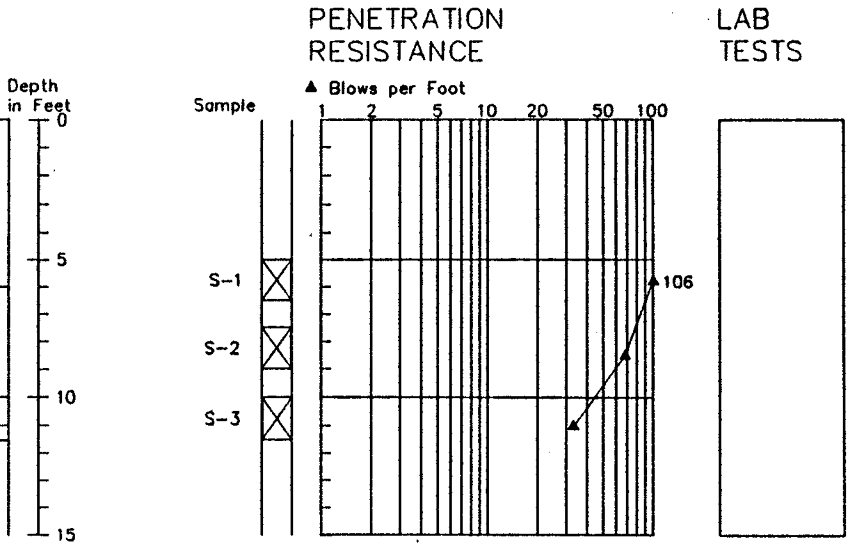
1/4-foot of asphalt pavement over dense, moist, brown, sandy, fine GRAVEL with silt.

Medium dense to dense, moist, brown, silty, gravelly SAND.

Loose, moist to wet, brown, silty, gravelly SAND.

Medium dense, wet, black, fine to medium SAND with silt.

Bottom of Boring at 11.5 Feet.
Completed 5/11/90.
Note: Drilled to 6.5-foot-depth (refusal).
Moved 1 foot north.



Boring Log B-3

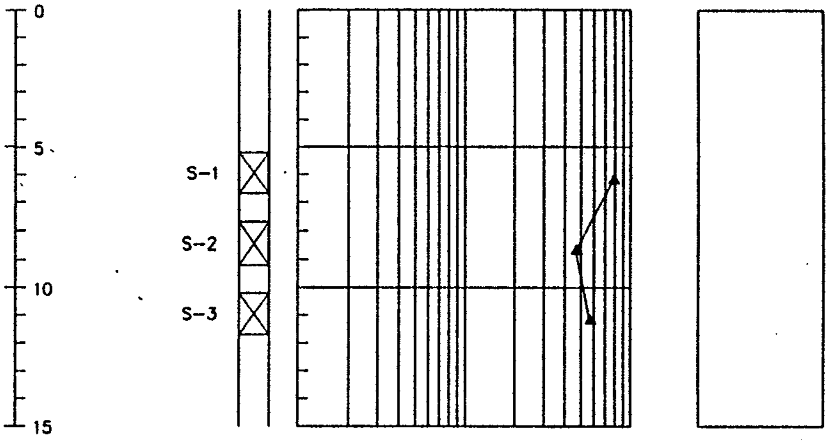
Approximate Ground Surface Elevation 7 Feet

1/4-foot of asphalt pavement over dense, moist, brown, silty, gravelly SAND.

Becomes wet with slight organic content.

Medium dense, moist to wet, black, fine to medium SAND with silt.

Bottom of Boring at 11.5 Feet.
Completed 5/11/90.



Boring Log B-4

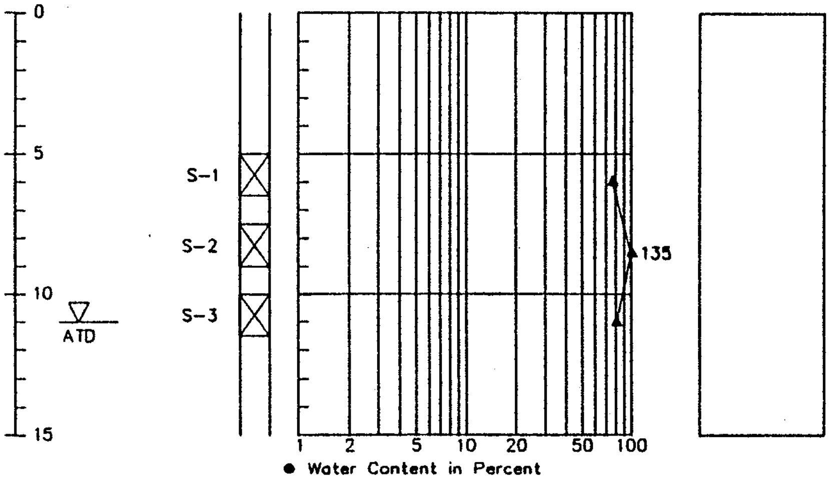
Approximate Ground Surface Elevation 7 Feet

1/4-foot of asphalt pavement over dense, moist, gray, gravelly SAND with silt.

Dense, moist to wet, brown, silty, gravelly, fine to medium SAND.

Dense, wet, black, fine to medium SAND to fine sandy SILT.

Bottom of Boring at 11.5 Feet.
Completed 5/11/90.



1. Refer to Figure A-1 for explanation of descriptions and symbols.
2. Soil descriptions and stratum lines are interpretive and actual changes may be gradual.
3. Groundwater level, if indicated, is at time of drilling (ATD) or for date specified. Level may vary with time.

HARTCROWSER
J-2489-04 10/90
J-2489-02 5/90
Figure A-4 1/1

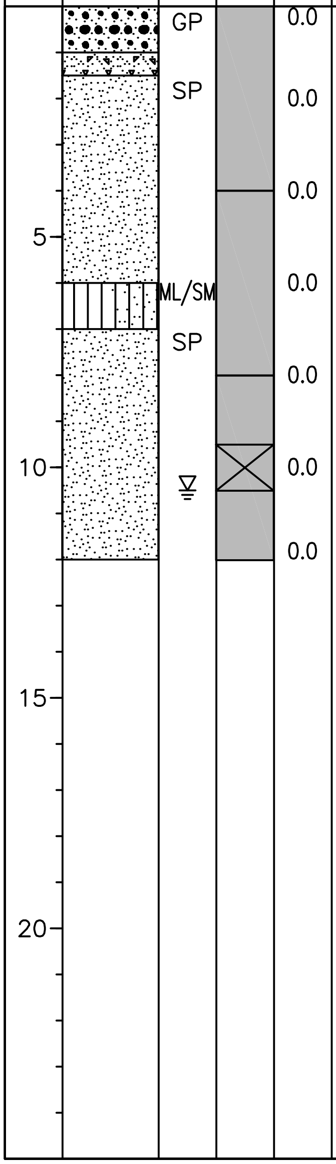
ERM
ERM
915 118th Avenue S.E.
Suite 130
Bellevue, Washington 98005
(425) 462-8591

BOREHOLE LOG

Site Id: B-2
Page 1 of 1

Project Number: 0025758.0001
Project Name: Phase II ESA
Location: Seattle, Washington
Contractor: Cascade Drilling
Drilling Method: GeoProbe
Date(s): 12/22/04

Total Depth: 12.00'
Borehole Dia.: 2.25in
Logged By: A. Musselman
Initial Water Level: 10.50'
Groundwater Screen Interval: 10.0–14.0'



Depth (ft)	USCS Code	PID (ppm)	Description/Soil Classificiation
	GP	0.0	GRAVEL (GP): brown, sandy, slightly silty.
			Concrete.
	SP	0.0	SAND (SP): brown, some rust coloring, fine to medium grained, moist.
		0.0	
5			
	ML/SM	0.0	SANDY SILT/SILTY SAND (ML/SM): gray, fine grained sand, moist to wet.
	SP		SAND (SP): brown, fine to medium grained, trace silt, moist.
		0.0	SAND (SP): as above, grades to gray, wet.
			Soil sample collected from 9.5–10.5'.
10	▽	0.0	Sheen on soil and odor
		0.0	Total Depth – 12.0' bgs.
15			
20			

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BOREHOLE LOG

Site Id: B-3
Page 1 of 1

Project Number: 0025758.0001

Project Name: Phase II ESA

Location: Seattle, Washington

Contractor: Cascade Drilling

Drilling Method: GeoProbe

Date(s): 12/22/04

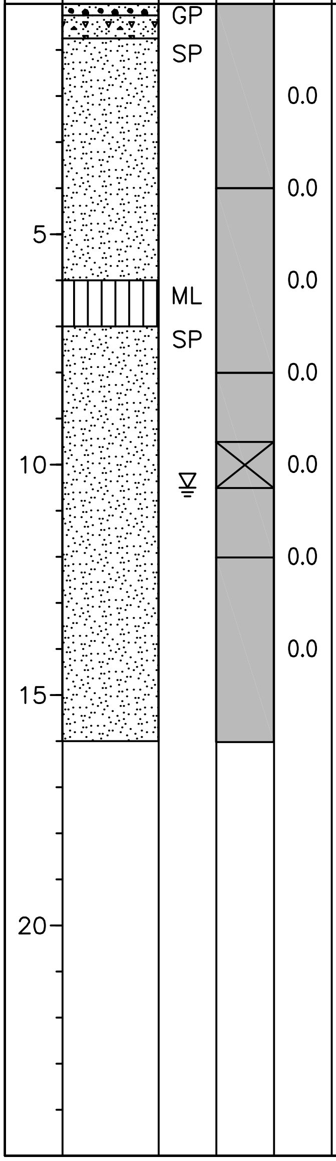
Total Depth: 16.00'

Borehole Dia.: 2.25in

Logged By: A. Musselman

Initial Water Level: 10.50'

Groundwater Screen Interval: 10.0–14.0'



Depth (ft)	Graphic Log	USCS Code	Sample Recovery	PID (ppm)	Description/Soil Classificiation
		GP			GRAVEL (GP): brown, angular gravel, sandy, slightly silty, dry. Concrete.
		SP			SAND (SP): dark brown to gray, fine to medium grained, trace silt, moist.
				0.0	
				0.0	
5					
		ML		0.0	SANDY SILT (ML): rust brown, fine grained sand, scattered wood/organics, wet.
		SP			SAND (SP): dark brown, fine to medium grained, trace silt, moist to wet.
				0.0	
10		▽	☒	0.0	Soil sample collected from 10.0–10.5'. Water at 10.5'.
				0.0	
				0.0	
15					
					Total Depth – 16.0'
20					

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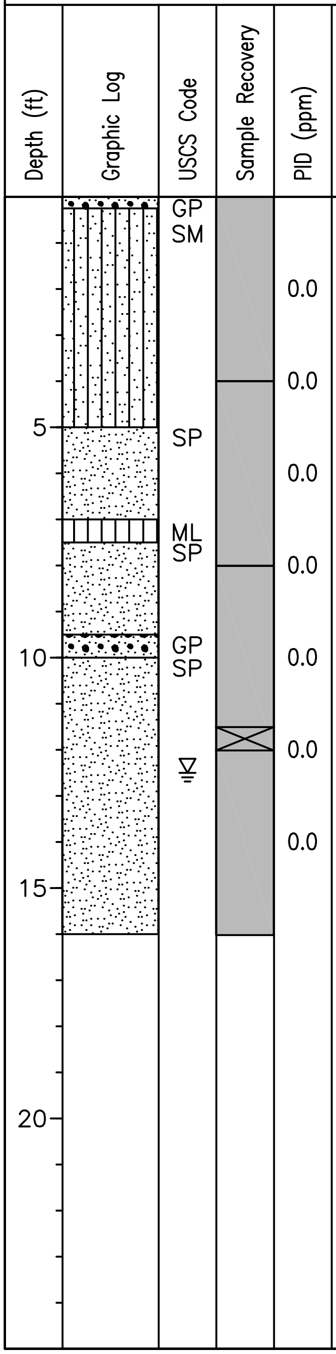
BOREHOLE LOG

Site Id: B-4
Page 1 of 1

Project Number: 0025758.0001
Project Name: Phase II ESA
Location: Seattle, Washington
Contractor: Cascade Drilling
Drilling Method: GeoProbe
Date(s): 12/22/04

Total Depth: 16.00'
Borehole Dia.: 2.25in
Logged By: A. Musselman
Initial Water Level: 12.50'
Groundwater Screen Interval: 11.0–15.0'



Description/Soil Classificiation

SILTY GRAVEL (GM): 2.0".
SILTY SAND (SM): dark brown, fine to medium grained, debris fragments, glass, coal, brick, moist.

SAND (SP): brown, fine to medium grained, moist.

SILT (ML): gray, moist.
SAND (SP): brown, fine to medium grained, wet (perched).

GRAVEL (GP)
SAND (SP): brown, fine to medium grained, scattered gravel, moist.

Soil sample collected from 11.5–12.0'.
SAND (SP): as above, brick fragment at 12.5', slough or fill, wet.
SAND (SP): gray, fine to medium grained.

Total Depth – 16.0' bgs

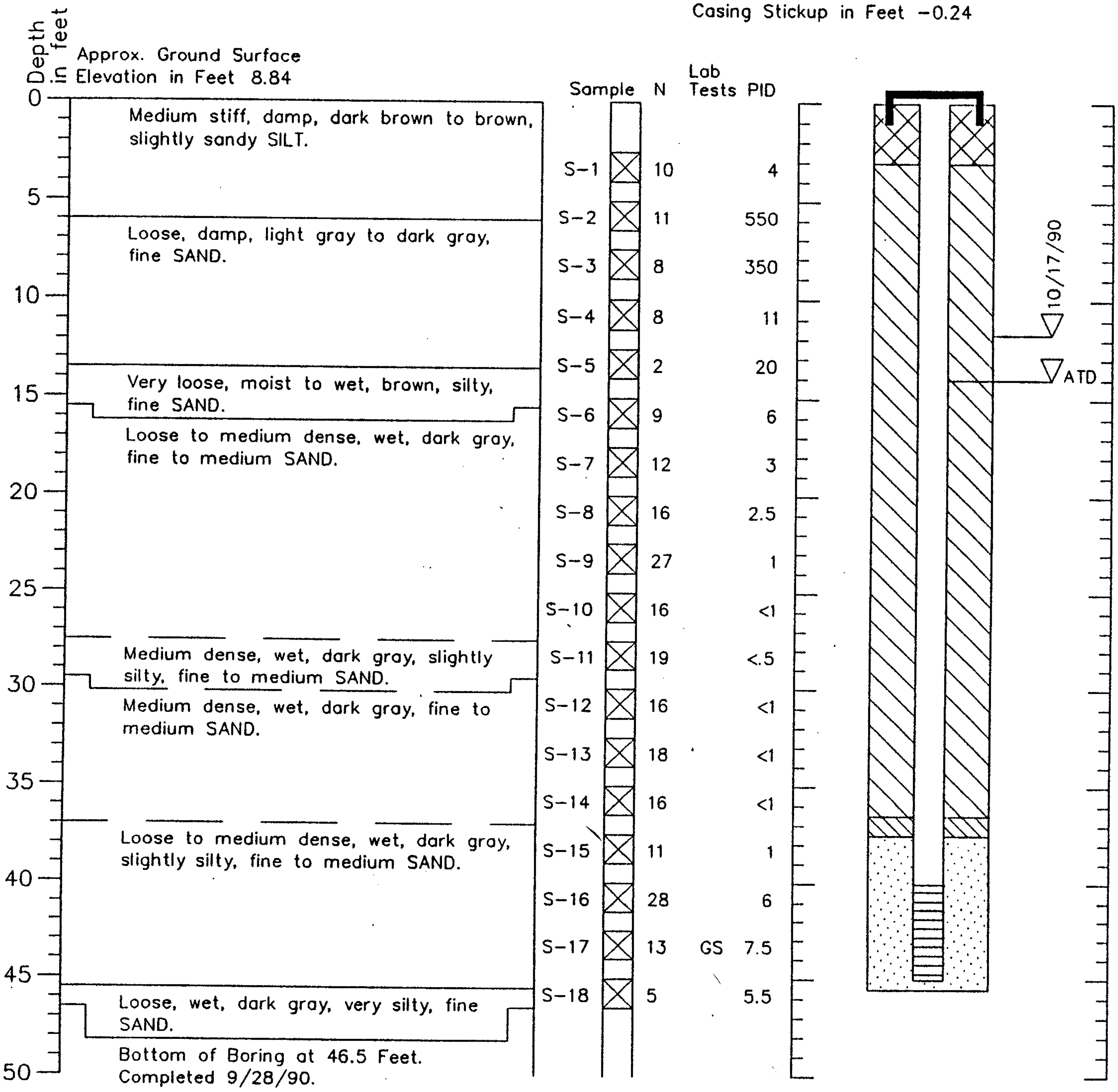
Boring Log and Construction Data for Monitoring Well B-5

Geologic Log

Monitoring Well Design

Casing Stickup in Feet −0.24

Approx. Ground Surface Elevation in Feet 8.84



Medium stiff, damp, dark brown to brown, slightly sandy SILT.

Loose, damp, light gray to dark gray, fine SAND.

Very loose, moist to wet, brown, silty, fine SAND.

Loose to medium dense, wet, dark gray, fine to medium SAND.

Medium dense, wet, dark gray, slightly silty, fine to medium SAND.

Medium dense, wet, dark gray, fine to medium SAND.

Loose to medium dense, wet, dark gray, slightly silty, fine to medium SAND.

Loose, wet, dark gray, very silty, fine SAND.

Bottom of Boring at 46.5 Feet.
Completed 9/28/90.

Sample	N	Lab Tests	PID
S-1	10		4
S-2	11		550
S-3	8		350
S-4	8		11
S-5	2		20
S-6	9		6
S-7	12		3
S-8	16		2.5
S-9	27		1
S-10	16		<1
S-11	19		<.5
S-12	16		<1
S-13	18		<1
S-14	16		<1
S-15	11		1
S-16	28		6
S-17	13	GS	7.5
S-18	5		5.5

1. Refer to Figure A–1 for explanation of descriptions and symbols.
2. Soil descriptions and stratum lines are interpretive and actual changes may be gradual.
3. Ground water level, if indicated, is at time of drilling (ATD) or for date specified. Level may vary with time.

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J-2489-04 **9/90**

Figure A-5

X

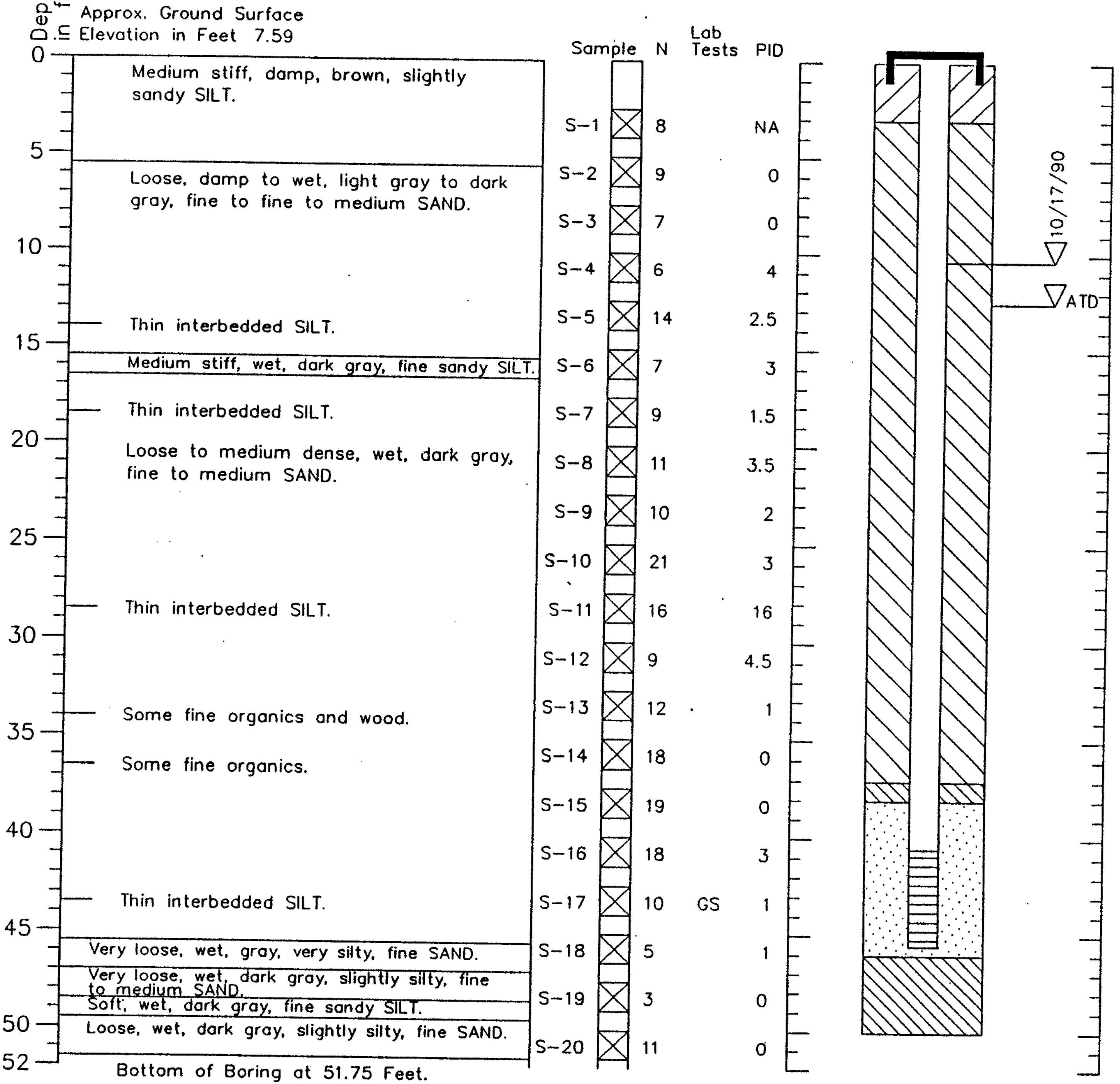
Boring Log and Construction Data for Monitoring Well B-6

Geologic Log

Monitoring Well Design

Casing Stickup in Feet -0.24

Approx. Ground Surface Elevation in Feet 7.59



Medium stiff, damp, brown, slightly sandy SILT.

Loose, damp to wet, light gray to dark gray, fine to fine to medium SAND.

Thin interbedded SILT.

Medium stiff, wet, dark gray, fine sandy SILT.

Thin interbedded SILT.

Loose to medium dense, wet, dark gray, fine to medium SAND.

Thin interbedded SILT.

Some fine organics and wood.

Some fine organics.

Thin interbedded SILT.

Very loose, wet, gray, very silty, fine SAND.

Very loose, wet, dark gray, slightly silty, fine to medium SAND.

Soft, wet, dark gray, fine sandy SILT.

Loose, wet, dark gray, slightly silty, fine SAND.

Sample	N	Lab Tests	PID
S-1	8		NA
S-2	9		0
S-3	7		0
S-4	6		4
S-5	14		2.5
S-6	7		3
S-7	9		1.5
S-8	11		3.5
S-9	10		2
S-10	21		3
S-11	16		16
S-12	9		4.5
S-13	12		1
S-14	18		0
S-15	19		0
S-16	18		3
S-17	10	GS	1
S-18	5		1
S-19	3		0
S-20	11		0

Bottom of Boring at 51.75 Feet.
Completed 9/27/90.

1. Refer to Figure A-1 for explanation of descriptions and symbols.
2. Soil descriptions and stratum lines are interpretive and actual changes may be gradual.
3. Ground water level, if indicated, is at time of drilling (ATD) or for date specified. Level may vary with time.

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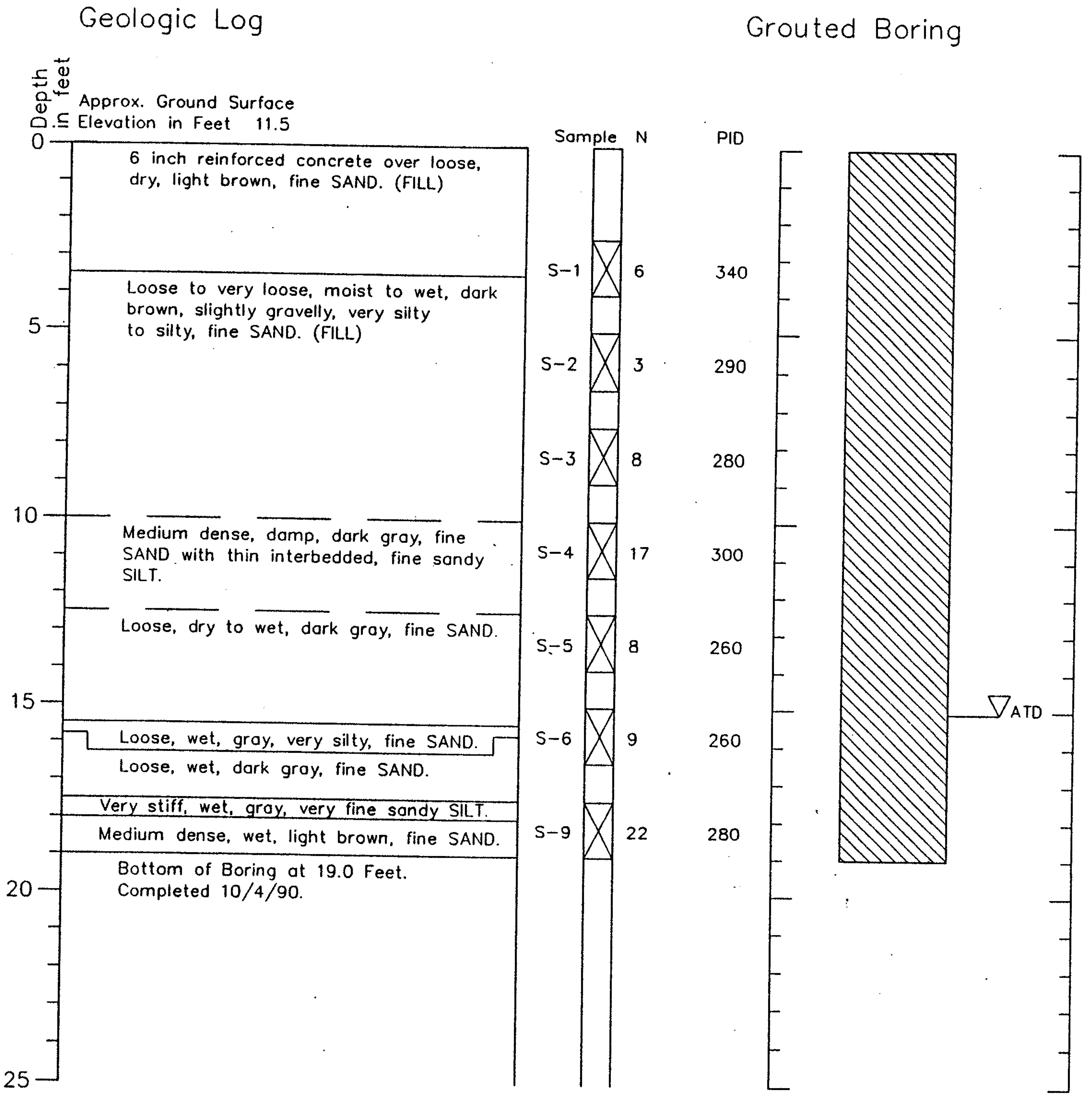
J-2489-04 **9/90**

Figure A-6

Boring Log B-7



Approx. Ground Surface Elevation in Feet 11.5

6 inch reinforced concrete over loose, dry, light brown, fine SAND. (FILL)

Loose to very loose, moist to wet, dark brown, slightly gravelly, very silty to silty, fine SAND. (FILL)

Medium dense, damp, dark gray, fine SAND with thin interbedded, fine sandy SILT.

Loose, dry to wet, dark gray, fine SAND.

Loose, wet, gray, very silty, fine SAND.

Loose, wet, dark gray, fine SAND.

Very stiff, wet, gray, very fine sandy SILT.

Medium dense, wet, light brown, fine SAND.

Bottom of Boring at 19.0 Feet.
Completed 10/4/90.

Sample	N	PID
S-1	6	340
S-2	3	290
S-3	8	280
S-4	17	300
S-5	8	260
S-6	9	260
S-9	22	280

1. Refer to Figure A-1 for explanation of descriptions and symbols.
2. Soil descriptions and stratum lines are interpretive and actual changes may be gradual.
3. Ground water level, if indicated, is at time of drilling (ATD) or for date specified. Level may vary with time.

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J-2489-04 10/90

Figure A-7

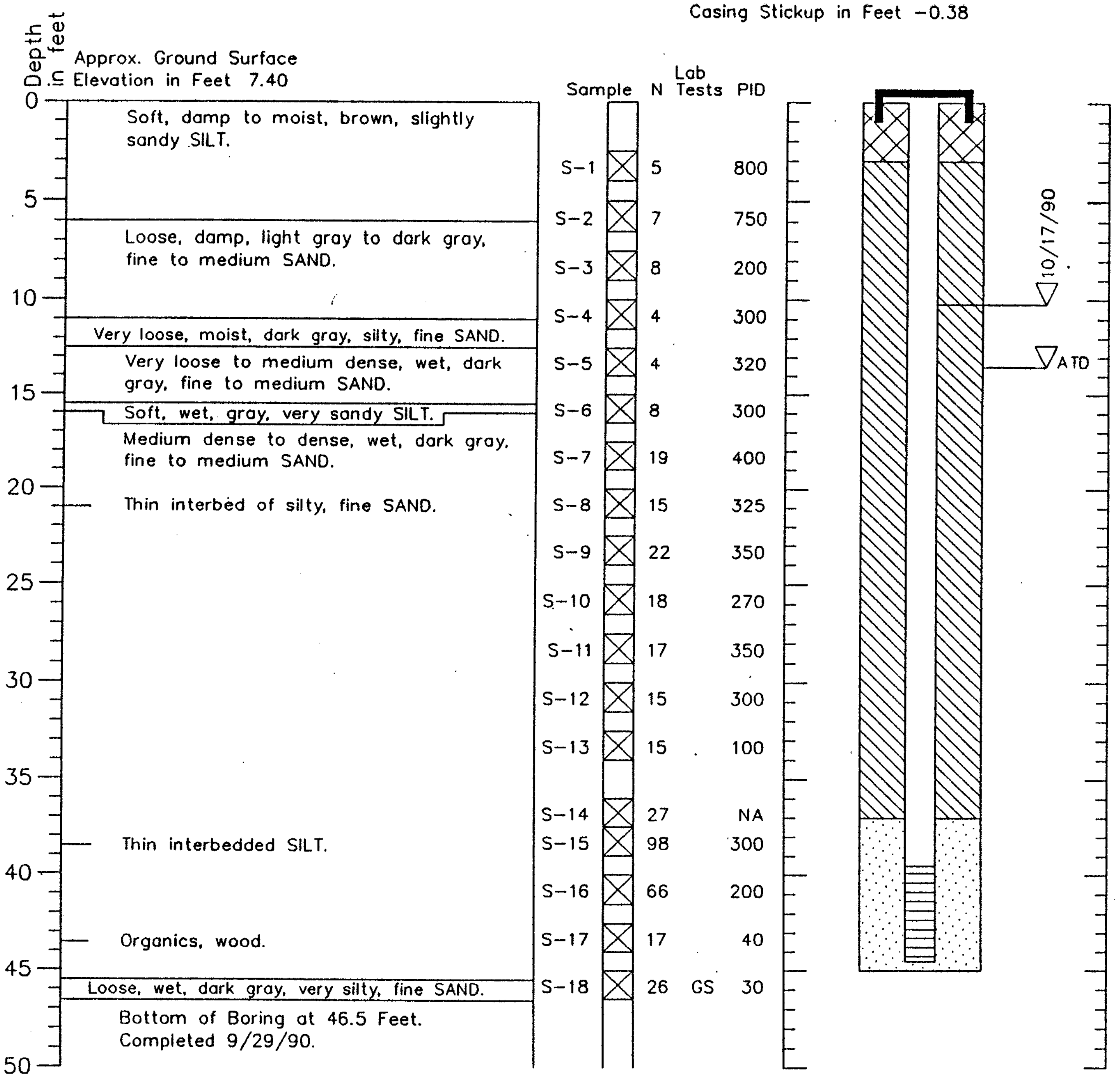
Boring Log and Construction Data for Monitoring Well B-8

Geologic Log

Monitoring Well Design

Casing Stickup in Feet -0.38

Approx. Ground Surface Elevation in Feet 7.40



Soft, damp to moist, brown, slightly sandy SILT.

Loose, damp, light gray to dark gray, fine to medium SAND.

Very loose, moist, dark gray, silty, fine SAND.

Very loose to medium dense, wet, dark gray, fine to medium SAND.

Soft, wet, gray, very sandy SILT.

Medium dense to dense, wet, dark gray, fine to medium SAND.

Thin interbed of silty, fine SAND.

Thin interbedded SILT.

Organics, wood.

Loose, wet, dark gray, very silty, fine SAND.

Bottom of Boring at 46.5 Feet.
Completed 9/29/90.

Sample	N	Lab Tests	PID
S-1	5		800
S-2	7		750
S-3	8		200
S-4	4		300
S-5	4		320
S-6	8		300
S-7	19		400
S-8	15		325
S-9	22		350
S-10	18		270
S-11	17		350
S-12	15		300
S-13	15		100
S-14	27		NA
S-15	98		300
S-16	66		200
S-17	17		40
S-18	26	GS	30

1. Refer to Figure A-1 for explanation of descriptions and symbols.
2. Soil descriptions and stratum lines are interpretive and actual changes may be gradual.
3. Ground water level, if indicated, is at time of drilling (ATD) or for date specified. Level may vary with time.

HARTCROWSER

J-2489-04 9/90

Figure A-8

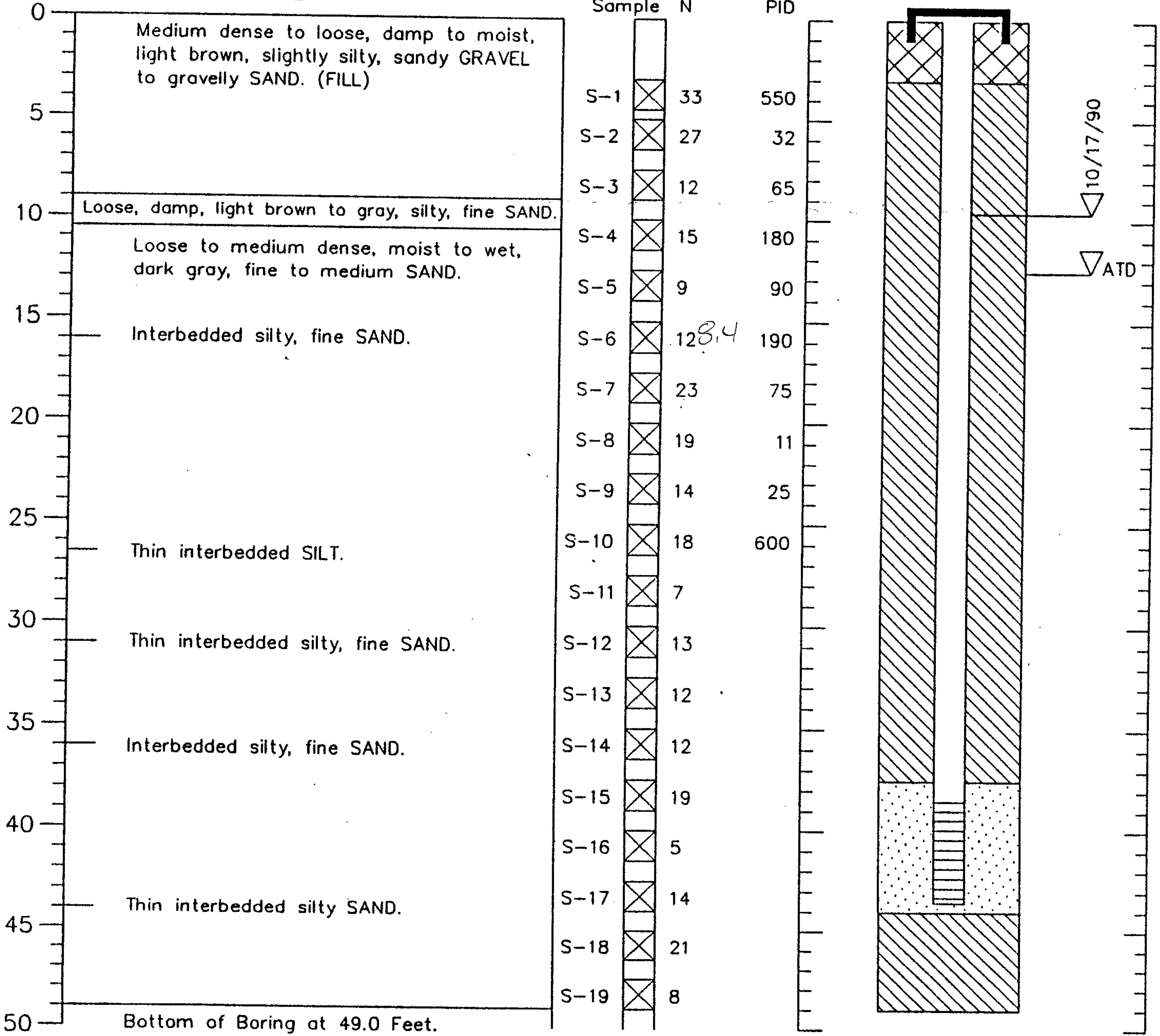
Boring Log and Construction Data for Monitoring Well B-9

Geologic Log

Monitoring Well Design

Casing Stickup in Feet -0.58

Approx. Ground Surface Elevation in Feet 6.92



Medium dense to loose, damp to moist, light brown, slightly silty, sandy GRAVEL to gravelly SAND. (FILL)

Loose, damp, light brown to gray, silty, fine SAND.

Loose to medium dense, moist to wet, dark gray, fine to medium SAND.

Interbedded silty, fine SAND.

Thin interbedded SILT.

Thin interbedded silty, fine SAND.

Interbedded silty, fine SAND.

Thin interbedded silty SAND.

Sample	N	PID
S-1	33	550
S-2	27	32
S-3	12	65
S-4	15	180
S-5	9	90
S-6	12 8.4	190
S-7	23	75
S-8	19	11
S-9	14	25
S-10	18	600
S-11	7	
S-12	13	
S-13	12	
S-14	12	
S-15	19	
S-16	5	
S-17	14	
S-18	21	
S-19	8	

Bottom of Boring at 49.0 Feet.
Completed 9/30/90.

1. Refer to Figure A-1 for explanation of descriptions and symbols.
2. Soil descriptions and stratum lines are interpretive and actual changes may be gradual.
3. Ground water level, if indicated, is at time of drilling (ATD) or for date specified. Level may vary with time.
4. PID not working after sample S-10.

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J-2489-04 **9/90**

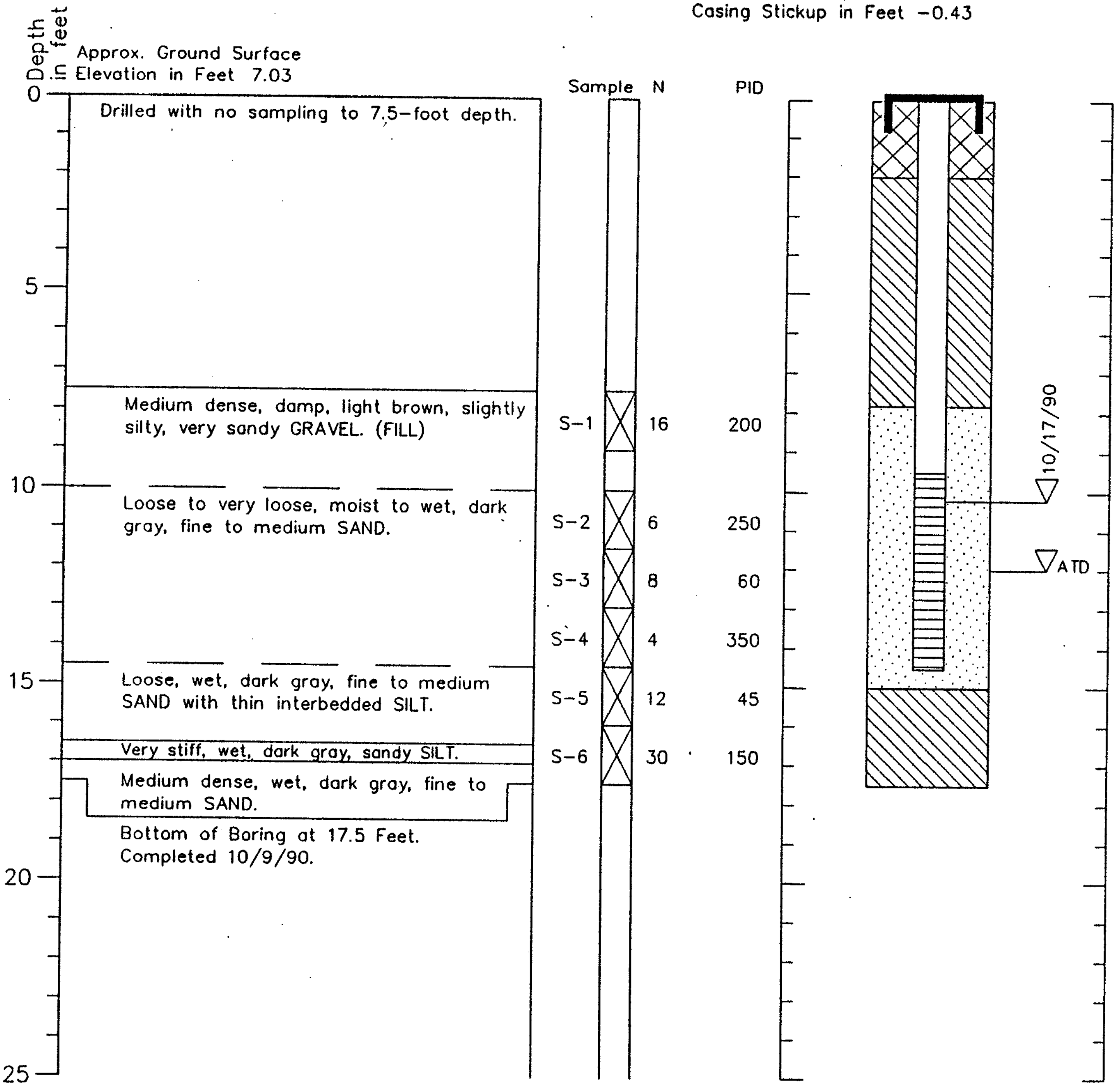
Figure A-9

Boring Log and Construction Data for Monitoring Well B-10A

Geologic Log

Monitoring Well Design

Casing Stickup in Feet −0.43



Drilled with no sampling to 7.5-foot depth.

Medium dense, damp, light brown, slightly silty, very sandy GRAVEL. (FILL)

Loose to very loose, moist to wet, dark gray, fine to medium SAND.

Loose, wet, dark gray, fine to medium SAND with thin interbedded SILT.

Very stiff, wet, dark gray, sandy SILT.

Medium dense, wet, dark gray, fine to medium SAND.

Bottom of Boring at 17.5 Feet.
Completed 10/9/90.

Sample	N	PID
S-1	16	200
S-2	6	250
S-3	8	60
S-4	4	350
S-5	12	45
S-6	30	150

1. Refer to Figure A-1 for explanation of descriptions and symbols.
2. Soil descriptions and stratum lines are interpretive and actual changes may be gradual.
3. Ground water level, if indicated, is at time of drilling (ATD) or for date specified. Level may vary with time.

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J-2489-04 10/90

Figure A-10

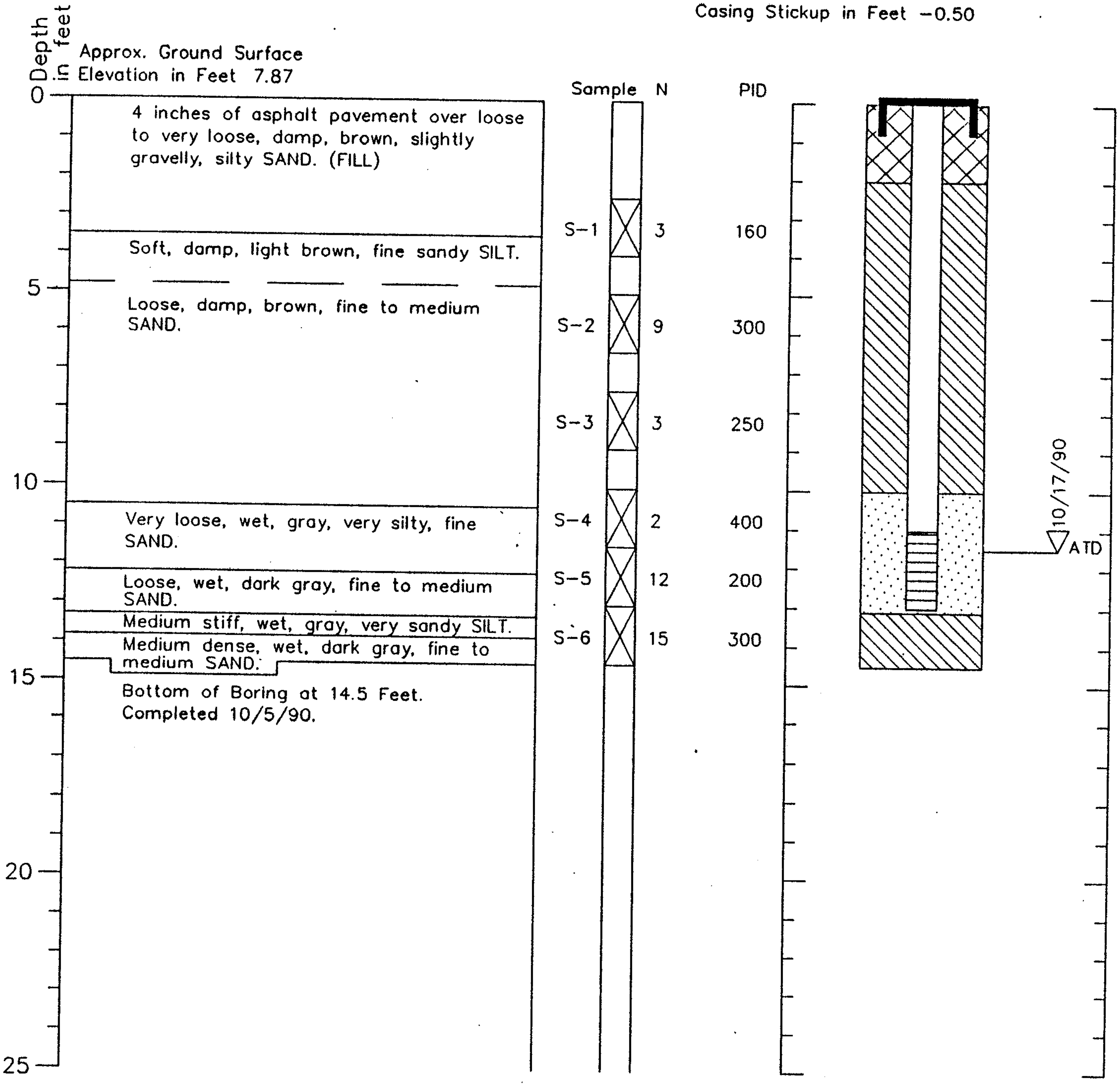
Boring Log and Construction Data for Monitoring Well B-11

Geologic Log

Approx. Ground Surface Elevation in Feet 7.87

Monitoring Well Design

Casing Stickup in Feet −0.50



4 inches of asphalt pavement over loose to very loose, damp, brown, slightly gravelly, silty SAND. (FILL)

Soft, damp, light brown, fine sandy SILT.

Loose, damp, brown, fine to medium SAND.

Very loose, wet, gray, very silty, fine SAND.

Loose, wet, dark gray, fine to medium SAND.

Medium stiff, wet, gray, very sandy SILT.

Medium dense, wet, dark gray, fine to medium SAND.

Bottom of Boring at 14.5 Feet.
Completed 10/5/90.

Sample	N	PID
S−1	3	160
S−2	9	300
S−3	3	250
S−4	2	400
S−5	12	200
S−6	15	300

1. Refer to Figure A−1 for explanation of descriptions and symbols.
2. Soil descriptions and stratum lines are interpretive and actual changes may be gradual.
3. Ground water level, if indicated, is at time of drilling (ATD) or for date specified. Level may vary with time.

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J-2489-04 **10/90**

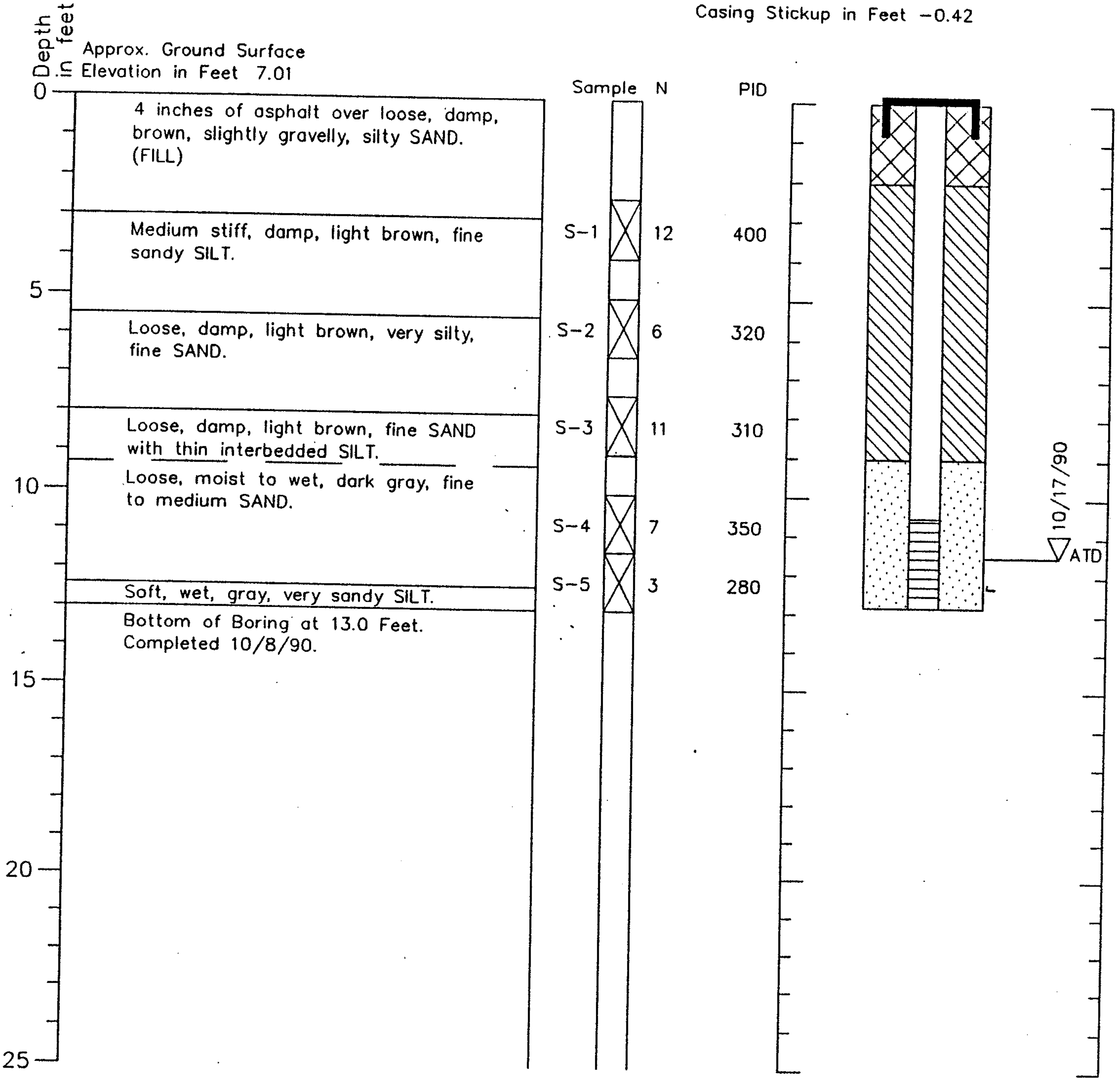
Figure A-11

Boring Log and Construction Data for Monitoring Well B-12

Geologic Log

Monitoring Well Design

Casing Stickup in Feet −0.42



Approx. Ground Surface Elevation in Feet 7.01

4 inches of asphalt over loose, damp, brown, slightly gravelly, silty SAND. (FILL)

Medium stiff, damp, light brown, fine sandy SILT.

Loose, damp, light brown, very silty, fine SAND.

Loose, damp, light brown, fine SAND with thin interbedded SILT.

Loose, moist to wet, dark gray, fine to medium SAND.

Soft, wet, gray, very sandy SILT.

Bottom of Boring at 13.0 Feet. Completed 10/8/90.

Sample	N	PID
S-1	12	400
S-2	6	320
S-3	11	310
S-4	7	350
S-5	3	280

1. Refer to Figure A-1 for explanation of descriptions and symbols.
2. Soil descriptions and stratum lines are interpretive and actual changes may be gradual.
3. Ground water level, if indicated, is at time of drilling (ATD) or for date specified. Level may vary with time.

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J-2489-04 **10/90**

Figure A-12