Feasibility Study Report
NuStar, Cadet, and Swan Manufacturing Company Sites

Prepared for

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CERTIFICATION

The technical material and data contained in this document were prepared under the supervision and direction of the undersigned, whose seal, as a professional engineer or geologist licensed to practice as such, is affixed below.

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ACRONYMS

AO	Agreed Orders
ARARs	applicable or relevant and appropriate requirements
AS	air sparging
AS/SVE	air sparging and soil vapor extraction
AST	above-ground storage tank
bgs	below ground surface
BNSF	Burlington Northern Santa Fe
Cadet	Cadet Manufacturing Company
CAMP	Comprehensive Vapor Intrusion Evaluation and Indoor Air Monitoring Plan
CSL	Cleanup Screening Level
CLARC	cleanup levels and risk calculation
CMMP	Contaminated Media Management Plan
COCs	chemicals of concern
COI	constituents of interest
COPCs	chemicals of potential concern
CPU	Clark Public Utilities
CSL	Cleanup Screening Level
DCA	dichloroethane
DCE	dichloroethylene
DNAPL	Dense non-aqueous phase liquid
DOH	Washington State Department of Health
Ecology	Washington Department of Ecology
ELCR	excess lifetime cancer risk
EPA	U.S. Environmental Protection Agency
EPCs	exposure point concentrations
FOD	frequency of detection
FS	feasibility study
GAC	granular activiated carbon
gpd/ft	gallons per day per foot

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gpm	gallons per minute
GPTIA	groundwater pump and treat interim action
GWM	Great Western Malting
HVOCs	halogenated volatile organic compounds
IA	interim actions
IAMP	indoor air monitoring plan
IRAP	Independent Remedial Action Program
MC	methylene chloride
MCLs	Maximum Contaminant Levels
MNA	monitored natural attenuation
MNR	monitored natural recovery
MRL	minimal risk level
msl	mean sea level
MTCA	Model Toxics Control Act
NAPL	non-aqueous phase liquid
NFVN	North Fruit Valley Neighborhood
NGVD	National Geodetic Vertical Datum
NPDES	National Discharge Elimination System
NuStar	NuStar Terminals Services, Inc.
ORNL	Oak Ridge National Laboratory
PAH	polycyclic aromatic hydrcarbon
PCE	tetrachloroethylene
PID	photoionization detector
POC	point of compliance
PRB	permeable reactive barrier
Port	Port of Vancouver, U.S.A.
PQL	practical quantification limit
RAIS	Risk Assessment Information System
RAO	Remedial Action Objective
RCRA	Resource Conservation and Recovery Act

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RGRW	recirculating groundwater remediation wells
RI	remedial investigations
RA	risk assessment
SCO	Sediment Cleanup Objective
SEPA	State Environmental Policy Act
SFVN	South Fruit Valley Neighborhood
SGA	Sand and Gravel aquifer
SMC	Swan Manufacturing Company
SMS	Sediment Management Standards
SQuiRTs	Screening Quick Reference Tables
SVE	soil vapor extraction
SVV	soil vapor vacuum
TCA	trichloroethane
TCE	trichloroethylene
TGA	Troutdale gravel aquifer
TPH-Dx	total petroleum hydrocarbon in the diesel range
TL	tax lot
TSA	Troutdale Sandstone aquifer
UIC	Underground Injection Control
USA	Unconsolidated Sedimentary Aquifer
USGS	United States Geological Survey
VC	vinyl chloride
VMC	Vancouver Municipal Code
VLL	Vancouver Lake Lowland
VOCs	volatile organic compounds
WAC	Washington Administrative Code

1. INTRODUCTION

On behalf of the Port of Vancouver, U.S.A. (the Port) and NuStar Terminals Services, Inc. (NuStar), Parametrix and Apex have prepared this combined Feasibility Study (FS) for the Cadet Manufacturing Company (Cadet), Swan Manufacturing Company (SMC), and NuStar properties located in Vancouver, Washington (Figure 1-1). The FS was conducted in accordance with the Model Toxics Control Act (MTCA) as defined in Washington Administrative Code (WAC) 173-340. Work was performed pursuant to separate Agreed Orders (AO) between the Washington State Department of Ecology (Ecology) and the Port (AO No. 07-TC-S DE5189) and NuStar (AO No. 07-TC-S DE3938). Ecology amended the previous AOs, effective January 24, 2014 to incorporate the combined nature of the FS and provided an amended schedule for submittal of the FS.

This FS Report was completed to present proposed final remedy(s) to address dissolved trichloroethylene (TCE), tetrachloroethylene (PCE) and other associated chemicals from the Cadet, SMC, and NuStar properties. As required by the AOs for each property, this FS presents an evaluation of a range of remedial alternatives to mitigate the groundwater plume throughout the project area (see Figure 1-1) and specific source areas at the individual properties. Remedial investigations (RI) were conducted at the facilities to develop the proposed cleanup action(s). The RIs included the collection of multi-media data (soil, soil gas, groundwater, sediment, indoor and outdoor air, etc.) and a quantitative evaluation of the potential risk to human health and the environment. Results of the RIs for each of the facilities have been presented and summarized in the NuStar (Apex 2013a), SMC (Parametrix 2009b), and Cadet (Parametrix 2010a) RI reports.

This FS Report primarily focuses on contaminants in groundwater at the source areas and throughout the Site. However, all media (soil, groundwater, air, and sediment) have been addressed by previous remedial or interim actions or will be addressed by the current selected remedial actions. Therefore, this FS Report constitutes the final evaluation of remedial actions for all media for all three sites, including the site-wide dissolved-phase groundwater plume.

As part of the Cadet and SMC RIs, the Port developed a numeric groundwater model to simulate groundwater movement and evaluate the effectiveness of cleanup action alternatives for the FS. The groundwater model is being used by the Port and NuStar in the evaluation of the cleanup action for the project area dissolved-phase plume, as well as supporting the selection of cleanup actions for specific source areas at SMC and NuStar.

1.1 DEFINITION OF SITE

The project area consists of three separate facilities on Port property – one currently occupied by NuStar, one currently occupied by Cadet, and the other formerly occupied by the SMC.

SMC operated in building 2220 (now removed) located between 2001 and 2501 West Fourth Plain Boulevard, at the intersection of West Fourth Plain and Mill Plain Boulevard Extension, in Vancouver, Washington. Cadet operates at 2500 West Fourth Plain Boulevard in Vancouver, Washington. NuStar operates at the Port of Vancouver Terminal No. 2 at 2565 NW Harborside Drive in Vancouver, Washington. The boundaries of these properties are shown on Figure 1-2.

Information about the project area has been collected in the respective RIs and has been used to define the physical characteristics, including geology and hydrogeology, which influence the migration of contaminants in the subsurface. Therefore, consistent with direction provided by Ecology and the rationale for incorporating all three sites into a combined FS, the project area has been defined to include the current aerial extent of the dissolved-phase plume, herein referred to as the “Site”. For the purposes of this combined FS, the Site is defined consistent with MTCA to include the area where a hazardous substance from a release has “come to be located”. Figure 1-1 shows the SMC, Cadet, and NuStar properties and the extent of the Site. When referring to the specific sites or source areas at the individual properties, and not the entire Site, the term “source area” or “site” may be used (i.e. NuStar source area, Cadet site, etc.).

The Site includes an extensive monitoring well network to evaluate groundwater flow and groundwater quality. Figure 1-3 shows the current groundwater monitoring well network at and beyond the Site.

1.2 PURPOSE

The purpose of the FS is to develop and evaluate cleanup action alternatives so that final cleanup actions can be selected for the source areas and Site. Procedures for conducting an FS under MTCA are described in WAC 173-340-350(8). WAC 173-340-350(8)(c)(i)(A) requires an FS to include cleanup action alternatives that protect human health and the environment by eliminating, reducing, or otherwise controlling risks posed through each exposure pathway and migration route. Each alternative may consist of one or more cleanup action components. Alternatives may include remediation levels to define when particular cleanup action components will be used. Each alternative shall be evaluated on the basis of the requirements stated in WAC 173-340-360:

- Protection of human health and the environment
- Compliance with cleanup standards
- Compliance with applicable state and federal laws
- Provision for compliance monitoring

The selected cleanup action(s) shall also use permanent solutions to the maximum extent practicable, provide for a reasonable restoration timeframe, and consider public concerns.

Cleanup standards under MTCA [WAC 173-340-700(3)] include:

- Cleanup levels for hazardous substances present at the Site
- The location where the cleanup levels must be met (point of compliance [POC])
- Other regulatory requirements applicable to the Site

MTCA specifies three methods (Methods A, B, and C) that can be used to develop cleanup standards for contaminated media. Method A, B, and C cleanup standards for groundwater are addressed in WAC 173-340-720. Cleanup levels for the Site have been developed and are presented in Section 5.0.

1.3 COLLABORATIVE APPROACH TO FEASIBILITY STUDY

As stated, RIs have been completed for the SMC, Cadet and NuStar sites and were generally conducted by independent parties (i.e. the Port [SMC/Cadet] and NuStar). However, due to the presence of the area-wide dissolved-phase plume, which is the result of releases on all three sites, Ecology determined that the Port and NuStar were responsible for overall cleanup actions. Therefore, the Port and NuStar agreed, with Ecology approval, that a combined FS for all three sites would be the most efficient and effective approach for achieving cleanup and closure. As stated in Section 1.1, the three sites for which individual RIs were prepared

(Cadet, Swan, and NuStar) are now collectively referred to as the Site. The collaboration on the FS allows the parties to develop a cleanup approach for the overall plume that minimizes the cleanup timeframe and is compatible with source area actions. In general, source area remedial actions were evaluated by the respective party, but the selected actions have the support of both parties and are intended to be complementary to each other and the overall Site cleanup approach.

1.4 REPORT ORGANIZATION

This report is organized as follows:

Section 1: Introduction – provides the regulatory context for the report, defines the Site, and describes the content of the report.

Section 2: Site Background – describes the location and historical use of each of the three properties and summarizes the AOs. This section also summarizes the initial activities leading to the discovery of release(s) at the properties, previous investigations, interim actions (IA) conducted at the properties, and the risk assessment findings.

Section 3: Groundwater Model – summarizes the model and its use in this FS.

Section 4: Applicable Federal, State, and Local Laws – summarizes laws applicable to cleanup levels, remedial approaches, and process.

Section 5: Development of Cleanup Standards – describes the requirements and procedures for selecting a cleanup standard for remediation of impacted groundwater.

Section 6: Cleanup Action Evaluation Criteria – summarizes criteria that affected the development of remedies in this FS report.

Section 7: NuStar Source Area Feasibility Evaluation – identifies and screens technologies for remediation of each medium that incorporates the interim actions, as well as combines the technologies into remedial alternatives, allowing evaluation of the alternatives.

Section 8: Cadet/Swan Source Area Feasibility Evaluation – identifies and screens technologies for remediation of each medium that incorporates the interim actions, as well as combines the technologies into remedial alternatives, allowing evaluation of the alternatives.

Section 9: Site Groundwater Feasibility Evaluation – identifies and screens technologies for intermediate zone and deeper groundwater remediation that incorporates the interim actions, as well as combines technologies into remedial alternatives, allowing evaluation of the alternatives.

Section 10: Recommended Cleanup Action – provides a summary of the preferred remedial actions described in Sections 7, 8, and 9 and shows how the actions meet the cleanup requirements and standards.

Section 11: References – lists the references cited in this report.

Appendices are included that provide technical and supporting information. The appendices are referenced throughout the report.

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2. BACKGROUND

This section provides background information on the NuStar, Cadet, and Swan facilities as well as summaries of the respective RI and risk assessments for the three properties. Section 2.1 describes the geology and hydrogeology for the area to provide the setting for physical conditions at the Properties. Sections 2.2 through 2.4 provide background information on each of the Properties, focusing on the source areas and the nature and extent of impacts to soil, sediments (NuStar only), and shallow groundwater, and summarize the risk assessments performed on the collected RI data. Historically, impacted groundwater has migrated vertically to the intermediate zone and deeper groundwater and has been identified as a dispersed plume underlying the NuStar, Swan, and Cadet Properties. Groundwater monitoring programs have been instituted by NuStar and the Port to assess groundwater concentration distributions and trends at the NuStar, Cadet, and Swan Properties and these programs are described in Sections 2.2.6, 2.3.7, and 2.4.7, respectively. Since 2009, the groundwater monitoring programs have been coordinated between NuStar and the Port to collect data simultaneously between the Properties to enhance data comparability and allow a better understanding of the extent of the dispersed plume.The chemical fate and extent of the dispersed plume is discussed in Section 2.5.

2.1 GEOLOGY AND HYDROGEOLOGY

The following sections summarize the geology and hydrogeology in the project area. Geologic and hydrogeologic conditions in the areas of the SMC, Cadet, and NuStar sites are detailed in their respective RI Reports (Parametrix 2009a and 2010b; Apex 2013a). A detailed description of regional geologic and hydrogeologic conditions is presented in the Vancouver Lake Lowlands Groundwater Model Summary Report (Parametrix et. al. 2008).

2.1.1 Geologic Conditions

The regional geologic framework and associated groundwater system detailed in the Final RI Reports are based on the geologic setting described and the nomenclature used in the United States Geological Survey (USGS) water resources investigation report, *A Description of Hydrogeological Units in the Portland Basin, Oregon and Washington* (Swanson et al., 1993). The *Vancouver Lake Lowlands Groundwater Model Summary Report* (Parametrix et al., 2008) presents a regional conceptual model and detailed discussion of geologic and hydrogeologic units in the region and their presence in the project area. The groundwater model was developed using site-specific geologic and hydrogeologic data collected throughout the Vancouver Lake Lowlands.

There are three regional geologic units (Quaternary alluvium, catastrophic flood deposits, Troutdale formation) in the project area, as indicated on Figure 2-1. Figure 2-2 shows the orientation of three cross-sections at the Site. The geology along these cross-sections is shown on Figures 2-3, 2-4, and 2-5. Figure 2-6 is a southern extension of the cross-section shown on Figure 2-3 and generally includes wells on the cross-section line in the NuStar area.

Groundwater in the Quaternary alluvium and catastrophic flood deposits is associated with the Unconsolidated Sedimentary Aquifer (USA), while groundwater in the upper section of the Troutdale formation is associated with the Troutdale gravel aquifer (TGA). The relationship between the regional geologic units and the regional aquifers (USA and TGA) and Site conditions is shown on Figure 2-1.

The three geologic units are described in the following sections.

2.1.1.1 Alluvial Deposits

The Quaternary alluvial deposits in the project area primarily consist of two main subunits: a lower sand and an upper silt. In the area adjacent to the Columbia River, two localized subunits have been identified; these represent overbank flood deposits and dredge fill. The variability in fines present in the Quaternary alluvial deposits can notably influence the rate at which groundwater passes through the material. The four alluvial subunits shown on Figure 2-1 are described below:

Dredge Fill (Sand 2) – Dredge fill deposits are present in the southern portion of the Site and generally within 1,500 feet of the Columbia River. Dredge fill consists predominantly of sand, but can include lenses of silt and gravel. Extensive dredge filling has occurred in the southern portion of the Site, particularly adjacent to the river where the thickness of the fill can reach up to 50 feet. Depending upon location, dredge fill can be saturated or situated above the water table.

Overbank Deposits (Silt 2) – This alluvial subunit is present along the Columbia River and is associated with the historical river bank. The overbank deposits represent the historical river bank and seasonal overbank flood deposits, consist of silt and clayey material, and are thickest adjacent to the historical river channel. The overbank deposits are thicker and contain more clayey material than the lowland area silt subunit (Silt 1). The water table is generally found within the basal portion of the overbank deposits. Consequently, its lower section is usually saturated and its upper section is within the vadose zone. Beginning in the mid-1930s, filling was completed along the historical river bank in the project area as part of the Port's terminal developments that resulted in the river being displaced approximately 500 feet south of its historical river channel.

Lowland Area Silt (Silt 1) – The lowland area silt is the same as the upper alluvium subunit and is generally present throughout the Site. However, the lowland area silt does not appear to be present south of Lower River Road. The lowland area silt is generally described as brownish silt and appears to have been deposited throughout most of the Vancouver Lake Lowlands area.

Lowland Area Sand (Sand 1) – The lowland area sand is present throughout the Site. The lowland area sand contains variable amounts of fines and is described in places as silty sand. This subunit overlies the catastrophic flood deposits and, in the area of the Swan site, appears to be contemporaneous with lowland area silt deposits. The lowland area sand can be differentiated from catastrophic flood deposits by its lack of gravel. The lowland area sand is present under the overbank deposits on the north side of the historical river bank. The water table is usually situated within the lowland area sand and silt subunit where overbank deposits are not present. Under these conditions its lower section is saturated, and its upper section in the vadose zone.

2.1.1.2 Catastrophic Flood Deposits

This unit consists predominantly of medium- to coarse-grained sand with gravel. The gravel can be coarse, ranging up to cobbles 6 inches or greater in diameter. These deposits are associated with the Late Pleistocene catastrophic floods of the Columbia River. This material was deposited throughout the Site and underlies the Quaternary alluvium. Due to the generally coarse nature of these deposits and the general lack of fines, these deposits are highly transmissive.

As shown on Figure 2-1, three catastrophic flood deposit subunits units have been identified at the Site; these subunits are described below.

Sand and Gravel – This subunit consists of sand with gravel to gravel with sand that consists of basaltic material. It underlies the alluvium deposits and is present throughout the Site. The sand and gravel subunit is not cemented, and is usually loose, with little to no fines present in the unit.

Channel Fill – This subunit consists of sand with typically only trace amounts of gravel. When present, it underlies the sand and gravel subunit. Sand in the channel fill subunit ranges from fine- to coarse-grained. Channel fill deposits are usually well graded, but can also be poorly graded with silt zones and include small lenses of gravel. The channel fill subunit is located in an erosional trough in the Troutdale formation located beneath the SMC and Cadet sites.

Reworked Troutdale Formation Material – This sandy gravel subunit overlies the Troutdale formation and is interpreted to be reworked Troutdale formation material. It is usually described as gravel with sand or sand with gravel. The type and range of material in this subunit is fairly variable. The size of clasts range from small gravels up to cobbles; its matrix can range from sand to silt, and it is generally described as well graded. It consists mostly of basalt clasts and sand, but in places contains quartzite clasts and/or a micaceous matrix. The sandy gravel subunit is generally not cemented, but indications of cementation can be observed prior to encountering the underlying Troutdale formation. The sandy gravel subunit is not consolidated like the Troutdale formation. Reworked Troutdale formation material is less prevalent in the area just north of the NuStar Terminal and east of Kotobuki Way.

2.1.1.3 Troutdale Formation

The Troutdale formation encountered at the Site consists of well-graded, cemented to semi-consolidated sandy gravel with varying amounts of sand, silt, and clay. The gravel clasts range up to 8 inches (i.e., cobble) in diameter and generally consist of basalt and quartzite. The matrix usually consists of brown to green fine-grained silty sand with varying amounts of silt and clay and is usually abundant with mica. The Troutdale formation underlies the catastrophic flood deposits throughout the Site. It is distinguished from the catastrophic flood deposits by the presence of cementation, consolidation, quartzite clasts, and a silty matrix containing mica. In places it can be difficult to distinguish the Troutdale formation from the reworked Troutdale formation material subunit. A noticeable reduction in water production is another characteristic that can be used to distinguish the Troutdale formation from the overlying catastrophic flood deposits.

The elevation of the top of the Troutdale formation varies substantially at the Site. Mapping the top of the Troutdale formation at the Site indicates the presence of an erosional trough or low area beneath the SMC and Cadet sites. The deepest portion of the erosional trough appears to occur beneath the SMC and Cadet sites. The top of the Troutdale formation rises very steeply directly east of the SMC site and rises relatively steeply to the southwest of the SMC site. The highest elevation of the Troutdale formation at the Site occurs just east of Kotobuki Way. As indicated on Figure 2-7, the erosional trough located beneath the SMC and Cadet sites was filled by channel fill deposits, which pinch out in the areas where the elevation of the top of the Troutdale formation is higher.

The top of the Troutdale formation beneath the NuStar site appears to be located between 197 and 210 feet below ground surface (bgs); around -174 feet mean sea level (msl). The Troutdale formation is present just north of the NuStar site, where it has been encountered at an elevation of approximately -65 feet msl (95 feet bgs) based on descriptions of sedimentary deposits encountered at deep borings ST-CMT-1, MW-32i and MW-31i. The NuStar site is located near the side of the pre-fill Columbia River channel. Upriver of the NuStar site, in the area of the Great Western Malting (GWM)/Port wellfield, the top of the Troutdale formation is encountered at an elevation of approximately -100 feet msl (130 feet bgs).

2.1.2 Hydrogeologic Units

Consistent with the USGS Portland Basin (Swanson et al., 1993) nomenclature, there are two regional hydrogeologic units at the Site; the USA and the underlying TGA. The USA occurs in the Quaternary alluvium and catastrophic flood deposits while the TGA occurs in the Pleistocene-aged Troutdale formation.

The distinction between the USA and the TGA is based on differences in the geologic units and resulting hydrogeologic conditions. The overall permeability of the USA is at least one order of magnitude greater than the permeability of the TGA (McFarland and Morgan 1996). Consequently, primarily due to pumping, groundwater flow conditions in the USA differ from conditions in the TGA. In addition, groundwater flow conditions within the three zones of the USA differ due to permeability contrasts between the alluvium and the catastrophic flood deposits.

The following sections describe the hydrogeologic conditions of the three USA groundwater zones and the TGA at the Site.

2.1.2.1 Unconsolidated Sedimentary Aquifer

Regionally, the USA receives recharge primarily from precipitation. Within the Site, the USA also receives recharge from the Columbia River or discharges to the river, depending upon relative river stage conditions and pumping stresses. The flow of groundwater in the USA has historically been dominated by pumping at the GWM site. Water levels in the USA respond quickly to changes in the Columbia River stage, indicating that the river is in direct hydraulic connection with the USA. This rapid response is attributed to the proximity of the river and the high hydraulic conductivity of the USA. These dynamic conditions make it difficult to define groundwater flow direction based on water level measurements collected during short periods of time. Water level measurements indicate very low hydraulic gradients with small-scale and local variations in apparent groundwater flow direction due in part to river stage changes. Groundwater flow model results indicate that the operation of high volume continuous-rate pumping of production wells in the USA is possible and sustainable due to high hydraulic conductivity and relative thickness (i.e., high transmissivity) and the presence of a substantial recharge source (i.e., the Columbia River). Groundwater recharge from the Columbia River due to high volume production well pumping primarily occurs in the intermediate zone.

Three groundwater zones have been established for the USA based on observed geologic and hydrogeologic conditions (Figure 2-1). Groundwater zones were adopted during the course of the SMC, NuStar, and Cadet RI efforts to evaluate and describe groundwater quality and groundwater flow trends. These zones are used to facilitate understanding of the hydrogeologic system and were originally defined by groundwater quality conditions observed during early phases of the SMC RI. Based on the presence and distribution of the alluvial and catastrophic flood deposits in the project area, the groundwater zone classification system has been retained, but has been modified and is now applied only to the USA. As shown on Figure 2-1, the groundwater zones for the USA are as follows:

- <u>Shallow USA groundwater zone:</u> This zone extends from the ground surface to -10 feet msl (approximately 40 feet bgs). The shallow groundwater zone of the USA primarily corresponds to the alluvial deposits. At the NuStar site, the bottom of the shallow zone is about -10 to -25 feet msl and is located in the fill deposit, historical river channel deposits, and overbank deposits.

- Intermediate USA groundwater zone: This zone extends from the bottom of the shallow zone (-10 feet msl to -25 msl, depending upon location within the Site) to -100 feet msl (approximately 130 feet bgs). The intermediate groundwater zone of the USA primarily corresponds with the catastrophic flood sand and gravel deposits. This zone can also include a portion of the channel fill deposits and reworked Troutdale formation material. At the NuStar site, the intermediate zone lies between approximately -15 and -100 feet msl and is located under the historical river channel deposits and the overbank deposits.

- Deep USA groundwater zone: This zone extends below -100 feet msl. The deep groundwater zone of the USA primarily corresponds with the channel fill deposits and reworked Troutdale formation material. The deep zone generally corresponds to those portions of the aquifer that are less influenced by groundwater pumping. At the NuStar site, the deep zone is not present and the hydrogeologic units grade from intermediate groundwater to the TGA.

The elevations of these zones continue to serve as general guidelines and have been adjusted slightly in certain areas based on encountered geologic conditions or other hydrogeologic observations. Characteristics of the three groundwater flow zones within the USA are described below.

2.1.2.2 Shallow USA Zone

The shallow USA zone consists primarily of the alluvial deposits. Depending on the thickness of the alluvial deposits, the shallow USA zone can extend into the upper part of the sand and gravel subunit of the catastrophic flood deposits. The alluvial deposits contain greater amounts of finer material than the underlying catastrophic flood deposits. Consequently, the transmissivity of the alluvial deposits is notably lower than the underlying sand and gravel deposits. Due to the overall presence of finer material with notably lower permeability, the distribution of contaminants in the shallow USA zone can differ from the distribution of contaminants in the underlying catastrophic flood deposits.

Prior to operation of the SMC groundwater pump and treat interim action (GPTIA), groundwater flow in the shallow USA zone at the SMC and Cadet sites was toward the southeast. This flow direction was reflected by contaminant distribution where high concentrations of solvents in groundwater at the two source areas decreased with distance southeast of the source area. Before groundwater pumping at SMC, potentiometric contour maps based on water level measurements from shallow monitoring wells also suggested a southeastern flow direction in the shallow USA zone in the SMC and Cadet areas. Groundwater flow model results indicated that, prior to starting the Port's GPTIA, flow in the shallow USA zone was primarily influenced by pumping occurring at the GWM site but also appeared to be influenced by city water station pumping. The flow direction at the Cadet Site was similar, based on the distribution of contaminants, potentiometric contour maps, and modeling. Groundwater flow in the shallow zone beneath the Cadet is now to the southeast due to the operation of the GPTIA at the SMC site.

The direction of shallow zone groundwater flow beneath the NuStar site has not been affected by the GPTIA due to the presence of a silty layer between the shallow and intermediate zones beneath the site, and the presence of a "silt ridge" in the shallow zone beneath the northern 2006 leasehold boundary (Figure 2-6). Groundwater flow in the shallow USA zone in the area of the NuStar site has been observed to fluctuate toward or away from the river in response to river stage changes. A groundwater divide in the shallow zone is present in the central portion of the NuStar site generally corresponding to the southern edge of the "silt ridge" along the northern side of the NuStar facility (Figure 2-6). The presence of the silt layer associated with the pre-fill Columbia River channel (former natural river bank) results in a low-permeability zone in the shallow zone along the northern boundary of the NuStar facility. The pre-fill river channel silty gravel layer beneath the NuStar Terminal facility also greatly impedes hydrogeologic communication between the shallow and intermediate zones (Apex, 2013). These pre-fill river channel features also serve to isolate the shallow zone at the NuStar site from the shallow zone north of the site.

Based on stable oxygen isotope data, recharge of the shallow USA zone appears to be primarily from precipitation along with indications of some recharge from the river. Oxygen isotope data indicate that the shallow USA zone at the NuStar site is recharged from precipitation. Due to the presence of overbank deposits (former natural river bank) just north of the NuStar site, northerly flow in the shallow USA tends to be restricted.

2.1.2.3 Intermediate USA Zone

The intermediate USA zone corresponds to the catastrophic flood deposits. The catastrophic flood deposits are more permeable than the overlying alluvial deposits or the underlying TGA. Based on well log descriptions, the sand and gravel subunit is the most permeable sedimentary unit in the USA (Mundorff 1964). Consequently, the rate of groundwater movement is highest in the intermediate USA zone where it is greatly influenced by pumping at high-volume production wells located in the lower terrace and Vancouver Lake Lowlands area, including wells operated by the City of Vancouver, Clark Public Utilities (CPU), GWM, and the Port of Vancouver. In response to high-volume pumping, recharge of the intermediate USA zone is primarily from the river.

Prior to operation of the GPTIA, groundwater flow in the intermediate zone near the SMC, Cadet, and NuStar sites was to the north/northeast (from the river) and curving to the east, and then toward the GWM production wells, which have been in operation since the 1940s. These flow patterns are supported by the distribution of contaminants from the SMC, Cadet, and NuStar sites, isotope data, and groundwater flow model results. After startup of the GPTIA, overall flow in the intermediate zone is towards the GPTIA. The gradient in the area between the SMC/Cadet and NuStar properties (former Carborundum pond area) is typically flat, although it does vary during periods of rapid river stage change.

2.1.2.4 Deep USA Zone

This zone of the USA includes the deeper area of the USA where the rate of groundwater flow is lower; less influenced by groundwater pumping and more regionally influenced. Groundwater flow in the deep USA zone has not subtaintially changed due to operation of the GPTIA. Based on the top of the Troutdale formation, the deep USA zone at the Site is primarily present in the Troutdale formation erosional trough. At the SMC and Cadet sites, the deep USA zone corresponds to channel fill deposits and reworked Troutdale formation material. At the NuStar site, the deep USA also appears to contain re-worked Troutdale formation material that is situated on top of the Troutdale formation. The channel fill deposit and the reworked Troutdale formation material are permeable, but not as permeable as the sand and gravel subunit of the intermediate USA zone. Both the channel fill deposits and the reworked Troutdale formation material are more permeable than the underlying consolidated to semi-consolidated Troutdale formation that makes up the TGA. The rate of groundwater movement is lower in the deep USA zone due to the zone's location primarily in an erosional trough or historical channel, the lower influence of pumping stresses from the GWM production wells, and the lower overall permeability of the material that makes up the deep USA zone.

Groundwater modeling indicates groundwater flow in the deep USA zone is toward the GWM production wells. Stable oxygen isotope data indicate that deep USA water is a mixture of Columbia River water and local precipitation. Potentiometric contour maps based on water level measurements from the deep wells do not indicate a clear or consistent groundwater flow direction. Rather, these maps suggest that groundwater in the deep USA zone flows in different directions at different times, and usually does not flow consistently at all measurement points.

2.1.2.5 Troutdale Gravel Aquifer

The TGA is associated with the Troutdale formation, which underlies the catastrophic flood deposits and alluvial deposits that make up the USA at the Site. The top of the Troutdale formation varies noticeably, and the presence of an erosional trough has been identified. The permeability of the TGA is at least one order of magnitude lower than the USA (McFarland and Morgan 1996). This is due to the presence of more fines in the Troutdale formation and the extent of its lithification/cementation, which ranges from consolidated to semi-consolidated. The combination of lower permeability and lack of groundwater extraction from the TGA at the Site produces much lower flow rates in the aquifer than in the overlying USA. There is hydraulic connection with the USA due to a lack of a confining layer. Water level measurements collected from TGA and deep zone USA wells do not indicate a noticeable vertical gradient difference, which also suggests that the two aquifers are hydraulically connected. It is anticipated that the TGA would exhibit similar river response behavior as the USA, but would be more attenuated due to its lower permeability and the fact that it appears not to be in direct contact with the river (i.e., the USA is situated between the river and the TGA).

Based on water level measurements, the flow pattern in the TGA is variable. Groundwater flow model results indicate that the flow pattern in the TGA is similar to the flow pattern observed in the USA, toward GWM production wells. However, stable oxygen isotope data indicate that the source of TGA water is local precipitation. This suggests that the TGA discharges to the Columbia River rather than receiving recharge from the river. The lack of pumping in the TGA in the project area is likely the primary reason that stable oxygen isotope data indicate no river water presence in the aquifer. These observations indicate that groundwater flow in the TGA is primarily influenced by regional conditions.

2.1.2.6 Hydrogeologic Characteristics

Wells completed in the USA have maximum yields between 1,000 and 6,000 gallons per minute (gpm). The most productive area of the USA is in the lower floodplain area of the Columbia River where the SMC, Cadet, and NuStar sites are located. In contrast, wells completed in the consolidated TGA commonly have yields that do not exceed 1,000 gpm (Swanson et al., 1993).

The USA's ability to transmit and yield large quantities of groundwater is the result of its relatively high intrinsic permeability and saturated thickness. It is able to sustain high production pumping due to receiving recharge from the Columbia River. Mundorff (1964) estimated that the transmissivity of the USA ranges from 1,900,000 to 3,500,000 gallons per day per foot (gpd/ft), based on aquifer tests completed at the former ALCOA facility located west of the project area. The aquifer tests indicate that the aquifer's transmissivity is fairly uniform throughout that facility's wellfield. The calculated transmissivities for City of

Vancouver Water Stations 1, 3, and 4, all producing from the USA, are 2,000,000 gpd/ft, 878,900 gpd/ft, and 586,000 gpd/ft, respectively (Robinson, Noble and Carr, Inc., 1980).

Several regional studies have estimated hydraulic conductivity of the USA. Based on a review of transmissivities calculated by consultants for the City of Vancouver water stations, and transmissivities estimated from reported pump test yields and drawdown, Swanson and Leschuk (1991) assigned a hydraulic conductivity of 1,000 feet per day (ft/day) to the aquifer. McFarland and Morgan (1996) assigned storage coefficients to the USA and TGA based on aquifer tests and published information. The storage coefficients for the USA and the TGA are 0.003 and 0.0008 (unitless), respectively. Based on specific capacity data, McFarland and Morgan (1996) estimated a median hydraulic conductivity for the USA across the Portland basin of 200 ft/day with a range of 0.03 to 70,000 ft/day and the TGA with a range of 7 to 16 ft/day. Site specific aquifer testing was performed to better assess the anticipated range in hydraulic conductivity in the project area. On November 20, 2008, a step-rate pump test was conducted on the extraction well for the GPTIA to examine the well's performance. Analysis of the extraction well drawdown data suggests that the transmissivity is likely in the range of 1,500,000 to 1,870,000 gpd/ft. If it is assumed that the effective aquifer thickness at the extraction well location is 210 feet, the estimated range of horizontal hydraulic conductivity is between 950 and 1,200 ft/day. Analysis of drawdowns observed at observation wells indicates the transmissivity is likely in the range of 1,500,000 to 3,000,000 gpd/ft. Assuming an effective aquifer thickness of 210 feet, yields a range of horizontal hydraulic conductivity of between 950 and 1,900 ft/day (Parametrix 2009d).

2.2 NUSTAR FACILITY

This section provides a summary of the NuStar facility, including the site history, remedial investigations, and completed cleanup actions. The NuStar RI report (Apex 2013a) includes a detailed discussion of the site and past activities, including data evaluation and interim remedial actions that comprise the basis for the FS.

2.2.1 Location, Description, and History

The following provides a summary of the location, description, and history of the NuStar facility.

2.2.1.1 Location

The NuStar facility is located at the Port of Vancouver Terminal No. 2 in Vancouver, Washington (as shown on Figure 2-8). The NuStar facility address is 2565 NW Harborside Drive, Port of Vancouver, Vancouver, Washington 98660 (Latitude: N45º 38.26'; Longitude: W122º 42.20'). The NuStar facility is owned by the Port and is leased by NuStar.

2.2.1.2 Physical Features

Until 2006, NuStar consisted of a roughly rectangular area with nominal dimensions of 600 by 1,300 feet; in 2006, the leasehold was expanded to include additional area to the north (see Figure 1-2). The total area of the facility is approximately 19 acres, which includes the leasehold extent up to 2006 and the additional leased area after 2006. The NuStar facility is on the north shore of the Columbia River. Land on all other sides is industrial property also owned by the Port. The NuStar facility is located on Clark County Tax Lot (TL) Nos.: 151979-000, 502010-002, 502010-000, and a portion of 502020-000, as well as a portion of the Washington Department of Natural Resources tideland area managed by the Port.

The NuStar facility includes five buildings (Warehouses 9, 13, 14, 15, and 17), a loading dock, three aboveground storage tank (AST) farms, two tank truck loading/unloading racks, a rail tank car loading/unloading area, marine vessel dock and piping, and an office. The ground surface is nearly flat at an elevation typically between 32 and 34 feet above msl. The majority of product piping is above ground except for the buried pipeline that extends from the marine vessel dock to the north to the NuStar Vancouver Annex terminal located approximately 1.7 miles to the north/northeast of the property. A NuStar facility Plan is provided on Figure 2-9.

The NuStar facility includes extensive underground utilities. All utilities are within about 12 feet of the ground surface, above the groundwater table.

The ground surface coverage consists of the following (with approximate aerial extent):

- Buildings (35 percent);
- Paved areas (45 percent);
- Tanks (5 percent); and
- Gravel/bare ground (15 percent).

2.2.1.3 NuStar Facility History

Historical aerial photographs were reviewed to identify the developmental history of the NuStar facility. Copies of the aerial photographs are included in Appendix A. The following summarizes the Property development as observed on the aerial photographs.

- 1935, 1939, 1940 – The NuStar facility was located within the Columbia River flood plain. The top of bank for the river was located near the location of the northern property line.
- 1948, 1956, 1959 – Filling is evident in each of these photographs. There is no development on the NuStar facility. By the 1959 photograph, the top of bank was extended nearly to the current location.
- 1961 – Warehouse 9 was present. Several ASTs that still exist were present. These included part of the tank farm immediately east of Warehouse 9 and three of the larger ASTs farther to the east. Filling is evident in the photograph on the west portion of the Property.
- 1966 – Warehouse 13 was the only addition since 1961.
- 1967 – Warehouse 15 and two ASTs (adjacent to the three easterly ASTs observed in the 1961 photograph) were the primary additions since 1966.
- 1971 – Between 1967 and 1971, a vertical bulkhead was constructed from Warehouse 13 eastward, extending the shoreline to its current location. Warehouse 9 was expanded southward to its current extent.
- 1974 – Warehouse 17 and two ASTs (further expanding the easterly tank farm) were the primary additions since 1971.
- 1980, 1983 – ASTs were added between 1974 and 1983. These were in the same area as prior ASTs, east of Warehouse 9.
- 1990, 1998 – Warehouse 14 was added between 1983 and 1990.
- 2002 – The AST farm east of Warehouse 14 was added between 1998 and 2002.

2.2.2 Terminal Operations

In general, the NuStar facility was developed to receive, store, and handle bulk fuel and chemicals. Typically, these chemicals were not owned by the terminal operator. Rather, the terminal operator entered into agreements as a wholesale distributor to handle chemicals for owners. The terminal was owned/operated by GATX from the early 1960s through 1998 (GATX has since been acquired by Kinder Morgan). The terminal was acquired in 1998 by Support Terminals (ST) Services, a subsidiary of Kaneb Pipeline Partners L.P. (Kaneb). Kaneb was acquired in 2005 by Valero L.P. Valero L.P. changed its name to NuStar Energy L.P. in 2007 and changed the name of ST Services to NuStar Terminals Services, Inc. The terminal property is currently leased and operated by NuStar Terminals Services, Inc.

Although a variety of products have been handled at the NuStar facility over the years, the historical sampling has identified chlorinated solvents as the chemicals of interest. Historical company records identified the following with respect to chlorinated solvent handling at the NuStar facility.

- PCE, TCE, methylene chloride (MC), and 1,1,1-trichloroethane (1,1,1-TCA) were handled for several companies beginning prior to 1976, but the start date is uncertain. The records suggest that handling of chlorinated solvents may have ended as early as 1990, but the end date is uncertain.
- Direct loading (direct transfer from rail tank cars to tank trucks) was the initial method used for transfer of chlorinated solvents. Direct loading occurred near Warehouse 13. Direct loading ended in 1982. Interviews with long-time employees support the records review.
- Indirect transfer (transfer from rail to ASTs, transfer from ASTs to tank trucks) began in 1981 and continued throughout the remainder of chlorinated solvent handling. Indirect transfer occurred in and around the AST farms located east of Warehouse 9 (rail car loading racks to the north, truck loading rack to the south).

Currently, sodium hydroxide is received via ship and transported out by rail and truck. Jet A fuel is received via ship and transported out via barge. Calcium chloride is received via rail and transported out via truck. Methanol is received via rail and transported out via truck and rail.

2.2.3 Surface Water and Surface Water Drainage

The Columbia River bounds the NuStar site to the southwest. The site is situated on the Columbia River flood plain. As described in Section 2.2.1, the majority of the NuStar facility is covered with an impermeable surface (e.g., buildings, asphalt, concrete). Surface stormwater in the terminal area is directed to a permitted stormwater system that is maintained by the Port.

2.2.4 Aquatic and Terrestrial Habitat

The Columbia River is located along the southwest boundary of the NuStar facility. Aquatic organisms, including anadromous and resident fish species, some of which are threatened or endangered, use parts of the river during various stages in their life cycles. As discussed in Section 2.2.1, the NuStar facility and surrounding area are covered with impermeable surfaces and provide no terrestrial habitat.

2.2.5 Summary of Remedial Investigations

Since 1980, numerous investigations have been conducted by various parties. These investigations identified the presence of chlorinated solvents and associated breakdown products, primarily PCE, TCE, and cis-1,2-dichloroethene (cis-1,2-DCE) in site soil, groundwater, river sediments, and soil vapor. Investigation activities were completed between 1980 and 2012. Together, these activities comprise the NuStar RI (Apex 2013a) summarized in Section 2.2.8. The prior investigations include the following.

- 1980 – Ecology conducted a potential hazardous waste preliminary site assessment at the terminal.
- 1984 – Ecology conducted a site inspection including the collection of one sediment sample.
- 1991 – Ecology conducted limited site investigation including installation of one monitoring well.
- 1993 – Additional investigations were conducted at the NuStar facility including the installation of six monitoring wells.
- 1995 – Groundwater was sampled in the seven monitoring wells at the site.
- 1996 – Additional site characterization activities including soil gas survey, groundwater monitoring, soil boring/monitoring well installation, and aquifer monitoring (transducer) survey.
- 1997 – Additional site characterization including surface soil sampling, soil boring/monitoring well installation, and groundwater monitoring.
- 1999 – Routine groundwater monitoring initiated and continued to the present (groundwater was generally monitored on a quarterly frequency; as wells were installed during site investigations, they were typically incorporated into the monitoring program).
- 2000 – Additional monitoring well installations to evaluate the vertical extent of halogenated volatile organic compounds (HVOCs) in groundwater and provide information on aquifer characteristics.
- 2005 – Direct-push borings advanced to further characterize and delineate the extent of VOCs in groundwater.
- 2006 – Push-probe investigations conducted to evaluate need for interim action.
- 2007 – Groundwater investigation conducted to support development of RI Work Plan.
- 2008 – Additional groundwater investigation to support development of RI and risk assessment.
- 2010 – Soil and groundwater interim action confirmation sampling to support additional interim action.
- 2011 – Groundwater investigation off-NuStar facility to the northwest to support development of RI, annual transducer study to support regional groundwater flow evaluation, deep-zone groundwater investigation to assess conditions in the TGA beneath the facility, and off-NuStar-property sediment investigation to support development of RI.

- 2012 – Additional sediment investigations to support development of RI. Investigation of potential jet fuel releases in the vicinity of a pipeline vault.

2.2.6 Quarterly Groundwater Monitoring

Groundwater has been monitored in on-property wells on a generally quarterly schedule since 1999. As wells were installed during the various investigations listed above, they were typically incorporated into the monitoring program during the next quarterly event, although not every well was sampled during each quarterly event. Groundwater monitoring is currently being conducted quarterly in accordance with the Groundwater Monitoring Plan (Ash Creek 2008b). A summary of historical sampling dates and analytical results through fourth quarter 2012 was presented in the NuStar RI report (Table 3 of Apex, 2013).

2.2.7 Interim Actions

The results of the NuStar RI indicate that the primary release area is located between Warehouses 13 and 15, beneath the rail siding north of these warehouses, and extending south toward the sea wall. Rail car off-loading historically occurred at the north end of this area. Soil vapor, vadose zone soil, saturated zone soil, and groundwater data support that releases occurred in this area. Three interim actions have been conducted at this release area. A summary of each is provided below.

2.2.7.1 Interim Action – 2000 through 2005

Pursuant to a 1998 AO between Ecology and Support Terminals Services, Inc. (a.k.a. ST Services), an interim remedial action system was installed at the NuStar facility in 2000. Detailed work scopes, procedures, and methods for these activities were presented in the Final Interim Action Pilot Study Work Plan, (SECOR 1999b), Response to Ecology's Comments Letter (SECOR 1999c), and the Final Interim Action Work Plan (SECOR 2000a). The primary objective of the interim action was to reduce chlorinated VOC concentrations within the areas of greatest impact and to complete cleanup of hazardous substances in these areas. The interim action consisted of two components: (1) a re-circulating system to treat groundwater and (2) vapor extraction to treat soil. The system was designed to treat shallow groundwater (less than 45 feet deep) with PCE concentrations in excess of 1 milligram per liter (mg/L). The interim action system pumped groundwater from extraction wells installed near the river (EX-3 through EX-5), treated the pumped water with potassium permanganate, and then filtered and pumped the water into a series of injection wells along the railroad tracks (IN-1 through IN-9). For soil, a soil vapor extraction (SVE) system withdrew soil vapors from wells IW-1, IN-2, IN-3, IN-4, EX-1, EX-3, EX-4, and EX-5. Locations of these wells are shown on Figure 2-9; a detailed description of the installation of the interim action system is provided in the Final Remedial Investigation Report (SECOR 2001). Interim remedial action continued through 2005. The interim action successfully removed HVOC mass at the NuStar facility (based on the drop in concentration of HVOCs in some wells), but overall, the system was not efficient at addressing the release area.

2.2.7.2 Interim Action – 2008 Enhanced Bioremediation and SVE

An IA was implemented to address the release area at the NuStar facility while the RI, RA, and FS were being completed. An analysis of IA alternatives was completed to select the appropriate action (Ash Creek 2006). The objective of the IA is to reduce threats to human health and the environment from chemicals within the source area. Based on the results of the IA analysis, an enhanced bioremediation and SVE IA was selected and described in detail in a design report (Ash Creek 2007). Ecology accepted the design report on January 10, 2008, contingent upon a response to comments. Ash Creek submitted a comment response letter to Ecology on May 7, 2008 (Ash Creek 2008c). The IA was initiated in April 2008 and consisted of installation of temporary injection points, injection of a bioremediation substrate, installation of SVE wells and associated trenching/pipe, installation and startup of the SVE system, and routine operations, maintenance and monitoring of the SVE system. The bio-injection substrate, CAP18-ME, was derived from food-grade vegetable oil components (triacylglycerols and esterified fatty acids), and provided a carbon source for the anaerobic reductive dechlorination treatment pathway. The bioremediation substrate was injected into shallow zone groundwater at 38 locations within the source area, as shown on Figure 2-10. The SVE system consisted of 18 soil vapor extraction wells, organized in four branches as shown on Figure 2-11. The SVE system operated nearly continuously (with the exception of minor shutdowns for maintenance or monitoring purposes) until the system was expanded in August 2011.

2.2.7.3 Interim Action – 2011 Additional Interim Action (Enhanced Bioremediation and Expanded SVE)

Results of the 2010 confirmation sampling site investigation supported the success of the 2008 IA and provided the data needed to develop a work scope for continued interim action. NuStar had previously submitted a Draft FS to Ecology on January 14, 2010 (Ash Creek 2010) to meet the requirements of (former) AO No. 07-TC-S-DE3938. The FS included an evaluation of remedial alternatives and proposed a final cleanup remedy for the Facility. After review of the remedial alternatives, the FS summarized that additional bioremediation injections and an expansion of the 2008 SVE system would be an appropriate and protective final cleanup action for the Facility. Ecology delayed approval of the FS until further activities were completed to finalize the RI for the Facility. In August 2010, Ecology and NuStar agreed that it would be beneficial to the cleanup effort if NuStar implemented the proposed final cleanup action as an additional interim action, rather than waiting until the RI and FS were completed for the facility. The 2011 Interim Action Work Plan (IA Work Plan) was submitted to Ecology on November 30, 2010 detailing the proposed additional 2011 interim action (Ash Creek 2011; Appendix O). Ecology approved the IA Work Plan in an email on March 30, 2011 and the expanded (2011) interim action was implemented from July through October 2011. The 2011 interim action included additional enhanced bioremediation injections and an expansion of the 2008 SVE system. The additional Interim Action doubled the areal extent of the 2008 SVE system and included four times the number of bio-substrate injections points across an area that was four times larger than the 2008 bioremediation area. During the 2011 interim action, the selected bio-injection substrate (EOS® electron donor, manufactured by EOS Remediation, Inc., of Raleigh, North Carolina) was injected at 155 locations within the primary release (source) area. The SVE system was expanded to include an additional 34 extraction wells and the installation of a second blower. The radius of influence of the SVE system expansion was designed to increase the coverage to the extent of the vadose zone impacts at the NuStar facility.

Approximately five months after the interim action was implemented, the 2011 Interim Action Evaluation Report was submitted to Ecology, summarizing the expansion of the SVE system and startup activities, the enhanced bioremediation injections, and groundwater and SVE effluent monitoring results during the first five months of operation (Ash Creek 2012).

2.2.8 Summary of Remedial Investigation and Risk Assessment

The NuStar RI was submitted to Ecology in August 2013 and was approved by Ecology in November 2013. In this section, key information relevant to the FS is summarized from the RI.

2.2.8.1 Land and Beneficial Water Use

Land Use

The NuStar facility is an industrial property as defined by MTCA (WAC 173-340-200). This conclusion is based on the following:

- The NuStar facility is located within the City of Vancouver that has conducted land use planning under the State Growth Management Act (Vancouver Municipal Code [VMC] 20.110.010.A).
- The City of Vancouver zoning map defines the property and surrounding area as IH: Heavy Industrial. The nearest non-industrial zoning is a residential area located about 1,900 feet northeast of the NuStar facility. According to VMC 20.440.020, IH zoning "…has been carefully located to minimize impacts on established residential, commercial and light industrial areas."
- The NuStar facility is a bulk storage facility located within a marine terminal.

Groundwater Use

The intermediate zone groundwater located beneath the NuStar site is a productive aquifer used within the region for municipal and industrial water supply. Nearby production wells are the Fabricated Products well 1,800 feet to the northwest of the property, the Westside Wastewater Reclamation Facility well located 2,000 feet to the east of the property, and the Great Western Malting wells located 3,000 to 3,500 feet southeast of the property. The Port maintains domestic use wells near the Great Western Malting site and provides water to the NuStar facility. Major water users in the area are the Port of Vancouver, Great Western Malting, City of Vancouver, Westside Wastewater Reclamation Facility, and Clark Public Utilities (Parametrix 2008).

Groundwater at the NuStar facility is not currently used for any purpose. Shallow zone groundwater at the NuStar facility generally flows to the south towards the Columbia River. Groundwater flow in the intermediate zone is more variable and can flow towards Columbia River, maintain a flat gradient, or flow off-property to the north at a slight gradient.

Surface Water

There are no surface waters on the NuStar facility. The Columbia River is located adjacent to the property, to the south.

The Columbia River must be protected for designated uses as defined under WAC 173-201 A-602. The river serves as an active channel for large commercial ships. Throughout its course, the river is used by many communities (not Vancouver) as a source of drinking water. However, within at least several miles of the Site, the river is not used for drinking water purposes and is not likely to be used within the foreseeable future. In 2006, the U.S. Environmental Protection Agency (EPA) designated the Troutdale aquifer beneath Clark County as a Sole Source Aquifer. In the designation, published in the Federal Register on September 6, 2006 (Vol. 71, No. 172), the EPA indicated that 99.4 percent of the county's population used the aquifer as their source of drinking water. Further, the EPA indicated that it was not economically feasible to replace groundwater with surface water. Along the course of the river, water is also used for stock, agriculture, and industrial water supplies.

Anadromous and resident fish species use parts of the river during various stages in their life cycles, including spawning, rearing, and migration. The Columbia River is also used for fishing for sport and consumption, recreational boating, general recreation, and aesthetic value. A number of local American Indian tribes have fishing rights on the Columbia River.

2.2.8.2 Summary of Chemicals of Potential Concern

The RI for the NuStar site included chemical analysis of up to 202 soil samples and 50 rounds of groundwater sampling and analysis for HVOCs, collected over a period of approximately 20 years. These data are of sufficient quality for use in risk assessment, FS, and cleanup level determination. A screening of chemical data identified the chemicals of potential concern (COPCs) in soil and groundwater at the NuStar site to be chlorinated solvents and associated degradation products. Three COPCs (PCE, TCE, and vinyl chloride [VC]) account for greater than 95.9 percent of potential risk based on comparison to screening levels (Apex 2013a). Although cis-1,2 DCE is not a risk driver, it is the daughter product of TCE and breaks down to form VC. Therefore, these four compounds represent the primary COPCs. VC is not widely detected across the Site; therefore, PCE, TCE, and cis-1,2-DCE were used in the RI as indicator compounds for assessing chemical fate and extent.

2.2.8.3 Summary of Chemical Fate and Extent (NuStar Source Area)

The purpose of the RI was to identify the hazardous substances that have been released to the environment as a result of historical site activities; to determine the nature, extent, and magnitude of hazardous substances in affected media; and to determine the direction and rate of migration of hazardous substances. A comprehensive review of historical investigations and relevant soil, soil vapor, sediment, and groundwater data for the NuStar site were presented in Section 2.2.5 (of the NuStar RI report), and relevant documents have been included in appendices.

Soil

Prior to implementation of the 2008 and 2011 interim actions, the highest molar VOC concentrations were present near location AGP-22 (in the former direct loading area) and locations AGP-28/AGP-29 (along the railroad tracks in the former direct loading area). The HVOCs in vadose zone soil are predominantly PCE, with lesser concentrations of TCE and cis-1,2-DCE. As shown on Figure 2-12, the extent of PCE in soil is defined by chemical analytical results up to the river and is confined to the NuStar facility.

Non-aqueous phase liquid (NAPL) has not been observed in the vadose zone during historical investigations at the NuStar facility. A soil investigation was conducted in 2010 to evaluate the overall performance of the 2008 soil interim action. The results of the investigation indicated that the majority of the VOCs had been removed from the coarse soils (e.g., sands and gravels), which is the predominant soil type of the vadose zone, but isolated pockets of high concentrations of VOCs, potentially indicative of limited residual NAPL, remained in isolated silt layers within the vadose zone of the source area (Ash Creek 2011). At the time of the 2010 soil investigation, 1,900 pounds of VOC mass had been removed from the source area by SVE. The 2010 investigation supported that the majority of the VOC mass had been removed within the SVE operational area (Ash Creek, 2011). SVE has been ongoing since the 2010 investigation, and the SVE system was expanded in 2011 to cover a larger area of influence. Since the 2010 soil confirmation event, SVE has removed an additional 2,600 pounds of VOC mass from the source area. The interim action data support that the extent of total molar chloroethenes remaining in soil is likely a lot smaller than defined in the NuStar RI.

Groundwater

Figures 2-13 through 2-15 show isocontours of PCE, TCE, and cis-1,2-DCE in shallow zone groundwater, respectively, for March 2008 and March 2013, as provided to Ecology in the NuStar RI report. As can be seen from the figures, HVOCs in the shallow zone on the northern portion of the leasehold have been and continue to be generally confined to the NuStar facility. There is a small, localized off-property source to the northwest of the NuStar facility; the extent of shallow groundwater impacted by this off-property source is limited to an area of approximately 100 by 300 feet and does not extend to the Columbia River (Figures 13 through 15). It is attenuating naturally, based on the comparison of concentrations and extent between 2008 and 2013 data and has not impacted the underlying intermediate zone. At the southern portion of the NuStar facility, groundwater flow is towards the river where it is understood to interact with river sediments. As can also be seen by the figures, there has been a significant reduction in shallow zone VOC concentrations since implementation of the 2008 and 2011 groundwater interim actions.

The source area at the NuStar facility is confined to the shallow zone groundwater. HVOC concentrations are one to two orders of magnitude less in the intermediate zone groundwater relative to shallow zone groundwater due to the presence of the silty gravel layer beneath the shallow zone in the central and southern portions of the property and the silt ridge at the northern property boundary. The intermediate zone groundwater at the NuStar facility extends beyond the property and is considered part of the project area dispersed plume. The nature and extent of the project area dispersed plume are described in Section 9.

Vault Area

As discussed in the NuStar RI, jet fuel impacts were observed in an isolated area of soil beneath a vault that houses a jet fuel pipeline and associated pipeline valves. Soil and groundwater investigation in the vicinity of the vault indicate that a historical jet fuel release was isolated to a small area beneath and in the immediate vicinity of the vault. The vault area source is shown on Figure 2-9. The only COPCs identified in the vault area were total petroleum hydrocarbons in the diesel range (TPH-Dx; Apex, 2013).

The network of buried and above-ground utilities and pipelines surrounding the vault area prohibited additional soil and groundwater sampling in the vicinity of the vault. Based on visual inspection at the base of the vault and groundwater data from monitoring wells in the surrounding area, the extent of the soil impacts does not likely extend past the footprint of the vault. Furthermore, the laboratory TPH-Dx chromatogram and high molecular weight-biased polycyclic aromatic hydrocarbon (PAH) concentrations were indicative of a weathered jet fuel. The lack of jet-fuel-range hydrocarbons in vault-area groundwater samples further supports that the jet fuel soil impacts were both aged and isolated and had not resulted in widespread impacts to groundwater. Based on these findings, the estimated extent of TPH-Dx-impacted soil is the footprint of the vault, as shown on Figure 2-9.

TPH-Dx concentrations beneath the vault area exceed the MTCA Method A cleanup level of 2,000 milligrams per kilogram (mg/kg). However, the cleanup levels for Industrial Land Use assume the potential for frequent direct contact by on-site workers. Realistically, the potential for direct contact exposure with impacted soils is very low, as the soils are located approximately 15 feet bgs and can only be accessed when performing subsurface work below the vault. Therefore, the slight exceedance of the TPH-Dx concentration above Method A levels will not present an unacceptable health risk to site workers. Because the historical jet fuel release is limited to a small isolated portion of the property, there is no soil direct contact risk for site workers, and groundwater is not impacted with respect to jet fuel, these isolated impacts are not considered a source area were not retained for further risk evaluation in the

RI (Apex 2013a). Because there is no unacceptable risk associated with this release, the Vault Area is not further evaluated in this FS.

Sediments

Figure 2-16 shows the approximate extent of VOC impacts to river sediments including those above applicable risk-based screening levels. Sediment data are presented for the uppermost samples collected (typically the mudline and first subsurface sample), as this definition of "sediment" is consistent with the Sediment Management Standards (SMS) Rule Proposed Amendments (Ecology 2013) and is representative of the portion of the river channel where "humans or biota may be exposed". A conceptual site model for the distribution of VOCs in sediments was initially presented to Ecology in the RI (Apex 2013a). The magnitude and distribution of sediment impacts suggests that river sediments were directly impacted from the migration of upland impacted groundwater. As evaluated in the NuStar risk assessment (Ash Creek 2008a) and in the updated NuStar risk assessment (NuStar RI, Section 5; Apex, 2013a), VOC exposure point concentrations (EPCs) in upland groundwater concentrations were used to estimate potential impacts to river sediments using the three-phase partitioning model in WAC 173-340-747(4) and (5). The modeled impacts to sediments from groundwater were consistent with the sediment data collected during investigations in 2011 and 2012.

VOCs detected one or more times in sediment were considered to be constituents of interest (COI). The maximum detected concentration was compared to ecological effects-based screening level concentrations in the NuStar RI. COI that exceeded screening levels included PCE, TCE, cis-1,2-DCE, 1,1-DCE, 1,1-dichloroethene, and VC (see table 14 of the NuStar RI; Apex, 2013). Because each of the sediment COI were included in the list of COPCs for groundwater, and the sediments are understood to be directly and solely impacted by groundwater, the full list of COI were retained as COPCs in sediments. Using the same rationale as for soil and groundwater, four indicator compounds were used to evaluate the extent of sediment impacts, and include: PCE, TCE, cis-1-2-DCE, and VC.

As shown on Figure 2-16, the extent of COPC impacts above risk-based screening levels is limited to a rectangular area extending approximately 600 feet along the southern property boundary and approximately 100 feet riverward from the property boundary. Similar to the one- to two-order-magnitude decrease in groundwater concentrations between the shallow and intermediate zone groundwater (see Figure 2-6), impacts to sediments in contact with intermediate zone groundwater are generally a half to one order of magnitude less than in sediments in contact with shallow zone groundwater. The most impacted sediments (locations "C" and "3") are located directly downgradient from the primary source area at the facility. The extent of sediment impacts to the west/northwest and east/southeast are also well delineated and generally correlate with the northwest-southeast boundaries of the shallow zone groundwater plume at the NuStar site.

2.2.8.4 Baseline Risk Assessment Update

A baseline human health risk assessment was conducted in accordance with the requirements for determining cleanup standards under MTCA (WAC 340-173-700 through – 760; Ash Creek, 2008a). The risk assessment evaluated reasonably likely exposure pathways based on the evaluation of land and water use and included both a human health risk assessment and ecological risk assessment. Exposure pathways evaluated included direct contact with soil, inhalation of vapors from soil or groundwater, future drinking water use of groundwater, leaching to groundwater with subsequent use of groundwater, and direct exposure of benthic/aquatic receptors to sediment or surface water. Exposure media included soil, groundwater, surface water, air, and sediments. The risk assessment was updated with the submittal of the NuStar RI in 2013, as new information was available that was relevant to the results of the baseline risk assessment. The baseline was updated to reflect conditions at the time of submittal of the 2013 RI. The results of the updated risk assessment are summarized below.

Non-Carcinogens

The updated baseline (at the time of submittal of the 2013 RI) non-carcinogenic hazards were identified to be acceptable except for the following pathways.

- <u>On-Property, Industrial Worker, Current Baseline Condition</u> – Hazards were potentially unacceptable for vapor intrusion (from soil and groundwater). The potential for unacceptable hazard resulted from cis-1,2-DCE. The majority of the potential hazard results from vapor intrusion from groundwater. An interim action is currently operating to mitigate this potential hazard.
- <u>On-Property, Industrial Worker, Future Baseline Condition</u> – Hazards are potentially unacceptable for vapor intrusion (from soil and groundwater) and drinking water. The potential unacceptable hazard results from cis-1,2-DCE. The majority of the potential hazard resulted from vapor intrusion from groundwater. An interim action is currently operating to mitigate this potential hazard.
- <u>Resident, Future Baseline Condition</u> – Potential hazards are unacceptable for the drinking water pathway. The potential unacceptable hazard results from cis-1,2-DCE.

Carcinogens

The updated baseline (at the time of submittal of the 2013 RI) excess lifetime cancer risk estimates were identified to be acceptable except for the following pathways.

- <u>On-Property, Industrial Worker, Current Baseline Condition</u> – Estimated risk was potentially unacceptable for vapor inhalation (from soil and groundwater). The potential for unacceptable risk resulted primarily from PCE and TCE. The majority of the potential risk results from vapor from soil. Current potential risks are lower than the estimated baseline risk because the baseline risks use a variety of conservative assumptions. In addition, an interim action is currently operating to mitigate this potential risk.
- <u>On-Property, Industrial Worker, Future Baseline Condition</u> – Estimated risk was potentially unacceptable for vapor intrusion (from soil and groundwater), drinking water, and leaching to groundwater. The potential for unacceptable risk resulted primarily from PCE, with TCE and VC accounting for the remainder. The majority of the potential risk resulted from vapor intrusion from soil for the indoor worker and drinking water for the outdoor worker.
- <u>Off-Property, Indoor Industrial Worker, Current Baseline Condition</u> – Estimated risk was potentially unacceptable for vapor intrusion from groundwater. The potential for unacceptable risk results primarily from TCE associated with a small area of groundwater immediately west of the property. Concentrations of TCE in this area appear to be influenced by an off-property source. However, the area of impact is attenuating and does not significantly underlie existing buildings; therefore, it is not anticipated to present a current unacceptable health risk.
- <u>Resident, Future Baseline Condition</u> – Estimated risk is potentially unacceptable for the drinking water pathway. The majority of the potential risk results from PCE.

In summary, the updated baseline human health risk assessment indicated that the potential hazards associated with non-carcinogens or the estimated excess lifetime cancer risks associated with carcinogens were acceptable with the exception of the vapor intrusion pathway and a hypothetical (future) drinking water pathway. Potential risks posed by vapor intrusion are mitigated via the interim action soil vapor extraction system and well-ventilated buildings at the NuStar facility.

2.2.9 Ecological Risk Assessment

The ecological risk assessment results are summarized as follows.

- Terrestrial – The NuStar site is within an industrial area, is generally covered with buildings and pavement, and has little or no habitat. The NuStar site therefore meets the requirements of WAC 173-340-7491(1) and a terrestrial ecological risk evaluation is not required.
- Aquatic Organisms, Surface Water – Using measured sediment concentrations and the partitioning equations from WAC 173-340-747(4), 1,1-DCA, cis-1,2-DCE, PCE, and TCE are predicted to exceed effects-based concentrations in surface water at the groundwater/surface water interface.
- Benthic Organisms, Sediment – Based on sediment sample data, the following exceed effects-based concentrations in sediment: 1,1-DCA, cis-1,2-DCE, PCE, TCE, and VC.

2.2.10 Chemicals of Concern in Surface Water/Sediments

The chemicals identified to have the potential for unacceptable risk in the risk assessment are defined as chemicals of concern (COCs). The COCs are listed in Table 2-1 together with media, pathways of concern, and receptors.

Table 2-1. COCs and Receptor Pathways

	Human, Non-Carcinogen		Human, Carcinogen		Ecological		
						Aquatic	
COC	**Vapor**	**Drinking Water**	**Vapor**	**Drinking Water**	**Terrestrial**	**Migration to Surface Water**	**Migration to Sediment**
PCE	--	--	S, GW	S, GW	--	GW	GW
TCE	--	--	S, GW	S, GW	--	GW	GW
cis-1,2-DCE	S, GW	GW	--	--	--	GW	GW-
VC	--	--	GW	GW	--	--	GW
1,2-DCA	--	--	--	GW	--	--	--
1,1-DCA	--	--	--	--	--	GW	GW

Note: “S” = Soil; “GW” = Groundwater; “--” = Not applicable or baseline risk acceptable.

2.3 CADET FACILITY

This section provides a summary of the Cadet facility, including the site history, remedial investigations, and completed cleanup actions. The Cadet RI report (Parametrix 2010a) includes a detailed discussion of the site and past activities, including data evaluation and interim remedial actions that comprise the basis for the FS.

2.3.1 Location, Description, and History

The Cadet site is a rectangular-shaped parcel located at 2500 Lower River Road in Vancouver, Washington (Figure 1-2). The Cadet site is currently occupied by an electric heater manufacturing facility and includes a single building (15,750 square feet) with associated asphalt and gravel parking areas, as well as landscaping. In addition to the Cadet parcel, significant Cadet-related investigations were conducted on two adjacent areas, including: (1) an “L Shaped Parcel” of undeveloped land located adjacent to the Cadet site’s northern and western boundaries; and (2) the North Fruit Valley Neighborhood (NFVN), which is defined here as the area of single-family residences located north and east of the Cadet site. The NFVN is bounded on the east by the Burlington Northern Santa Fe Railroad (BNSF), on the south by West Fourth Plain Boulevard, to the west by Yeoman Avenue, and on the north by West 39th Street and La Frambois Road (Figure 1-2). The Cadet site is surrounded predominantly by residential and industrial properties.

Prior to the mid-1960s, the site was an undeveloped field, sometimes cultivated, with an orchard present in the northwest portion for an unknown length of time. In the mid-1960s, a single building was constructed in the same location as the present-day building. Swan Manufacturing occupied this building until 1972, at which time Cadet acquired Swan Manufacturing Company and assumed ownership of the property. Cadet continues to operate at the site, but in May 2006, ownership of the property was transferred to the Port as part of a settlement agreement.

In January 2000, Cadet entered into an AO with Ecology to conduct investigations and interim remedial actions for VOCs in the subsurface at the Cadet site. Cadet documented its investigations in a Draft Remedial Investigation Report (AMEC 2003) and a Remedial Investigation Update Report (AMEC 2005). TCE and PCE were detected in groundwater samples at maximum concentrations of 78,000 micrograms per liter (µg/L) and 70,000 µg/L, respectively. Interim remedial actions implemented by Cadet included the installation of an air sparging and soil vapor extraction (AS/SVE) system under Cadet's manufacturing building, with operation beginning in October 2003. In 2004 and 2005, Cadet also installed eight recirculating groundwater remediation wells (RGRWs) at the Cadet facility and in the NFVN to treat impacted groundwater beneath the area. In addition, Cadet installed in-home soil vapor vacuum (SVV) systems in six houses in the NFVN to mitigate VOCs detected in indoor air. A summary and current status of these interim actions is included in Section 2.3.8.

The Port acquired the Cadet property on May 29, 2006, as part of a settlement agreement, and has assumed responsibility for cleanup. Additional historical information for the Cadet site is included in the final Cadet RI report (Parametrix 2010a).

2.3.2 Property Operations

At the time Cadet took over the property in 1972, Swan Manufacturing reportedly used TCE as a degreaser in their parts cleaning process. This process involved a large dip tank or vault into which parts would be lowered on a rack. Parts were lowered to just above the liquid TCE level, the lid of the tank was closed, and the tank was heated to produce TCE vapor. Once cleaning was complete, the temperature of the tank was lowered so the TCE would return to a liquid phase. Excess TCE was shaken off the parts inside the tank. The TCE tank was approximately 10 feet long by 5 feet wide by 12 feet deep, with 8 feet of the tank set below surface level inside a concrete containment bunker. Spent TCE from the tank was removed by pumping the product into drums placed next to the tank, which were subsequently placed outside for recycling pickup. Fresh TCE was pumped into the tank from new drums of TCE. No remote pumping of TCE was performed (such as from outside the building), and no underground piping was in place for the remote delivery or removal of TCE (AMEC 2003).

Cadet continued to use TCE and the vapor degreasing process until approximately 1976 when they changed to a water soak cleaning process that used hot water and an alkaline cleaner, with discharge of wastewater to the City's sanitary sewer system. In 1987, Cadet switched to a powder-coating system for painting metal that includes a three-stage cleaning system. Rinse water from the cleaning system is continuously discharged to the sanitary sewer. The powder-coating system continues to be used.

In the early 1990s, a break was identified in the sanitary sewer line at the Cadet facility. In the mid-1990s, a second break in the sanitary sewer line was discovered during construction of a 20,000-square-foot addition to the original building. The second break, at approximately the same location as the first break, was discovered during installation of water and sewer line extensions to the north end of the building. Contaminated wastewater was believed to have been released to the subsurface as a result of the pipeline breaks.

2.3.3 Agreed Orders

Cadet entered into AO No. DE 00-TCPVA-847 prior to the Port acquiring the site. Ecology prepared a new AO (No. 07-TC-S DE5189) for future work being conducted by the Port. As specified by Ecology, the AO was a new instrument that replaced the existing AOs: Nos. DE 98-TC-S337 and DE 01-TCPVA-3257 to which the Port is a party (SMC site) and AO No. DE 00-TCPVA-847 to which Cadet is a party. This AO (No. 07-TC-S DE5189) requires the Port to complete an RI, implement interim action cleanup at the SMC and Cadet sites, and conduct an FS in accordance with the stipulated project schedule.

2.3.4 Surface Water and Surface Water Drainage

There is no surface water present in the immediate vicinity of the Cadet facility. Stormwater drainage occurs at the Site and is directed to on-site drywells. Due to the location and nature of contaminants at the site, surface water and stormwater are not a consideration for the Cadet site in this FS.

2.3.5 Aquatic and Terrestrial Habitat

The Cadet site is an upland property with no surface water in the immediate vicinity; thus, aquatic habitat was not a consideration for the Cadet site in this FS. Terrestrial habitat is also limited due to the developed nature of the Cadet property. An ecological risk evaluation was completed as part of the RI and is discussed in the risk assessment summary in Section 2.3.9.5.

2.3.6 Summary of Remedial Investigations

Since 1998, approximately 20 investigations and/or phases of investigation have been conducted at or in the vicinity of the Cadet site to delineate the nature and extent of subsurface TCE, PCE, and other VOCs. Most of the investigations were completed by AMEC, an environmental consulting firm hired by Cadet. Investigations conducted after 2006 were completed by the Port. The details of the investigations and results are included in the Cadet RI report (Parametrix 2010a). Specific RI activities included:

- Source area investigation and soil interim action
- Installation and sampling of groundwater monitoring wells
- Depth-specific groundwater sampling during drilling of monitoring wells
- Groundwater interim action
- Geologic and hydrogeologic evaluation
- Stable isotope analysis and evaluation of groundwater samples
- Groundwater elevation measurements
- Installation of soil gas wells and soil gas monitoring
- Monitoring of indoor air and ambient air

Due to the number of investigations and detailed data evaluation presented in the Cadet RI report (Parametrix 2010a), only a brief summary of the investigations is presented below and is arranged by medium.

2.3.6.1 Soil Investigations

Since 1998, seven soil sampling events have been conducted at the Cadet site. Based on these soil investigations, the distribution of VOCs in soil was determined to be limited in extent. No VOCs were detected in soil samples collected in the NFVN, and only very low concentrations of VOCs were detected in samples collected on the eastern portion of the Cadet site. This indicated the source material for the contamination was not a surface release on the east side of the Cadet property or in the NFVN.

The highest concentrations of PCE and TCE were detected in soil samples collected beneath the Cadet building. The soil contamination was determined to be limited in extent to the area under the Cadet building. The source of VOCs in groundwater was determined to be the result of spills or releases in the Cadet building and in the subsurface along the sewer line breakage. Concentrations of VOCs were not detected above regulatory cleanup levels. It is expected that the low concentrations of VOCs beneath the Cadet building were further reduced by operation of the AS/SVE system from 2003 through 2012 (see Section 2.3.8.1).

2.3.6.2 Soil Gas Investigations

In June and November 2000, soil gas samples were collected from borings inside the Cadet building and in the NFVN along the sanitary sewer easement east of the Cadet facility. Additional samples were collected in August 2001 along the existing sewer line locations. The highest concentrations of VOCs were detected in the soil gas probes along the sewer line beneath W 28th Street and Unander Avenue. Based on the preliminary soil gas investigation, it was determined that there was a potential to impact indoor air. The Washington State Department of Health (DOH) prepared a Health Consultation (DOH 2002) and recommended indoor air sampling in the NFVN.

Based on the preliminary soil gas results and initial indoor air sampling results obtained in January and September 2002, Ecology required additional soil gas sampling in the NFVN to further evaluate potential vapor intrusion issues. In January 2004, Cadet installed soil gas monitoring wells in the NFVN and initiated a soil gas monitoring program. The intent of the program was to try to establish a site-specific correlation between soil gas and indoor air and to delineate the extent and distribution of VOCs in soil gas in the NFVN. Soil gas wells were sampled during 19 sampling events, between January 2004 and March 2011.

VOCs were detected in soil gas near the Cadet site and in the NFVN. In general, the presence of VOCs in soil gas was correlated with the occurrence of VOCs in groundwater. In most cases, concentrations of VOCs in soil gas increased with depth, which was expected due to volatilization of the groundwater source material into the overlying vadose zone. The concentrations of VOCs in soil gas decreased significantly since initial soil gas wells were installed in 2004. Soil gas sampling was discontinued as it was being used primarily to supplement the vapor intrusion (indoor air) investigation at the Site, which has since been resolved (see Section 2.3.6.4). There are no Ecology cleanup levels associated with soil gas; thus, soil gas is not directly addressed in this FS report. Final remedial actions implemented in the project area to address cleanup of groundwater will be sufficient to address any residual soil gas concerns.

2.3.6.3 Groundwater

Groundwater investigations have been conducted at the Cadet site since 1998. The Cadet groundwater monitoring well network is a component of the project area well network and includes wells and piezometers monitored by the Port and NuStar on a regular basis for groundwater quality. The Cadet site monitoring well network currently consists of 69 monitoring locations: 65 shallow, intermediate, and deep USA monitoring wells (3 are inactive) and 4 TGA monitoring wells. Specific monitoring wells associated with the Cadet site have been sampled on a quarterly and/or semi-annual basis since mid-1998.

Analytical results for groundwater samples have been documented in various quarterly, semi-annual, and/or annual monitoring reports since 1999. The distribution of groundwater contaminants at Cadet was described in detail in the Cadet RI report (Parametrix 2010a). The 2013 distribution of groundwater contaminants in the project area is included on Figures 2-17 through 2-23. A brief summary of 2013 conditions is included below.

Shallow USA Zone

VOC concentrations in all Cadet shallow wells have declined significantly since startup of the GPTIA in June 2009. Cadet well CM-MW-01d-040, which has historically had the highest concentrations of TCE in the shallow zone, is the only Cadet shallow well with VOC concentrations above 10 µg/L since 2010.

In 2013, the shallow plume associated with the Cadet site plume (as defined by the 4 µg/L and 5 µg/L MTCA Method B cleanup level for TCE and PCE, respectively) is generally confined to the Cadet facility and a small portion of the NFVN to the east, with lower concentrations extending farther east and northeast (Figures 2-17 and 2-18). The plume has contracted and concentrations within the defined plume have decreased in comparison to 2011 and 2012 data.

Intermediate USA Zone

The highest concentration of TCE in an intermediate zone Cadet well during 2013 was detected in CM-MW-20i. CM-MW-20i is located southeast of the Cadet source area, between the facility and the GPTIA extraction well. Concentrations of VOCs increased in this well after startup of the GPTIA in June 2009 as contaminants were drawn southeast from the Cadet source area. VOC concentrations in CM-MW-20i peaked in early 2010 and have declined over the past 3 years.

TCE and PCE isoconcentration maps for intermediate wells during the first quarter of 2013 are presented on Figures 2-19 and 2-20. Overall, TCE and PCE concentrations detected in intermediate zone wells associated with the Cadet site continue to decline, with a few low-VOC concentration wells remaining stable.

Deep USA Zone

Isoconcentration maps for TCE and PCE during the first quarter of 2013 are presented on Figures 2-21 and 2-22. Overall, concentrations of TCE and PCE detected in deep zone wells have declined since startup of the GPTIA in 2009.

TGA

VOCs were detected in one of the four Cadet TGA wells, CM-MW-29TGA. VOCs were not detected in TGA wells CM-MW-10d, CM MW 27TGA, and CM-MW-28TGA. TCE and PCE analytical results for TGA wells are included on Figure 2-23. Concentrations of TCE and PCE detected in CM-MW-29TGA have decreased since startup of the GPTIA in 2009.

2.3.6.4 Indoor Air

In January 2002, an indoor air investigation was initiated in the NFVN. The investigation included the collection of indoor air samples in selected homes, primarily in the southern portion of the NFVN, where VOC levels in groundwater and soil gas were highest. In 2009, the Port prepared a Comprehensive Vapor Intrusion Evaluation and Indoor Air Monitoring Plan (Parametrix 2009e), which was subsequently approved by Ecology. The following provides a brief overview of the indoor air issues at the Cadet site.

Indoor air sampling within the NFVN was conducted from January 2002 to September 2011. At Ecology’s request, the DOH conducted a health consultation (DOH 2003) to evaluate whether residents of the NFVN were being exposed to solvent vapors migrating from groundwater into indoor air. The health consultation indicated that the cancer risk from VOCs detected in samples from the initial sampling event at six NFVN homes was approximately one to two orders of magnitude greater than would be expected in background air. Ecology required that action be taken to eliminate exposure in the six residences. SVV systems were installed in the six homes in October 2003 and operated through approximately 2010 (see Section 2.3.8.3).

In addition to the SVV remedial action, Ecology required a comprehensive indoor air investigation to be completed. Between 2002 and 2008, approximately 700 residential indoor air samples (living space, basement, and crawlspace) were collected from more than 120 homes in the NFVN. The indoor air data were compiled and evaluated in the final Comprehensive Vapor Intrusion Evaluation and Indoor Air Monitoring Plan (CAMP), which was submitted to Ecology and DOH in December 2009 (Parametrix 2009e). Based on previous investigations completed at the Cadet site, it was determined that vapor intrusion represented a complete exposure pathway at some residences in the NFVN and the indoor air quality in some homes had exceeded MTCA ambient air cleanup levels (some cleanup levels have since been revised by Ecology). However, it was also determined that there was some contribution from sources other than groundwater contamination (e.g., outdoor air, indoor use of chemicals).

Conclusions of the CAMP indicated the potential risk from vapor intrusion was low, but additional monitoring in select homes would support a decision to conclude vapor intrusion analysis and meet all Ecology requirements. The indoor air monitoring plan (IAMP) was initiated in September 2009 and was completed in September 2011.

The IAMP included 15 homes. Evaluation of indoor air data for each of 15 homes included in the IAMP indicated that vapor intrusion was not an issue of continued concern in the NFVN. With the exception of one residence (2113 W 28th Street), PCE and TCE in indoor air at the residences evaluated in the IAMP were below the MTCA indoor air cleanup levels which were adopted in September 2012.

Indoor air conditions at the 2113 W 28th Street residence are at concentrations above the MTCA cleanup level (primarily for TCE). However, this home was the subject of many previous investigations, and it was determined that contamination in the home was significantly related to chemical products stored in the basement or other in-home activities (cleaning, painting, use of glues, etc.). The elevated concentrations in the home were not the result of vapor intrusion from groundwater contamination; thus, as approved by Ecology (Ecology 2013), no further investigation or sampling was conducted.

Based on the data collected during the IAMP, as well as all data collected at the Cadet site since 2002, vapor intrusion impacts resulting from VOC-contaminated groundwater beneath the NFVN is not a current or future issue of concern in the NFVN. No further indoor air investigations will be conducted in the NFVN. Ecology approved the results and recommendations of the IAMP in 2013 (Ecology 2013).

2.3.7 Quarterly Groundwater Monitoring

Groundwater monitoring has been conducted at the Cadet site since approximately 1999. The general results are presented above in Section 2.3.6.3. The 2013 distributions of groundwater contaminants in the project area are included on Figures 2-17 through 2-23.

2.3.8 Interim Actions

Several interim actions have been implemented at the Cadet site and in the NFVN to reduce or mitigate the presence of VOCs in particular media. These actions are summarized below.

2.3.8.1 Air Sparging/Soil Vapor Extraction System

One air sparging (AS) and two soil vapor extraction (SVE) systems were installed at the Cadet Site in 2002 and 2003 to address VOCs in source area soil and groundwater and to prevent further migration of VOCs to the east towards the NFVN. The first SVE system installation is documented in the Soil Vapor Extraction System Installation and Start-Up Report (AMEC 2002) and the AS/SVE installation and startup is described in the Air Sparging and Soil Vapor Extraction Remediation System Installation and Startup Report (AMEC 2004b).

The completed AS/SVE remediation system began operation in October 2003 as an interim groundwater source control measure. The influence of the AS/SVE system includes the area beneath the Cadet building and the areas of the property to the north and east of the building. The AS portion of the system includes 73 AS wells, and the SVE portion of the system includes 41 vapor extraction wells.

The AS/SVE system operated continuously through approximately 2007. A performance evaluation of the AS/SVE system was conducted between August 2007 and April 2008 to summarize the effectiveness of the AS/SVE system and recommend an operational strategy for future use of the system, if appropriate. The evaluation consisted of a rebound test (also known as pulsing), which was conducted in a manner consistent with the AS/SVE performance evaluation plan (Parametrix 2007c). Details of the evaluation are included in the AS/SVE performance evaluation report (Parametrix 2009a).

Full-time operation of the AS/SVE system was not recommended. Based on the evaluation, it was determined that periodic pulsing of the system provided benefit to remove persistent contamination in soil gas and groundwater. This method provided the most cost-efficient way of operating the AS/SVE system in the interim and phasing out its operation in the long term. Parametrix proposed pulsing and then shutdown of the AS/SVE system. In October 2009, Ecology approved the AS/SVE operating and sampling plan, which included changing system operation from full time to a pulsing schedule.

The AS/SVE system was put into a pulsing mode in November 11, 2009. After 2 years of pulsing, the AS/SVE system was permanently shut down in January 2012. It is expected that the AS/SVE system will be decommissioned after final approval from Ecology.

2.3.8.2 Recirculating Groundwater Remediation Wells

The RGRWs were designed by AMEC to reduce concentrations of VOCs in shallow groundwater in the source area beneath the Cadet building and in the NFVN. The shallow groundwater contamination was the primary source of VOCs detected in the indoor air of homes located in the NFVN. Between February 2004 and July 2005, eight RGRWs (labeled RGRW-1A and RGRW-1 through RGRW-7) were installed by Cadet in the vicinity of the Cadet facility and the NFVN.

In 2007, a contaminant reduction analysis was completed by the Port to evaluate the effectiveness of the RGRWs in reducing concentrations of contaminants in various media at the Cadet site. The results of this analysis were discussed in detail in the final RGRW operation plan (Parametrix 2007a). Operation of the RGRWs was determined to be effective at reducing VOC concentrations in groundwater in the NFVN. A relatively large “clean” zone developed in the vicinity of the RGRWs starting in 2006, indicating that a significant portion of the source material had been removed. As VOC concentrations reduced, the effectiveness of the RGRWs lessened due to the amount of groundwater needed to treat the lower concentrations. Operation of the RGRWs did not significantly impact the overall extent of the TCE plume greater than 5 µg/L; i.e., the overall contaminated shallow groundwater footprint had not changed significantly. It was determined that the RGRWs had limited effect going forward, specifically in terms of operating costs and the planned installation of the Port's GPTIA, which would treat groundwater contamination associated with the Cadet site. Therefore, the Port recommended that the RGRWs be decommissioned. Ecology approved the decommissioning in 2010.

Four of the eight RGRWs, including RGRW-1, RGRW-1A, RGRW-2, and RGRW-7, were decommissioned in 2010 (Parametrix 2010b). The remaining RGRWs, including RGRW-3, RGRW-4, RGRW-5, and RGRW-6, were decommissioned in April and May of 2012 (Parametrix 2012). Decommissioning of the RGRWs consisted of removing the well string from the well, grouting of each well, filling and paving over of utility vaults, and removal of associated utilities.

2.3.8.3 Residential Soil Vapor Vacuum Systems

In 2002, Cadet initiated indoor air sampling in the NFVN. Based on the initial indoor air sample results, several of the residences had elevated concentrations of TCE (i.e., significantly above the average) or other VOCs in indoor air. Due to elevated levels, Ecology required the installation of SVV systems in six homes in the NFVN in October 2003. The SVVs were continuously operated through January 2010. The residences with the SVV systems were:

- 2809 Unander Avenue
- 2805 Unander Avenue
- 2206 W 28th Street
- 2202 W 28th Street
- 2105 W 28th Street
- 2103 W 28th Street

SVV systems were installed and activated in the basement and/or crawlspaces of the six residences between August 26, 2003 and September 3, 2003. The SVV systems in each of the six residences were fully operational by the end of October 2003. The equipment for each SVV system included a blower and soundproof enclosure, intake and discharge piping, electrical conduit and wiring, gauges, and filter units containing granulated activated carbon (GAC).

Cadet's Residential Soil Vapor Vacuum Installation and Start-up Report (AMEC 2004a) includes details of the SVV system design and installation in the six residences. Additional information is included in the Cadet Remedial Investigation Update Report (AMEC 2005). In addition, the Port prepared a letter entitled Evaluation of SVV System Performance (Parametrix 2007b), which summarized the construction of the systems and influent/effluent concentrations and current status of indoor air quality.

By 2009, VOCs had been reduced in indoor air in all homes to very low levels. In November 2009, the Port requested that Ecology approve temporary shutdown of the SVV systems to allow evaluation of potential VOC rebound and/or to determine whether the SVV systems could be permanently decommissioned. Ecology approved the rebound evaluation and indoor air sampling schedule in December 2009 (Ecology 2009). The SVV rebound evaluation was conducted between February and December 2010.

In December 2010, at the conclusion of the SVV rebound evaluation, it was determined that systems in five of the six homes should be permanently shut down and that no further indoor air sampling was recommended for these homes. Additional indoor air sampling was recommended for the 2809 Unander Avenue residence to determine if the concentrations detected during December 2010 were an anomaly.

Decommissioning of three SVVs (2103 W 28th, 2105 W 28th, and 2206 W 28th) was completed by the Port in accordance with the Final Soil Vapor Vacuum System Rebound Evaluation in July 2011. The residents at 2805 Unander and 2202 W 28th chose to keep the SVV systems in place. However, in September 2013, decommissioning of the system at 2805 Unander was requested by the estate representative and completed after approval by Ecology. Decommissioning of the SVV at 2809 Unander was conducted in December 2013 after approval from Ecology that indoor air was no longer an issue in that home (Ecology 2013). No further indoor air investigation or remedial activities are being conducted, as approved by Ecology.

2.3.9 Summary of Risk Assessment

This section presents a summary of the human health risk assessment presented in the Cadet RI report. The risk assessment primarily focused on the risk to applicable receptors from groundwater exposure and associated pathways. The potential human health risks from the release of TCE at the Cadet site were examined by evaluating soil, soil gas, indoor air, and groundwater data collected within the project area. Exposure to VOCs was estimated for workers and residents within the project area for the following pathways:

- Inhalation exposure to indoor air or vapor intrusion via groundwater
- Ingestion or skin contact with groundwater used for potable purposes
- Skin (dermal) contact with or incidental ingestion of groundwater from digging or trenching activities

The risk assessment was completed in 2009, prior to installation and operation of some of the interim actions discussed in previous sections, including the Port's GPTIA. Use of data collected prior to the interim actions overstates the potential risk associated with remaining contamination. Therefore, where applicable, the discussions below include additional information as necessary where it impacts the FS evaluation and/or potential remedial actions.

2.3.9.1 Land and Beneficial Water Use

Land use and beneficial water use was evaluated to support the risk assessment completed for the Site, primarily to establish the applicable potential exposure pathways.

Land use for the Cadet property is industrial in nature. This is supported by the City of Vancouver zoning for the property, which is Heavy Industrial. The use and designation of the Cadet property is not expected to change in the near future. Residential properties are located to the north and east of the Cadet site. The residential use was considered during evaluation of exposure pathways in these areas (groundwater, indoor air, etc.).

Groundwater on the Cadet site is not currently used as a potable water source. However, the intermediate groundwater zone in the vicinity of the project area is used as a productive aquifer for municipal and industrial water supplies, including by the City of Vancouver, GWM, the Port, and Clark Public Utilities. In general, shallow groundwater is not a source of current potable water but does have limited potential for potable water extraction. In addition, the aquifer in the project area is designated as a sole-source aquifer (which includes all zones). There is no confining layer that distinctly separates the shallow and intermediate zones. Therefore, all groundwater in the project area is considered to have a beneficial use in the form of a potential drinking water source and/or connection to a drinking water source.

2.3.9.2 Chemicals of Potential Concern

COPCs were evaluated based on potential exposure routes and analytical data in various media at the Site. The selection of indicator hazardous substances (i.e., COPCs) was conducted in accordance with WAC 173-340-703. VOCs further evaluated in the risk assessment were determined based upon: (1) the frequency of detection; (2) the potential for adversely affecting human health; (3) the chemical and physical characteristics of the contaminants; and (4) the identification of potential degradation by-products of TCE (e.g., 1,1-DCA, 1,2-DCE, cis-1,2-DCE).

Groundwater: Analysis of chemical concentrations from all groundwater zones indicated that the following chemicals were detected above a frequency of detection (FOD) of 5 percent and at least one sample exceeded the MTCA Method B cleanup standards for groundwater: 1,1,1-trichloroethane, 1,1-DCE, 1,1-DCA, chloroform, cis-1,2-DCE, PCE, toluene, TCE, and trichlorofluoromethane. These chemicals were carried forward through the risk assessment for groundwater. In addition, several compounds had minimal risk levels (MRLs) above the MTCA Method B cleanup levels. These were further evaluated for inclusion as COPCs and, after evaluation, only vinyl chloride was selected as an additional COPC for groundwater.

Soil: In general, only five VOCs (1,1,1-trichloroethane, cis-1,2-trichloroethene, methylene chloride, PCE, and TCE) were detected in soil samples. These chemicals were further evaluated in the risk assessment for soil contact pathways for site workers and for the terrestrial ecological evaluation.

Indoor Air: The following chemicals were either detected at or above an FOD of 5 percent, exceeded the MTCA B cleanup level, or are known TCE degradation by-products and were further evaluated in the risk assessment: 1,1,1-trichloroethane, 1,1-DCA, 1,1-DCE, 1,2-DCA, chloroethane, cis-1,2-DCE, PCE, trans-1,2-DCE, TCE, and vinyl chloride.

Outdoor Air: The following chemicals were either detected at or above an FOD of 5 percent, exceeded the MTCA B cleanup level, or are known TCE degradation by-products and are further evaluated in the risk assessment: 1,1,1-trichloroethane, 1,1-DCA, 1,1-DCE, 1,2-DCA, chloroethane, cis-1,2-DCE, PCE, trans-1,2-DCE, TCE, and vinyl chloride.

2.3.9.3 Summary of Chemical Fate and Extent

The extent of soil and groundwater contamination at the Cadet site is summarized in Section 2.3.6. Figures 2-17 through 2-23 show the extent of groundwater contamination at the site in 2013.

2.3.9.4 Human Health Risk Assessment

An exposure assessment is conducted to estimate the magnitude, frequency, duration, and route of exposure of a receptor to a contaminant source. Information about waste sources, exposure pathways, and receptors at the Cadet site was used to develop a conceptual understanding in order to evaluate potential risks to human health.

Receptors are defined as persons who may come into contact with site chemicals. Receptors in this analysis are individuals who work or live within the project area. “Workers” include individuals who work regularly at the Cadet facility or other Port-owned or non-owned property downgradient of the Cadet site. Temporary workers were also evaluated, such as excavation workers. Residents include people who live east of the Cadet site in the NFVN and South Fruit Valley Neighborhood (SFVN) where groundwater containing VOCs has migrated.

The human health risk assessment consists of an analysis of multiple locations, exposure pathways, and receptors. Since multiple locations and groundwater wells were assessed (representing variable exposure rates), a range of risk estimates was prepared. In addition, cumulative risks from all pathways were evaluated. According to MTCA, non-cancer risks should not exceed a hazard quotient of 1 for individual chemicals or a hazard index of 1 for multiple chemicals (i.e., the sum of the hazard quotient values). Cancer risks should not exceed $1x10^{-6}$ (i.e., one additional chance of contracting cancer per one million) for exposure to individual chemicals or $1x10^{-5}$ (one per one hundred thousand) for exposure to multiple chemicals. Conclusions for each type of receptor evaluated in the risk assessment are discussed below.

Cadet Site Workers: Exposure and risk estimates for Cadet site workers initially suggested that VOC contaminants in indoor air (Cadet building) posed a slightly elevated risk if workers are chronically exposed (maximum excess lifetime cancer risk [ELCR] $5.4x10^{-6}$). However, since the time of the indoor air risk assessment, EPA has changed the toxicity factor that must be used to calculate risk for TCE and PCE. Because of EPA's change (and subsequently Ecology-adopted values), the potential risk is substantially lower than originally calculated. Further evaluation conducted subsequent to the RI and CAMP indicates that no potential risk is present to current workers. The indoor air issue has been completely addressed and Ecology has indicated that no further investigation or remedial actions are required (Ecology 2013).

Exposure and risk estimates for source area workers suggest that VOC contaminants in groundwater pose a potential risk if workers are chronically exposed (maximum ELCR $5.2x10^{-4}$).

Cadet Site Excavation Worker: Outdoor air and soil concentrations pose minimal risk to Cadet excavation workers at 2013 concentrations. Exposure and risk estimates for on-site excavation workers suggest that VOC contaminants in groundwater posed a slight potential risk if workers are chronically exposed (maximum ELCR $4x10^{-6}$). However, groundwater is not currently used at the Cadet site for domestic purposes at the levels evaluated in the risk assessment. Therefore, when considering only air and soil pathways, estimated risks to Cadet excavation workers are considered to be negligible.

NFVN Residents: Exposure and risk estimates for NFVN residents were completed and suggested that VOC contaminants in indoor air had the potential to cause risk if residents were chronically exposed (ELCRs ranging from $7.2x10^{-7}$ to $2.7x10^{-4}$). However, since the time of the indoor air risk assessment, EPA has changed the toxicity factor that must be used to calculate risk for TCE and PCE. Because of EPA's change (and subsequently Ecology-adopted values), the potential risk is substantially lower than originally calculated. Further evaluation conducted subsequent to the RI and CAMP indicates that no potential risk is present to current residents. The indoor air issue has been completely addressed and Ecology has indicated that no further investigation or remedial actions are required (Ecology 2013).

Exposure and risk estimates for NFVN residents suggest that VOC contaminants in groundwater pose a potential risk if residents are chronically exposed.

2.3.9.5 Ecological Risk Assessment

As required under MTCA (WAC 173-340-7490), a terrestrial ecological evaluation must be considered to:

- Determine whether a release of hazardous substances to soil may pose a threat to the terrestrial environment;
- Characterize existing or potential threats to terrestrial plants or animals exposed to hazardous substances in soil; and
- Establish site-specific cleanup standards for the protection of terrestrial plants and animals.

Exposure pathways to sediments, surface water, or wetlands are not considered complete for the Cadet site because these media do not exist at this location. Therefore, the terrestrial ecological evaluation did not include an evaluation of potential threats to ecological receptors in these media or habitat areas. Since the residual contaminated soil is located on an area designated for industrial or commercial use only, the evaluation focused only on exposure to soil contamination for terrestrial wildlife protection (per WAC 173-340-7490-03b).

A simplified terrestrial ecological evaluation was conducted for the Cadet site in accordance with WAC 173-340-7492. The soil contamination on the Cadet site is generally limited to a confined area, thus there does not appear to be a substantial potential threat of significant adverse effects to terrestrial ecological receptors. The terrestrial wildlife evaluation consisted of calculating ecological indicator soil concentrations for the chemicals of concern at the Cadet site. The methods for obtaining information and calculating ecological soil concentrations followed methodologies developed in MTCA. A comparison of the ecological indicator soil concentrations to the reasonable maximum soil concentrations found at the Cadet site indicated that no chemical exceeded its respective indicator soil concentration. Thus, contaminant concentrations in soil at the Cadet site do not pose a significant threat to terrestrial ecological receptors. Therefore, based on the size of the contaminated area, the land use at the site, and the relatively low contaminant concentrations (compared to ecological indicator soil concentrations), the Cadet site was excluded from further ecological assessment per WAC 173-340-7492.

2.3.9.6 Risk Assessment Conclusions/Chemicals of Concern

The risk assessment was conducted in accordance with MTCA risk assessment guidance. Potential risks to human health from exposure to contaminants in groundwater, soil, indoor air, and outdoor air were examined. Based on the results of the risk assessment, Parametrix reached the following conclusions for each medium at the Cadet site.

1. **Groundwater:** The potential risk associated with groundwater was evaluated for a Cadet site worker, a Cadet site excavation worker, and an NFVN resident. While previous and ongoing remedial actions have significantly reduced groundwater concentrations, current concentrations are still at levels that suggest potentially elevated risks to human health for all receptors and exposure pathways evaluated. The results indicated continued remedial actions are necessary to reduce groundwater concentrations to levels that are protective of potential future receptors, which are part of the evaluation in this FS. Chemicals of concern include TCE, PCE, and 1,1-DCA. Drinking water for the NFVN is currently supplied by the City of Vancouver.
2. **Soil**: The potential risk associated with soil was evaluated for a Cadet site worker and a Cadet excavation worker. Based on the human health risk assessment, the current risk associated with COPCs in soil in the source area is within the acceptable risk range. Further remediation of soil is not warranted, based on the potential receptor scenarios evaluated.

3. **Indoor Air**: The potential risk associated with indoor air was evaluated for Cadet site workers and NFVN residents. The results suggested that VOC contaminants in indoor air had the potential to cause risk if residents were chronically exposed (ELCRs ranging from $7.2x10^{-7}$ to $2.7x10^{-4}$). However, since the time of the indoor air risk assessment, EPA has changed the toxicity factor that must be used to calculate risk for TCE and PCE. Because of EPA's change (and subsequently Ecology-adopted values), the potential risk is substantially lower than originally calculated. Further evaluation conducted subsequent to the RI and CAMP indicates that no potential risk is present to current residents. The indoor air issue has been completely addressed and Ecology has indicated that no further investigation or remedial actions are required. No further evaluation of indoor air in this FS is necessary.
4. **Outdoor Air**: The risk from outdoor air was evaluated for a Cadet site worker and an NFVN resident (child and adult). Based on the human health risk assessment, the current risk associated with COPCs in outdoor air is within the acceptable risk range.

2.4 SMC FACILITY

This section provides a summary of the SMC facility, including the site history, remedial investigations, and cleanup actions. The SMC RI report (Parametrix 2009b) includes a detailed discussion of the site and past activities, including data evaluation and interim remedial actions that comprise the basis for the FS.

2.4.1 Location, Description, and History

The SMC site is adjacent to and west of the intersection of Fourth Plain Boulevard and Mill Plain Boulevard in Vancouver, Washington (Figure 1-2). The building formerly occupied by SMC was located between 2001 and 2501 West Fourth Plain Boulevard and was demolished in 1986. The northern portion of the site is currently occupied by a pump building associated with the GPTIA system. The southern portion of the SMC site is currently being used as a staging area for metal rebar products.

The Port's AOs define the SMC site as follows: "The Port of Vancouver/Building 2220 Site, also known as the former Swan Manufacturing Site, is located between 2001 and 2501 West Fourth Plain, near the southwest corner of Fourth Plain and Kotobuki Way, in an industrial-zoned area at the Port of Vancouver." As discussed previously, the Site is considered to include the current areal extent of the dissolved-phase plume associated with the three separate source areas. The Site is shown on Figure 1-2.

TCE was first discovered by the City of Vancouver in 1997 as part of the Mill Plain Boulevard Extension Project (Mill Plain project). The Mill Plain project involved the extension and rerouting of Mill Plain Boulevard, a major arterial road in Vancouver, Washington. In 1998, the Port initiated an RI and FS at the SMC site to address TCE and other related VOCs in soil and groundwater in the project area. From 1998 to 1999, the Port completed an interim action for soil that included the excavation and treatment of approximately 13,800 cubic yards of VOC-contaminated soil from the SMC source area. From 2002 to 2004, the Port completed an interim action for groundwater that included injecting Fenton's Reagent and potassium permanganate to treat VOCs in groundwater in the SMC source area.

In 2009, the Port completed construction of the groundwater pump and treat system at the SMC site. The groundwater pump and treat system provides hydraulic containment of groundwater in the project area and treats dissolved-phase VOCs in extracted groundwater through the use of an air stripping process. Additional historical information for the SMC site is included in the final RI report (Parametrix 2009b).

2.4.2 Property Operations

From 1956 to 1964, electric heaters were manufactured by SMC at the site. Sheet metal was formed, cleaned, painted, and assembled into heaters. The sheet metal parts were cleaned using a TCE vapor degreasing tank prior to painting. The degreasing tank was set into a concrete pit in the floor of the building. After degreasing, the metal parts were transferred to two rinse tanks, where the parts were rinsed to remove any remaining TCE. The parts were then dried and painted.

Occasionally, TCE was spilled while the degreasing tank was being refilled. This spilled TCE would accumulate in a sump below the degreasing tank. In order to remove the spilled TCE, water was added to the sump, and the mixture of water and TCE was pumped into barrels. In 1964, SMC transferred its operations to a new facility at 2500 Fourth Plain Boulevard, discontinuing operations at the SMC site. Cadet purchased SMC in 1972 and continues to operate at the 2500 Fourth Plain facility.

TCE was first discovered by the City of Vancouver in 1997 as part of the Mill Plain Boulevard Extension Project (Mill Plain project). The Mill Plain project involved the extension and rerouting of Mill Plain Boulevard, a major arterial road in Vancouver, Washington. The former SMC building was demolished by the Port in 1986, 11 years prior to the contaminant discovery.

2.4.3 Agreed Orders

Ecology prepared an AO No. 07-TC-SDE5189 for future work being conducted by the Port. As specified by Ecology, the AO was a new instrument that replaced the existing AOs: Nos. DE 98-TC-S337 and DE 01-TCPVA-3257 to which the Port is a party and AO No. DE 00-TCPVA-847 to which Cadet is a party. This AO (No. 07-TC-SDE5189) requires the Port to complete an RI, implement interim action cleanup at the SMC and Cadet sites, and conduct an FS in accordance with the stipulated project schedule.

2.4.4 Surface Water and Surface Water Drainage

There is no surface water present in the immediate vicinity of the former SMC facility. Stormwater drainage occurs at the site and is directed to the City of Vancouver stormwater system. Due to the location and nature of contaminants at the site, stormwater is not a consideration for the SMC site in this FS.

2.4.5 Aquatic and Terrestrial Habitat

The SMC site is an upland property with no surface water in the vicinity; thus, aquatic habitat was not a consideration for the SMC site in this FS. Terrestrial habitat is also limited due to the developed nature of the SMC property. An ecological risk evaluation was completed as part of the RI and is discussed in the risk assessment summary in Section 2.4.9.5.

2.4.6 Summary of Remedial Investigations

Since 1998, a number of investigations and/or phases of investigation have been conducted at or in the vicinity of the SMC site to delineate the nature and extent of TCE and other VOCs. The details of the investigations and results are included in the SMC RI report (Parametrix 2009b). Specific RI activities included:

- Source area investigation and soil interim action
- Installation and sampling of groundwater monitoring wells
- Depth-specific groundwater sampling during drilling of monitoring wells
- Groundwater interim action
- Geologic and hydrogeologic evaluation
- Development of a regional groundwater hydrogeologic model
- Stable isotope analysis and evaluation of groundwater samples
- Groundwater elevation measurements
- Installation of soil gas wells and soil gas monitoring
- Monitoring of indoor air and ambient air

Due to the number of investigations and detailed data evaluation presented in the SMC RI report, only a brief summary of the investigations is presented below and is arranged by medium.

2.4.6.1 Soil Investigations

Soil investigations were initiated in 1998 associated with the SMC source area. The distribution of VOCs in soil was determined to be limited in extent and confined to the source area. TCE-impacted soil (maximum concentration of 17,000 micrograms per kilogram [μg/kg] in the vadose zone) was detected in the vicinity of the SMC Site. The TCE-impacted soil was the primary source material for impacting groundwater. Therefore, the Port completed an interim action in 1998 to remove the source material. Approximately 13,800 cubic yards of TCE-impacted soil were excavated from the area and treated using enhanced soil vapor extraction. The treated soil was used as fill material under bridge abutments for a new Port entrance overpass that crosses the railroad tracks southwest of the SMC site or as fill material at Parcel 1A, located at Terminal 4.

Overall, interim actions have successfully treated VOC-contaminated soil in the unsaturated zone beneath the SMC site. Analytical results for groundwater samples collected from wells in the SMC site source area suggest that residual TCE may be present in small areas of the fine-grained sand layer located in the saturated zone beneath the SMC Site. VOCs were not detected at concentrations above the Method B cleanup levels in samples of the soil remaining in place after the interim actions. It is expected that low concentrations of VOCs in soil beneath the former SMC facility were further reduced by the interim actions completed to date.

2.4.6.2 Soil Gas Investigations

Evaluation of the distribution of soil gas is based on soil gas sampling from probe borings and soil gas wells during the RI. TCE and other VOCs were expected to be present in soil gas as a result of volatilization of contaminants from groundwater. In general, VOC concentrations are higher in soil gas closer to the groundwater and decrease as soil gas moves upward through the vadose zone to the surface. Results of the soil gas investigations are included in the SMC RI report (Parametrix 2009b).

In the SMC area, the highest concentrations of TCE in soil gas were detected in soil gas well POV-SG-04, immediately adjacent to monitoring wells MW-7s and MW-7i. These monitoring wells typically had relatively high TCE concentrations in groundwater. Between

July 2005 and November 2006, TCE was detected at 10 feet bgs in soil gas well POV-SG-04 at concentrations between 16,000 micrograms per meter cubed (µg/m3) and 23,000 µg/m3. Concentrations of TCE were higher in the soil gas samples collected from 15 feet bgs (maximum concentration of 33,000 µg/m3) and 20 feet bgs (maximum concentration of 46,000 µg/m3). The vertical profile of TCE in soil gas in this area is consistent with a groundwater source (i.e., the highest soil gas concentrations are closest to groundwater). The distribution of impacted soil gas in the remaining wells is also consistent with a groundwater source.

Currently, there are no MTCA cleanup levels for soil gas. The primary consideration for evaluating soil gas is potential vapor intrusion to overlying structures or volatilization to outdoor air, both of which can create a complete exposure pathway. The results of the Port tenant property and SFVN soil gas investigations were used to select buildings and/or houses for indoor air sampling. In addition, an evaluation of the soil gas results and the relationship to potential indoor air conditions in overlying properties was completed in the CAMP (Parametrix 2009a).

VOCs were detected in soil gas near the SMC site, within the Port property, and across the SFVN. In general, the presence of VOCs in soil gas can be correlated with the occurrence of VOCs in groundwater. In most cases, concentrations of VOCs in soil gas increase with depth, which is expected due to volatilization of the groundwater source material into the overlying vadose zone. The concentrations of VOCs in soil gas have decreased significantly since initial soil gas wells were installed in 2004. Soil gas sampling has been discontinued as it was being used to supplement the vapor intrusion (indoor air) issue at the site, which has since been resolved (see Section 2.4.6.4). There are no Ecology cleanup levels associated with soil gas; thus, soil gas was not directly addressed as part of this FS. Final remedial actions implemented in the project area to address cleanup of groundwater will be sufficient to address any residual soil gas concerns.

2.4.6.3 Groundwater

Groundwater investigations have been conducted at the SMC site since 1998. The SMC groundwater monitoring well network is a component of the project area well network and currently consists of 69 monitoring locations: 65 shallow, intermediate, and deep USA monitoring wells; and 4 TGA monitoring wells. Specific monitoring wells associated with the SMC site have been sampled on a quarterly and/or semi-annual basis since mid-1998.

Analytical results for groundwater samples have been documented in various quarterly, semi-annual, and/or annual monitoring reports since 1999. The distribution of groundwater contaminants at SMC was described in detail in the SMC RI report (Parametrix 2009b). The 2013 distribution of groundwater contaminants in the project area is included on Figures 2-17 through 2-23. A brief summary of 2013 conditions is included below.

Shallow USA Zone

TCE, PCE, cis-1,2-DCE, 1,1,1-TCA, 1,1-DCA, 1,1-DCE, and 1,2-DCA were the most frequently detected VOCs in shallow SMC wells. Also consistent with historical analytical results, the highest concentrations of TCE (3,500 µg/L) and PCE (170 µg/L) during 2013 sampling events were detected in MW-05 (SMC source area shallow monitoring well) during the third quarter. TCE and PCE isoconcentration maps for shallow wells during the 2013 first quarter sampling event are included on Figures 2-17 and 2-18.

SMC shallow well TCE and PCE concentrations in 2013 were generally consistent with results from 2012. Overall, the data indicate a continued decrease in VOC concentrations in response to completed interim actions and the GPTIA. With the exception of wells located in the SMC source area, concentrations of TCE and PCE in shallow wells have been reduced to below 25 µg/L. Concentrations of TCE and PCE in shallow source area wells have also decreased significantly since startup of the GPTIA in June 2009.

As TCE is the dominant contaminant at the SMC site, trends and plume geometry are discussed in terms of the extent of this compound. In 2013, the shallow TCE plume (as defined by the 4 µg/L MTCA Method B cleanup level for TCE) associated with the SMC source extended in a generally east-southeast direction with its eastern boundary just beyond Kotobuki Way and its southern boundary extending south of NW 24th Street. The plume has continued to contract, with concentrations within the defined plume also having decreased (Figures 2-17 and 2-18).

Intermediate USA Zone

TCE, PCE, cis-1,2-DCE, 1,1,1-TCA, 1,1-DCA, and 1,1-DCE were the most frequently detected VOCs in intermediate USA SMC wells. The highest concentration of TCE in an intermediate zone SMC well during 2013 was detected in MW-37i. This well is located east of GWM. Historically, the highest concentrations of TCE were detected in samples collected from well MW-07i, located directly downgradient of the SMC source area. VOC concentrations detected in groundwater samples collected from MW-07i have decreased consistently since the start of the GPTIA.

TCE and PCE isoconcentration maps for intermediate wells during the 2013 first quarter sampling event are included on Figures 2-19 and 2-20. Overall, TCE and PCE concentrations detected in intermediate zone wells associated with the SMC site continued to decline. In 2013, the intermediate plume associated with the SMC source extended in a south-southeast direction with a southern extent just north of W 22nd Street. A remnant portion of the plume is still extant in the vicinity of GWM. The plume has continued to contract, with concentrations within the defined plume also having decreased.

Deep USA Zone

TCE, PCE, cis-1,2-DCE, 1,1,1-TCA, 1,1-DCA, and 1,1-DCE were the most frequently detected VOCs in deep USA SMC wells. TCE and PCE isoconcentration maps for deep wells during the 2013 first quarter sampling event are included on Figures 2-21 and 2-22. Concentrations of TCE and PCE detected in deep zone wells have decreased since startup of the GPTIA in 2009.

TGA

VOCs were not detected in SMC TGA wells (MW-02d, MW-13d, MW-16d, and MW-17d) during 2013. These results are consistent with past findings and are shown on Figure 2-23.

2.4.6.4 Indoor Air

Indoor air investigations associated with the SMC site have been limited in extent due to the results from investigations. Most of the indoor air investigations have focused on the NFVN, although limited sampling was conducted in the SFVN. Section 2.3.3.6 summarizes the results of the NFVN investigations.

Based on the data collected during the IAMP, as well as all data collected at the site since 2002, vapor intrusion in the NFVN or SFVN is not a current or future issue of concern. No further indoor air investigations will be conducted in the FVN. Ecology approved the results and recommendations of the IAMP in 2013.

Port Tenant Buildings

Two Port tenant buildings, 2400 and 2401, were selected for preliminary indoor air sampling. Buildings 2400 and 2401 contain large open area warehouse space with no closed office space in either building. Building 2400 was selected for indoor air sampling because it was near (less than 70 feet from) soil gas well POV-SG-04, which had soil gas concentrations of TCE detected at up to 23,000 µg/m3 in the 10-foot level. Building 2401 was selected to provide an additional sampling point and context for indoor air in the Port buildings.

PCE and TCE were detected in Building 2400 at maximum concentrations of 0.26 µg/m3 and 1.2 µg/m3, respectively. PCE and TCE were detected in Building 2401 at maximum concentrations of 0.13 µg/m3 and 0.07 µg/m3, respectively. Based on the sample results, significant concentrations of VOCs are not present in buildings 2400 and 2401. Indoor air in Port buildings was determined not to be of concern.

2.4.7 Quarterly Groundwater Monitoring

Groundwater monitoring has been conducted at the SMC site since approximately 1998. The results were summarized in Section 2.4.6.3. The 2013 distribution of TCE and PCE in groundwater in the project area is shown on Figures 2-17 through 2-23.

2.4.8 Interim Actions

Interim actions have been conducted at the SMC site to reduce or mitigate the presence of VOCs in particular media. The following provides a summary of the SMC interim actions.

2.4.8.1 Source Area Excavation

In 1998, soil interim actions were performed with oversight from Ecology and in accordance with MTCA’s Independent Remedial Action Program (IRAP) requirements. Soil cleanup activities included:

- Excavating and stockpiling TCE-impacted soil with concentrations greater than 500 µg/kg (MTCA Method A cleanup standard for TCE in soil at that time).
- Treating the stockpiled soil using enhanced soil vapor extraction until TCE concentrations in the soil were below the 500 µg/kg cleanup standard.

The Port conducted the first phase of the soil interim action, which included the excavation and stockpiling of soil with TCE concentrations greater than 500 µg/kg. The work was completed with oversight from Ecology’s IRAP program. Building 2220 was demolished in early February 1998 to facilitate removal of the TCE-impacted soil. Excavation and stockpiling of the TCE-impacted soil began in February 1998. During soil excavation, a concrete slab was discovered directly north of former Building 2220. With the exception of a small area of TCE-impacted soil that was discovered and excavated in April 1998, excavation of the TCE-impacted soil in the vicinity of Building 2220 was completed by March 1998.

Because of the hourglass shape of the soil impacted by TCE, clean overburden also had to be removed to excavate TCE-contaminated soil at 17 feet bgs. As it was excavated, the clean soil was separated from the TCE-impacted soil and stockpiled as “clean” soil. Approximately 13,800 cubic yards of TCE-impacted soil were excavated and stockpiled on the SMC site. Also excavated were approximately 6,300 cubic yards of clean overburden; 4,100 cubic yards of this soil and 2,200 cubic yards of dredge sands were placed as backfill in the excavation. The remaining 2,200-cubic-yard stockpile of clean overburden soil was used as fill material at other Port locations.

Sampling was conducted during the course of the interim removal actions to evaluate the effectiveness of the soil excavation. Where verification sampling indicated TCE in soil at concentrations greater than 500 µg/kg, additional soil removal was conducted and the area re-sampled. Twelve verification soil samples were collected from the two remedial excavations (under the northeast section of the SMC slab) in the vicinity of four test pits that contained soil with TCE exceeding 500 µg/kg. VOCs were not detected in any of the verification samples.

With the exception of a small area located to the south of the remedial excavation, all soil in the vadose zone that contained TCE at concentrations greater than 500 µg/kg was excavated and stockpiled for treatment.

The Port selected enhanced soil vapor extraction as the most cost-effective technology to treat the stockpiled TCE-impacted soil. Philip Services Corporation was contracted by the Port to complete the soil treatment. Three treatment cells were constructed by trenching into the stockpiled soils with a trackhoe to lay the piping system. The cells were treated one at a time, with a new cell constructed upon the successful treatment of the previous cell.

The piping consisted of a series of air inlets (perforated PVC pipes) that were placed in the stockpiled soil to allow air into the soil. As needed, air was forced into the soil stockpile using these air inlets. A series of air extraction wells, also consisting of perforated PVC pipe, were also constructed to vent soil pore gases. The combined inlets and extraction wells allowed an average of approximately 362 to 377 cubic feet per minute of soil vapor to move along the induced flow path to the treatment system. The soil vapors removed from the treatment cells passed through a vapor/water separator prior to being treated using a 1,000-pound granular activated carbon unit. Captured TCE and other VOCs were destroyed during carbon regeneration. Influent and effluent air monitoring was conducted in order to evaluate the effectiveness of the treatment system.

Cell treatment was initiated in March 1999. TCE and PCE were not detected in the effluent samples taken from each cell after treatment. Soil samples collected from each of the subcells within each treatment cell were analyzed for TCE and PCE. Based on the analytical results, Ecology issued letters allowing re-use of the treated soil from each cell as fill on Port property. The treated soil from Cell 1, Cell 2, and Cell 3 was used as fill material at Parcel 1A, located at Terminal 4, or under bridge abutments for a new Port entrance overpass.

2.4.8.2 Groundwater Source Area Interim Action

A groundwater source area treatment program was initiated at the SMC site in January 2002. The treatment program consisted of introducing Fenton's Reagent below the water table using a combination of injection wells and temporary direct-push injection points. Seven treatment events were conducted between January 2002 and October 2004. Details of the various injection and monitoring events are included in the SMC RI report.

The remedial action objective (RAO) for the groundwater interim action was to destroy, to the extent possible, residual TCE from the groundwater source area. Thus, dissolved TCE concentrations less than 10,000 µg/L were deemed indicative of successful treatment and achievement of the RAO. The RAO was achieved at 28 of 30 wells monitoring groundwater quality in the treatment area, with the exception of the area defined by DSI-6-40 and VMW-9.

Groundwater samples collected after each treatment event consistently detected TCE at concentrations above 10,000 µg/L in VMW-9. As a result, soil conditions in the source area were evaluated to identify the source of the residual TCE. The suspected source of the residual TCE was a fine-grained soil layer that had been previously identified in the vicinity of VMW-9. The investigation focused on defining the extent of the fine-grained layer and evaluating residual TCE concentrations in the layer.

TCE data from the fine-grained layer also showed that, in general, the highest concentrations of TCE in soil corresponded to the locations of the highest groundwater TCE concentrations (wells DSI-6-40, VMW-9, and VMW-2).

2.4.8.3 Groundwater Pump and Treat System

The GPTIA was constructed by the Port in 2008 and 2009 and started up in June 2009. The objectives of the GPTIA are to provide hydraulic containment of the dissolved-phase plume and to remove VOCs in groundwater. Specific design details are included in the Engineering Design Report (Parametrix 2008b), and complete specifications and drawings are included in the As-Built Report for Groundwater Pump and Treat Interim Action SMC/Cadet Commingled Plume (Parametrix 2009c).

The interim action involves pumping groundwater from below the former SMC site and treating the groundwater through an air stripping process. Specifically, a groundwater extraction well is used to recover TCE-impacted water from the aquifer, and a forced pipeline transports the water to the treatment system. The air strippers remove the TCE and other VOCs from the water and transfer them to an air stream for discharge to the atmosphere under a Southwest Clean Air Agency permit. The treated water is then discharged to the Columbia River via an existing stormwater outfall under a National Discharge Elimination System (NPDES) Permit.

Extraction Well

The interim action includes one groundwater extraction well (labeled EW-1) located on the former SMC site. EW-1 was drilled in this location for two reasons: (1) this location included the highest concentrations of VOCs associated with the SMC site; and (2) groundwater modeling indicated pumping at this location would capture the dissolved-phase plume in the overall project area.

Well construction consists of a 26-inch-diameter casing with grout seal to approximately 40 feet bgs, a 22-inch-diameter screen from 40 to 104 feet bgs, and a 22-inch-diameter casing from 104 to 120 feet bgs as a pump chamber sump. Flow rates from the well are variable and controlled by a programmable logic controller located at the treatment plant. A flow meter was installed on the discharge line from the well to monitor and record flow continuously. The average flow rate from the well since startup is approximately 2,500 gpm.

The well head and associated piping are located in the well house at the former SMC site. All piping and electrical conduits run underground from the well house to the treatment plant. Flow from the well is measured and monitored with an electronic flow meter installed on the discharge piping leading from the well to the treatment plant. The flow rate is monitored and controlled locally by the treatment plant operator from a control screen located in the control room next to the treatment plant.

Treatment System

The treatment system includes pretreatment of the water to remove iron and manganese via manganese dioxide filters. The manganese dioxide filter media operates both as a classical filter working with an oxidant and as a catalytic media due to its ability to accelerate the reaction between the oxidizing agent and with the iron and manganese present (Layne 2007).

Two air strippers operate in parallel to treat the maximum flow and TCE concentration. Each air stripper is approximately 10 feet in diameter with a packing height of 40 feet. Each air stripper is equipped with a 60-horsepower blower connected to a variable frequency device. The blowers and treatment system controls are enclosed in a concrete block building for noise control and ease of maintenance. The off-gases from each air stripper are discharged to the atmosphere via a 2-foot-diameter stack.

The treatment system design was based on removing TCE from a maximum concentration of 200 µg/L down to the analytical reporting limit of 0.5 µg/L. The highest TCE concentration observed since startup is 52 µg/L, while the highest PCE concentration observed since startup was 21 µg/L. The treatment system continues to sufficiently remove VOCs down to the analytical reporting limit of 0.5 µg/L.

Treatment Plant Discharge

The treated water is conveyed by gravity through the discharge line. The discharge line connects to the City-owned portion of a 36-inch stormwater line that runs beneath the Port/BNSF railroad tracks for approximately 333 linear feet. The flow then travels by gravity through the existing 36-inch storm line that runs beneath the rail spur and the Port Terminal 2 area. The 36-inch storm line discharges though an existing bank outfall beneath the Terminal 2 dock. The existing outfall is located beneath the Terminal 2 dock on the south side of the Port near Building 500. The effluent is monitored per requirements of the NPDES permit issued by Ecology.

Performance

The performance of the GPTIA has been significant with respect to the total mass of VOCs removed from the groundwater. Since startup in June 2009, the GPTIA has extracted and treated over 5 billion gallons of groundwater and removed approximately 840 pounds of VOCs (as of June 2013).

The overall size of the shallow and intermediate contaminant plume has been reduced significantly as well as the concentrations in individual wells. Figure 2-24 shows the shallow dissolved-phase plume in 2009 prior to GPTIA startup and in March 2013. Figure 2-25 shows the intermediate dissolved-phase plume in 2009 prior to GPTIA startup and in March 2013. Figure 2-26 shows the deep USA zone in 2009 and in March 2013.

2.4.9 Summary of Risk Assessment

This section presents a summary of the human health risk assessment presented in the SMC RI report. The risk assessment primarily focused on the potential risk to applicable receptors from groundwater exposure and associated pathways. The potential human health risks from the release of TCE at the SMC site were examined by evaluating soil, soil gas, indoor air, and groundwater data collected within the project area. Exposure to VOCs was estimated for workers and residents within the project area for the following pathways:

- Inhalation exposure to indoor air from soil gas or groundwater
- Inhalation exposure to outdoor air originating from soil gas or groundwater
- Ingestion or skin contact with groundwater used for potable purposes
- Skin (dermal) contact with or incidental ingestion of groundwater from (occasional) digging or trenching activities

The risk assessment was completed in 2008, prior to installation and operation of some of the interim actions discussed in previous sections, including the Port's GPTIA. Use of data collected prior to the interim actions overstates the potential risk associated with remaining contamination. Therefore, where applicable, the discussions below include additional information as necessary where it impacts the FS evaluation and/or potential remedial actions.

2.4.9.1 Land and Beneficial Water Use

Land use and beneficial water use were evaluated to support the risk assessment completed for the site, primarily to establish the applicable potential exposure pathways.

It is assumed that the Port will retain ownership of the SMC site and other properties it currently owns in the project area. It is also assumed that future use of the project area will remain as zoned (i.e., Heavy and Light Industrial at the Port and Light Manufacturing north of Fourth Plain Boulevard). In addition, Single Family Residential zoning is assumed to continue in the areas north and east of Fourth Plain Boulevard.

A beneficial water use survey was conducted to evaluate the use of water in the project area. The following conclusions are based on the information available during the RI regarding the beneficial use of groundwater and surface water in the study area. The current and potential future beneficial uses of groundwater in the project area include:

- Drinking water
- Irrigation
- Industrial

Groundwater on the SMC property is not currently used as a potable water source. However, the intermediate groundwater zone in the vicinity of the project area is used as a productive aquifer for municipal and industrial water supplies, including by the City of Vancouver, GWM, the Port, and CPU. In general, shallow groundwater is not a source of current potable water but does have limited potential for potable water extraction. In addition, the aquifer in the project area is designated as a sole-source aquifer (which includes all zones). There is no confining layer that distinctly separates the shallow and intermediate zones. Therefore, all groundwater in the project area is considered to have a beneficial use in the form of a potential drinking water source and/or connection to a drinking water source.

2.4.9.2 Chemicals of Potential Concern

COPCs were evaluated based on potential exposure routes and analytical data in various media at the SMC site. The selection of indicator hazardous substances (i.e., COPCs) was conducted in accordance with WAC 173-340-703. VOCs further evaluated in the risk assessment were determined based upon: (1) the frequency of detection; (2) the potential for adversely affecting human health; (3) the chemical and physical characteristics of the contaminants; and (4) the identification of potential degradation by-products of TCE (e.g., 1,1-DCA, 1,2-DCE, cis-1,2-DCE).

Groundwater: Analysis of chemical concentrations from all groundwater zones indicated that the following chemicals were detected above a FOD of 5 percent and/or at least one sample exceeded the MTCA Method B cleanup standards for groundwater: 1,1-DCE, 1,2-DCA, bromodichloromethane, carbon tetrachloride, cis-1,2-DCE, dibromochloromethane, methylene chloride, PCE, and TCE. These chemicals were carried forward through the risk assessment for groundwater. In addition, 1,1-DCA was assessed in the risk assessment since this chemical is a known TCE degradation by-product (EPA, 2001).

Soil: Soil samples collected in 1998 from probe borings and verification samples during excavation activities represent residual contaminant concentrations after removal of TCE contaminated soil. Only three VOCs (methylene chloride, PCE, and TCE) were ever detected in verification soil samples. These chemicals were further evaluated in the risk assessment for soil contact pathways for site workers and for the terrestrial ecological evaluation.

Indoor Air: The following chemicals were either detected at or above a FOD of 5 percent, exceeded the MTCA B cleanup level, or are known TCE degradation by-products and were further evaluated in the risk assessment: 1,1,1-trichloroethane, 1,1-DCA, 1,1-DCE, 1,1-DCE, chloroethane, cis-1,2-DCE, PCE, trans-1,2-DCE, and TCE.

Outdoor Air: The following chemicals were either detected at or above a FOD of 5 percent, exceeded the MTCA B cleanup level, or are known TCE degradation by-products and were further evaluated in the risk assessment: 1,1,1-trichloroethane, 1,1-DCA, 1,1-DCE, 1,1-DCA, chloroethane, cis-1,2-DCE, PCE, trans-1,2-DCE, and TCE.

2.4.9.3 Summary of Chemical Fate and Extent

The extent of soil and groundwater contamination at the SMC site was summarized in Section 2.4.6. Figures 2-17 through 2-23 show the extent of groundwater contamination at the site as of 2013.

2.4.9.4 Human Health Risk Assessment

An exposure assessment is conducted to estimate the magnitude, frequency, duration, and route of exposure of a receptor to a contaminant source. Information about waste sources, exposure pathways, and receptors at the SMC site were used to develop a conceptual understanding in order to evaluate potential risks to human health.

Receptors are defined as persons who may come into contact with site chemicals. Receptors in this analysis are individuals who work or live within the project area. “Workers” include individuals who work regularly at Port-owned or non-owned property downgradient of the SMC site. Temporary workers were also evaluated, such as excavation workers on Port property. Residents include people who live east of the SMC site in the SFVN where impacted groundwater has migrated.

The human health risk assessment consists of an analysis of multiple locations, exposure pathways, and receptors. Since multiple locations and groundwater wells were assessed (representing variable exposure rates), a range of risk estimates was prepared. In addition, cumulative risks from all pathways were evaluated. According to MTCA, non-cancer risks should not exceed a hazard quotient of 1 for individual chemicals or a hazard index of 1 for multiple chemicals (i.e., the sum of the hazard quotient values). Cancer risks should not exceed $1x10^{-6}$ (i.e., one additional chance of contracting cancer per one million) for exposure to individual chemicals or $1x10^{-5}$ (one per one hundred thousand) for exposure to multiple chemicals. Conclusions for each type of receptor evaluated in the risk assessment are discussed below.

Source Area Workers: Exposure and risk estimates for source area workers suggested that VOC contaminants in indoor air (Port buildings) posed a slightly elevated risk if workers are chronically exposed (maximum ELCR $2x10^{-6}$). However, since the time of the indoor air risk assessment, EPA has changed the toxicity factor that must be used to calculate risk for TCE and PCE. Because of EPA’s change (and subsequently Ecology-adopted values), the potential risk is substantially lower than originally calculated. Further evaluation conducted subsequent to the RI and CAMP indicates that no potential risk is present to current workers. The indoor air issue has been completely addressed and Ecology has indicated that no further investigation or remedial actions are required (Ecology 2013).

Exposure and risk estimates for source area workers suggest that VOC contaminants in groundwater pose a potential risk if workers are chronically exposed (maximum ELCR $1x10^{-2}$).

Project Area Worker: Outdoor air VOC concentrations do not pose an elevated risk to project area workers at current concentrations. Exposure and risk estimates for project area workers suggest that VOC contaminants in groundwater pose a potential risk if workers are chronically exposed (maximum ELCR $2x10^{-3}$).

On-SMC Site Port Excavation Worker: Outdoor air and soil concentrations pose minimal risk to Port excavation workers at current concentrations. Exposure and risk estimates for on-site excavation workers suggest that VOC contaminants in groundwater pose a potential risk if workers are chronically exposed (maximum ELCR $3x10^{-4}$).

Off-Site Residents: Exposure and risk estimates for SFVN residents suggested that VOC contaminants in indoor air pose a potential risk if residents are chronically exposed (ELCRs ranging from $2x10^{-6}$ to $8x10^{-5}$). However, since the time of the indoor air risk assessment, EPA has changed the toxicity factor that must be used to calculate risk for TCE and PCE. Because of EPA's change (and subsequently Ecology-adopted values), the potential risk is substantially lower than originally calculated. Further evaluation conducted subsequent to the RI and CAMP indicates that no potential risk is present to current residents. The indoor air issue has been completely addressed and Ecology has indicated that no further investigation or remedial actions are required (Ecology 2013).

Exposure and risk estimates for SFVN residents suggest that VOC contaminants in groundwater pose a potential risk if residents are chronically exposed.

2.4.9.5 Ecological Risk Assessment

As required under MTCA (WAC 173-340-7490), a terrestrial ecological evaluation must be considered to:

- Determine whether a release of hazardous substances to soil may pose a threat to the terrestrial environment;
- Characterize existing or potential threats to terrestrial plants or animals exposed to hazardous substances in soil; and
- Establish site-specific cleanup standards for the protection of terrestrial plants and animals.

Exposure pathways to sediments, surface water, or wetlands are not considered complete for the SMC site. Therefore, the terrestrial ecological evaluation did not include an evaluation of potential threats to ecological receptors in these media or habitat areas. Since the residual contaminated soil is located on an area designated for industrial or commercial use only, the evaluation focused only on exposure to soil contamination for terrestrial wildlife protection (per WAC 173-340-7490-03b).

A simplified terrestrial ecological evaluation was conducted for the SMC site in accordance with WAC 173-340-7492. The soil contamination on the SMC site is generally limited to a confined area (and at depth), thus there does not appear to be a substantial potential for posing a threat of significant adverse effects to terrestrial ecological receptors. The terrestrial wildlife evaluation consisted of calculating ecological indicator soil concentrations for the chemicals of concern at the SMC site. The methods for obtaining information and calculating ecological soil concentrations followed methodologies developed in MTCA. A comparison of the ecological indicator soil concentrations to the reasonable maximum soil concentrations at the SMC site indicates that no chemical exceeded its respective indicator soil concentration. Thus, contaminant concentrations in subsurface soil at the SMC site do not pose a significant threat to terrestrial ecological receptors. Therefore, based on the size of the contaminated area, the land use at the site, and the relatively low contaminant concentrations (compared to ecological indicator soil concentrations), the SMC site was excluded from further ecological assessment per WAC 173-340-7492.

2.4.9.6 Risk Assessment Conclusions/Chemicals of Concern

The risk assessment was conducted in accordance with MTCA guidance. Potential risks to human health from exposure to contaminants in groundwater, soil, indoor air, and outdoor air were examined. Based on the results of the risk assessment, Parametrix reached the following conclusions for each medium at the SMC site.

1. **Groundwater:** The potential risk associated with groundwater was evaluated for source area and project area workers, an excavation worker, and an SFVN resident. While previous remedial actions have significantly reduced groundwater concentrations, current concentrations are still at a level that suggests potential elevated risks to human health for all receptors and exposure pathways evaluated. Additional remedial actions are necessary to reduce groundwater concentrations to levels that are protective of potential future receptors. Chemicals of concern include TCE, PCE, and 1,1-DCA. Drinking water for the SFVN is currently supplied by the City of Vancouver.
2. **Soil**: The potential risk associated with soil was evaluated for a source area worker and excavation worker. Based on the human health risk assessment, the current risk associated with COPCs in soil in the source area is within the acceptable risk range. Further remediation of soil is not warranted based on the potential receptor scenarios evaluated.
3. **Indoor Air**: The potential risk associated with indoor air was evaluated for the source area workers and SFVN residents. Measured concentrations of VOCs at SFVN residences indicated potentially elevated cancer risks (i.e., above $1x10^{-6}$) from chronic exposure to indoor air (ELCRs ranging from $2x10^{-6}$ to $8x10^{-5}$). However, since the time of the indoor air risk assessment, EPA has changed the toxicity factor that must be used to calculate risk for TCE and PCE. Because of EPA's change (and subsequently Ecology-adopted values), the potential risk is substantially lower than originally calculated. Further evaluation conducted subsequent to the RI and CAMP indicates that no potential risk is present to current residents. The indoor air issue has been completely addressed and Ecology has indicated that no further investigation or remedial actions are required (Ecology 2013).
4. **Outdoor Air**: The risk from outdoor air was evaluated for a source area worker and an SFVN resident (child and adult). Based on the human health risk assessment, the current risk associated with COPCs in outdoor air is within the acceptable risk range.

2.5 SITE

This section defines the Site and describes the extent of the dissolved-phase groundwater plume.

2.5.1 Definition of the Site

As described in Section 1.1, due to the presence of three source areas and the recent effort to complete this combined FS, the definition for what constitutes the Site was completed and includes the dissolved-phase groundwater plume.

Historically, the Site has been much larger than current conditions would suggest. The dissolved-phase groundwater plume has been reduced significantly, both in terms of concentration and aerial footprint. This is primarily due to the various interim actions conducted at the NuStar, Cadet, and SMC source areas. In addition, the GPTIA (located at the SMC source area) has been very successful at treating the project area dissolved-phase groundwater plume (see Figures 2-24 through 2-26). Current conditions of the Site are described below.

2.5.2 Current Groundwater Conditions at the Site

In general, the description of the current distribution of VOCs at the Site is based on groundwater samples collected from monitoring wells during the first quarter 2013 monitoring event. The first quarter event represents a comprehensive event when all active SMC, Cadet, and NuStar site monitoring wells are sampled during the same period. Consequently, results associated with the first quarter 2013 event provide the most recent comprehensive dataset regarding VOC groundwater concentrations at the Site.

The examination of the distribution of VOCs in groundwater is based on the presence of TCE and PCE. These two compounds have the highest frequency of detection, are the primary contaminants released at the known source areas, are the focus of cleanup actions, and are the primary contaminants of concern in groundwater at the Site (i.e., indicator hazardous substances).

Figures 2-17 through 2-23 present isoconcentration maps for TCE and PCE in the three (shallow, intermediate, and deep) USA water quality zones described in Section 2.1. These isoconcentration maps are based on first quarter 2013 sample results. The lowest isoconcentration shown for TCE is 4 µg/L, which is based on its MTCA Method B cleanup level (see Section 5.0). Similarly, the lowest isoconcentration shown for PCE is 5 µg/L which is based on its MTCA Method B cleanup level (see Section 5.0). Higher isoconcentrations are used if concentrations at those levels are present. Isoconcentration maps have not been developed for the TGA due to detections occurring in only one TGA monitoring well (see Figure 2-23).

More recent interim corrective actions have further reduced TCE and PCE concentrations as depicted in the first quarter 2013 isoconcentration maps. Interim actions completed on the NuStar source area have notably reduced shallow and intermediate zone TCE and PCE concentrations. Operation of the GPTIA located at the SMC source area has notably reduced TCE and PCE concentrations in the intermediate zone. Interim actions completed at the Cadet site have resulted in substantially reduced concentrations associated with that source area.

The distribution of VOCs in groundwater in the three USA water quality zones and the TGA based on first quarter 2013 results are described in the following sections. Concentrations and distribution areas continue to reduce in response to current interim actions.

2.5.2.1 Shallow USA Zone

The distribution of contaminants in shallow groundwater at the Site was previously described in the NuStar, Cadet, and SMC background sections. Figures 2-17 and 2-18 show the current distribution of TCE and PCE in the shallow USA zone at the Site. For completeness, a brief overview of the current conditions in the shallow USA zone is provided below.

In the Cadet site area, which includes the area north of Fourth Plain Boulevard and Lower River Road, the distribution of TCE above 4 µg/L is limited to five wells located near the south side of the Cadet Manufacturing building. There is also an area approximately 600 feet to the east where TCE is detected in three wells above 4 µg/L. The distribution of PCE is similar, but is observed at lower concentrations. The area where PCE is above 5 µg/L is limited to well CM-MW-01d-040, located adjacent to the southeast side of the Cadet Manufacturing building. The PCE concentration in this well is 6.4 µg/L. PCE concentrations are also present in the three wells east of the Cadet Manufacturing building, but at concentrations below 5 µg/L.

In the SMC site area, which includes the area just north of Fourth Plain Boulevard and east of Mill Plain Boulevard, the concentration of TCE is highest at well MW-05 and adjacent wells VMW-08 and VMW-09. TCE is not detected west or south of the SMC source area. A TCE plume from the SMC source area extends to the east. TCE concentrations above 20 µg/L are not detected east of Mill Plain Boulevard. Concentrations above 4 µg/L are detected in 4 wells located between Mill Plain Boulevard and Thompson Avenue. Concentrations detected in the wells decline in the eastern direction. Similar to conditions observed at the Cadet site, the distribution of PCE is also more limited and detected at lower concentrations at the SMC site. The highest concentration of PCE is also detected at MW-05 and adjacent wells VMW-08 and VMW-09. PCE concentrations above 5 µg/L are limited to and not detected beyond the SMC source area. Similar to the observed TCE distribution, PCE is also detected in the wells located east of the SMC site area.

In the NuStar site area, which includes the area between the Columbia River and NW Harborside Drive, the highest concentrations of TCE are detected in wells located between the river and Warehouses No. 13 and 15. An area where TCE concentrations are less than 4 µg/L is present northeast of Warehouse No. 13 in response to recent and ongoing soil and groundwater interim actions. TCE concentrations above 50 µg/L are detected in wells located east and west of the concentration low area. The distribution of PCE at the NuStar site is similar to TCE, but is generally observed at higher concentrations. Higher concentrations of PCE are detected in wells east of the concentration low area while higher concentrations of TCE are detected in the areas north and west of the concentration low area.

2.5.2.2 Intermediate USA Zone

The intermediate (and deep) USA zone is the focus of the evaluation of remedial alternatives for the Site. Figures 2-19 and 2-20 show the current distribution of TCE and PCE in the intermediate USA zone in the project area.

The highest concentrations of TCE in the intermediate USA zone are detected in well MW-05i at the SMC site and well MW-37i located in the southeast corner of the Site east of Northwest Packing. TCE concentrations at these two wells are both above 25 µg/L; 27 µg/L in MW-05i and 42 µg/L in MW-37i. The highest concentrations of PCE in the intermediate zone are detected in two NuStar site wells (MGMS1-60 and MGMS2-60) and well MW-32i located just north of NuStar.

TCE and PCE concentrations are lower and more dispersed in the intermediate zone than observed in the shallow zone. Since operation of the GPTIA at the SMC site, the presence of TCE and PCE in the intermediate zone has decreased in terms of concentrations detected and size of the dissolved plume. Figure 2-20 shows four areas where TCE concentrations remain above 4 µg/L.

The distribution of TCE versus PCE in the intermediate zone is slightly different. The area where TCE concentrations are higher than 4 µg/L is approximately twice as large as the area where PCE concentrations are higher than 5 µg/L. There are also more locations where TCE is detected above 10 µg/L than for PCE. As indicated on the PCE intermediate zone map (Figure 2-20), PCE above 5 µg/L is detected in the area west and northeast of the SMC site, with a small area extending up to the east side of the Cadet Manufacturing building. PCE above 5 µg/L is also detected in the mid-section of the NuStar site. TCE above 4 µg/L is detected at the SMC site and in the area to the north with a small area extending to the east side of the Cadet Manufacturing building. There is a remnant area located to the north of the Cadet Manufacturing building. A similar distribution is present at the NuStar site where TCE above 4 µg/L is detected in the mid-section of the site. A second remnant area is located in the southeast site area where Northwest Packing is located, to the north of GWM.

2.5.2.3 Deep USA Zone

Figures 2-21 and 2-22 show the current distribution of TCE and PCE in the deep USA zone. The highest concentrations of TCE in the deep USA zone are detected at CM-MW-05d (36 µg/L) and MW-01d (28 µg/L). The two wells are located in the area west of the SMC site and east of the Cadet Manufacturing building. All other deep well TCE concentrations are below 25 µg/L. The highest concentration of PCE in the deep zone is detected in well MGMS2-132 (19 µg/L) located at the NuStar site. All other detected PCE concentrations are less than 10 µg/L.

PCE concentrations are lower and less dispersed than TCE in the deep zone. TCE is detected above 4 µg/L in 16 wells compared with PCE above 5 µg/L in 5 wells. The distribution of TCE detected in the USA deep zone is in part controlled by the extent or presence of the deep USA zone. The USA deep water quality zone represents the area that is less than 100 feet msl and above the Troutdale formation. Elevation of the top of the Troutdale formation varies across the site. In general, the deep USA zone is not present east of the SMC and NuStar sites and generally east of Fruit Valley Road. The deep USA zone is also not present in the area just north of the NuStar site.

2.5.2.4 TGA

VOCs are typically not detected in the nine TGA wells associated with the SMC, Cadet, and NuStar sites. Consequently, the TGA is not considered impacted by the three source areas at any significant level and remedial actions specifically for the TGA are not being considered as part of this FS.

Very low concentrations of TCE and PCE are detected in Cadet site TGA well CM-MW-29TGA. During the first quarter 2013 event TCE and PCE were detected at 13 µg/L and 8.2 µg/L in well CM-MW-29TGA, respectively. Concentrations of TCE and PCE detected in CM-MW-29TGA have decreased since start-up of the GPTIA in 2009 (Figure 2-23).

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3. GROUNDWATER MODEL

This section presents an overview of the groundwater flow and transport model and its use in the FS to evaluate cleanup alternatives. Detailed discussion of model design, calibration, and verification is presented in the Vancouver Lake Lowlands Groundwater Model Summary Report (Parametrix 2008a). Discussions of previous model simulations are presented in the SMC (Parametrix 2009b) and Cadet RI Reports (Parametrix 2010a). Earlier model development, evaluation, and use to simulate historical plume development are presented in the Groundwater Model Summary Report (Parametrix 2004). More detailed discussion of FS simulations and evaluation is presented in Appendix B of this report.

3.1 BACKGROUND

The Port developed a three-dimensional, finite difference groundwater flow and contaminant transport model for the SMC site as part of the RI. Development of a groundwater model was proposed in the Swan Phase II Interim Data Report (Parametrix 2001) to describe groundwater flow conditions and the fate and transport processes at the SMC site. Activities at that point of the RI had found that characterization of groundwater flow beneath the SMC site was complicated by the influence of river stage elevations, tidal fluctuations, and water supply well pumping and concluded that water level contour maps based on manual water level measurements represented over-generalizations of actual groundwater flow conditions. The combination of small-scale and local variations in groundwater flow direction, associated with local recharge characteristics, along with very low horizontal gradients, resulted in complicated water level interpretations. The distribution of the contaminant plume suggested that the flow of groundwater was heavily influenced by production well pumping. Thus, a groundwater flow model was developed to help with interpretation of groundwater flow in the project area.

Refinement, evaluation, and confirmation of the model was completed over time and facilitated through ongoing collection of hydrogeologic data in the project and active model areas during the course of the RI effort. In 2006, the Port and CPU agreed to conduct further model calibration and validation to confirm that the model is an appropriate tool to evaluate remedial alternatives for the dispersed plume originating from the Swan, Cadet, and NuStar sites and to evaluate those alternatives with respect to proposed water supply development in the Columbia River Lowlands. CPU had developed a similar flow model to assist in their evaluation of potential water supply wellfield sites in the Vancouver Lake lowlands area. The result of the joint Port and CPU modeling effort completed in 2008 was the Vancouver Lake Lowland (VLL) groundwater flow model (Parametrix 2008a). This effort resulted in Ecology’s approval to implement the 2008 VLL groundwater flow model for the SMC and Cadet cleanup site (Ecology 2008).

Hydrogeologic-related modifications to the model in the NuStar site area were made in 2011 to reflect understanding of the site’s historical river channel setting. This modification was used in modeling associated with evaluation of the Port’s groundwater pump and treat system (Parametrix 2011). Other than modification of the NuStar site area to capture the site’s historical river channel setting, no additional modifications were made to the VLL groundwater flow model.

3.2 MODEL DESCRIPTION

The model consists of a groundwater flow model and a contaminant transport model. The flow model uses the USGS three-dimensional, finite difference MODFLOW code (McDonald and Harbaugh 1988). The contaminant transport model uses the three-dimensional MT3D-99 code (Papadopulos 1999) that utilizes flow model results. MODFLOW and MT3D are widely used codes for groundwater modeling and are essentially the industry standard for simulation of groundwater flow and contaminant transport in groundwater.

The model computes groundwater flow and contaminant transport over an area defined by the model grid. The VLL model area covers the entire Columbia River Lowlands from McLoughlin on the east to the mouth of Salmon Creek on the west. From north to south, the model extends from the south shore of the Columbia River to the top of the bluffs north of Burnt Bridge Creek. This area is needed to reach the physical boundary conditions of the USA in the project area rather than applying artificial boundary conditions. The entire model grid covers 74 square miles. The active flow model area covers 41 square miles, and the active transport model area covers 25 square miles. The transport model can be smaller than the flow model area to save computation time, as long as the active transport model area includes the contaminant plumes.

To represent the groundwater system in the VLL, the model utilizes a finite difference grid consisting of 16 layers extending from the water table to the base of the TGA. The model area is broken down into cells using a non-uniform grid that is oriented with a principal axis parallel to the Columbia River to minimize the number of inactive cells in the model structure. Non-uniform grid spacing was used to allow a large number of cells in the area of the three known source areas (Swan, Cadet, and NuStar), where groundwater flow and contaminant transport are of interest. In the vicinity of the known source areas, a grid spacing of 50 feet was selected. This area is referred to as the detailed model area.

The hydrogeologic units within the model area are represented by layers within the numerical model. The model includes silty recent alluvium, sandy recent alluvium, the USA, and the TGA. The bottom of the model is Confining Unit 1, so the model includes the entire thickness of the Upper Sedimentary Subsystem (see Section 2.1). The top of the TGA was used as the primary reference for building the model layers by initially setting the top of model layer 10 as top of the TGA. This provides nine model layers to define the thickness of the USA. The model layering was then modified to account for locations where the TGA, USA, and alluvial sand are at the water table by having parts of layers 1 through 9 assigned to deeper units. For instance, the TGA is generally a deep unit in the model area. However, the top of the TGA rises to the northeast and is found at the water table (model layer 1) along some parts of the northern model boundary. This layering approach improves the model's stability.

Flow model boundary conditions for the model were selected to coincide with physical (hydrologic) boundaries of the groundwater flow system wherever possible. The following boundary conditions were assigned to the regional model area:

- Specified head
- Drain
- No flow
- Specified flux

Specified head boundaries are appropriate when head in the boundary water body will not be affected by changes in head and flow in the aquifer. Specified head boundary cells were assigned to Vancouver Lake, the Columbia River, and the upgradient (northeast) portion of Burnt Bridge Creek. Drain boundary conditions were assigned to simulate groundwater discharge to Burnt Bridge Creek along the northern boundary. No flow boundaries were assumed on the south, west, east and northwest model boundaries in layers that are not intersected by the Columbia River. The south and west no flow boundary assumes that no flow occurs under the Columbia River from Oregon. The bottom of the model was assigned no flow conditions based on the assumption that there is no significant flow between the TGA and the underlying Troutdale Sandstone aquifer (TSA) or deeper Sand and Gravel aquifer (SGA) due to the presence of Confining Units 1 and 2. Specified flux boundaries were used to simulate recharge and discharge from the groundwater system that are not a function of head. Both recharge and pumping wells were simulated as specified flux boundaries.

Transport model boundary conditions consist of zero mass flux and concentration boundaries. Zero mass flux boundaries were defined along the edge of the active transport model area. Concentration cells were used to define the current dissolved plume based on recent isoconcentration maps and to represent the SMC, Cadet, and NuStar source areas. All three source areas are assumed to be a non-constant depleting source. Fate and transport of contaminants is primarily a function of dispersion through advection caused by groundwater flow. Degradation is not assumed for the source areas. Discussion of significant model parameters and inputs are included in Appendix B.

3.3 FS MODEL APPLICATION

The model was used to assess corrective action strategies for the Site. Objectives of this modeling effort were to assess cleanup timeframes, identify the impact on potential receptors, evaluate the feasibility of monitored natural attenuation, assess the need for further remedial actions at source areas, and evaluate the impact of EW-1 (SMC extraction well) operation timeframe on plume configuration.

The first step to address these questions was to develop future pumping rate projections for the major users of groundwater in the model area. Twenty-five-year pump rate projections (representing years 2012 to 2037) were developed for the three COV water stations (WS-1, WS-3, and WS-4), pumping in the USA at the CPU Southlake Wellfield, and at the GWM and Portwellfield. Future pumping projections were developed through discussion with COV, CPU, GWM, and Port with the objective of establishing projections based on best understanding of probable future water demands while maintaining generally conservative assumptions (i.e., higher usage rate projections). Future usage at the wellfields in the model area is dependent on a number of factors including anticipated area and regional growth, economic conditions, and long-term effectiveness of conservation measures.

A primary component of the modeling to support the FS was to evaluate the effects and timeframe for when EW-1 could be turned off. To evaluate this question, the 25-year pumping projections were used along with EW-1 pumping at current rate of 2,500 gpm through several scenarios:

- EW-1 shut down (e..g, model assumes no pumping at EW-1 starting in January 2014)
- EW-1 Operating for 5 years (January 2014 to January 2019)
- EW-1 Operating for 10 years (January 2014 to January 2024)

Using the flow model results, the contaminant transport model was then used to evaluate fate and transport. PCE and TCE concentrations based on first quarter 2013 data were used as the source to establish existing contaminant distribution. Conservative estimates associated with the SMC, Cadet, and NuStar source areas were used to develop an understanding of source area concentration declines over time and their fate and transport in the scenario considered. The modeled plume configuration for Year 5, Year 10, and Year 15 were evaluated for TCE and PCE for each of the operating scenarios. Under these scenarios, the impact to current and potential receptors (CPU, COV, Port) was evaluated, including the estimated concentration at the wellhead and year in which maximum concentrations could be expected.

A summary of the model scenarios, significant assumptions, relevant parameters, and results are included in Appendix B. As applicable, the results and explanation of potential impacts or effects on the dissolved-phase groundwater plume are included in the individual alternatives evaluation in Section 9.

The model was also used to evaluate the NuStar source area to assess whether additional cleanup was needed to protect the intermediate zone and to assess the impact of the SMC source area. The results of the assessment of the SMC source area was used to establish a source area contaminant concentration that would not impact the dissolved-phase groundwater plume above the MTCA Method B cleanup levels. The results of the NuStar source area modeling are discussed in Section 7 and Appendix D. Further discussion of the use of the model for the SMC source area is included in Section 8 and Appendix B.

4. APPLICABLE FEDERAL, STATE, AND LOCAL LAWS

The MTCA rules (WAC-173-340-710) require that cleanup actions comply with applicable state and federal laws, which are defined as "legally applicable requirements and those requirements that the department determines…are relevant and appropriate requirements" (i.e., ARARs). A cleanup action performed under MTCA authority (e.g., an Agreed Order) is exempt from the procedural requirements of certain state and local environmental laws, although the cleanup action must still comply with the substantive requirements of applicable federal, state, and local laws.

"Legally applicable" requirements include cleanup standards or environmental protection requirements under state or federal laws that specifically address a hazardous substance or cleanup action for a site. "Relevant and appropriate" requirements include cleanup standards or environmental requirements (e.g., cleanup standards, standards of control, environmental criteria, environmental limits, etc.) under state and federal law that, while not legally applicable to the cleanup action, address problems or situations that are considered sufficiently similar to those encountered at the Site. A comprehensive list of federal, state, and local laws that may affect the development of cleanup standards and the selection and implementation of cleanup actions is presented in Table 4-1. A detailed description of these laws as they may pertain to cleanup activities is provided in Appendix C.

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5. DEVELOPMENT OF CLEANUP STANDARDS

This section summarizes the development of cleanup standards and points of compliance for various media at the Site. Cleanup standards were developed in accordance with WAC 173-340-720 through WAC 173-340-760. In accordance with WAC 173-340-700(3), cleanup standards were developed for hazardous substances identified at the Site and the specific areas or exposure pathways where humans or the environment could potentially become exposed to these substances. Establishing cleanup standards requires identifying the following:

- Cleanup levels – concentrations of contaminants that do not pose a risk to human health and the environment.
- Points of compliance – the location within the Site where cleanup levels must be attained.
- Other regulatory requirements – requirements that apply to a site cleanup action because of the type of action and/or location of the site (i.e., applicable or relevant and appropriate requirements [ARARs]).

A cleanup level is the concentration of a hazardous substance in soil, water, air, or sediment that is determined to be protective of human health and the environment under specified exposure conditions. In general, the cleanup levels and points of compliance were developed for the media which indicated unacceptable potential risk pathways identified in the risk assessments associated with the NuStar, Cadet, and SMC sites (see Sections 2.2, 2.3 and 2.4, respectively). The following sections summarize the development of cleanup levels and points of compliance. Potential additional regulatory requirements (i.e., ARARs) are discussed in Section 4.

5.1 INDICATOR HAZARDOUS SUBSTANCES

As specified in WAC 173-340-703, indicator hazardous substances may be selected for the purpose of defining Site cleanup requirements. COCs representing potential unacceptable baseline risks were selected as indicator hazardous substances for the specific source areas, sediments, and overall Site. As described in the respective RI reports and associated risk assessments, the majority of the potential risk within the Site can be attributed to PCE, TCE, and cis-1,2-DCE. The selection of a cleanup standard for human receptors will consider the risk pathways (i.e., potable use of groundwater) and specific contaminants that remedial actions need to address.

The cleanup levels for the indicator hazardous substances (PCE, TCE, and cis-1,2-DCE) are consistent with established MTCA procedures. MTCA specifies three methods (Methods A, B, and C) that can be used to develop cleanup standards for contaminated media. Method A, B, and C cleanup standards for impacted groundwater are addressed in WAC 173-340-720.

Method A cleanup levels can only be used at simple sites with few hazardous substances and “routine” cleanups (WAC 173-340-704). Method A cleanup levels must be at least as stringent as concentrations developed under state and federal law or the concentrations included in MTCA Table 720-1 (WAC 173-340-720(3)). Due to the complexity of this project, Method A cleanup levels are not applicable.

Method B can be used to establish cleanup levels at any site (WAC 173-340-705). Method B cleanup levels must be at least as strict as concentrations developed under state or federal law and are calculated using risk equations specified in WAC 173-340-720(4).

Method C cleanup levels are protective of human health and the environment, but are generally less restrictive than those developed using Methods A and B. Method C can be used to develop cleanup levels when the cleanup levels comply with applicable state and federal laws, all practicable treatment methods have been used, institutional controls are implemented, and Methods A and B result in cleanup levels that are below technically achievable concentrations or pose a greater overall threat to human health or the environment (WAC 173-340-706). Method C cleanup levels are calculated through the use of a risk assessment to define acceptable cleanup levels (WAC 173-340-720(5)).

The development of cleanup levels for each medium is addressed in the following sections and, where applicable, the justification for the use of MTCA Methods A, B, or C is specified.

5.2 SOIL

Soil cleanup standards were developed in accordance with WAC 173-340-745. As discussed in the risk assessment summaries for each site, the land use for all three source areas (Cadet, SMC, and NuStar) qualifies as industrial properties. Soil contamination within the source areas does not extend beyond any property boundaries. Therefore, soil cleanup standards were developed in accordance with MTCA Method C, which is appropriate for industrial properties (WAC 173-340-706(1)(b)).

5.2.1 Soil Cleanup Levels

Based on the industrial designation of the properties, MTCA Method C was deemed appropriate and soil cleanup levels were developed in accordance with WAC 173-340-745(5). The following elements were considered during the development of soil cleanup levels:

- ARARs – No numerical cleanup level ARARs associated with soil were identified for any of the three sites.
- Environmental Protection – No significant terrestrial habitat exists at any of the three source areas – the only areas where it might be possible for shallow soil to have been impacted; therefore, development of cleanup levels for soil to protect wildlife is not necessary.
- Groundwater Protection – Potential cleanup levels to protect groundwater as a drinking water source are included in Table 5-1. All impacted groundwater zones are considered a drinking water source unless otherwise specified. The methodology for derivation of PCE and TCE cleanup levels (obtained from the Cleanup Levels and Risk Calculation [CLARC] database) is presented in Ecology CLARC guidance documents (Ecology 2012a; 2012b).
- Human Health Direct Contact – The potential cleanup levels included in Table 5-1 were obtained from the Ecology CLARC database for Method C (industrial properties).
- Human Health Soil Vapors – In accordance with WAC 173-340-745, if soil cleanup levels are selected to protect drinking water, the soil vapor pathway does not need to be further evaluated.
- Table 5-1 includes the soil cleanup levels developed for the Site.

5.2.2 Soil Point of Compliance

Per WAC 173-340-745(7) and -740(6)(b), the standard point of compliance for soil cleanup levels is throughout each of the sites.

5.3 GROUNDWATER

Cleanup standards used to protect groundwater were developed in accordance with WAC 173-340-720. For groundwater, Method B was used to develop the groundwater cleanup levels. Method A was not selected because the sites have multiple hazardous substances. The Site does not qualify for use of Method C groundwater cleanup levels because it has not been demonstrated that the Method B levels are below background, will increase risk, or are below technically possible concentrations (WAC 173-340-706(1)(a)).

5.3.1 Groundwater Cleanup Levels

Under MTCA, the establishment of groundwater cleanup levels depends upon the classification of groundwater as either potable (a current or potential source of drinking water) or non-potable (WAC 173-340-700). Groundwater cleanup levels must be established based on the highest beneficial use of groundwater, assumed to be drinking water unless it can otherwise be demonstrated (WAC 173-340-720(1)(a)). Groundwater at the Site is currently classified as a drinking water resource and will likely continue to be classified as a drinking water resource in the future. Groundwater at the Site is therefore considered potable and includes all groundwater within the USA zone (i.e., shallow, intermediate, and deep zones). Groundwater has also been designated as a Sole Source Aquifer by the EPA.

MTCA requires groundwater cleanup levels to be based on the reasonable maximum exposure expected to occur under both current and future site conditions. For potable groundwater, this means that the cleanup level must be set for COCs at concentrations that allow the water to be safely used as a source of drinking water. As identified in Section 5.1, PCE, TCE and cis-1,2-DCE are present at the Site at concentrations above the MTCA cleanup levels. In addition, groundwater cleanup levels must be established that are protective of other media including air, sediment, and surface water.

- Groundwater Levels Protective of Air – In accordance with WAC 173-340-750(1)(a)(i), if groundwater cleanup levels are selected to protect use of groundwater as potable water, it is presumed that levels are adequate to protect the air pathway.
- Groundwater Levels Protective of Sediment – An evaluation of groundwater levels which are protective of sediment was conducted for the NuStar site. The results of the evaluation and the determination of cleanup levels are included in Section 5.4.
- Groundwater Levels Protective of Surface Water – The September 2012 Ecology CLARC guidance document derives the Method B cleanup level for protection of surface water. In addition, further evaluation of surface water cleanup levels was conducted for the NuStar site. The results of the evaluation and the determination of cleanup levels are included in Section 5.5.

Table 5-1 includes applicable groundwater cleanup levels primarily obtained from the Ecology CLARC database associated with MTCA Method B levels.

5.3.2 Groundwater Point of Compliance

Per WAC 173-340-720(8)(b), the standard point of compliance is throughout the Site and throughout the saturated zone. This point of compliance shall correspond to the drinking water pathway cleanup level. For the purpose of this project, the saturated zone is defined as all groundwater within the USA zone (i.e., shallow, intermediate and deep zones).

5.4 SEDIMENT

In accordance with WAC 173-340-760, cleanup standards used to protect sediment were developed in accordance with WAC 173-204. The specific sections relevant to determination of freshwater sediment standards are WAC 173-204-560, -561, -563, and -564.

5.4.1 Sediment Cleanup Levels

The sediment cleanup level is established within a range of concentrations defined by the sediment cleanup objective at the lower end and the cleanup screening level at the upper end. Each is determined based on consideration of protection of human health, benthic toxicity, toxicity to higher trophic level species, and requirements of other applicable laws. In addition, the cleanup level shall not be less than natural background or the practical quantitation limit.

Table 5-2 presents the derivation of the sediment cleanup levels, and the basis for the evaluation is presented below. In accordance with WAC 173-204-560(3) and (4), cleanup objectives and screening levels were selected as the highest of the following:

- Risk-Based Concentration Protective of Human Health and the Environment – The risk-based concentration is the lowest of the following.
  - Human Health – Human health risk was evaluated in accordance with WAC 173-204-561(2). Human health risk is evaluated based on a tribal fish/shellfish consumption scenario. Based on the following lines of evidence, fishing within the area of impacted sediments is very limited, so human health risk is not likely to be the controlling risk pathway and human health risk was not quantified.
    - The COCs consist of VOCs that are not considered bioaccumulative (not listed in WAC 173-333-310 and the log of the octonal-water partitioning coefficient is less than 3.5 for each COC);
    - The area of sediments with detectable concentrations of VOCs is on the order of two acres;
    - The NuStar terminal shoreline is located within a larger industrial area which extends approximately 3 miles adjcant to the river. The channel is straight through this industrial corridor, with no calm water inlets, and frequent large vessel traffic;
    - There is no public access to the shore adjacent to the impacted sediments. The nearest public access point on the north side of the river is located approximately 4 miles to the east of the NuStar terminal; and
    - The area of impacted sediments is entirely within active ship berthing areas.
  - Benthic Toxicity – Benthic toxicity was evaluated in accordance with WAC 173-204-563. In accordance with WAC 173-204-563(2), cleanup levels for freshwater sediments are obtained from Table VI of the code. The COCs at the Site are not listed in Table VI, and in that event, in accordance with WAC 173-204-563(2)(p)(iii), an alternative approach consistent with WAC 173-204-130 was used to establish cleanup levels. Protective levels for sediments were assessed from published effects-based concentrations for aquatic organisms, specifically

the Risk Assessment Information System (RAIS) of the Oak Ridge National Laboratory (ORNL) and National Oceanic and Atmospheric Administration (NOAA) Screening Quick Reference Tables (SQuiRTs) sediment screening levels. Table 5-2 lists the screening levels identified. Where ORNL data were limited (one or less published screening value), SQuiRT levels were selected. The target/intervention SQuiRT screening values were interpreted to be essentially analogous with the no effects/minor effects screening values that were selected from the ORNL values. Consistent with WAC 173-204-563(2)(a) and (b), sediment cleanup objectives are based on a no adverse effects level, and cleanup screening levels are based on a minor adverse effects level.

- Higher Trophic Level Species Toxicity – Toxicity to higher trophic level species was evaluated in accordance with WAC 173-204-564. Based on the following lines of evidence (consistent with WAC 173-204-564(2)(c)), toxicity to higher trophic level species is unlikely to be the controlling risk pathway so higher trophic level species toxicity was not quantified.
  - The area of sediments with detectable concentrations of VOCs is on the order of two acres; this area is small relative to home ranges of potential predators (e.g., fish and raptors);
  - The COCs consist of VOCs that are not considered bioaccumulative (not listed in WAC 173-333-310 and the log of the octonal-water partitioning coefficient is less than 3.5 for each COC); and
  - The concentrations of COCs present in sediments at the Site are not known or suspected of causing adverse or minor effects on higher trophic level species.
- Other Applicable Laws – No other applicable laws were identified for sediments.

- Natural Background – The COCs consist of man-made organic compounds. For the purpose of the sediment cleanup standards evaluation, it was assumed that the natural background concentration is zero.
- Practical Quantification Limit (PQL) – The PQL was determined for each COC based on the PQL for sediment samples with no detected VOCs from the sediment investigation at the Site. Potential sediment screening levels were above the PQL.

Table 5-2 lists the cleanup levels derived as described above. The table includes both the Sediment Cleanup Objective (SCO) and the Cleanup Screening Level (CSL). In accordance with WAC 173-204-560(2)(a)(i), the initial cleanup level is the sediment cleanup objective. The final cleanup level may be adjusted upward, but not greater than the sediment cleanup level (WAC 173-204-560(2)(a)(ii) and (iii)), based on whether it is technically possible to achieve the sediment cleanup level at the applicable point of compliance and whether meeting the sediment cleanup level will have a net adverse impact on the aquatic environment. Consideration of upward adjustments in the cleanup level is discussed in the evaluation of alternatives in Section 7.

5.4.2 Sediment Point of Compliance

Per WAC 173-204-560(6), the point of compliance is established to be protective of both aquatic life and human health. As indicated above, benthic toxicity is presumed to control sediment Site risk, so the point of compliance is the upper 6 inches of sediment at the Site.

5.5 SURFACE WATER

Cleanup standards used to protect surface water were developed in accordance with WAC 173-340-730. For surface water, Standard Method B was used to develop the cleanup levels. Method A was not selected because the Site has multiple hazardous substances and numerical standards are not available for all indicator substances (WAC 173-340-704(1)). The Site does not qualify for Method C surface water cleanup levels because it has not been demonstrated that Method B levels are below background, will increase risk, or are below technically possible concentrations (WAC 173-340-706(1)(a)).

5.5.1 Surface Water Cleanup Levels

Surface water cleanup levels must be established based on the highest beneficial use of surface water as determined from WAC 173-201A. Table 602 in WAC 173-201A-602 defines uses of the Columbia River adjacent to the Site as follows:

- Aquatic Life Uses
  - Fish spawning, rearing, and migration
- Recreation Uses
  - Primary contact recreation (e.g., swimming, surfing, and diving)
- Water Supply Uses
  - Domestic water
  - Industrial water
  - Agricultural water
  - Stock water
- Miscellaneous Uses
  - Habitat
  - Fish harvesting
  - Commerce and navigation
  - Boating
  - Aesthetics

From the list above, human health risk was presumed to be controlled by domestic drinking water or fish harvesting, and ecological risk was presumed to be controlled by fish spawning/rearing/migration or other habitat. Cleanup levels to address these uses are evaluated below.

Consistent with WAC 173-340-730(3)(b), cleanup levels were evaluated considering applicable state and federal laws, environmental effects, and human health protection, as appropriate. Table 5-3 lists potential surface water cleanup levels from these sources and identifies the selected surface water cleanup level. The following discusses the sources of the information in the table and presents the rationale for the selection of the cleanup levels.

- There are no state water quality criteria for the COCs.
- Under federal criteria, there are no values for aquatic protection for the COCs. For human health, some COCs have criteria that combine drinking water and

consumption of organisms and other COCs have criteria for consumption of organisms only. The values listed were obtained from the CLARC database.

- Because there are no state or federal criteria for environmental effects-based concentrations, protective levels for surface water were assessed from published effects-based concentrations for aquatic organisms, specifically the ORNL RAIS. The SQuiRTs were also reviewed, but the source data were the same as the ORNL RAIS. Table 5-4 lists the relevant screening levels identified. To represent the no adverse effects level, as required by WAC 173-340-730(b)(ii), the minimum value for each COC is listed in Table 5-3 and the relevant screening levels are identified in Table 5-4.
- For human health for each COC, the drinking water cleanup level from Table 5-1 is listed in Table 5-3.
- The recommended cleanup level for surface water was selected from the minimum value in Table 5-3, except that criteria based on fish consumption were not used. As discussed in Section 5.4.1, fishing in the area of impacted sediments is likely very limited given the industrial location of the NuStar terminal. Appropriate habitat for benthic organisms (primarily benthic amphipods and bivalves) and fish (both resident and migratory) is also very limited; therefore, criteria based on fish consumption are not appropriate for surface water cleanup levels for this Site. This is based on the following lines of evidence:
    - The majority of the impacted sediment area is located between the vessel berthing docks and the NuStar terminal seawall. This area is in an active part of the river channel and is subject to energetic processes such as boatwash and tidal (and other river stage) fluctuations. It is unlikely that benthic organisms, such as amphipods and bivalves, would find suitable habitat in this area. Higher bottom water velocities associated with the Lower Columbia River main channel (as opposed to littoral areas, backwaters and side channels) typically result in less favorable habitat for such species. For example, higher water velocities could limit standing crops of amphipods by scouring them out of the main channel habitats during periods of high river flow (McCabe, et. al., 1997). Without suitable habitat for sediment dwelling species, there would be unsuitable food supplies to sustain higher trophic species such as resident and migratory fish.
    - A database search of anadromous and resident fish that have been identified in the vicinity of the NuStar terminal area was conducted using StreamNet (2014). The search indicated five anadromous fish species/runs including Spring and Fall Chinook Salmon, Winter and Summer Steelhead Salmon and Chum Salmon, as well as one resident fish species, the Bull Trout.
    - It is unlikely that the salmonids being fished from the Columbia River would spend a significant amount of their lifetime in the area adjacent to the NuStar site. Bull Trout are members of the family Salmonidae; however, compared to other salmonids, have more specific habitat requirements that influence their abundance and distribution (U.S. Department of Fish and Wildlife, 2014). The Bull Trout requires cold water, stable stream channels, clean spawning and rearing gravel, complex and diverse cover, and (in the case of migratory forms) unblocked migratory corridors. The water in the vicinity of the NuStar terminal is somewhat turbid, likely due to vessel and other boatwash activity. The stream habitat in the impacted sediment area primarily consists of sediment “mud” located between larger rip-rap and cobbles. Clean gravel was not observed at any

of the sediment sampling locations during the 2011-2012 investigations and is likely not present in large enough quantities to support spawning and rearing habitat. Based on field observations while sediment sampling, the habitat adjacent to the NuStar terminal does not seem adequate to support Bull Trout populations.

- Finally, as discussed in Section 5.4.1, there is little potential for VOCs identified in groundwater and sediment, associated with the NuStar site, to bioaccumulate in fish tissue. Therefore, if limited populations of fish were to find habitat in the vicinity of the NuStar terminal, there is little risk to humans from consumption of those fish.

- Criteria were not established at less than the practical quantitation limit (WAC 173-340-730(5)(c)).
- In accordance with WAC 173-340-730(5)(a), potential cleanup levels in Table 5-3 were evaluated to determine adjustments necessary to account for multiple chemicals and/or multiple pathways of exposure. To assess multiple chemicals, the total risk was estimated by assuming each chemical was present at the cleanup level determined as discussed above. The risks were separately summed for non-carcinogens and carcinogens. The corresponding hazard index and excess cancer risk were 2 and 2×10^{-5}, respectively. The carcinogenic risk is greater than the acceptable value of 1×10^{-5}. However, the total exceeds as a result of the vinyl chloride cleanup level established at the practical quantitation limit, so no adjustments were made. For non-carcinogens, the hazard index is greater than the acceptable value of 1. Therefore, the cleanup level for cis-1,2-DCE was adjusted downward from 16 µg/L to 8 µg/L, and the cleanup level for 1,1-DCE was adjusted downward from 7 µg/L to 3 µg/L. The resulting hazard index is an acceptable value of 0.9. No adjustments were made for multiple pathways because drinking water was the only substantive pathway evaluated.

5.5.2 Surface Water Point of Compliance

Per WAC 173-340-730(6)(a) and (b), the point of compliance is the point where groundwater enters the surface water, without consideration of a mixing zone.

5.6 AIR

Air cleanup standards were developed in accordance with WAC 173-340-750. An extensive indoor air evaluation was previously conducted on behalf of the Port for the residences in the FVN. The results of the evaluation were presented in the CAMP (Parametrix 2009a). As discussed in Section 2.2, residential indoor air issues in the project area have been completely addressed and Ecology has determined that no further investigation or remedial actions are required. Therefore, air cleanup levels were developed in this FS for current or future industrial buildings only.

5.6.1 Air Cleanup Levels

As specified above, air cleanup levels were developed for the industrial properties only. Method C (industrial) indoor air cleanup levels were selected from Ecology's CLARC database to assess the potential risk associated with indoor air in industrial buildings. Table 5-1 includes the applicable indoor air cleanup levels developed for the Site.

5.6.2 Air Point of Compliance

The standard point of compliance for indoor air cleanup levels is throughout the sites, specifically in the interior of the buildings or future buildings, if any.

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6. CLEANUP ACTION EVALUATION CRITERIA

Cleanup actions were evaluated and selected based on the requirements of WAC 173-340-360. The following summarizes these requirements. Cleanup actions for the sediment portion of the combined upland and sediment cleanup site were evaluated and selected based on the requirements of WAC-204-570.

- Threshold requirements:
  - Protect human health and the environment;
  - Comply with cleanup standards;
  - Comply with ARARs; and
  - Provide for compliance monitoring.
- The selected cleanup action shall:
  - Use permanent solutions to the maximum extent practicable (see below);
  - Provide for a reasonable restoration timeframe (see below);
  - Consider public concerns;
  - Prevent or minimize present and future releases and migration of hazardous substances in the environment; and
  - Not rely primarily on dilution and dispersion unless the incremental costs of any active remedial measures over the costs of dilution and dispersion grossly exceed the incremental degree of benefits of active remedial measures over the benefits of dilution and dispersion.
- For groundwater cleanup actions:
  - If practicable, a permanent cleanup action shall be used to achieve the cleanup levels for groundwater at the standard point of compliance; or
  - Where a permanent cleanup action is not practicable, the following measures shall be taken:
    - Conduct treatment or removal of the source; and
    - To the maximum extent practicable, implement groundwater containment, including barriers or hydraulic control through groundwater pumping, or both, to avoid lateral and vertical expansion of the groundwater volume affected by the hazardous substance.
- Institutional controls shall be used if concentrations above Method A or B cleanup levels remain at the Site.
- For sediment cleanup actions, in addition to the requirements above, minimum requirements include:
  - Comply with sediment standards in WAC 173-204-560 through 173-204-564.
  - Where source controls are necessary as part of a cleanup action, preference shall be given to alternatives that include source control measures that are more effective in minimizing the accumulation of contaminants in sediment caused by discharges.

- If a sediment recovery zone is necessary as part of a cleanup action, must meet the requirements of WAC-173-204-590.
- Cleanup action should not rely exclusively on monitored natural recover or institutional controls and monitoring where it is technically feasible to implement a more permanent cleanup action. (see above).

6.1 USE OF PERMANENT SOLUTIONS

The selected cleanup action must use permanent solutions to the maximum extent practicable, as determined by the following disproportionate cost analysis. A disproportionate cost analysis is not required if a permanent solution is selected. A permanent solution is a cleanup action that achieves cleanup standards without further action being required at the Site, other than the approved disposal of residue from a treatment system (WAC 173-340-200).

The disproportionate cost analysis compares the costs and benefits of the cleanup action alternatives evaluated in the FS using the following process.

- Rank the potential alternatives from most to least permanent using the following criteria.
  - Protectiveness – Overall protectiveness of human health and the environment, including the degree to which existing risks are reduced, time required to reduce risk at the facility and attain cleanup standards, on-site and off-site risks resulting from implementing the alternative, and improvement of the overall environmental quality.
  - Permanence – The degree to which the alternative permanently reduces the toxicity, mobility, or volume of hazardous substances, including the adequacy of the alternative in destroying the hazardous substances, the reduction or elimination of hazardous substance releases and sources of releases, the degree of irreversibility of waste treatment process, and the characteristics and quantity of treatment residuals generated.
  - Cost – The cost to implement the alternative, including the cost of construction, the net present value of any long-term costs, and agency oversight costs that are cost-recoverable. Long-term costs include operation and maintenance costs, monitoring costs, equipment replacement costs, and the cost of maintaining institutional controls. Cost estimates for treatment technologies shall describe pretreatment, analytical, labor, and waste management costs. The design life of the cleanup action shall be estimated and the cost of replacement or repair of major elements shall be included in the cost estimate.
  - Long-term Effectiveness – Long-term effectiveness includes the degree of certainty that the alternative will be successful, the reliability of the alternative during the period of time hazardous substances are expected to remain on site at concentrations that exceed cleanup levels, the magnitude of residual risk with the alternative in place, and the effectiveness of controls required to manage treatment residues or remaining wastes. The following types of cleanup action components may be used as a guide, in descending order, when assessing the relative degree of long-term effectiveness: reuse or recycling; destruction or detoxification; immobilization or solidification; on-site or off-site disposal in an

engineered, lined and monitored facility; on-site isolation or containment with attendant engineering controls; and institutional controls and monitoring.

  - Management of Short-Term Risks – The risk to human health and the environment associated with the alternative during construction and implementation, and the effectiveness of measures that will be taken to manage such risks.
  - Technical and Administrative Implementability – Ability to be implemented including consideration of whether the alternative is technically possible, availability of necessary off-site facilities, services and materials, administrative and regulatory requirements, scheduling, size, complexity, monitoring requirements, access for construction operations and monitoring, and integration with existing facility operations and other current or potential remedial actions.
  - Consideration of Public Concerns – Whether the community has concerns regarding the alternative and, if so, the extent to which the alternative addresses those concerns. This process includes concerns from individuals, community groups, local governments, tribes, federal and state agencies, or any other organization that may have an interest in or knowledge of the Site.

- The most permanent cleanup action alternative shall be the initial baseline cleanup action.
- Compare the next most permanent cleanup action alternative to the baseline cleanup alternative. The alternative whose costs are disproportionate to the benefits shall be eliminated. Costs are disproportionate to benefits 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. The comparison of benefits and costs may be quantitative, but will often be qualitative and require the use of best professional judgment.
- Repeat until only one alternative remains.

6.2 DETERMINATION OF REASONABLE RESTORATION TIMEFRAME

To determine whether a cleanup action provides for a reasonable restoration timeframe, the following factors were considered:

- Potential risks posed by the Site to human health and the environment;
- Practicability of achieving a shorter restoration timeframe;
- Current and potential future uses of the Site, surrounding areas, and associated resources that are or may be affected by releases from the Site;
- Availability of alternative water supplies;
- Likely effectiveness and reliability of institutional controls;
- Ability to control and monitor migration of hazardous substances from the Site;
- Toxicity of the hazardous substances at the Site; and
- Natural processes that reduce concentrations of hazardous substances and have been documented to occur at the Site or under similar site conditions.

When area background concentrations would result in recontamination of the Site to levels that exceed cleanup levels, that portion of the cleanup action which addresses cleanup below area background concentrations may be delayed until the off-site sources of hazardous substances are controlled. In that case, the remedial action shall be considered an interim action until cleanup levels are attained.

6.3 QUALITATIVE FACTORS CONSIDERED IN EVALUATING CLEANUP ACTIONS

In evaluating potential cleanup actions, the following factors from WAC 173-340-370 were considered.

- Treatment technologies should be emphasized at sites containing liquid wastes, areas contaminated with high concentrations of hazardous substances, highly mobile materials, and/or discrete areas of hazardous substances that lend themselves to treatment.
- For sites with small volumes of hazardous substances, hazardous substances should be destroyed, detoxified, and/or removed to concentrations below cleanup levels throughout the Site.
- For portions of sites that contain large volumes of materials with relatively low levels of hazardous substances where treatment is impracticable, engineering controls – such as containment – may be needed.
- Active measures should be taken to prevent precipitation and runoff from coming into contact with contaminated soils and waste materials.
- When hazardous substances remain on site at concentrations that exceed cleanup levels, those hazardous substances should be consolidated to the maximum extent practicable.
- For facilities adjacent to a surface water body, active measures should be taken to prevent/minimize releases to surface water via surface runoff and groundwater discharges in excess of cleanup levels. Dilution should not be the sole method for demonstrating compliance with cleanup standards in these instances.
- Natural attenuation of hazardous substances may be appropriate at sites where:
  - Source control (including removal and/or treatment of hazardous substances) has been conducted to the maximum extent practicable;
  - Leaving contaminants on Site during the restoration timeframe does not pose an unacceptable threat to human health or the environment;
  - There is evidence that natural biodegradation or chemical degradation is occurring and will continue to occur at a reasonable rate at the Site; and
  - Appropriate monitoring requirements are conducted to ensure that the natural attenuation process is taking place and that human health and the environment are protected.

7. NUSTAR SOURCE AREA FEASIBILITY EVALUATION

7.1 EXTENT OF IMPACTED MEDIA

This section discusses the extent of COPCs in soil, groundwater, and sediment at the NuStar site. This information is the basic input used to assess technologies and cleanup action alternatives.

7.1.1 Soil

The discussion of extent presented in this section focuses on vadose zone soil (generally corresponding to a depth of up to 25 feet). Although the standard point of compliance for soil (for protection of groundwater) is throughout the soil column, the concentrations of COPCs present in groundwater make differentiating between COPCs in saturated soil and groundwater difficult. Furthermore, actions to clean up groundwater will address saturated soil as well, so saturated soil will be addressed together with groundwater in Section 7.1.2. Finally, for other potential soil cleanup levels (i.e., Method C or vapor intrusion), the point of compliance is entirely within the vadose zone.

To evaluate the nature and extent of impacted soil, the vadose zone soil data from the RI were compared to the cleanup levels. Tables of soil data and cleanup levels are presented in Appendix D. Only PCE and TCE were detected in vadose zone soil above cleanup levels. The extent of vadose zone soil with concentrations of PCE and TCE detected above cleanup levels is shown on Figure 2-12. To better assess extent of impacts to soil, the figure identifies relative concentrations of PCE in the soil samples. As the primary COC and risk driver in soil, PCE was used as a surrogate for defining extent in soil. Figure 2-12 shows that the primary area of impact to soil is around Warehouse 13.

It should be noted that data from borings CB-1 through CB-4 are not included in Figure 2-12. Samples from these borings were collected in 2010 to evaluate the effectiveness of the 2008 vadose zone interim action and to determine if SVE system expansion was warranted. Soil analytical and photoionization detector (PID) measurements from these soil samples indicated that VOCs were low to non-detect throughout the majority of the soil column. Areas of elevated VOC concentrations were limited to small, isolated silty zones. Soil samples were collected from the isolated zones of high concentrations and were analyzed for VOCs. The concentrations of PCE and TCE in these samples were highly elevated, and are representative of fine grained and less permeable layers that retain VOCs in the vadose zone . Less elevated VOC levels are found in more permeable areas of the vadose zone soil. The elevated levels are not considered representative of overall vadose zone conditions as they represent only 20% of the vadose zone soil volume (Ash Creek 2011). Each of the other areas with detectable concentrations of PCE or TCE are either likely associated with groundwater or are low residuals that have since attenuated. A location-specific rationale justifying this conclusion was provided in the approved NuStar RI (Apex, 2013) and is summarized below.

- At GP-8 completed in 1997, PCE was detected at 0.073 mg/kg at a depth of 5 feet and at 2.1 mg/kg at a depth of 20 feet. In 2006, borings AGP-1 through AGP-3 were completed in this area and there were no field indications of VOCs. One soil sample from the vadose zone was analyzed for VOCs, and PCE and TCE were not detected.
- At IN-8 completed in 2000, PCE was detected at 8.2 mg/kg at a depth of 25 feet. Other, much lower concentrations of PCE were detected in borings completed in this area from 1993 to 2000 (MW-2 through MW-5, MW-16, GP-5 through GP-7, and IN-9). The result from IN-8 was likely associated with groundwater. In 2006, five

borings (AGP-30 through AGP-34) were completed around IN-8 and, except for one sample, there were no field indications of VOCs above the water table. Two soil samples from the vadose zone were analyzed for VOCs (including the one sample with field indications of VOCs) and PCE and TCE were not detected. Also in 2006, four soil borings (AGP-35 through -37, and AGP-39) were completed in the surrounding area. There were no or low field indications of VOCs above the water table. Three soil samples from the vadose zone were analyzed for VOCs (including a sample with field indications of VOCs) and PCE and TCE were not detected.

- At AGP-38 completed in 2006, PCE was detected at 0.204 mg/kg at a depth of 24 feet. This depth corresponds to the water table at the time of drilling.
- At IN-5 completed in 2000, PCE was detected at 0.255 mg/kg at a depth of 25 feet. This depth likely corresponds to the water table at the time of drilling.
- At IN-2 completed in 2000, PCE was detected at 0.267 mg/kg at a depth of 20 feet. Other, lower concentrations of PCE were detected in borings completed in this area in 1996 and 1997 (GP-1 and MW-9). In 2006 and 2007, borings AGP-25, -47, -50, -52, and -53 were completed in this area and there were no field indications of VOCs (AGP-50 was not logged for soil). One vadose zone soil sample from this boring group was analyzed for VOCs, and PCE and TCE were not detected. From 2000 to 2005, well IN-2 was operated as an SVE well as part of an interim action.
- At MW-13 completed in 1996, PCE was detected at 1.6 mg/kg at a depth of 24.5 feet (PCE was not detected at a depth of 20 feet). This depth likely corresponds to the water table at the time of drilling. From 2000 to 2005, well EX-3, located approximately 15 feet from MW-13, was operated as an SVE well as part of an interim action.
- At EX-4 completed in 2000, PCE was detected at 0.384 mg/kg at a depth of 20 feet. In 2006, borings AGP-16 and -17 were completed in this area and there were no field indications of VOCs above the water table. From 2000 to 2005, well EX-4 was operated as an SVE well as part of an interim action.
- At IN-3, completed in 2000, PCE was detected at 61 mg/kg at a depth of 20 feet. In 2006, boring AGP-25 was completed in this area and there were no field indications of VOCs above the water table. From 2000 to 2005, well IN-3 was operated as an SVE well as part of an interim action.

Because the presence of localized areas of elevated VOC concentrations suggested the potential for residual dense non-aqueous liquid (DNAPL) in isolated silt layers in the vadose zone, SVE optimization techniques have been used to remove HVOC mass from soils that are typically challenging to address using SVE. Prior to the 2011 SVE expansion, the SVE wells were routinely measured with a PID for relative VOC content. The wells with the highest amounts of VOCs were left open, while the others with lower VOC concentrations were closed. By closing wells with lower VOC concentrations, the radius of effectiveness of the associated (open) vapor extraction wells was increased, allowing for the removal of more VOC mass. The "optimization" of the SVE system has been continued through the 2011 interim action, although effluent concentrations in the SVE wells installed in 2011 are relatively low, and the additional mass removed after optimization has been minimal.

Ecology has provided NuStar with comments on the RI that expressed concern about the permanence of SVE implemented at the property. Specifically, concerns were raised about the potential for concentration rebound once the SVE system was stopped. As Ecology has noted, the interim actions were both characterized by high rates of initial mass removal/SVE effluent concentration reduction, which have diminished over time to a near asymptotic level. The north and south SVE system were periodically shut down during 2013 to evaluate the potential for VOC rebound. While some rebound was noted, effluent concentrations were only slightly above the effluent concentrations noted prior to the shutdown period, suggesting that residual DNAPL is no longer present in source area vadose zone soils. Additional evaluation of effluent concentration will continue in 2014, and results will be reported in subsequent semi-annual monitoring reports to Ecology.

7.1.2 Groundwater

7.1.2.1 Summary of Shallow Groundwater Extent

Groundwater data have been collected over the period from 1993 through 2013. The NuStar RI (Apex 2013a) summarized data through fourth quarter 2012; however, this FS includes additional data from first quarter 2013 as those data were included in presentations to Ecology during the FS preparation process. Furthermore, given seasonal variability in groundwater data at the NuStar facility, first quarter data are typically elevated relative to other quarterly data, thus represent a conservative evaluation of groundwater conditions at the property. Figures 7-1 through 7-3 show the extent of PCE, TCE and cis-1,2-DCE, respectively, in shallow zone groundwater at the NuStar facility. The extent of the COPCs during first quarter 2008 and first quarter 2013 are compared, as they depict reductions in VOCs in response to the 2008 and 2011 interim actions. As can be seen in the figures, HVOCs in the shallow zone have been and continue to be confined to the footprint of the NuStar facility and in adjacent sediments, as detailed in Section 7.1.3. An area of elevated groundwater concentrations (relative to other sample results in the area) has been identified to the northwest of the NuStar facility. The source has not been definitively identified, but the area appears to be attenuating naturally, based on the comparison of concentrations and extent between 2008 and 2013 data.

Groundwater concentration trend plots provided in the first semi-annual 2013 groundwater monitoring report (Apex 2013b) indicate decreasing groundwater concentration trends in all shallow zone groundwater monitoring wells on the NuStar facility (Appendix D-2). Total molar trend plots for source area wells (MGMS2-40, EX, MP-1 and MW-7; Appendix D-2) show strong decreasing trends since implementation of the interim actions, further supporting the success of the interim actions within the source area. Attenuation rates are much slower outside of the 2008 and 2011 injection areas, indicating that the injection substrate was most effective in the immediate vicinity of the injection area, and did not migrate substantially from the injection locations.

The most notable decrease in VOC concentrations was observed in shallow zone well MW-7, which was not only the most impacted source area well prior to the 2008 interim action (31,000 µg/L in 2007), but was also located in the footprint of both the 2008 and 2011 groundwater injections (Figure 7-4). As shown on the trend plot for MW-7, concentrations of HVOCs in MW-7 have decreased rapidly in response to both the 2008 and 2011 enhanced bioremediation injections. The concentrations of PCE and TCE during the most recent groundwater monitoring event (September 2013) were below the analytical reporting limit of 0.5 µg/L (Apex 2014). It is important to note that, while not as steep as the decline in well MW-7, most of the wells at the property, including MW-1, MW-3, MW-5, MW-8, MW-9, MW-12, MW-13, MW-14, MW-16, MW-17, MW-10, EW-1, MGMS1, and MGMS3 have exhibited an overall decreasing COPC trend. These wells are outside of the treatment area and, therefore, the decline in concentrations cannot be attributed to the interim actions and indicate that COPCs are attenuating naturally at the NuStar facility.

7.1.2.2 Development of Shallow Zone Cleanup Approach

In preparing the FS, three goals were considered when evaluating the extent of groundwater impacts, developing cleanup levels, and evaluating remedial alternatives for the NuStar source area. These goals were developed based on the information supporting that VOCs in shallow groundwater in the NuStar source area are the source of VOCs in intermediate zone groundwater beneath the NuStar facility (as defined by the 2006 leasehold boundaries) and sediments in the adjacent riverbank. The three goals include meeting shallow zone remedial objectives (i.e., MCLs) in a timely manner, protection of intermediate zone groundwater as drinking water, and the protection of river sediments. In order to evaluate whether or not monitored natural attenuation of groundwater would meet these three goals once the 2011 interim action was completed (Note: groundwater interim action is considered complete once bioremediation substrate is fully utilized), the Vancouver Lowlands Regional Groundwater Model (Parametrix 2008a) was utilized to model source area groundwater at the NuStar facility. The model analysis assumed the following scenario and associated parameters:

- There is no ongoing source at the NuStar facility (i.e., no DNAPL is present in the shallow groundwater zone). This has been demonstrated by the consistent attenuation of VOCs in site monitoring wells, both inside and outside of the interim action areas. The estimated VOC mass is the total mass in the shallow zone as represented by fourth quarter 2012 data.
- Advection and dispersion act upon the shallow zone plume. The model does not simulate degradation.
- Several pumping scenarios were evaluated to assess the intermediate zone groundwater beneath the NuStar facility without influence from the Port extraction well including pumping and not-pumping at GWM; to better assess the influence of the Port's extraction well, EX-1, model runs were performed with and without pumping from EX-1 and the results compared.

A summary of the model analysis and input parameters is provided in Appendix D-3. The results of the model analysis indicated that for pumping scenarios specified in the above bullet, concentrations of COPCs in the intermediate zone would be below MCLs in 15 years or less. In other words, the current NuStar interim action of soil and shallow zone groundwater treatment followed by monitored natural attenuation would be protective of intermediate zone groundwater in a reasonable timeframe. This finding was significant as it focused the shallow zone cleanup evaluation on protection of shallow zone groundwater as a drinking water source and being protective of river sediments. As is detailed in Section 7.1.3, because sediments are believed to be impacted from upland shallow zone groundwater, the cleanup goals for shallow drinking water and river sediments therefore would be inherently similar. The NuStar source area modeling was also valuable in that it isolated the NuStar source area cleanup action from the regional intermediate zone cleanup effort because the modeling demonstrated that pumping from the POV well would not affect cleanup of intermediate zone groundwater at and north of the NuStar facility.

As seen on Figures 7-1 through 7-3, the residual source at the NuStar facility is limited to the central portion of the facility, immediately adjacent to the river seawall. A much smaller isolated area of COPC concentrations is also present off-site to the northwest of the Site. This off-site area is limited in extent, groundwater monitoring shows it has not migrated to intermediate zone groundwater nor to the Columbia River, and is naturally attenuating without any additional cleanup action. Additionally, this area of impacted groundwater does not significantly underlie existing buildings and it was not identified as an area with the potential to cause unacceptable risk via indoor air vapor intrusion in the risk assessment.

Because this off-site area does not present an unacceptable risk to current workers, is naturally attenuating such that shallow groundwater is anticipated to achieve cleanup goals (drinking water standards) in a reasonable timeframe and is not impacting intermediate zone groundwater or river sediments, no further action for this area is warranted and is not evaluated herein. Therefore, the source area further evaluated in this FS will consist of the area immediately adjacent to the river and within the (200 µg/L) isocontour for PCE and TCE (see Figures 7-1 and 7-2). This generally consists of an area extending 50 feet landward from the seawall and approximately 500 feet along the extent of the seawall. This extent of residual source in groundwater is also consistent with the downgradient most impacted areas of river sediment, as will be further discussed in Section 7.1.3.

7.1.2.3 Rationale for Active Remediation of Source Area

The source area on the NuStar leasehold is proposed for active remediation for two primary reasons: as source control of VOCs to river sediments to allow river sediments to attenuate; and to mitigate VOCs in the shallow zone from entering intermediate zone water, which is accessed by city and county wells for a potable water source. Higher concentrations remain in the NuStar source area and these concentrations are adjacent to the river. For example, the average PCE concentration in the remaining NuStar source area is 1400 ug/L while the average PCE concentration in the northwest hotspot area is 220 ug/L. As stated above, remediation of the shallow zone at the NuStar leasehold is proposed, in part, to allow the adjacent sediment in the river to clean up. VOCs in the “northwest hotspot” area do not extend laterally to the river and adjacent sediment in this area has not been impacted.

Additionally, the shallow zone on the NuStar leasehold has historically been a source of VOCs to the intermediate zone beneath the leasehold. The intermediate zone beneath the “northwest hotspot” area has not been and is not likely to be impacted by VOCs; therefore, remediation of the shallow zone at the “northwest hotspot” is not needed to be protective of the intermediate zone. Finally, concentration trends of the VOCs in the northwest area are decreasing and the area is attenuating naturally. Because this area does not present a risk to adjacent river sediments nor to underlying intermediate zone groundwater and it is attenuating naturally, active remediation of this area does not appear warranted.

7.1.3 Sediment

Sediment data have been collected from 18 locations downgradient from the NuStar facility in the Columbia River, as shown on Figure 7-5. The two surface-most samples collected from each borehole (typically 0 to 0.5 foot below mudline and 1 to 2 feet below mudline) have been delineated to cleanup standards. The development of sediment cleanup standards is summarized in Section 5.0. The extent of sediment exceeding cleanup standards is shown on Figure 7-5, and is limited to a rectangular area approximately 600 feet long and 130 feet wide. As summarized in Section 5.0 of the NuStar RI (Apex 2013a), the magnitude and distribution of sediment impacts suggested that river sediments were directly impacted from the migration of upland impacted groundwater. Available data on the historical handling of solvents, facility infrastructure and processes, and river morphology were reviewed to assess the likely contributing factors to the observed extent and distribution of VOCs in the sediments adjacent to the NuStar facility; Appendix G describes this data and the sediment conceptual model that has been developed to assist in the evaluation of appropriate remedial technogies for sediment. The conceptual model was developed to evaluate the likely extent that VOCs in shallow groundwater have and are continuing to contribute to the observed sediment impacts and whether other sources to sediments may exist. As detailed in

Appendix G, sediment concentrations are consistent with those that would be expected if groundwater containing VOCs at the concentrations recently observed at the NuStar site were migrating through the river sediments. The sediment samples with the highest COPC concentrations are immediately downgradient of the residual source area. As described in Appendix G, other potential sources at the facility, such as historical storm water outfalls or direct releases from vessels servicing the NuStar facility, do not appear to be significant contributors, if at all, because solvents have not been handled for more than 20 years and it would not be anticipated that VOCs from surface releases to sediments would persist in the area given the adjacent routine river dredging actions and prop wash from vessels utilizing the NuStar berth. Because the sediment conceptual model supports that the extent of COPC impacts to groundwater is closely correlated with the extent of COPC impacts to sediments, the cleanup alternatives evaluated for these two media may also be closely correlated.

7.2 TECHNOLOGY EVALUATION AND CLEANUP ACTION ALTERNATIVE DEVELOPMENT

This section describes the development of the cleanup action alternatives to be evaluated for the NuStar source area. The alternative development process used the following steps:

- Identify general response actions that broadly describe approaches for site cleanup;
- For each impacted medium (e.g., soil, groundwater, sediment), describe specific technologies within each general response action and conduct a screening-level evaluation to eliminate technologies that are clearly not feasible;
- If appropriate, conduct a more detailed screening of technologies to focus the evaluation on the most feasible technologies; and
- Assemble the technologies into a list of site-specific cleanup action alternatives that represent a range of cleanup options.

7.2.1 General Response Actions

General response actions are broad descriptions of actions that will address the remedial action objectives. Starting with these broad descriptions assures that a wide range of actions is considered. The following lists the general response actions evaluated.

- No Action is used as a comparison to assure that at least some cleanup is warranted; the no-action response assumes that there is no cleanup or protections of any kind implemented.
- Institutional Controls are non-engineered instruments, such as administrative and legal controls, that reduce the potential for human exposure to contamination and/or protect the integrity of a remedy. Institutional controls do not treat or remove the hazard. Institutional controls are usually combined with other responses and are almost always required when at least some hazard remains at the site.
- Engineering Controls are constructed systems that control the hazard at its source. Engineering controls do not treat or remove the hazard and are usually combined with other responses.
- Source Control (Sediment Only) describes an action in upland soil or groundwater that eliminates an ongoing source of contaminants to sediment. Source control generally needs to be implemented prior to or concurrent with direct sediment responses to eliminate the potential for recontamination.

- Containment is a special type of engineering control that involves placing a barrier between the hazard and the receptor. This could be a structure (e.g., cap, wall) or an induced gradient (e.g., pumping). Containment does not treat or remove the hazard.
- Removal consists of the physical extraction of the contaminant or contaminated medium for subsequent treatment, recycling, and/or disposal. Disposal can be on-site or off-site.
- *In Situ* Physical/Chemical/Thermal Treatment involves in-place (i.e., no removal) reduction in toxicity, mobility, or volume of contaminants through any means other than biological processes.
- *In Situ* Biological Treatment is in-place reduction in toxicity, mobility, or volume of contaminants through the action of microbes or plant communities.
- *Ex Situ* Physical/Chemical/Thermal Treatment consists of any process other than biological actions applied after removal to reduce toxicity, mobility, or volume of contaminants.
- *Ex Situ* Biological Treatment consists of any process applied after removal to reduce toxicity, mobility, or volume of contaminants through the action of microbes or plant communities.

7.2.2 Technology Identification and Screening

For each general response action, remedial technologies were identified and screened for effectiveness in achieving the RAOs, implementability, and cost. Tables 7-1 through 7-3 list technologies considered and present the results of the technology screening for soil, groundwater, and sediment, respectively. For each technology, the tables present a brief description and a qualitative evaluation within each of the screening criteria (effectiveness, implementability, and cost). Remedial technologies that were not applicable due to site conditions or constraints, or that were not potentially cost effective, were eliminated from further consideration. The final column in the tables summarizes the rationale for retaining or eliminating technologies.

7.2.2.1 Soil Technologies

Table 7-1 lists technologies and provides a screening evaluation for soil. Technologies remaining after the initial screening are listed below. Retained soil technologies are developed into cleanup action alternatives in Section 7.2.3.

General Response Action	Technology
No Action	No Action
Institutional Controls	Deed Restrictions/Soil Management Plan
Monitoring	Monitoring/soil sampling/vapor sampling
Engineering Controls	Vapor Barrier
In Situ Physical/Chemical/Thermal Treatment	SVE
In Situ Biological Treatment	Monitored Natural Attenuation (MNA)

7.2.2.2 Groundwater Technologies

Table 7-2 lists technologies and provides a screening evaluation for groundwater. Technologies remaining after the initial screening are listed below. Retained groundwater technologies are developed into cleanup action alternatives in Section 7.2.4.

General Response Action	Technology
No Action	No Action
Institutional Controls	Groundwater Use Restrictions Monitoring
Engineering Controls	Vapor Barrier
Containment	Pumping/Hydraulic Containment
Removal/Discharge	Discharge to Sewer/Surface Water Discharge to Reinjection Wells
Ex Situ Physical/Chemical/Thermal Treatment	Adsorption Air Stripping
In Situ Biological Treatment	Enhanced Bioremediation MNA

7.2.2.3 Sediment Technologies

Table 7-3 lists technologies and provides a screening evaluation for sediment. Technologies remaining after the initial screening are listed below. Retained sediment technologies are further evaluated in Section 7.2.5.

General Response Action	Technology
No Action	No Action
Institutional and Engineering Controls	Sediment Management Plan Signage/Notifications/Advisories Monitoring
Source Control	Groundwater Source Cleanup Permeable Reactive Barrier (PRB)
Containment	Reactive Cap
Removal/Disposal	Dredging Off-Site Disposal
In Situ Natural Processes	Monitored Natural Recovery (MNR)
Ex Situ Physical/Chemical Treatment	Dredging/Dewatering

7.2.3 Soil Cleanup Action Alternatives

Vapor barrier technology is considered redundant to SVE (and SVE is already an interim action) and is not retained for further evaluation. If SVE operations ceased and soil impacts remained in place, vapor barrier technology could be utilized to manage interim risk. Of the soil technologies retained for further evaluation, only SVE addresses the leaching to groundwater pathway. The other technologies may be used in conjunction with SVE to address other potential pathways during the operational period of the SVE system. Therefore, the soil cleanup action alternatives evaluated in detail consist of the following.

- No Action – No action is retained to provide a comparison for evaluation of SVE.
- Soil Vapor Extraction – For this alternative, SVE is the primary means to address unsaturated soil containing HVOCs. If needed, the vapor stream would be treated by passing through activated carbon. Depending on the timeframe to complete soil treatment, a soil management plan and deed restrictions could be used to manage interim risk. Soil sampling would be used to verify cleanup and residual contamination would be addressed through MNA.

7.2.4 Groundwater Cleanup Action Alternatives

For the groundwater technologies retained for further evaluation, hydraulic containment and enhanced bioremediation each address protection of drinking water use. Therefore, groundwater cleanup action alternatives evaluated in detail consist of the following.

- No Action – No action is retained to provide a comparison for evaluation of the other alternatives.
- Hydraulic Containment – Groundwater pumping would be used to contain the impacts to groundwater to within the groundwater source area. The water would be treated using air stripping and/or carbon adsorption and discharged to surface water, sanitary sewer, or reinjection wells. Use of groundwater would be legally restricted on the property containing the source area. Long-term groundwater monitoring would be used to verify performance of the containment system. In the event that a more intensively used building is constructed in the impacted area, a vapor barrier could be incorporated into the building to address the potential vapor intrusion pathway.
- Enhanced Bioremediation – A liquid substrate such as emulsified vegetable oil would be injected into the source area to induce conditions suitable for reductive dechlorination of the HVOCs. Depending on the timeframe to reach cleanup levels, use of groundwater could be legally restricted on the property containing the impacted area. Groundwater monitoring would be used to verify performance of the treatment. In the event that a more intensive use building is constructed in the impacted area prior to achieving cleanup levels, a vapor barrier could be incorporated into the building to address the potential vapor intrusion pathway.

7.2.5 Sediment Cleanup Action Alternatives

The sediment technologies retained for further evaluation were assembled into the following cleanup action alternatives.

- No Action – No action is retained to provide a comparison for evaluation of the other alternatives.
- Monitored Natural Recovery (MNR) – Periodic sampling would be used to monitor the long-term natural reduction in HVOC concentrations in sediments. The primary identified source of HVOCs in sediments is groundwater flux containing HVOCs. If this ongoing source is not addressed, it is presumed that cleanup levels in sediment would not be achieved within a reasonable timeframe.
- Source Control – For this alternative, active treatment of the upland groundwater source would be used to eliminate the ongoing source of HVOCs to sediments via the groundwater pathway. Sediment and groundwater monitoring would be used to verify natural reduction after completion of source control, and advisories and signs would be used as appropriate to notify potential users of the impacted area of the presence of the HVOCs.
- Permeable Reactive Barrier (PRB) – For this alternative, a PRB would be installed as close to the top of the bank along the river as possible. For this alternative to be successful, the PRB would need to be placed such that it is downgradient of groundwater containing elevated concentrations of HVOCs. Monitoring would be used to verify natural reduction after installation of the PRB.
- Reactive Cap – A cap would be placed over the impacted sediments providing a clean sand surface habitat. A lower layer of the cap would include a mixture of sand

and reactive materials assumed to include activated carbon and zero-valent iron. The reactive layer would treat groundwater containing HVOCs prior to reaching the upper portions of the cap in the biologically active zone. The believed source of HVOCs in sediments is groundwater flux containing HVOCs. If this ongoing source is not addressed, the cap would have a limited lifetime and would require replacement.

- Dredging – Impacted sediments would be dredged, dewatered, and disposed of in an upland landfill. . If the ongoing groundwater source is not addressed, the dredged area would likely be re-contaminated.

These cleanup action alternatives were further refined by noting the following.

- Because source control is required for any of the alternatives to be effective, MNR and source control alternatives are essentially identical so only the source control alternative was retained as representative.
- The PRB could be effective in addressing sediments, but is not practicable when considered within the overall context of Site cleanup. The use of the barrier wall for source control is compromised by constructability issues. It is not practicable to build the wall on the river side of the seawall due to concerns about undermining the seawall and construction below the high-water elevation for the river. Construction on the inland side of the seawall would need to avoid the tieback structures for the seawall (to avoid compromising the structural integrity of the seawall). The length of the tieback structures is not specifically known, but would be expected to be on the order of 20 feet from the wall. Installation of the reactive barrier at this distance inland would be relatively close to the area of groundwater being addressed by the interim action. Therefore, by completion of the interim action, groundwater upgradient of the PRB would be essentially “clean” and there would be little benefit to the implementation of the PRB relative to the high cost of the installation (expected to be on the order of $2,100,000, given the wall length of about 560 feet and a depth of about 30 feet, and a typical unit cost of between $110 and $140 per unit of wall area as presented in published EPA literature for PRBs that use zero-valent iron as the reactive material). The PRB, therefore, is not considered further in the evaluation.

The final list of sediment alternatives that were evaluated in detail is no action, source control, dredging, and reactive cap.

7.3 EVALUATION OF CLEANUP ACTION ALTERNATIVES

In this section, the cleanup action alternatives developed in Section 7.2 are evaluated in more detail. Sections 7.3.1 through 7.3.3 describe and evaluate cleanup action alternatives for soil, groundwater, and sediments, respectively.

7.3.1 Evaluation of Cleanup Action Alternatives for Soil

As described in the following sections, two soil cleanup action alternatives were evaluated in detail – Soil Alternative 1: No Action and Soil Alternative 2: SVE.

7.3.1.1 Soil Alternative 1: No Action

Description

The No Action alternative is evaluated as a cleanup action alternative for the purpose of comparison to active cleanup action alternatives. The No Action alternative assumes that no action is taken, no monitoring is performed, and no costs are incurred.

Threshold Requirements

The No Action soil cleanup action alternative does not meet the threshold requirements due to the following.

- This alternative is not protective of human health and the environment as unacceptable exposures to COCs are not addressed.
- This alternative does not comply with the cleanup standards that require COC concentrations at the Site to be reduced to below cleanup levels.
- Numerical standard ARARs were incorporated into the cleanup level determination. This alternative does not comply with the cleanup standards so does not meet the numerical ARARs. Because there is no action, there are no procedural ARARs applicable to this alternative.
- The alternative does not include compliance monitoring to evaluate compliance with cleanup levels.

Use of Permanent Solutions

The No Action cleanup alternative is not a permanent solution as defined by WAC 173-340-200.

Restoration Timeframe

It is not expected that this alternative would achieve cleanup goals within a reasonable timeframe.

Public Concerns

It is anticipated that there would be substantive public concerns with the implementation of the No Action alternative.

Prevent/Minimize Releases and Migration of Hazardous Substances in the Environment

The No Action alternative does not prevent current or future releases of the hazardous substances to the environment.

Degree to Which Cleanup Action Relies on Dilution/Dispersion

The No Action alternative would rely on a combination of natural processes including dispersion for reduction of COC concentrations. It is anticipated that anaerobic biodegradation and volatilization/dispersion/chemical degradation would dominate long-term reduction of COCs in soil.

Institutional Controls

This alternative does not include institutional controls that are required if concentrations above Method A or B cleanup levels are present.

7.3.1.2 Soil Alternative 2: SVE

Description

SVE is an *in situ* vadose zone soil remediation technology in which a vacuum is applied to the soil to induce the controlled flow of air and remove volatile compounds from the soil. Soil vapor is extracted through vertical wells (or horizontal vents) and is typically treated by passing through activated carbon prior to being discharged to outdoor air. SVE has been used at the Site as in interim action to address source area vadose zone soils above cleanup levels.

Figure 7-6 shows the layout of the interim action SVE system, the approximate area treated by the system, and the soil area above cleanup levels. As the observed area of HVOC concentrations above cleanup levels is within the area treated by the interim action SVE system, the SVE cleanup action alternative consists of the continued operation of the existing interim action SVE system. The interim action SVE system is described in Sections 2.2.7.2 and 2.2.7.3. Since startup in September 2008 through June 2013, the system has removed on the order of 4,500 pounds of VOCs, and the instantaneous rate of removal has dropped from an initial rate on the order of 5 pounds of VOCs per day to 1 to 2 pounds of VOCs per day as of June 2013. Much of the VOC mass that had been bound in the relatively porous sand portion of the vadose zone soil has been removed by the operation of the SVE system and the residual mass is predominantly contained within the relatively thin silt layers. This was verified during the 2010 soil confirmation sampling event described in Section 2.2. The continued removal of mass from the fine-grained soil is limited by the concentration gradient within the silt layers, resulting in a relatively low but fairly constant generation of VOCs. During the operation period, the SVE system would also address potential vapor emissions from soil or groundwater by intercepting those emissions in the subsurface (preventing migration to indoor air).

It is anticipated that operation of the SVE system will eventually reach the point of negligible marginal benefit. Additionally, low residual concentrations of COCs may be present outside of the SVE treatment area (for example, from adsorption of vapor emanating from underlying contaminated groundwater). These residual concentrations would be addressed through natural attenuation. Based on the rate of VOC removal of SVE systems in similar soil conditions and the performance of the interim action SVE system, it is anticipated that the SVE system would require three years or less to remove residual VOC mass from the sandier portions of the soil and an additional three to five years to address the VOC mass within the silt layers. The current interim action system has been operating for over five years in in the northern area and over two years in the southern area. Therefore, it was assumed that an additional three years of operation would be required before shutdown of the SVE system. Substantive treatment of the underlying groundwater (see discussion in Section 7.3.2.3) would be achieved within three to five years and natural attenuation of the overlying vadose zone is assumed to follow within an additional two years. The overall estimated timeframe to achieve soil cleanup levels (assuming concurrent groundwater cleanup) is on the order of eight to 10 years.

During the time period until cleanup levels are achieved, soils generated from any construction projects on the property within the soil source area could contain residual levels of COCs. A soil management plan would be prepared to identify protocols for the handling and management of contaminated soil during future site work to protect workers, public health, and the environment.

Compliance monitoring would consist of vapor discharge monitoring during operation of the SVE system. The SVE system operation may be pulsed (turned off for some designated timeframe, then restarted) to evaluate the potential for concentration rebound. If discharge concentrations are low and rebound does not occur, this would indicate that the remedial objectives for the SVE system had been achieved. Final verification monitoring would be conducted by sampling soil to verify that cleanup levels have been achieved.

The estimated present worth cost for this alternative is $240,000. This present worth cost includes operation, maintenance, monitoring, and Ecology oversight over a three-year period, verification sampling at the completion of active operation of the SVE system, and a final round of verification sampling following completion of groundwater cleanup and natural attenuation of residual VOCs in vadose soil (year 10). A detailed breakdown of the cost estimate is provided in Appendix D-4.

Threshold Requirements

The SVE soil cleanup action alternative meets the threshold requirements, as follows.

- This alternative protects human health and the environment by removing COCs from soil and treating the soil vapor stream with activated carbon as needed to prevent unacceptable exposures. Residual COCs in soil outside the zone treated with SVE would be addressed by natural attenuation. Cleanup levels in soil are expected to be achieved in 10 years or less.
- The alternative complies with the cleanup standards by reducing COC concentrations throughout the soil column (together with the groundwater alternative to address saturated soil; see below) and throughout the Site to below cleanup levels.
- Numerical standard ARARs were incorporated into the cleanup level determination. Procedural ARARs applicable to this alternative include the following.
    - Resource Conservation and Recovery Act (RCRA) and State Hazardous Waste Management Act – The spent carbon generated from treatment of the vapor stream would be a hazardous and dangerous waste and would be managed and disposed/recycled in accordance with the requirements of these laws.
    - Federal and State Clean Air Acts – Vapor discharges would be managed and permitted as required by these laws.
    - State Environmental Policy Act (SEPA) – In accordance with WAC 197-11-253 through -268, Ecology, as the lead agency, would conduct an environmental review to make a determination as to whether the project would have a significant adverse environmental impact. As presented above, it is unlikely that the project would have an adverse impact, but, if necessary, changes could be made to address identified adverse impacts.
- The alternative includes compliance monitoring to verify that cleanup levels have been achieved.

Use of Permanent Solutions

This soil cleanup action is a permanent solution as defined by WAC 173-340-200, so a disproportionate cost analysis is not required.

Restoration Timeframe

Active treatment of source area vadose zone soil would be complete within approximately three years. Current potential pathways (direct contact, vapor intrusion) are addressed immediately by the operating SVE system and the soil management plan. Residual COCs would be addressed to cleanup levels by natural attenuation within an additional seven years or less (allowing for concurrent groundwater cleanup) for a total estimated restoration time of 10 years or less. Therefore, this proposed restoration timeframe is reasonable.

Public Concerns

The proposed action would be submitted for public comment and concerns raised would be addressed prior to design and implementation. This system has been operating as an interim action for five years and no public concerns have been identified. Based on the proposed action addressing the site soil to cleanup levels, and the location of the site within an industrial area, it is anticipated that there would not be substantive public concerns with the proposed soil cleanup action.

Prevent/Minimize Releases and Migration of Hazardous Substances in the Environment

Upon implementation of the remedy, migration of COCs from soil to groundwater or to overlying air would be controlled by the SVE system. During the following period of natural attenuation, soil concentrations would be below concentrations protective of vapor intrusion, and concurrent groundwater treatment would address potential migration to groundwater. Upon completion of the remedy (including the period of natural attenuation during groundwater treatment), concentrations of COCs would meet cleanup levels. Therefore, the proposed remedy prevents current or future releases of the hazardous substances to the environment.

Degree to Which Cleanup Action Relies on Dilution/Dispersion

The alternative primarily relies on SVE that is a permanent solution and does not rely on dilution or dispersion. MNA to address residual COCs would rely on a combination of natural processes including dispersion for reduction of COC concentrations. It is anticipated that anaerobic biodegradation and volatilization/dispersion/chemical degradation would dominate long-term reduction of COCs in soil.

7.3.2 Evaluation of Cleanup Action Alternatives for Groundwater

As described in the following sections, three groundwater cleanup action alternatives were evaluated in detail – Groundwater Alternative 1: No Action, Groundwater Alternative 2: Hydraulic Containment, and Groundwater Alternative 3: Enhanced Bioremediation.

7.3.2.1 Groundwater Alternative 1: No Action

Description

The No Action alternative is evaluated as a cleanup action alternative for the purpose of comparison to active cleanup action alternatives. The No Action alternative assumes that no action is taken, no monitoring is performed, and no costs are incurred.

Threshold Requirements

The No Action groundwater cleanup action alternative does not meet the threshold requirements due to the following.

- This alternative is not protective of human health and the environment as unacceptable exposures to COCs are not addressed.
- The alternative does not comply with the cleanup standards that require COC concentrations at the source area to be reduced to below cleanup levels.
- Numerical standard ARARs were incorporated into the cleanup level determination. This alternative does not comply with the cleanup standards so does not meet the numerical ARARs. Because there is no action, there are no procedural ARARs applicable to this alternative.
- The alternative does not include compliance monitoring to evaluate compliance with cleanup levels.

Use of Permanent Solutions

The No Action cleanup alternative is not a permanent solution as defined by WAC 173-340-200.

Restoration Timeframe

It is not expected that this alternative would achieve cleanup goals within a reasonable timeframe.

Public Concerns

It is anticipated that there would be substantive public concerns with the implementation of the No Action alternative.

Prevent/Minimize Releases and Migration of Hazardous Substances in the Environment

The No Action alternative does not prevent current or future releases of the hazardous substances to the environment.

Degree to Which Cleanup Action Relies on Dilution/Dispersion

The No Action alternative would rely on a combination of natural processes including dispersion for reduction of COC concentrations. It is anticipated that anaerobic biodegradation and volatilization/dispersion/chemical degradation would dominate long-term reduction of COCs in groundwater.

7.3.2.2 Groundwater Alternative 2: Hydraulic Containment

Description

For this alternative, groundwater pumping wells would be installed within the shallow zone and a groundwater treatment system would be constructed. Figure 7-7 shows the conceptual layout of this alternative. The goal of the groundwater wells would be to create a cone of depression that encompasses the groundwater cleanup area, acting to contain migration of relatively higher concentrations of dissolved-phase HVOCs within the shallow zone (laterally and vertically), effectively preventing migration of HVOCs away from the source area.

Containment pumping would also remove contaminant mass from groundwater and saturated soil.

Based on the previous aquifer testing at the NuStar facility, the average shallow zone aquifer transmissivity is 3.6 ft2/min (Apex 2013a). This results in an estimated total extracted flow on the order of 40 gpm for a single well with a target radius of influence of 90 feet (see Appendix D-5; suitable to cover the width of the target treatment area). To cover the full groundwater source area, a total of four wells would be needed (as shown on Figure 7-7) for an expected total groundwater extraction rate of about 160 gpm. The extracted groundwater would be treated to approved levels and discharged to surface water (i.e., the storm sewer system or directly to the Columbia River) under an NPDES permit. The groundwater treatment would consist of aqueous-phase activated carbon. The final design of the layout and treatment system would require pilot testing to verify the design parameters prior to implementation.

Operation and maintenance requirements are based on the estimated flow rate of 160 gpm for the total extraction rate, and an estimated design influent concentration for the groundwater treatment system of an initial average of 2.6 mg/L total VOCs that is assumed to drop to a long-term concentration of 0.5 mg/L total VOCs within four years of operation (based on experience with similar extraction systems). Water discharges would be monitored in accordance with discharge permits, assumed to be monthly monitoring in accordance with presumed NPDES permit requirements.

Monitoring of shallow and intermediate zone groundwater would be conducted quarterly upon startup for a period of two years, semi-annually for the next three years, and annually for several decades thereafter.

Restrictions on groundwater use at the property containing the source area would be required.

Currently, the area above the source area groundwater is not accessed on continuous basis by site workers and the building structures have intact concreate flooring and are naturally ventilated (open garage doors, roof and/or wall vents, etc.), allowing constant flow from outdoor air, therefore unacceptable vapor intrusion risks were not identified.. In the event that a more intensive use building is constructed in the impacted area, a vapor barrier could be incorporated into the building to address the potential vapor intrusion pathway.

The pumping system would likely achieve cleanup levels at the NuStar facility boundary within less than 5 years, but would likely require greater than 30 years to reduce concentrations of COCs in the source area to below cleanup levels. For cost estimating purposes, it was assumed that the pumping system would operate for a period of 30 years. Thereafter, MNA would be used to address residual concentrations within the treatment area. It is anticipated that MNA would likely require greater than 20 additional years to treat the area within the pumping zone after pumping is terminated. Therefore, it is likely that greater than 50 years would be required to achieve cleanup levels.

The estimated present worth cost for this alternative is $2,110,000. The capital cost is estimated to be approximately $410,000. The present worth of the operation, maintenance, monitoring, and Ecology oversight costs are estimated to be $1,700,000 over a 50-year period. A detailed breakdown of the cost estimates is provided in Appendix D-4.

Threshold Requirements

The hydraulic containment alternative meets the threshold requirements as follows.

- This alternative protects human health and the environment by containing COCs within the source area and treating the water stream with aqueous-phase activated carbon. MNA is used to treat residual concentrations of COCs after pumping is complete. This alternative also prevents migration of COCs away from the source area and to adjacent sediments. Using the property boundary as an alternative point of compliance, cleanup levels would be achieved within 5 years. Cleanup levels would be achieved throughout the source area groundwater within approximately 50 years.

- The alternative complies with the cleanup standards by containing COCs within the source area in the short term. In the long term, cleanup standards are achieved by reducing COC concentrations to below cleanup levels using a combination of active treatment and MNA to address residual concentrations.
- Numerical standard ARARs were incorporated into the cleanup level determination. Procedural ARARs applicable to this alternative include the following.
  - RCRA and State Hazardous Waste Management Act – The spent carbon generated from treatment of the water stream would be a hazardous and dangerous waste and would be managed and disposed/recycled in accordance with the requirements of these laws.
  - Federal Clean Water Act and State Water Pollution Control Act – Discharges of water from the treatment system would meet these requirements by being permitted under NPDES requirements, including a water quality certification from Ecology.
  - State Water Resources Act – The state has jurisdiction over water resources. Withdrawal of groundwater for treatment would be conducted in accordance with water resources requirements.
  - SEPA – In accordance with WAC 197-11-253 through -268, Ecology, as the lead agency, would conduct an environmental review to make a determination as to whether the project would have a significant adverse environmental impact. As presented above, it is unlikely that the project would have an adverse impact, but, if necessary, changes could be made to address identified adverse impacts.
- The alternative includes compliance monitoring to verify that cleanup levels have been achieved.

Use of Permanent Solutions

This groundwater cleanup action is a permanent solution as defined by WAC 173-340-200.

Restoration Timeframe

It is estimated that the hydraulic containment alternative would require on the order of 50 years to achieve cleanup levels. For the following reasons, this restoration timeframe is considered to be reasonable.

- The potential risks associated with the groundwater at the NuStar site are drinking water, vapor intrusion, and migration to the river and river sediments. There are no current drinking water exposures at the property containing the source area. There is potential risk from future pumping of groundwater for use as drinking water, but this is not likely to occur within the restoration timeframe. Much of the risk from migration to the river and river sediments would be addressed soon after implementation by reversal of the groundwater gradient induced by the pumping in the source area. Potential vapor intrusion risk for future buildings would be addressed with a vapor barrier.

- Through more aggressive treatment of the source area, it is possible to achieve a shorter restoration timeframe, but the potential risks to human health and the environment can be managed during the additional time required by the hydraulic containment alternative.
- In general, the groundwater impacts do not have a substantive impact on property uses or resources.
- Because municipal water and other off-site domestic water (Port of Vancouver) is available, groundwater at the property is not currently used for drinking water.
- Institutional controls to address groundwater would include restrictions on groundwater use. This type of institutional control is effective and reliable.
- There is a long history of groundwater monitoring at the NuStar site. The migration of hazardous substances is understood, and the pumping alternative would control the migration at the source area.
- Although the hazardous substances at the site have relatively high toxicities, exposures to the hazardous substances would be controlled relatively quickly.
- Natural biodegradation has been demonstrated to be occurring in the shallow zone in the vicinity of the source area.

Public Concerns

The proposed action would be submitted for public comment and concerns raised would be addressed prior to design and implementation. It is anticipated that potential concerns of the public would be similar between the potential groundwater cleanup action alternatives, but there could be greater concern for this alternative relative to others because of the potential restoration timeframe.

Prevent/Minimize Releases and Migration of Hazardous Substances in the Environment

Upon implementation of the remedy, migration of COCs from the source area groundwater would be prevented. Reductions in extent would occur as the source area concentrations are reduced by the pump/treat system.

Degree to Which Cleanup Action Relies on Dilution/Dispersion

The alternative relies upon active removal and treatment for the bulk of the risk reduction. Some of the benefit of MNA results from dilution and dispersion, but the primary mechanism for MNA is biological breakdown.

7.3.2.3 Groundwater Alternative 3: Enhanced Bioremediation

Description

The enhanced bioremediation alternative increases the rate of the natural anaerobic reductive dechlorination of chlorinated COCs through the addition of a long-term carbon source (acting as an electron donor for the microbially induced dechlorination reaction). The technology generally involves injecting an emulsified vegetable oil substrate (or equivalent) into the groundwater cleanup action area. Figure 7-8 shows the proposed design of the enhanced bioremediation alternative as further summarized below. The proposed design is based on the interim action using the same approach that was successfully implemented at the NuStar facility beginning in 2008 and expanded in 2011.

As discussed in Section 7.1.2, the proposed groundwater cleanup action area is essentially the portion of the groundwater source area that was not previously addressed by previous interim action activity. Because of concerns over impacting surface waters with the substrate injections, the interim action maintained a 120-foot buffer zone along the river where no injections were conducted. Subsequent monitoring of the groundwater chemistry downgradient of the injection area (toward the river) has shown little if any impacts at distances of 35 to 50 feet away from the injection zone. The groundwater velocity in the vicinity of the seawall is expected to be higher than the interim action portion of the source area, primarily due to the daily flushing of water due to the tides. Migration of bioinjection substrate from areas closer to the seawall may extend beyond 50 feet from the injection point. There is a wedge of soil ranging in thickness from 20 to 60 feet between the seawall and the shoreline that is likely also impacted with respect to COPCs. Injecting dissolved substrate material as far downgradient as the seawall will ensure that bioremediation in the soil wedge is enhanced. Although some substrate could reach the river, it would be limited in extent, degrade readily, and the net benefit (e.g., addressing the VOCs in the “wedge area”) would be greater than the short term release of the substrate to the river..

Calculations to estimate the amount of the bioremediation substrate to inject are included in Appendix D-5. The calculations use a vendor-provided spreadsheet and basic information on the contamination and subsurface conditions to estimate the amount of oil required. In summary, input parameters included the following (consistent with the design of the interim action bioremediation injection):

- Dimensions of the total area proposed for injection treatment is 540 by 80 by 25 feet. There is the potential for the injected substrate to deplete before the source area contamination targeted by the injections is fully degraded. This alternative, therefore, includes a follow-up injection that is assumed to be 15 percent of the total groundwater treatment area (i.e., the follow-up area is the equivalent of an area 200 feet by 80 feet for a total of 16,000 square feet).
- The soil default of “sand” was selected and the corresponding default soil properties were used.
- Based on previous aquifer testing, the average shallow zone aquifer transmissivity is 3.6 ft2/min (Apex 2013a). The saturated thickness in the injection zone is 23 feet on average, resulting in a hydraulic conductivity of 230 feet per day.
- Based on average annual groundwater elevations across the treatment area, a hydraulic gradient of 0.0005 was selected.
- A design life of three years was selected, with a microbial degradation factor of 5 (recommended value).
- Chemical parameters for both the target chemicals and competing electron donors were entered.
- Concentrations used for the near-river injection zone were average concentrations in the source area during the first quarter of 2013. As previously discussed, first quarter concentrations represent the highest concentrations in 2013 given annual seasonal variability. Concentrations for the follow-up injection were assumed to be similar to

current conditions (allowing for rebound in the groundwater concentrations after the depletion of the injection substrate).

The output of the calculations is the estimated amount of oil substrate needed – in this case a total of about 109,000 pounds (plus 40,000 pounds for the follow-up injection). The total includes the amount needed for the target compounds, the amount needed based on competing electron donors, and the amount needed taking into consideration the movement of groundwater through the area (thereby removing the oil substrate from the target area). Based on the experience from the interim action, this quantity may be high because the loss from migration is likely less than estimated from the model. This would be further evaluated during final design.

The layout of the injection points would be determined in the implementation work plan such that the indicated mass of oil is injected uniformly across the treatment area. The proposed design spacing (see Figure 7-8) is the same as used for the interim action. A total of 250 drums of oil substrate would be injected in the target zone (90 drums for the follow-up). The substrate is typically mixed with water at a ratio on the order of 9:1 water to substrate. This would result in an injection volume on the order of 136,000 gallons (50,000 gallons in the follow-up). Diffusion/advection throughout the life of the substrate (at least three years) would distribute the substrate through areas not directly injected.

There are no operation and maintenance requirements for this alternative.

Groundwater monitoring would be conducted quarterly on initial injection for a period of two years and semi-annually for the next eight years.

Restrictions on groundwater use at the property containing the source area would be required.

Based on experience at the NuStar site during the interim action and experience at other sites, it is expected that enhanced bioremediation can treat groundwater to below detection limits within 3 to 5 years. Small pockets of DNAPL may be present in the subsurface (particularly bound in zones of relatively fine-grained soil), potentially causing groundwater concentrations to rebound after several years. However, groundwater data collected between the 2008 and 2011 groundwater interim actions suggest that rebound, if any, has been minimal. Additional oil substrate may need to be injected in focused areas, extending the time period to achieve cleanup. The design includes a second injection to address residual areas within the treatment area. Therefore, the estimated time to achieve cleanup levels within the groundwater source area is 6 to 10 years.

The estimated present worth cost for this alternative is $750,000. The capital cost (including oversight) is estimated to be approximately $430,000. Groundwater monitoring (including oversight) over a 10-year period has a present worth cost of $320,000. A detailed breakdown of these costs is presented in Appendix D-4.

Threshold Requirements

The enhanced bioremediation alternative meets the threshold requirements as follows.

- This alternative protects human health and the environment by treating COCs in groundwater and saturated soil to below cleanup levels. Cleanup levels would be achieved in six to 10 years.
- The alternative complies with the cleanup standards by reducing COC concentrations throughout the source area groundwater to below cleanup levels using active biological treatment.

- Numerical standard ARARs were incorporated into the cleanup level determination. Procedural ARARs applicable to this alternative include the following.
  - Federal Clean Water Act and State Water Pollution Control Act – The injection program would be designed to limit organic carbon in groundwater discharging to the river.
  - Underground Injection Control (UIC) – The injection program would be permitted under the state UIC program (implementing both state and federal requirements).
  - SEPA – In accordance with WAC 197-11-253 through -268, Ecology, as the lead agency, would conduct an environmental review to make a determination as to whether the project would have a significant adverse environmental impact. As presented above, it is unlikely that the project would have an adverse impact, but, if necessary, changes could be made to address identified adverse impacts.
- The alternative includes compliance monitoring to verify that cleanup levels have been achieved.

Use of Permanent Solutions

This groundwater cleanup action is a permanent solution as defined by WAC 173-340-200.

Restoration Timeframe

It is estimated that the enhanced bioremediation alternative would require six to 10 years to achieve cleanup levels within the source area. For the following reasons, this restoration timeframe is considered to be reasonable.

- The potential risks associated with the groundwater at the Site are drinking water, vapor intrusion, and migration to the river. There are no current drinking water exposures at the property containing the source area. There is potential risk from future pumping of groundwater for use as drinking water, but this is not likely to occur within the restoration timeframe. Much of the risk from migration to the river would be addressed by actively treating the majority of groundwater with the potential to impact surface water. Similarly, groundwater with the potential to contribute to vapor intrusion would be addressed within a few years by active treatment. In the interim, if necessary, potential vapor intrusion for future buildings would be addressed with a vapor barrier.
- Based on experience with chlorinated solvents in groundwater and the interim action, it is not practicable to achieve a shorter restoration timeframe.
- In general, the groundwater impacts do not have a substantive impact on property uses or resources.
- Because municipal water and other off-site domestic water (Port of Vancouver) is available, groundwater at the property is not currently used for drinking water.
- Institutional controls to address groundwater would include restrictions on groundwater use. This type of institutional control is effective and reliable.
- There is a long history of groundwater monitoring at the site. The migration of the hazardous substances is understood, and the higher-concentration areas acting as ongoing sources for migration would be treated within a few years.

- Although the hazardous substances at the NuStar site have relatively high toxicities, significant concentration reductions occur relatively quickly (within one to two years) and the remainder of the restoration time is associated with cleanup of residual concentrations.
- Natural biodegradation has been demonstrated to be occurring in the shallow zone in the vicinity of the source area.

Public Concerns

The proposed action would be submitted for public comment and concerns raised would be addressed prior to design and implementation. It is anticipated that potential concerns of the public would be similar between the potential groundwater cleanup action alternatives.

Prevent/Minimize Releases and Migration of Hazardous Substances in the Environment

The source area groundwater would be treated within a few years.

Degree to Which Cleanup Action Relies on Dilution/Dispersion

The alternative relies upon active treatment for the risk reduction.

7.3.2.4 Disproportionate Cost Analysis of Groundwater Alternatives

The potential groundwater cleanup action alternatives were subjected to a disproportionate cost analysis following the procedure from WAC 173-340-360(3)(e) to rank the alternatives from most to least permanent (see Section 6).

Ranking of Alternatives

The groundwater alternatives were ranked from most to least permanent based on a comparative analysis using the criteria from WAC 173-340-360(3)(f) as summarized in Section 6. The comparative analysis is a one-to-one assessment of the relative merits of each alternative for each of the evaluation criteria. Table 7-4 summarizes the comparative analysis. Each alternative was ranked as favorable (+), equal (0), or unfavorable (-) in relation to the other alternatives for each of the evaluation criteria. The rankings of (+), (0), or (-) were given a score of 1, 0, or -1, respectively. The scores are summed at the right of the table for each alternative, and the alternatives are ranked. The following discussion provides a rationale for the comparative evaluation presented in Table 7-4.

- Protectiveness – The no action alternative is not protective. The remaining alternatives are similar in overall protectiveness except that the hydraulic containment alternative would take longer to achieve cleanup levels.
- Permanence – The no action alternative is not permanent. Each of the remaining alternatives is similar in permanence in that each treats the source area constituting the majority of site risk.
- Cost – The total present worth costs for the groundwater alternatives are summarized as follows:
  - No Action – $0
  - Enhanced Bioremediation – $750,000
  - Pump/Treat – $2,100,000

- Long-Term Effectiveness – The long-term effectiveness of the enhanced bioremediation alternative is considered the highest because the technology has been demonstrated to be effective at the site and experience demonstrates that the COCs can be treated to below detection limits. Hydraulic containment is ranked lower because experience has shown that pump/treat may not achieve MCLs within a reasonable timeframe for chlorinated COCs. The pumping alternative also requires constant maintenance and upkeep to remain effective. No action has no long-term effectiveness.
- Management of Short-Term Risks – No action has no short-term risks. Enhanced bioremediation has a slightly higher risk than hydraulic containment, associated with the potential for groundwater with high organic carbon to migrate to surface water. This risk is relatively low based on the observed behavior of the interim action injections and the limited groundwater flow from the treatment area relative to the surface water flow, and the risk would be addressed through careful design and monitoring of the injection program.
- Technical and Administrative Implementability – No action is easily implemented. The enhanced bioremediation and hydraulic containment alternatives have a similar degree of implementability. Both use proven technologies that are readily available.
- Consideration of Public Concerns – No action is likely to have significant public concerns. Enhanced bioremediation is unlikely to have substantive concern. Hydraulic containment may have some concerns based on the relatively long timeframe for restoration.

Based on the comparative analysis, the alternatives are ranked from most to least permanent as follows:

- Enhanced Bioremediation;
- Pump/Treat; and
- No Action.

Disproportionate Cost Comparison of Groundwater Alternatives

The enhanced bioremediation alternative is the most permanent alternative. Additionally, it is the least costly of the protective alternatives. Therefore, the enhanced bioremediation alternative is recommended for implementation for groundwater cleanup.

7.3.3 Evaluation of Cleanup Action Alternatives for Sediment

As described in the following sections, three sediment cleanup action alternatives were evaluated in detail – Sediment Alternative 1: No Action, Sediment Alternative 2: Source Control, and Sediment Alternative 3: Reactive Cap.

7.3.3.1 Sediment Alternative 1: No Action

Description

The No Action alternative is evaluated as a cleanup action alternative for the purpose of comparison to active cleanup action alternatives. The No Action alternative assumes that no action is taken, no monitoring is performed, and no costs are incurred.

Threshold Requirements

The No Action sediment cleanup action alternative does not meet the threshold requirements due to the following.

- This alternative is not protective of human health and the environment as unacceptable exposures to COCs are not addressed.
- The alternative does not comply with the cleanup standards that require COC concentrations in the sediments to be reduced to below cleanup levels.
- Numerical standard ARARs were incorporated into the cleanup level determination. This alternative does not comply with the cleanup standards so does not meet the numerical ARARs. Because there is no action, there are no procedural ARARs applicable to this alternative.
- The alternative does not include compliance monitoring to evaluate compliance with cleanup levels.

Use of Permanent Solutions

The No Action cleanup alternative is not a permanent solution as defined by WAC 173-340-200.

Restoration Timeframe

It is not expected that this alternative would achieve cleanup goals within a reasonable timeframe.

Public Concerns

It is anticipated that there would be substantive public concerns with the implementation of the No Action alternative.

Prevent/Minimize Releases and Migration of Hazardous Substances in the Environment

The No Action alternative does not prevent current or future releases of the hazardous substances to the environment.

Degree to Which Cleanup Action Relies on Dilution/Dispersion

The No Action alternative would rely on a combination of natural processes including dispersion for reduction of COC concentrations. It is anticipated that dispersion and chemical degradation would dominate long-term reduction of COCs in sediments.

7.3.3.2 Sediment Alternative 2: Source Control

Description

For this alternative, active treatment of the groundwater source would be used to eliminate the ongoing source of HVOCs to sediment via the groundwater pathway. Thereafter, MNR would result in reduction of sediment concentrations to below cleanup levels. For the purpose of the sediment cleanup action alternative analysis, it is assumed that a groundwater cleanup action is implemented for the sole purpose of groundwater cleanup. Therefore, the groundwater cleanup actions are not included in this sediment alternative.

This alternative includes restrictions on access to the impacted sediments such as notifications and advisories.

For the purpose of the restoration timeframe discussion, it was assumed that enhanced bioremediation is implemented as the shallow groundwater remedial action and also acts as a source control action for sediment. Based on the assessment of this approach described in Section 7.3.2, groundwater concentrations are anticipated to be below MCLs in 3 to 5 years in most areas of the NuStar site. The limited areas that have not achieved goals would not be anticipated to provide a significant recontamination source to sediments. Based on Darcy's Law and a three-phase partitioning evaluation, it was estimated that approximately 2 years would be required for sediments to reach cleanup levels after groundwater cleanup levels are predominantly achieved. Supporting calculations are presented in Appendix D-5. Therefore, the overall timeframe to achieve sediment cleanup levels is estimated to be 5 to 7 years.

Three rounds of sediment monitoring would be conducted. A baseline sediment sampling event would be conducted prior to the final groundwater cleanup. A second sediment sampling event would be conducted when groundwater cleanup is near completion, and a third event would be conducted for possible compliance purposes.

The estimated present worth cost for this alternative is $248,100. This cost is for sediment confirmation sampling that is assumed to be completed in years 3, 5, and 7. A detailed breakdown of these costs is presented in Appendix D-4.

Threshold Requirements

The source control alternative meets the threshold requirements as follows.

- This alternative protects human health and the environment using MNR to treat residual COCs in sediments. The alternative relies on source control to prevent re-contamination.
- The alternative complies with the cleanup standards by reducing COC concentrations in site sediments to below cleanup levels.
- Numerical standard ARARs were incorporated into the cleanup level determination. Procedural ARARs applicable to this alternative include the following.
    - SEPA – In accordance with WAC 197-11-253 through -268, Ecology, as the lead agency, would conduct an environmental review to make a determination as to whether the project would have a significant adverse environmental impact. As presented above, it is unlikely that the project would have an adverse impact, but, if necessary, changes could be made to address identified adverse impacts.
- The alternative includes compliance monitoring to verify that cleanup levels have been achieved.

Use of Permanent Solutions

This sediment cleanup action is a permanent solution as defined by WAC 173-340-200.

Restoration Timeframe

It is estimated that the source control alternative would require 5 to 7 years to achieve cleanup levels in the sediments. For the following reasons, this restoration timeframe is considered to be reasonable.

- The primary human health risks are based on potential lifetime exposures that are generally not currently present (the site is in an industrial area that is generally not conducive to recreation or fishing and there are no nearby water intakes). Therefore, actual risks to human health during the restoration period are negligible. Notices/signage could be used to further reduce this potential risk. Ecological risks are limited because of the relatively small area of impact and the poor habitat (presence of riprap, nearby dredged ship channel, and the river reach is relatively unprotected from currents).
- The restoration timeframe is primarily controlled by the time required to complete source control, and that time is the practicable shortest restoration timeframe for source control.
- In general, the sediment impacts do not have a substantive impact on property uses or resources.
- Institutional controls would include restrictions on access to the area of impacted sediments. The area is generally unsuitable for recreational uses and access restrictions would be effective to minimize human health risks. Institutional controls would not be effective for ecological exposures.
- Although the hazardous substances at the Site have relatively high toxicities for human health, access to the sediments is limited and it is not practicable to address the source to the sediments in a shorter timeframe. Because the hazardous substances are generally not bioaccumulative, ecological toxicity is relatively lower.
- The hazardous substances present in the sediments are sustained by the ongoing groundwater source. Multiple processes, dominated by dispersion/chemical degradation in the sediment/surface water environment, will reduce concentrations once the source is eliminated.

Public Concerns

The proposed action would be submitted for public comment and concerns raised would be addressed prior to design and implementation. It is anticipated that potential concerns of the public would be similar between the potential sediment cleanup action alternatives, except that the source control alternative may have greater concern because of the longer restoration timeframe.

Prevent/Minimize Releases and Migration of Hazardous Substances in the Environment

The primary mechanism for migration of hazardous substances is the ongoing groundwater source. Once the source is eliminated, the potential for further migration would be eliminated.

Degree to Which Cleanup Action Relies on Dilution/Dispersion

The bulk of the hazardous substance mass that could potentially impact sediments in the long term will be treated by the source control action. The residual mass in the sediments will be reduced by multiple natural processes, dominated by desorption and degradation in the sediment/surface water environment.

7.3.3.3 Sediment Alternative 3: Dredging

Description

The extent of sediments containing VOCs is shown on Figure 7-5. Alternative 3 would consist of dredging the upper 1 to 3 feet of sediment in this area to remove sediment containing VOCs above sediment cleanup objectives (Table 5-2). An anticipated 9,000 tons of sediment across an approximate 500 foot by 150 foot area as shown on Figure 7-5 would be removed.

Several methods are available for the sediment dredging, including mechanical wet dredging (such as using a barge-mounted excavator to remove sediments), mechanical dry dredging (dewatering the area to be dredged and removing sediments using traditional excavation methods), and hydraulic dredging (using suction to remove sediments). Mechanical dry dredging would not be feasible along the river as it would require the installation of a significant coffer dam that would be impractical in the vicinity of the dock). The presence of the dock also complicates the implementation of the mechanical wet dredging option, particularly among the dock and dolphin piling. For the purposes of this evaluation, therefore, it is assumed that hydraulic dredging will be used.

In general, hydraulic dredging involves lowering a boom with a rotating cutterhead or horizontal auger into the sediment together with a suction hose to pull in the loosened sediment. The boom crane and associated equipment would be mounted on a small barge that could navigate across the sediment removal area and around the dock piling. The sediment slurry is pumped through a pipeline to a centralized upland location for dewatering. An advantage of hydraulic dredging is that it typically generates less turbidity than do mechanical dredges, but it does generate significantly more water which needs to be managed properly.

There are similarly several available options for dewatering the removed sediment, including the use of geotubes, dewatering basins, mechanical dewatering, or bulk transport. The upland Site in the vicinity of the area to be dredged is not suitable for the construction of dewatering basins due to the large size of the basins that would be needed which would be incompatible with the Site use. A similar issue would be realized with the bulk transport option, as significant storage capacity would be needed either in temporary storage tanks or in a high volume of tanker traffic – neither of which would be practicable. Given the relatively high volume of water that would be generated by the hydraulic dredging operation it is expected that mechanical dewatering may be less practical than geotube dewatering, as mechanical dewatering rates are generally slow compared to hydraulic dredge recovery rates, suggesting that numerous filter presses would be needed and geotube dewatering methods are therefore considered for the purposes of this evaluation.

The geotube methods of dewatering generally includes pumping the dredge slurry into the tube, which acts as a filter media to contain the sediment solids while allowing the water fraction to permeate through the geotube membrane. The water fraction is then collected and processed through a treatment system to remove turbidity (i.e., sediment fines that are passed through the geotube membrane) and VOCs. The treated water is then piped to a discharge point, such as back into the river, as regulatory and permitting requirements allow.

Design considerations include the following.

- Riprap is present along the shoreline to prevent erosion from wave action, and this riprap would be replaced and/or maintained.

- Dredging operations require significant permitting and are allowed only during certain seasonal windows of opportunity.
- Operation of the hydraulic dredge within the footprint of the wharf and dolphin pilings will likely require in-water divers to manipulate the suction head.
- Dewatering operations will require an upland area that will need to be coordinated with ongoing site activities.

There are no operation and maintenance requirements for this alternative. This alternative would have significant short-term disruption to the existing habitat, but would be protective immediately after implementation. If this approach is implemented prior to cleanup of shallow groundwater, the sediments may be recontaminted by upland groundwater containing VOCs. Following achievement of acceptable groundwater quality, sediment sampling would be used to document the final sediment quality.

The estimated present worth cost for this alternative is $3,400,000. The capital cost (including oversight) is estimated to be approximately $3,310,000. Long-term costs consist of sediment verification sampling at a present value cost of $90,000. A detailed breakdown of these costs is presented in Table 7.4-5.

Threshold Requirements

The dredging alternative meets the threshold requirements as follows.

- This alternative protects human health and the environment by removing contaminant mass from the area of impacted sediments and treating COCs in groundwater/sediments.
- The alternative complies with the cleanup standards by preventing contact with impacted sediments; however, if implemented prior to source control, it is likely that the sediment area will become recontaminated.
- Numerical standard ARARs were incorporated into the cleanup level determination. Procedural ARARs applicable to this alternative include the following.
    - RCRA and State Hazardous Waste Management Act – Removed sediments would be solid, hazardous, and/or dangerous wastes and would be managed and disposed/recycled in accordance with the requirements of these laws.
    - Hazardous Materials Transportation Act – These requirements are applicable to transport of hazardous materials.
    - Federal Clean Water Act and State Water Pollution Control Act – Applicable to dredging activities in the river; also applies to discharges to the river.
    - Federal Emergency Management Act – Flood rise requirements resulting from the action must be considered. Because there will be no net fill, this alternative would meet these requirements.
    - Rivers and Harbors Act – The remedial action must not result in unauthorized obstruction or alteration to any navigable water. The work will be conducted outside of the navigation channel.
    - SEPA – In accordance with WAC 197-11-253 through -268, Ecology, as the lead agency, would conduct an environmental review to make a determination as to whether the project would have a significant adverse environmental impact. As

presented above, it is unlikely that the project would have an adverse impact, but, if necessary, changes could be made to address identified adverse impacts.

- The alternative includes compliance monitoring to verify that cleanup levels have been achieved.

Use of Permanent Solutions

This sediment cleanup action is a permanent solution as defined by WAC 173-340-200.

Restoration Timeframe

The dredge alternative would be effective immediately after installation, but the area may become recontaminated if dredging is performed prior to treatment of shallow groundwater. In conjunction with a groundwater source control action, the dredge alternative would be needed for an anticipated period of approximately 5 to 7 years. For the following reasons, this restoration timeframe is considered to be reasonable.

- The potential risks associated with the currently impacted sediments would be immediately addressed by the dredging action and future impacts to sediments from groundwater contamination would be mitigated by the natural attenuation once source control is complete.
- The restoration timeframe is immediately after construction.
- In general, the sediment impacts do not have a substantive impact on property uses or resources.
- Institutional controls would include restrictions on uses in the area of impacted sediments. The area is generally unsuitable for recreational uses and access restrictions would be effective to minimize human health risks. Institutional controls would not be effective for ecological exposures.
- Although the hazardous substances at the NuStar site have relatively high toxicities for human health, human exposure would be controlled almost immediately. Because the hazardous substances are generally not bioaccumulative, ecological toxicity is relatively lower.
- The hazardous substances present in the sediments are sustained by the ongoing groundwater source. Multiple processes, dominated by desorption, dispersion/degradation in the sediment/surface water environment, will reduce concentrations once the upland source is eliminated. The dredging will address the hazardous substances in the interim until source control is complete.

Public Concerns

The proposed action would be submitted for public comment and concerns raised would be addressed prior to design and implementation. It is anticipated that potential concerns of the public would be similar between the potential sediment cleanup action alternatives.

Prevent/Minimize Releases and Migration of Hazardous Substances in the Environment

The primary mechanism for migration of hazardous substances is the ongoing groundwater source. Once the source is eliminated, the potential for further migration would be eliminated. The dredging will address the hazardous substances in the interim until source control is complete.

Degree to Which Cleanup Action Relies on Dilution/Dispersion

The active cap alternative relies upon removal for the bulk of the risk reduction.

7.3.3.4 Sediment Alternative 4: Reactive Cap

Description

Figure 7-9 presents the proposed cap design. An engineered reactive cap prevents exposure to impacted sediments and treats groundwater prior to passing through the biological active portion of the cap. In general, the technology involves the placement of a covering layer of a suitable habitat material (sand) or armor material (gravel or riprap) over a reactive layer consisting of a mixture of sand, activated carbon, and zero-valent iron. Design considerations include the following.

- The cap would have a hydraulic conductivity similar to the existing soil/sediment. Therefore, the cap would not cause a change in groundwater flow so the extent of the cap matches the impacted sediment area.
- For caps in an active portion of a river, an erosion protection layer (e.g., gravel or riprap) would be required. To maintain the adjacent ship berthing area, the Port must periodically dredge accumulated sediments. This suggests that this area is not subject to severe erosive forces and a sand cap is suitable. Riprap is present along the shoreline to prevent erosion from wave action, and this riprap would be maintained.
- To provide adequate contact time with the active media in the reactive cap (given an assumed average groundwater velocity of up to 0.1 foot per minute and a minimum contact time of 30 minutes), the active zone of the cap would need to be on the order of 3 feet. A 2-foot-thick sand layer would result in a full cap thickness of 5 feet. The cap would be placed across the approximate 500 by 150-foot area of impacted sediment; the aerial extent of impacted sediment is shown on Figure 7-5.
- Depending on the time period associated with the completion of the source control action, the reactive cap could be exhausted. Additionally, the near-shore groundwater gradient is affected by tides, so flow across the cap would be subject to periodic reversals (discharging into the river and recharging the aquifer from the river). This could decrease the effectiveness of the active cap materials as organics and other impurities in river water may affect or react with the carbon or the reactant material. For the purpose of the FS, it was assumed that the source control would be completed within a timeframe that would not require replacement of cap materials.
- The river-ward edge of the cap extends into the ship berthing area. The remainder of the cap is on the river bank with slopes ranging from 2.8H:1V to 1.7H:1V. The need to maintain the berthing area elevations and constructability issues on relatively steep submerged slopes will require dredging of existing sediments to accommodate the cap. Dredging would be conducted as outlined in Alternative 3.

There are no operation and maintenance requirements for this alternative. This alternative would have significant short-term disruption to the existing habitat, but would be protective immediately after implementation. Longer term, it was assumed that enhanced bioremediation is implemented as a source control action and that sediments would reach cleanup levels without the need for the reactive layer within 5 to 7 years (see discussion in Section 7.3.3.2). Following achievement of acceptable groundwater quality, sediment sampling would be used to document the final sediment quality.

The estimated present worth cost for this alternative is $6,720,000. The capital cost (including oversight) is estimated to be approximately $6,630,000. Long-term costs consist of sediment verification sampling at a present value cost of $90,000. A detailed breakdown of these costs is presented in Table 7.4-6.

Threshold Requirements

The reactive cap alternative meets the threshold requirements as follows.

- This alternative protects human health and the environment by removing contaminant mass from the area of impacted sediments and treating COCs in groundwater/sediments. The alternative relies on source control to prevent re-contamination.
- The alternative complies with the cleanup standards by preventing contact with impacted sediments until source control and the reactive layer eliminate ongoing sources.
- Numerical standard ARARs were incorporated into the cleanup level determination. Procedural ARARs applicable to this alternative include the following.
    - RCRA and State Hazardous Waste Management Act – Removed sediments would be solid, hazardous, and/or dangerous wastes and would be managed and disposed/recycled in accordance with the requirements of these laws.
    - Hazardous Materials Transportation Act – These requirements are applicable to transport of hazardous materials.
    - Federal Clean Water Act and State Water Pollution Control Act – Applicable to dredging and capping activities in the river; also applies to discharges to the river.
    - Federal Emergency Management Act – Flood rise requirements resulting from the action must be considered. Because there will be no net fill, this alternative would meet these requirements.
    - Rivers and Harbors Act – The remedial action must not result in unauthorized obstruction or alteration to any navigable water. The work will be conducted outside of the navigation channel.
    - SEPA – In accordance with WAC 197-11-253 through -268, Ecology, as the lead agency, would conduct an environmental review to make a determination as to whether the project would have a significant adverse environmental impact. As presented above, it is unlikely that the project would have an adverse impact, but, if necessary, changes could be made to address identified adverse impacts.
- The alternative includes compliance monitoring to verify that cleanup levels have been achieved.

Use of Permanent Solutions

This sediment cleanup action is a permanent solution as defined by WAC 173-340-200.

Restoration Timeframe

The reactive cap alternative would be effective immediately after installation (protecting the river sediments from ongoing impacts from the groundwater source area), but would need to remain viable until groundwater source concentrations were addressed to protective levels. In conjunction with a groundwater source control action, the reactive cap would be needed for an anticipated period of approximately 5 to 7 years. For the following reasons, this restoration timeframe is considered to be reasonable.

- The potential risks associated with the currently impacted sediments would be immediately addressed by the active cap and future impacts to sediments from groundwater contamination would be mitigated by the active cap materials until source control is complete.
- The restoration timeframe is immediately after construction.
- In general, the sediment impacts do not have a substantive impact on property uses or resources.
- Institutional controls would include restrictions on uses in the area of impacted sediments. The area is generally unsuitable for recreational uses and access restrictions would be effective to minimize human health risks. Institutional controls would not be effective for ecological exposures.
- Although the hazardous substances at the NuStar site have relatively high toxicities for human health, human exposure would be controlled almost immediately. Because the hazardous substances are generally not bioaccumulative, ecological toxicity is relatively lower.
- The hazardous substances present in the sediments are sustained by the ongoing groundwater source. Multiple processes, dominated by dispersion/chemical degradation in the sediment/surface water environment, will reduce concentrations once the source is eliminated. The reactive cap will address the hazardous substances in the interim until source control is complete.

Public Concerns

The proposed action would be submitted for public comment and concerns raised would be addressed prior to design and implementation. It is anticipated that potential concerns of the public would be similar between the potential sediment cleanup action alternatives, except that the reactive cap may have a better acceptance because it is protective immediately upon implementation.

Prevent/Minimize Releases and Migration of Hazardous Substances in the Environment

The primary mechanism for migration of hazardous substances is the ongoing groundwater source. Once the source is eliminated, the potential for further migration would be eliminated. The reactive cap will address the hazardous substances in the interim until source control is complete.

Degree to Which Cleanup Action Relies on Dilution/Dispersion

The active cap alternative relies upon active treatment for the bulk of the risk reduction and does not use dilution/dispersion for cleanup.

7.3.3.5 Disproportionate Cost Analysis of Sediment Alternatives

The potential sediment cleanup action alternatives were subjected to a disproportionate cost analysis using the same procedure as used for groundwater in Section 7.3.2.4.

Ranking of Alternatives

Table 7-5 summarizes the comparative analysis for sediment. The following discussion provides a rationale for the comparative evaluation presented in the table.

- Protectiveness – The no action alternative is not protective. The reactive cap has slightly greater protectiveness because it achieves protection in a shorter timeframe.
- Permanence – The no action alternative is not permanent. Each of the remaining alternatives is similar in permanence in that each treats the source area constituting the majority of site risk.
- Cost – The total present worth costs for the sediment alternatives are summarized as follows:
  - No Action – $0
  - Source Control – $248,100
  - Dredging - $3,400,000
  - Reactive Cap – $6,720,000
- Long-Term Effectiveness – No action has no long-term effectiveness. The long-term effectiveness of the remaining alternatives is the same because each relies on source control in the long term.
- Management of Short-Term Risks – No action and source control alternatives have no short-term risks. The dredging and active cap alternatives have moderate short-term risks related to water quality impacts during dredging and capping, transport of dredged sediments to a landfill, and emissions associated with diesel-powered equipment and trucks.
- Technical and Administrative Implementability – No action and source control are easily implemented. The dredging and reactive cap alternatives use readily available equipment. However, the access to the dredging and cap area is behind berthing structures that are actively used which would require significant coordination to prevent impact to the facility operations. In addition, reactive caps are a relatively new technology with limited industry experience.
- Consideration of Public Concerns – No action is likely to have significant public concerns. Dredging and reactive cap will likely have less public concern than source control because of the shorter restoration timeframe for reactive cap.

Based on the comparative analysis, the alternatives are ranked from most to least permanent as follows:

- Source Control;
- Dredging;
- Reactive Cap; and
- No Action.

Disproportionate Cost Comparison of Alternatives

The source control alternative is the most permanent alternative. Additionally, it is the least costly of the protective alternatives. Therefore, the source control alternative is recommended for implementation for sediment cleanup.

7.4 RECOMMENDED CLEANUP ACTION ALTERNATIVE

Based on the overall evaluation in Sections 7.1 through 7.3, the recommended cleanup actions for the NuStar source area are SVE/Enhanced Bioremediation/Source Control. Together, these cleanup actions include the following technologies.

- Soil SVE:
  - Continued operation, inspection, and maintenance of the interim action SVE system;
  - Development of a soil management plan to ensure that proper controls are implemented during future activities at locations where impacted soils may be exposed;
  - Monitoring of the SVE vapor discharges;
  - Regular reporting of system operation and monitoring results; and
  - Post-remediation soil sampling to verify that soil cleanup levels are achieved.
- Groundwater Enhanced Bioremediation:
  - Injection of a vegetable-oil-based substrate in the shallow zone groundwater between the interim action injection area and the river;
  - Monitoring of groundwater concentrations to evaluate effectiveness of the cleanup action;
  - If necessary, conduct secondary injection to address residual impacts to groundwater;
  - Implementation of groundwater use restrictions (restrictive covenant, media management plan, or equivalent); and
  - Regular reporting of monitoring results.
- Sediment Source Control:
  - Groundwater source control actions as described above for groundwater cleanup actions;
  - Natural recovery of sediments as the groundwater source is eliminated; and
  - Baseline, during source area cleanup and post-remediation sediment sampling to verify that sediment cleanup is underway and cleanup levels can be achieved. If sediment sampling indicates that some areas are not meeting cleanup goals in the anticipated restoration time frame, limited dredging could be completed as needed to meet objectives within the anticipated restoration time of 7 years.

These cleanup actions were selected for the following reasons.

- The cleanup actions meet the threshold requirements: protecting human health and the environment, complying with cleanup standards and ARARs, and providing for compliance monitoring.
- The cleanup actions are the most permanent of the potential cleanup actions evaluated. The actions use permanent approaches to the maximum extent practicable to treat the source area and cleanup sediments.
- The restoration timeframe is the most reasonable of the cleanup actions evaluated.

- The cleanup actions address the potential for present and future releases or migration of hazardous substances by treating the source area.
- The cleanup actions address the source area risk by treatment.

The final design of the cleanup actions will be determined at the time of development of the cleanup action plan and will be based on the conditions present at the time of design.

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8. SMC/CADET SOURCE AREA FEASIBILITY EVALUATION

This section provides a summary of the SMC source area feasibility evaluation and selection of a preferred remedy. As summarized in Section 2.3, interim actions conducted at the Cadet site have been successful in reducing source area concentrations to near or below MTCA cleanup levels (see Figures 2-17 and 2-24). Therefore, no additional remedial actions are required to achieve cleanup levels and additional remedies are not being evaluated in this FS for the Cadet site source area. The following sections focus only on the SMC source area and evaluation of remedial actions to address residual contamation in that area.

8.1 EXTENT OF IMPACTED MEDIA

A summary of the soil and groundwater contamination in the SMC source area is provided in the following sections. An extensive discussion of the source area is provided in the SMC RI report (Parametrix 2009b), including the past release mechanisms, fate and transport, interim actions conducted, extent of contamination through time, and site-specific geology. The FS assessment is completed using current and projected future contaminant concentrations in the source area.

8.1.1 Soil

The SMC source area is southwest of the Mill Plain, St. Francis Lane, and Fourth Plain Boulevard intersection. As discussed in the SMC RI report, TCE-impacted soil (maximum concentration of 17,000 µg/kg in the vadose zone) was previously detected in the vicinity of the SMC site. The TCE-impacted soil was the primary source material for impacting groundwater at the SMC site. Therefore, the Port completed an interim action in 1998 to remove the source material. Approximately 13,800 cubic yards of TCE-impacted soil were excavated and treated using enhanced soil vapor extraction. The excavation was completed to a depth of approximately 17 feet bgs, where it was terminated due to encountering groundwater. Confirmation sampling indicated that limited impacts in the vadose zone remained after the excavation activities.

Evaluation of all data in the source area, including pre-excavation data and confirmation samples, indicated that soil samples with TCE exceeding the MTCA Method C soil cleanup level (1,800 mg/kg) were collected at the soil/water interface or below. In addition, all samples with detectable concentrations of TCE were collected at depths greater than 15 feet bgs, which is below the standard depth used for excavation/utility workers in a risk evaluation. These factors suggest that no risk is associated with TCE in vadose zone soil at the site. A number of "soil" samples were collected below the water table and indicated concentrations of TCE. It is apparent that the soil samples were saturated with contaminated groundwater and that the concentrations detected are likely representative of groundwater conditions rather than soil. Further reference to the SMC "source area" should be associated with the saturated zone, including TCE bound within the fine-grained sand layer. Therefore, this FS focuses on remedial alternatives that may be appropriate for the removal of the TCE in the fine-grained sand layer from a groundwater remedy perspective. Figure 8-1 shows the estimated extent of "soil" contamination in the source area, as well as the extent of elevated groundwater concentrations. Figure 8-2 shows the source area TCE isoconcentrations from the March 2013 groundwater monitoring event (see Section 8.1.2 below).

The thickness of the fine-grained sand layer varies significantly and ranges from approximately 3 feet to 12 feet thick. The depth to the top of the fine-grained sand layer ranges from 12 feet bgs (15 feet National Geodetic Vertical Datum [NGVD]) to 20 feet bgs (5 feet NGVD). The bottom of the fine-grained sand layer is relatively consistent at approximately 23 feet bgs (3 feet NGVD). The historical high water elevation is approximately 8.6 feet NGVD, which suggests that the majority of the fine-grained sand layer is saturated throughout most of the year. Figure 8-3 shows a cross-section of the fine-grained sand layer, which is the primary source area.

8.1.2 Groundwater

Figures 8-1 and 8-2 show the current extent of the SMC source area contamination (as of March 2013). In general, the source area groundwater is represented by monitoring wells IMW-05, MW-05, VMW-08, VMW-09, VMW-10, and VMW-11. Based on the data collected from these wells, as well as the project area monitoring well network, the source area is currently confined to an area encompassing approximately 200 feet by 250 feet. This extent is estimated using areas where current TCE concentrations exceed 50 µg/L (see Figure 8-2). In general, the current source area extent is located beneath a gravel lot and well house and extends west to St. Francis Lane and north and east to Mill Plain Boulevard. It is generally confined to the SMC property, with some extension beneath St. Francis Road and the Mill Plain Boulevard right of way.

Since operation of the GPTIA began 2009, the source area extent and concentrations have decreased significantly. Thus, the total mass available in the source area to migrate to the intermediate zone has been reduced. The remaining contamination within the source area appears to be primarily bound within the fine-grained sand layer, which is located between approximately 12 and 25 feet bgs. The tighter-grained material has slowed the cleanup of the shallow source area relative to the zone immediately below the fine-grained sand layer.

Six wells are located within the footprint of the SMC source area, including IMW-05, MW-05, VMW-08, VMW-09, VMW-10, and VMW-11. TCE concentrations in three wells (IMW-05, VMW-10, and VMW-11) have generally remained below 500 µg/L. In June 2013, TCE was detected at concentrations of 53 µg/L, 280 µg/L, and 80 µg/L, respectively, in these three wells. TCE concentrations detected in VMW-08 have generally been below 500 µg/L, and TCE concentrations in well VMW-09 have recently ranged between 500 µg/L and 2,500 µg/L. In June 2013, TCE concentrations in these two wells were 1,200 µg/L and 2,700 µg/L, respectively (see Figure 8-2).

The highest concentrations of TCE in the source area are detected in monitoring well MW-05 and have ranged from 21,000 µg/L (December 2009) to 1,600 µg/L (June 2011) during operation of the GPTIA. TCE was detected in MW-5 at a concentration of 3,200 in June 2013. It is suspected that monitoring well MW-5 gives the best representation of groundwater cleanup effectiveness in the source area. In June 2009, prior to operation of the GPTIA, monitoring well MW-5 had a TCE concentration of 2,700 µg/L. Once the GPTIA was operational, the TCE concentration in monitoring well MW-5 increased to a high of 21,000 µg/L in December 2009. This significant concentration increase is a result of contaminants being mobilized from the source area and flowing to extraction well EW-1. Monitoring well MW-5 is located within approximately 50 feet of EW-1, between the main source area and the extraction well. Since December 2009, the TCE concentration in monitoring well MW-5 has decreased steadily to 2,700 µg/L in November 2013 (see Figure 8-4).

8.2 TECHNOLOGY EVALUATION AND CLEANUP ACTION ALTERNATIVE DEVELOPMENT

This section describes the development of the cleanup action alternatives to be evaluated. The alternative development process includes identifying general response actions and corresponding technologies, screening technologies to eliminate those that are clearly not feasible, and assembling remaining technologies into a list of cleanup action alternatives. In order to evaluate feasible technologies, the following RAOs have been established for the SMC source area:

- Achieve the cleanup standards for COCs.
- Protect human health and the environment.
- Use permanent solutions to the maximum extent practicable (which includes consideration of cost effectiveness).
- Contain the source area plume from further dispersion.

The following sections provide the rationale for technology screening and the selection of remedial alternatives.

8.2.1 Technology Screening

EPA technology screening guidance provides an assessment of general classes of technologies classified by medium and type of treatment. The guidance is relatively comprehensive and was used to identify potential technologies for the SMC source area. The general technologies identified for the SMC source area include:

- Institutional controls
- Engineering controls
- Containment
- Removal/discharge
- *Ex situ* biological or physical/chemical treatment (used for treatment of extracted groundwater)
- *In situ* biological treatment or physical/chemical treatment

The specific technologies for soil and groundwater are presented on Table 8-1 and Table 8-2, respectively. For the first screening step, technologies that are not applicable to the medium of concern or the goals of the cleanup were eliminated. As discussed previously, the SMC source area is relatively complex in nature and includes soil and groundwater impacts. However, the majority of contamination is present and bounded within a distinct and thin soil layer (i.e., the fine-grained sand layer). Based on the mean groundwater elevation, the majority of the fine-grained sand layer is saturated throughout most of the year. Contaminants in the vadose zone above the fine-grained sand layer were removed during a previous remedial excavation; thus, there are no significant vadose zone impacts in the source area. Therefore, the SMC source area is generally considered to be a groundwater contamination issue and, as such, soil remedies without a groundwater component were generally eliminated (the lone exception being direct excavation of source material at depth).

For the technologies identified, three criteria (effectiveness, implementability, and cost) were used to provide an initial screen (Tables 8-1 and 8-2). After this initial screening, the specific technologies that were retained as potential alternatives are as follows:

- Groundwater use restrictions (Institutional controls)
- Monitoring (Institutional controls)
- Control of building HVAC System (Engineering controls)
- Vapor barriers (Engineering controls)

- Sub-slab depressurization or sub-floor venting (Engineering controls)
- Excavation of contaminated soil (Removal)
- Pumping/hydraulic containment (Containment)
- Pumping/pump and treat (Removal/discharge)
- Discharge to sewer/surface water (Removal/discharge)
- Discharge to reinjection wells (Removal/discharge)
- Source removal/excavation (Removal/discharge)
- Adsorption (*Ex situ* physical/chemical)
- Air stripping (*Ex situ* physical/chemical)
- Enhanced bioremediation (*In situ* biological)
- Aeration/air sparging (*Ex situ* physical/chemical)
- Injection of chemical oxidant (*In situ* physical/chemical)
- MNA (*In situ* physical/chemical)

These potential technologies were further evaluated based on site-specific conditions to develop a set of remedial alternatives that could be applied to the SMC source area. As applicable, some technologies could be combined with others for a specific remedial alternative. The development of the alternatives and site-specific conditions is summarized in the following section.

8.2.2 Development of Cleanup Action Alternatives

The identified technologies were further screened to select those that are suitable for the site conditions and COCs, as well as to determine whether the action uses permanent solutions to the maximum extent practicable. The technologies that pass this screening were assembled into remedial alternatives that will be evaluated for use at the site. Remedial alternatives were developed based on the nature and extent of contamination, potential future use of the site, technological feasibility, and engineering/logistical considerations. The following are the site-specific conditions that serve as screening criteria to determine relevant technologies from the list in Section 8.2.1 above:

- Medium – shallow groundwater flowing through a fine-grained sand layer (20 to 25 feet deep)
- Contaminants – dissolved-phase HVOCs (primarily TCE and PCE)
- Site usage – light and heavy industrial usage with heavy traffic

As a result of these considerations, the potential remedial alternatives evaluated for groundwater were generally limited to the physical removal, treatment, and discharge of contaminated material or *in situ* treatment. Because soil in the vadose zone is generally not impacted, applicable technologies for soil were eliminated, with the exception of removal of the source area material (in the saturated fine-grained sand layer). The saturated soil that contains the majority of site contaminants would require *in situ* treatment. Engineering controls were not considered for any remedial alternatives at this time, as no building is located on the site. However, engineering controls were retained as a standby technology in the event of future property development (Section 8.3.1). Institutional controls were considered for all options and are generally included as a viable technology for all the assembled alternatives. Enhanced bioremediation was not considered as a final alternative, as site conditions are not conducive to the decomposition of TCE and PCE. However, *in situ* chemical oxidation was considered.

After consideration of the nature and extent of contamination in the SMC source area, potential future use of the site, technological feasibility, and engineering/logistical considerations, the remedial alternatives were reduced to the following five for evaluation in this FS:

Alternative A – Monitored Natural Attenuation (MNA)

Alternative B – Remedial Excavation of Source Area

Alternative C – Air Sparging and Soil Vapor Extraction

Alternative D – *In Situ* Substrate Injection (Chemical Oxidation)

Alternative E – Pump and Treat, Institutional Controls, and MNA

Detailed descriptions of the alternatives and evaluation against MTCA criteria are discussed in the following sections.

8.3 SCREENING AND EVALUATION OF CLEANUP ACTION ALTERNATIVES

Detailed descriptions of the alternatives and evaluation against MTCA criteria are discussed in the following sections.

8.3.1 Discussion of Common and Standby Technologies

As discussed previously, several of the retained technologies are potentially applicable to each cleanup strategy that may be selected and would be incorporated as appropriate into each of the cleanup action alternatives. Common and standby technologies area summarized below.

8.3.1.1 Common Technologies

The technologies that are common to all alternatives include:

- Contaminated Media Management Plan – A contaminated media management plan would be prepared to ensure proper controls are implemented during future site activities. Protocols would be established for the handling and management of soil and shallow groundwater during future site work to protect workers, public health, and the environment.
- Groundwater Use Restriction – In accordance with WAC 173-340-440(4)(a), groundwater restrictions are required until the cleanup levels are achieved. Therefore, it is expected that some form of institutional controls (i.e., restrictive covenant, media management plan, or equivalent) will be placed on the SMC site. Restriction of site use and groundwater usage at the site would be effective at preventing exposure to COCs.
- Monitoring – Monitoring includes the sampling and laboratory analysis of various media to assess current risks and evaluate the effectiveness of implemented cleanup actions. The site and project area have an extensive groundwater monitoring well network which is expected to be utilized during and post-remedial actions.
- Monitored Natural Attenuation – MNA involves utilizing natural processes to reduce COC levels to acceptable concentrations. These processes include natural

biodegradation, dispersion, dilution, sorption, volatilization, and chemical and biological stabilization, transformation, or destruction of hazardous substances (WAC 173-340-200). Monitoring is used to verify that these processes are actively reducing hazardous substance concentrations. An extensive monitoring well network is in place at the Site. MNA is one of the primary components evaluated and is expected to be used as part of the Site remedial efforts (Section 9.0) and in support of the SMC source area remedial action. In the context of the SMC source area, MNA is specifically included as part of Alternatives A and E (see Section 8.3.2).

8.3.1.2 Standby Technologies

The site currently is not developed and, with the exception of the building associated with the groundwater extraction well and equipment, no buildings are located on the property. In the event of future site development, standby technologies could be employed for a building as part of construction requirements. The standby technologies are primarily to mitigate potential vapor intrusion into a future building resulting from contaminated groundwater and could include vapor barriers, venting, or any of a number of similar technologies. An evaluation of the necessity and appropriate technologies would be conducted as part of building development options.

8.3.2 Evaluation of Cleanup Action Alternatives for the Source Area

MTCA established minimum requirements and procedures for selecting cleanup actions in WAC 173-340-360. MTCA requires that all cleanup actions meet the threshold requirements that are part of the minimum requirements. Any alternatives that do not meet the threshold requirements are dropped from further consideration. This section uses the threshold requirement to screen the initial list of alternatives developed. Under MTCA, remediation alternatives must meet the following threshold requirements ((WAC 173-340-360(2)(a)):

- Protection of human health and the environment
- Compliance with cleanup standards
- Compliance with ARARs
- Provision for compliance monitoring

Each alternative is evaluated individually against the threshold. Alternatives that do not meet the threshold requirements are not carried forward to the evaluation of other requirements (WAC 173-340-360(2)(b)). The other requirements were defined in Section 6.0 and include:

- Use of permanent solutions
- Reasonable restoration timeframe
- Consideration of public concerns
- Prevent or minimize releases and migration of hazardous substances in the environment
- Degree to which cleanup action relies on dilution/dispersion

The following sections evaluate each of the individual alternatives against the threshold requirements and other criteria.

8.3.2.1 Alternative A – Monitored Natural Attenuation

The MNA alternative involves utilizing natural processes to reduce COC levels to acceptable concentrations. These processes include natural biodegradation, dispersion, dilution, sorption, volatilization, and chemical and biological stabilization, transformation, or destruction of hazardous substances. Monitoring is used to verify that these processes are actively reducing hazardous substance concentrations.

This alternative assumes that the existing pump and treat system would be turned off and no further remedial efforts would be completed. However, costs incurred with this alternative include monitoring the source area (only) until levels reach cleanup levels, which is expected to be greater than 30 years. The associated costs for 30+ years of monitoring is $234,000 and is included in Appendix E.

Threshold Criteria

An evaluation of the MNA alternative indicates that it does not meet the threshold requirements, as summarized below:

- This alternative does not protect human health and the environment from the source area COCs. Source area contaminants above the applicable MTCA cleanup levels exist in the shallow zone extending beyond the boundaries of the SMC site and outside of Port property and control.
- The alternative does not comply with the MTCA cleanup standards in the source area.

Use of Permanent Solutions

This alternative does not meet the requirement for a permanent solution.

Reasonable Restoration Timeframe

MNA alone (for the source area) does not meet the requirement for a reasonable restoration timeframe. It is expected that source area reduction to cleanup levels would take more than 30 years at present rates of decrease.

Consideration of Public Concerns

It is not expected that MNA alone (for the source area) would address public concerns, primarily due to the concentrations left in place and beyond the SMC property, as well as the lack of a reasonable timeframe for restoration.

Prevent or Minimize Releases and Migration of Hazardous Substances in the Environment

This alternative is not effective at preventing or minimizing releases of hazardous substances.

Degree to Which Cleanup Action Relies on Dilution/Dispersion

This alternative relies heavily on dilution and dispersion.

8.3.2.2 Alternative B – Remedial Excavation of Source Area

This alternative primarily includes excavation and off-site disposal of impacted source area material. As discussed previously, contaminants are concentrated in the fine-grained sand layer within the source area and the contaminants continue to slowly migrate from this layer to shallow groundwater. The fine-grained sand layer is generally saturated most of the year. It is expected that much of the contaminants reside in the pore space of the soil particles and is slowly leaching to shallow groundwater.

While excavation is primarily a vadose zone soil remedial action, the relatively shallow depth and the unique complexity of this site lend itself to consider a removal action for saturated material. Based on an evaluation of site data, the removal action area is approximately 70 feet by 100 feet and would extend to a depth of 27 feet bgs. This yields an approximate excavation volume of 7,000 cubic yards. A conceptual design of the removal action area is presented in Appendix E.

The top 17 feet is considered overburden material and is expected to be free of any contamination. Much of the overburden is clean fill (about 4,500 cubic yards) that was placed during the remedial excavation in 1998. The former excavation was terminated at approximately 17 feet bgs due to the presence of groundwater. This alternative would primarily target the 10 feet of material underlying from the previous excavation depth, which includes the fine-grained sand layer. Due to the expected presence of groundwater at less than 20 feet bgs, this alternative would require significant shoring and dewatering. Extracted groundwater from the dewatering would be required to be treated prior to discharge to a sanitary sewer or other method of disposal.

Based on the conceptual design, approximately 2,500 cubic yards of excavated contaminated soil (saturated) would be placed into lined trucks and transported to a permitted municipal landfill (Subtitle D) for disposal under an approved permit. Confirmation sampling would be conducted in accordance with an Ecology-approved sampling and analysis plan and quality assurance project plan.

The excavation would be backfilled with a combination of imported clean fill and the stockpiled clean overburden material. The conceptual design of the alternative and estimated costs are included in Appendix E. The estimated cost is approximately $875,000. ***This does not include any operating costs of the pump and treat system to supplement this alternative***.

Threshold Criteria

An evaluation of the source area remedial excavation alternative indicates that it meets the threshold requirements, as summarized below:

- This alternative protects human health and the environment by directly removing COCs from the source area. The excavated soil would be placed in a permitted landfill and groundwater (dewatering) would be treated and discharged.
- This alternative complies with the MTCA cleanup standards by removing COCs from the source area.
- Numerical standard ARARs were incorporated into the cleanup level determination.
- This alternative provides for compliance monitoring, both in terms of performance monitoring during the excavation and conformation monitoring to monitor the long-term effectiveness of the remedy.

Use of Permanent Solutions

This alternative removes contaminated soil (largely saturated) through excavation and off-site landfill disposal. Therefore, it meets the requirement for a permanent solution.

Reasonable Restoration Timeframe

Due to the direct removal of contaminants, it is expected that the timeframe for cleanup would be relatively short. However, residual concentrations could remain outside the removal action area and could impact nearby groundwater monitoring wells. These could be addressed by continued operation of the pump and treat system and/or MNA.

Consideration of Public Concerns

The proposed action would be submitted for public comment and concerns raised would be addressed prior to design and implementation. It is anticipated that potential concerns of the public could be addressed as appropriate. It is not expected that any public concerns that would prevent the implementation of this alternative would be received or could not otherwise be rectified. It is anticipated that potential concerns of the public would be similar among the alternatives.

Prevent or Minimize Releases and Migration of Hazardous Substances in the Environment

This alternative provides for removal of the most impacted soil; thus, it is effective at preventing or minimizing releases of hazardous substances.

Degree to Which Cleanup Action Relies on Dilution/Dispersion

Direct removal of the source area contamination does not rely on dispersion or dilution. However, dilution and dispersion are part of the residual contamination remedy for the Site (MNA).

8.3.2.3 Alternative C – Air Sparging and Soil Vapor Extraction System

This alternative includes the construction of an AS/SVE system in the source area and primarily targets the fine-grained sand layer. The AS/SVE system includes the injection of air into the groundwater to volatilize contaminants. The volatilized contaminants in the air phase rise into the vadose zone where they are captured by the SVE wells under a vacuum influence. As necessary, the volatilized contaminants are then adsorbed using a granulated activated carbon canister prior to ventilation to the atmosphere. Given ideal conditions, a typical timeframe for remediation of groundwater contaminants to beneath levels of concern is 2 to 4 years.

Based on the extent and depth of source area contamination (target area), the preliminary conceptual design indicates eight AS wells would be adequate to treat the SMC source area. The AS wells would be installed to the bottom of the fine-grained sand layer (approximately 25 feet bgs) with a 0.5-foot well screen at the bottom (groundwater is approximately 20 feet bgs). Seven to 10 SVE wells would be installed around the AS wells to capture soil vapors in the vadose zone. The SVE wells would be drilled to approximately 15 to 20 feet bgs, with a 10-foot well screen. A conceptual design is included in Appendix E.

The AS wells would be connected via a hose or piping to an air blower and the SVE wells connected via 2-inch PVC piping to a vacuum unit. A small equipment shed would likely be required to house the blower, vacuum, electrical unit, sound insulation, and other equipment. As necessary, the air collected by the vacuum would be discharged through a granulated activated carbon canister for treatment, prior to ventilation to the atmosphere.

Due to the complexity of the source area, installation of an AS/SVE system would be extremely difficult and potentially problematic. A design study would be required to evaluate the precise geology of the fine-grained sand layer and placement of AS wells effectively. The relatively thin depth of the fine-grained sand layer would make it very difficult to place the AS wells. In addition, based on past evaluation, the fine-grained sand layer is not always fully saturated, thus limiting the effectiveness of air sparging in that layer. Completion of AS wells below the fine-grained sand layer would not be effective due to the tight formation of the sand, which would promote lateral movement of air at the fine-grained sand layer interface, rather than vertical movement through the contaminated zone.

The conceptual design of the alternative and estimated costs are included in Appendix E. The estimated cost is approximately $219,000. ***This does not include any operating costs of the pump and treat system to supplement this alternative.***

Threshold Criteria

An evaluation of the AS/SVE remedial alternative indicates that it meets the threshold requirements, as summarized below:

- This alternative protects human health and the environment by removing COCs from the source area. The extracted contaminants would be treated (as necessary) and discharged to the air.
- This alternative complies with the MTCA cleanup standards by removing COCs from the source area.
- Numerical standard ARARs were incorporated into the cleanup level determination.
- This alternative provides for compliance monitoring, both in terms of performance monitoring during the AS/SVE remedy and conformation monitoring to monitor the long-term effectiveness of the remedy.

Use of Permanent Solutions

This alternative treats contaminated soil (largely saturated) through air sparging and vapor extraction. The extracted air stream would be treated prior to discharge. Therefore, it meets the requirement for a permanent solution.

Reasonable Restoration Timeframe

Under ideal conditions, it is expected that the timeframe for cleanup would be on the order of 2 to 4 years in the source area. This meets the reasonable timeframe criteria. However, given the complexity of the geology/hydrogeology in the source area (i.e., fine-grained sand layer), the timeframe for cleanup could be substantially increased and/or residual concentrations could remain that could impact groundwater monitoring wells. These could be addressed by continued operation of pump and treat system and/or MNA.

Consideration of Public Concerns

The proposed action would be submitted for public comment and concerns raised would be addressed prior to design and implementation. It is anticipated that potential concerns of the public could be addressed as appropriate. It is not expected that any public concerns that would prevent the implementation of this alternative would be received or could not otherwise be rectified. It is anticipated that potential concerns of the public would be similar among the alternatives.

Prevent or Minimize Releases and Migration of Hazardous Substances in the Environment

This alternative provides for removal of the most impacted zone; thus, it is effective at preventing or minimizing releases of hazardous substances.

Degree to Which Cleanup Action Relies on Dilution/Dispersion

Direct removal of the source area contamination does not rely on dispersion or dilution. However, dilution and dispersion are part of the residual contamination remedy for the Site (MNA).

8.3.2.4 Alternative D – Substrate Injection (Chemical Oxidation)

This alternative consists of injecting a chemical oxidant (likely Fenton's Reagent) below the water table using a combination of injection wells and temporary direct-push injection points.

As is typical of *in situ* oxidizing treatments, the injection of Fenton's Reagent disrupts aquifer equilibrium conditions in two ways: (1) physical agitation of the aquifer; and (2) liberation of bound TCE from the soil matrix. Both of these actions can result in dissolved TCE concentrations that are initially higher after treatment than those observed prior to treatment. After mobilizing the bound TCE, subsequent treatments are aimed at destroying the resulting dissolved TCE. After the final treatment, equilibrium conditions would be re-established naturally and TCE concentrations decreased. Given ideal conditions, it is estimated that two to three treatment events would occur, followed by monthly monitoring of the wells for 1 to 3 years.

Chemical oxidation was used in the source area during previously completed interim actions (Section 2.3) and proved to be an effective method of destroying residual TCE. This alternative includes additional injection points and direct delivery to the fine-grained sand layer, approximately 20 to 25 feet bgs.

The conceptual design of the injection system is included in Appendix E. Approximately 50 to 60 injection borings would be completed up to 30 feet bgs throughout the 70-foot by 100-foot source area. The size and shape of the source area would make implementing an effective delivery system manageable. Because of the rapid decomposition of oxidizing agents, injection points would have to be located throughout the source area in order to achieve the cleanup goals.

As documented during interim actions previously completed in the source area, the complexity of the subsurface in the source area makes it very difficult to effectively target the narrow fine-grained sand layer with chemical oxidation injections. A design study would be required to evaluate the precise geology of the fine-grained sand layer and placement of injection points. The relatively thin depth of the fine-grained sand layer would create challenges for the placement of the chemical oxidant. Distribution of chemical oxidants may also be difficult in the tight formation of the fine-grained sand layer. Past experience during the source area interim action indicated that the radius of influence from injection points is limited; thus requiring a high concentration of injection points within the target area.

Costs would be moderately high due to the number of injection points needed. The conceptual design of the alternative and estimated costs are included in Appendix E. The estimated cost is approximately $350,000. ***This does not include any operating costs of the pump and treat system to supplement this alternative***.

Threshold Criteria

An evaluation of the chemical oxidation by injection remedial alternative indicates that it meets the threshold requirements, as summarized below:

- This alternative protects human health and the environment by treating COCs in the source area *in situ*.
- This alternative complies with the MTCA cleanup standards by treating COCs in the source area.
- Numerical standard ARARs were incorporated into the cleanup level determination.
- This alternative provides for compliance monitoring, both in terms of performance monitoring during the injection remedy and conformation monitoring to monitor the long-term effectiveness of the remedy.

Use of Permanent Solutions

This alternative treats contaminated soil (largely saturated) through injection of chemical oxidants. Therefore, it meets the requirement for a permanent solution.

Reasonable Restoration Timeframe

Under ideal conditions, it is expected that the timeframe for cleanup would be on the order of 2 to 5 years in the source area. This meets the reasonable timeframe criteria. However, given the complexity of the geology/hydrogeology in the source area (i.e., fine-grained sand layer), the timeframe for cleanup could be substantially increased and/or residual concentrations could remain that could impact groundwater monitoring wells. These could be addressed by continued operation of the pump and treat system and/or MNA.

Consideration of Public Concerns

The proposed action would be submitted for public comment and concerns raised would be addressed prior to design and implementation. It is anticipated that potential concerns of the public could be addressed as appropriate. It is not expected that any public concerns that would prevent the implementation of this alternative would be received or could not otherwise be rectified. It is anticipated that potential concerns of the public would be similar among the alternatives.

Prevent or Minimize Releases and Migration of Hazardous Substances in the Environment

This alternative provides for treatment of the most impacted zone; thus, it is effective at preventing or minimizing releases of hazardous substances.

Degree to Which Cleanup Action Relies on Dilution/Dispersion

Treatment of the source area contamination does not rely on dispersion or dilution. However, dilution and dispersion are part of the residual contamination remedy for the Site (MNA).

8.2.3.5 Alternative E – Pump and Treat and MNA

This alternative includes pump and treat to reduce the source area concentrations. As discussed previously, a pump and treat system was installed at the SMC site as an interim action. The GPTIA has been operational since June 2009 and was primarily designed to capture the overall project area plume in the intermediate zone and treat dissolved-phase concentrations. However, as the GPTIA was installed in the SMC source area, it also was designed to provide concurrent treatment of the source area groundwater concentrations.

Extraction well EW-1 has operated at a rate of approximately 2,500 gpm. The system involves pumping groundwater from below the SMC source area and treating the groundwater through an air stripping process. The air strippers remove the TCE and other VOCs from the water and transfer them to an air stream for discharge to the atmosphere. The treated water is then discharged to the Columbia River using a pre-existing stormwater outfall.

The GPTIA has been very successful at treating the project area plume and the source area and provides capture of the dissolved phase groundwater plume. As shown on Figure 2-8, the source area groundwater concentrations have been reduced significantly since operation of the GPTIA began. Figures 8-1 and 8-2 show the 2013 groundwater concentrations in the shallow zone. As previously discussed, monitoring well MW-5 has generally had the highest concentrations of TCE in the source area and provides the best representation of groundwater cleanup in the source area. In June 2009, prior to operation of the GPTIA, monitoring well MW-5 had a TCE concentration of 2,700 µg/L. Once the GPTIA was operational, the TCE concentration in monitoring well MW-5 jumped to 5,000 µg/L (later in June 2009) and then to a high of 21,000 µg/L in December 2009. This significant concentration increase is a result of contaminants being mobilized from the source area to extraction well EW-1. Monitoring well MW-5 is located within approximately 50 feet of EW-1, between the main source area and the extraction well. Since the high of 21,000 µg/L in December 2009, the TCE concentration in monitoring well MW-5 has decreased steadily to 2,700 µg/L in November 2013 (see Figure 8-4).

This alternative includes institutional controls combined with further operation of the pump and treat system until concentrations in shallow groundwater are reduced to acceptable levels. Analysis and design of this alternative are included in Appendix E. In summary, the conceptual plan is to operate the GPTIA until two criteria are met:

1. The extent (footprint) of shallow groundwater above the MTCA Method B cleanup levels is confined to the SMC property.
2. The concentration in shallow groundwater in the source area (SMC site) is at levels that will not impact the intermediate zone groundwater above the MTCA Method B cleanup levels.

These criteria will be used in conjunction with the criteria developed for the project area dissolved-phase plume to determine when the pump and treat system can be shut down, which include:

1. The concentration in all intermediate wells is below the threshold at which MNA can be employed for the Site dissolved-phase groundwater plume (Section 9.0).
2. The concentrations in the intermediate zone are at levels that will not impact regional pumping wells in the vicinity (CPU, City of Vancouver, Port of Vancouver, etc.) in the absence of EW-1 operation (i.e., turn the GPTIA off) (Section 9.0).

The first two conditions are specifically for the source area remedy. It is expected that this alternative will include institutional controls in the form of a restrictive covenant at the source area. The restrictive covenant would be expected to include a limitation on groundwater use at the source area.

As summarized in Appendix E, an evaluation using the Ecology-approved model indicates that a concentration of 250 µg/L in the source area is protective of the underlying intermediate zone remedy. Therefore, once the average groundwater concentration in the source area (monitoring wells IMW-5, MW-5, VMW-8, VMW-9, VMW-10, and VMW-11) have been reduced to this level, it would be expected that further impacts to the intermediate zone would not occur and further active treatment of the source area would not be necessary.

The timeframe in which the first two conditions above would be met was evaluated and is included in Appendix E. It is estimated that approximately 5 to 10 years of continued pumping would be required (see Figures 8-5 and 8-6). The pumping rate could be reduced to only contain the SMC source area, as it does not impact the timeframe for source area cleanup as described in Section 9.0.

Long-term monitoring would be necessary to demonstrate that contaminant concentrations continue to decrease at a rate sufficient to ensure that they do not become a health threat or violate regulatory criteria. Monitoring will be designed to verify that potentially toxic transformation products are not created at levels that are a threat to human health and that the source area is not expanding.

The conceptual design of the alternative and estimated costs are included in Appendix E. Capital costs associated with the GPTIA were not allocated to this alternative; they are part of the costs associated with capture and treatment of the dissolved-phase plume. As summarized in Appendix E, the annual operation and maintenance costs for the GPTIA are approximately $125,000 per year at a flow rate of 1,250 gpm. An evaluation was completed to provide an allocation of these costs to just the source area remedy using quantitative and qualitative means. The estimated cost for the source area remedy (starting at the time of remedy selection) ranges from approximately $500,000 to $1,000,000 depending on the length of time to reach the protective level criteria.

Threshold Criteria

An evaluation of the pump and treat remedial alternative indicated that it meets the threshold requirements, as summarized below:

- This alternative protects human health and the environment by treating COCs in the source area via pump and treat.
- This alternative complies with the MTCA cleanup standards by treating COCs in the source area.
- Numerical standard ARARs were incorporated into the cleanup level determination.
- This alternative provides for compliance monitoring, both in terms of performance monitoring during the pump and treat remedy and conformation monitoring to monitor the long-term effectiveness of the remedy.

Use of Permanent Solutions

This alternative treats contaminated groundwater through pump and treat. Therefore, it meets the requirement for a permanent solution.

Reasonable Restoration Timeframe

Due to the removal of contaminants, it is expected that the timeframe to cease operation of the GPTIA would be on the order of 5 to 10 years in shallow groundwater. When shallow groundwater contaminants are confined to the SMC site, institutional controls (Restrictive

Covenant) would be applied to prevent exposure to COCs. Thus, this meets the reasonable timeframe criteria. However, residual concentrations will remain and will rely on MNR for final remedy.

Consideration of Public Concerns

The proposed action would be submitted for public comment and concerns raised would be addressed prior to design and implementation. It is anticipated that potential concerns of the public could be addressed as appropriate. It is not expected that any public concerns that would prevent the implementation of this alternative would be received or could not otherwise be rectified. It is anticipated that potential concerns of the public would be similar among the alternatives.

Prevent or Minimize Releases and Migration of Hazardous Substances in the Environment

This alternative provides for treatment of the most impacted zone; thus, it is effective at preventing or minimizing releases of hazardous substances.

Degree to Which Cleanup Action Relies on Dilution/Dispersion

Treatment of the source area contamination does not rely on dispersion or dilution. However, dilution and dispersion are part of the residual contamination remedy for the Site (MNA).

8.3.3 Disproportionate Cost Analysis

Costs are determined to be disproportionate to benefits if the incremental cost of a more expensive alternative over that of a lower cost alternative exceeds the incremental degree of benefits achieved by the more expensive alternative. As specified in WAC 173-340-360(3)(e) and (f), the disproportionate cost analysis includes evaluation criteria that are a mix of qualitative and quantitative factors. The primary evaluation criteria include:

- Protectiveness – The overall protectiveness of human health and the environment including the degree to which existing risks are reduced, time required to reduce risk at the facility and attain cleanup standards, on-site and off-site risks resulting from implementing the alternative, and improvement of the overall environmental quality.
- Permanence – The degree to which the alternative permanently reduces the toxicity, mobility or volume of hazardous substances, including the adequacy of the alternative in destroying the hazardous substances, the reduction or elimination of hazardous substance releases and sources of releases, the degree of irreversibility of waste treatment process, and the characteristics and quantity of treatment residuals generated.
- Cost – The cost to implement the alternative including the cost of construction, the net present value of any long-term costs, and agency oversight costs that are cost recoverable. Long-term costs include operation and maintenance costs, monitoring costs, equipment replacement costs, and the cost of maintaining institutional controls. Cost estimates for treatment technologies shall describe pretreatment, analytical, labor, and waste management costs. The design life of the cleanup action shall be estimated and the cost of replacement or repair of major elements shall be included in the cost estimate.
- Long-term Effectiveness – This includes the degree of certainty that the alternative will be successful, the reliability of the alternative during the period of time

hazardous substances are expected to remain on site at concentrations that exceed cleanup levels, the magnitude of residual risk with the alternative in place, and the effectiveness of controls required to manage treatment residues or remaining wastes. The following types of cleanup action components may be used as a guide, in descending order, when assessing the relative degree of long-term effectiveness: reuse or recycling; destruction or detoxification; immobilization or solidification; on-site or off-site disposal in an engineered, lined, and monitored facility; on-site isolation or containment with attendant engineering controls; and institutional controls and monitoring.

- Short-term Risks – The risk to human health and the environment associated with the alternative during construction and implementation and the effectiveness of measures that will be taken to manage such risks.
- Implementability – Ability to be implemented including consideration of whether the alternative is technically possible, availability of necessary off-site facilities, services and materials, administrative and regulatory requirements, scheduling, size, complexity, monitoring requirements, access for construction operations and monitoring, and integration with existing facility operations and other current or potential remedial actions.
- Consideration of Public Concerns – Whether the community has concerns regarding the alternative and, if so, the extent to which the alternative addresses those concerns. This process includes concerns from individuals, community groups, local governments, tribes, federal and state agencies, or any other organization that may have an interest in or knowledge of the site.

A comparative analysis of the alternatives was completed using these criteria. The comparative analysis allowed for each alternative to be compared relative to others with respect to the primary evaluation criteria. Each alternative was scored relative to the other alternatives. It is understood that remediation alternative ranking using relative criteria values is inherently subjective. Because the nature of the criteria is subjective, a qualitative or semi-quantitative evaluation based on currently available information and professional judgment was employed. A scale of zero (0) (least beneficial) to five (5) (most beneficial) was used for each criterion. Qualitative scoring for the criteria is appropriate and is typically conducted when the information to provide meaningful and defensible quantitative scoring is not available.

Table 8-3 presents an overall comparative summary of the five alternatives. Important differences and similarities among the alternatives are discussed below for each of the criteria.

8.3.3.1 Protectiveness

Alternative A (Source Area MNA) did not meet all the RAOs and, thus, did not meet the protectiveness criterion. Alternative B (Remedial Excavation) appears to achieve protectiveness in the timeliest manner due to direct removal of the source area. Alternatives C (AS/SVE) and D (Substrate Injection) are similar in terms of protectiveness due to similar target areas and technologies. Alternative E (Pump and Treat) meets the protectiveness criterion by reducing COCs in the source area and implementing institutional controls.

8.3.3.2 Permanence

Alternative A (Source Area MNA) is not deemed permanent as it is not effective and does not address the potential unacceptable risks posed by the site. Alternative B (Remedial

Excavation) is generally permanent as it includes direct removal of contaminants; however, the contaminants are transferred to a landfill. Alternatives C (AS/SVE) and D (Substrate Injection) generally have similar permanence as they are both treating/destroying contaminants. Alternative E (Pump and Treat) is permanent in that contaminants are removed by pump and treat.

8.3.3.3 Long-Term Effectiveness

Alternative A (Source Area MNA) does not achieve long-term effectiveness as no further actions are conducted. Alternatives B through D are similar, relying on remedial efforts to provide continued protection. Alternative B (Remedial Excavation), however, provides a greater level of long-term effectiveness due to the complete removal of impacted soil for off-site disposal. Alternatives C (AS/SVE) and D (Substrate Injection) are scored slightly lower due to some uncertainty regarding the remedial actions. Alternative E (Pump and Treat) is a proven and reliable method of remedial action for groundwater. Alternative E has continued ongoing operation and maintenance requirements.

8.3.3.4 Short-Term Risks

The implementation risk for Alternative A (Source Area MNA) is high due to perceived lack of agency acceptance and not achieving the RAOs. Alternative B (Remedial Excavation) has relatively high short-term risk related to the significant construction project that must occur to implement the action. In addition, shoring and dewatering issues contribute to a high short-term risk. Alternatives C (AS/SVE) and D (Substrate Injection) have similar short-term risks due to the complexity of the source area geology. Alternative C was scored lower than Alternative D due to the infrastructure involved for the AS/SVE system. Alternative E (Pump and Treat) has relatively low short-term risk as the pump and treat system has already been constructed, and the implementation of the alternative only relies on continued operation and maintenance.

8.3.3.5 Implementability

Alternative A (Source Area MNA) is the easiest to implement as it requires no action (shut-down of the GPTIA). Alternative B (Remedial Excavation) would be difficult to implement due to the significant dewatering and shoring involved, as well as available space for stockpiling and disruption of the site. Alternative C (AS/SVE) is implementable but has significant issues associated with the geology and target area; precise placement of the AS wells may not be feasible. There are similar concerns with the implementability for Alternative D (Substrate Injection) relating to the target area. Alternative E (Pump and Treat) is easily implementable as the current GPTIA is operational and can be continued without modification.

8.3.3.6 Consideration of Public Concerns

The proposed actions would be submitted for public comment and concerns raised would be addressed prior to design and implementation. It is expected that there would be significant public concerns associated with Alternative A as it requires no further action or cleanup. Some concerns associated with Alternative B may be realized due to disruption of the site and surrounding area for a large construction/excavation project. It is anticipated that potential concerns of the public would be similar among the remaining alternatives.

8.3.3.7 Cost

Cost estimates for each alternative are included in Appendix E. Long-term monitoring costs are not included in the evaluation, as they are similar for all the alternatives. In general, the costs include implementation costs for each alternative. The estimated alternatives' completion costs are as follows:

Alternative A – MNA (No Action in Source Area)	$234,000
Alternative B – Remedial Excavation of SMC Source Area	$875,000
Alternative C – Air Sparging and Soil Vapor Extraction	$219,000
Alternative D – *In Situ* Substrate Injection	$350,000
Alternative E – Pump and Treat, Institutional Controls and MNA	$500K – 1,000K

Based on the cost estimate for each alternative, a relative score was assigned as is shown on Table 8-3. ***Note that the cost for Alternatives B through D do not include continued pump and treat for the existing system, but would likely be required to supplement the alternative.*** These costs would be similar to those incurred for Alternative E alone; thus, costs associated with Alternatives B through D are higher than just for implementing Alternative E.

8.4 SCORING AND RANKING OF ALTERNATIVES

The scoring for each alternative, shown in Table 8-3, was conducted using a relative basis from 0 to 5 for each of the criteria (prior to evaluation of costs). As discussed above, each of the alternatives was scored for each criterion based on professional judgment. The total score for each alternative is as follows:

Alternative A – 10

Alternative B – 18

Alternative C – 18

Alternative D – 19

Alternative E – 25

After consideration of the individual screening and comparative analysis, the highest scored remedial alternative was Alternative E – Pump and Treat, Institutional Controls, and MNA. Alternative E was shown to be effective, reliable, implementable, and has little implementation risk. Alternative E also achieves all of the RAOs established for the SMC source area. Based on these considerations, Alternative E scored higher than Alternatives A through D (Table 8-3).

8.5 SELECTION OF PREFERRED ALTERNATIVE

After consideration of the individual screening and comparative analysis, the preferred remedial alternative selected for the SMC source area is Alternative E – Pump and Treat, Institutional Controls, and MNA.

9. SITE FEASIBILITY EVALUATION

The following sections provide a summary of the feasibility evaluation for the Site and selection of a preferred remedy. The intent of this section is to evaluate remedial alternatives for the Site (dissolved-phase groundwater plume), after selection of preferred remedial actions have been made for the SMC and NuStar source areas, and which are complementary to and compatible with the selected actions.

The Site is defined in Section 1.1, and is generally determined by the extent of the dissolved-phase groundwater plume (i.e., “location in which contaminants have come to be located”) from the three source areas. Due to natural processes, pumping from historical and current water supply wells, and interim actions completed at the NuStar, Cadet and SMC sites, the distribution of the dissolved-phase groundwater plume has varied over time, but has significantly decreased in aerial extent and concentrations since investigations and remedial actions were initiated. Section 9.1 describes the extent of the dissolved-phase groundwater plume in 2013 that was considered during development and evaluation of the remedial alternatives. In accordance with the goals of this FS, the remedial alternatives evaluation for the Site (dissolved-phase groundwater plume) was focused on actions that support the preferred alternatives for each of the source areas (Sections 7 and 8).

9.1 EXTENT OF IMPACTED GROUNDWATER AT THE SITE

As described in Section 2.3, a pump and treat system (GPTIA) was installed by the Port at the SMC site in 2009 to extract and treat dissolved-phase groundwater contaminants in the project area. Operation of this system has significantly reduced the overall distribution of dissolved-phase contaminants. In addition, interim actions conducted for the Cadet site, including RGRWs and AS/SVE system, decreased groundwater concentrations and contaminant mass in the Cadet area (beneath the Cadet facility and to the east beneath the NFVN), which has reduced the magnitude and extent of the overall plume. Additionally, groundwater interim actions at the NuStar facility (in 2008 and 2011) have decreased the mass of shallow zone VOCs in groundwater, thus reducing the mass available to migrate to intermediate zone groundwater and further decreasing the magnitude and extent of the dissolved-phase groundwater plume. Plume maps showing a comparison of TCE concentrations in the project area between 2009 and 2013 are shown on Figures 2-24 through 2-26.

The current distribution of VOCs at the Site is based on groundwater samples collected from monitoring wells during the first quarter 2013 monitoring event. The first quarter event was a comprehensive sampling event, when all active SMC, Cadet, and NuStar site monitoring wells were sampled. Consequently, results associated with the first quarter 2013 event provide the most recent comprehensive dataset to assess the dissolved-phase groundwater plume. The distribution of VOCs in groundwater is primarily based on the presence of TCE and PCE. These two compounds have the highest frequency of detection, are the primary contaminants released at the source areas, are the focus of cleanup actions, and are the primary contaminants of concern in groundwater at the Site (i.e., indicator hazardous substances). It should be noted that the extent of cis-1,2-DCE, particularly associated with the NuStar facility, is not evaluated further in this Site FS discussion. As determined by the NuStar risk assessment, the majority of site risk is associated with PCE and TCE. While cis-1,2-DCE data are particularly useful in evaluating the anaerobic degradation of VOCs at the NuStar facility, the bulk of VOC mass at the Site (below the NuStar site) is comprised of PCE and TCE; therefore, cis-1,2 DCE is not evaluated when selecting remedial alternatives for the Site.

Figures 2-19 through 2-22 present the first quarter 2013 isoconcentration maps for TCE and PCE in the intermediate and deep USA water quality zones. The extent of TCE and PCE in intermediate and deep zone groundwater has been summarized in detail in Section 2.5. The extent of TCE and PCE in the shallow USA water quality zone has been previously discussed in the source area extent discussions for NuStar and SMC properties (Sections 7.1 and 8.1). The extent of VOCs and evaluation of cleanup alternatives associated with the shallow zone source areas are not evaluated further in this section as the Site cleanup technologies evaluated in this section all assume that source areas are addressed in accordance with the feasibility analyses in Sections 7 and 8.

9.2 TECHNOLOGY EVALUATION

This section describes the development of the cleanup action alternatives to be evaluated based on the contaminant distribution in 2013 and remedial requirements. The remedial alternative development process includes identifying general response actions and corresponding technologies, screening technologies to eliminate those that are clearly not feasible, and assembling remaining technologies into a list of cleanup action alternatives. In order to evaluate feasible technologies, the following RAOs have been established for the Site dissolved-phase groundwater plume:

- Achieve the cleanup standards for COCs.
- Protect human health and the environment, including groundwater, surface water, and sediment considerations.
- Use permanent solutions to the maximum extent practicable (which includes consideration of cost-effectiveness).
- Ensure protection of current or future public groundwater pumping wells (i.e., CPU, City of Vancouver, Port of Vancouver) from the existing dissolved-phase groundwater plume.

EPA technology screening guidance provides an assessment of general classes of technologies classified by media and type of treatment. The guidance is relatively comprehensive and was used to identify potential technologies for the Site. The general technologies identified for the project area include:

- Institutional Controls
- Engineering Controls
- Containment
- Removal/Discharge
- *Ex Situ* Biological or Physical/Chemical Treatment (used for treatment of extracted groundwater)
- *In Situ* Biological Treatment or Physical/Chemical Treatment

The specific technologies for the dissolved-phase groundwater plume are presented on Table 9-1. For the first screening step, technologies that are not applicable to the media of concern or the goals of the cleanup were eliminated. Three criteria (effectiveness, implementability, and cost) were used to complete an initial screening of the remaining technologies (Table 9-1). After this initial screening, the specific technologies retained for assembly of potential alternatives are as follows:

- Groundwater Use Restrictions (Institutional Controls)
- Monitoring (Institutional Controls)
- Pumping/Hydraulic Containment (Containment)
- Pumping/Pump and Treat (Removal/Discharge)
- Discharge to Sewer/Surface Water (Removal/Discharge)
- Discharge to Reinjection Wells (Removal/Discharge)
- Air Stripping (*Ex Situ* Physical/Chemical)
- Constructed Wetlands (*Ex Situ* Physical/Chemical)
- MNA (*In Situ* Physical/Chemical)

These potential technologies were further evaluated based on site-specific conditions to develop a set of remedial alternatives that could be applied to the dissolved-phase groundwater plume. As applicable, some technologies were combined with others to define a specific remedial alternative. The development of the alternatives and site-specific conditions are summarized in the following section.

9.3 CLEANUP ACTION ALTERNATIVE DEVELOPMENT

The technologies were further screened to select those suitable for the site conditions and contaminants of concern, and to determine whether the action uses permanent solutions to the maximum extent practicable. The technologies that pass this screening were used for assembly into remedial alternatives that will be evaluated for use at the Site. Remedial alternatives were developed based on the nature and extent of contamination, potential future use of the site, technological feasibility, and engineering/logistical considerations. The following are the site-specific conditions that serve as screening criteria to determine relevant technologies from the list in Section 9.2 above:

- Media: shallow, intermediate and deep groundwater aquifer designated as a Sole Source Aquifer.
- Contaminants: dissolved-phase HVOCs (primarily TCE and PCE).
- Site Usage: light and heavy industrial usage with heavy traffic. Some residential areas are located in and near the Site.
- Known public drinking water wells in the project vicinity (CPU, Port of Vancouver, and City of Vancouver).
- Industrial use of groundwater in the project vicinity, including for malt production by GWM.
- Presence of an existing pump and treat system at the SMC source area (used as an interim action) that was designed to extract and contain groundwater at the Site, including the dissolved-phase groundwater plume.
- Interim actions that have been conducted in the NuStar, Cadet, and SMC source areas to reduce source area concentrations. Additional remedial actions are recommended for the NuStar and SMC source areas (see Sections 7 and 8) and the Site remedial alternatives were developed to supplement and support any selected additional source area remedial actions.

Using these considerations, the potential remedial alternatives evaluated for groundwater were generally limited to the physical removal, treatment, and discharge of contaminated material or *in situ* treatment. The presence of the pump and treat system at the SMC site was the primary factor in screening of technologies and developing alternatives. In addition, as discussed in Section 9.1, the concentrations of contamination in the dissolved-phase groundwater plume have been reduced significantly and are close to the MTCA Method B cleanup levels for TCE and PCE. Therefore, the availability and success of the pump and treat system focused this current technological evaluation on supplementing the source area preferred alternatives (Sections 7 and 8) and evaluating the feasibility of alternatives that support Site closure. This was generally limited to continued operation of the pump and treat system and/or MNA. After consideration of the above site-specific conditions, the remedial alternatives for the dissolved-phase groundwater plume were reduced to the following two for evaluation in this FS:

Alternative A –Source Control/Treatment and Monitored Natural Attenuation

Alternative B – Source Control/Treatment and Pump and Treat

Detailed descriptions of the alternatives and evaluation against MTCA criteria are discussed in Section 9.4.

9.3.1 Use of Groundwater Model in Evaluating Cleanup Action Alternatives

The following sections provide a summary of the groundwater model evaluations for the source areas and dissolved-phase plume to support remedial action evaluation.

9.3.1.1 Summary of Source Area Model Evaluations

As discussed in Sections 7.1 and 8.0, the groundwater model was utilized to evaluate whether residual concentrations of VOCs in shallow zone groundwater concentrations in the NuStar and SMC source areas were protective of the intermediate and deep zone groundwater with no further remedial action. At the NuStar source area, the model indicated that the current mass in the source area was not impacting the dissolved-phase plume at concentrations that would render MNA infeasible, and that intermediate zone groundwater concentrations would attenuate to below cleanup levels beneath the source in less than 15 years. This scenario would occur given current conditions with no additional source interim action or groundwater pumping in the region. Similarly, the groundwater model was utilized to evaluate whether groundwater concentrations in the SMC source area were protective of deeper groundwater. The source area remedy proposed in Section 8 (focused groundwater pump and treat) will contain the source area and reduce concentrations to 250 µg/L within approximately 5 to 10 years. As summarized in Appendix B, an evaluation using the model indicates that a concentration of 250 µg/L in the source area is protective of the underlying intermediate zone remedy. Because ongoing interim actions at the NuStar and SMC source areas are protective of the intermediate zone groundwater, this opens up MNA as a viable alternative to be considered for the intermediate and deep zone groundwater along with other technologies.

9.3.1.2 Summary of Model Evaluations for the Dissolved-Phase Plume

For the dissolved-phase groundwater plume, the groundwater model was primarily used to evaluate the effectiveness of the two remedial alternatives. This included use of the model to assess the effectiveness of MNA and/or continued pump and treat on the future plume extent, groundwater concentrations, and protection of nearby pumping centers (City of Vancouver, Port of Vancouver, and CPU). A summary of the model scenarios, significant assumptions, relevant parameters, and results are included in Appendix B.

The following pumping scenarios were evaluated with the groundwater model to assess a range of future results for MNA (Alternative A) or continued Pump and Treat (Alternative B):

- Pump and treat system shutdown (January 2013): Plume configuration Year 5, Year 10, and Year 15 (i.e., 2018, 2023, and 2028, respectively).
- Pump and treat operating for 5 years: Plume configuration Year 5, Year 10, and Year 15.
- Pump and treat operating for 10 years: Plume configuration Year 5, Year 10 and Year 15.

The first scenario essentially evaluates the dissolved-phase plume starting with current groundwater concentrations (1st Quarter 2013) and does not include any potential treatment of the source areas through actions selected in Sections 7 and 8. This provides the most conservative basis of analysis by which the other scenarios can be measured against. The second scenario includes operation of the pump and treat system for 5 years, which corresponds to the minimum timeframe for SMC source area cleanup (see Section 8.0). The third scenario includes operation of the pump and treat system for 10 years, which corresponds to a conservative estimate of the maximum time required for SMC source area cleanup (see Section 8.0). Under all three scenarios, the current groundwater conditions (1st Quarter 2013) at NuStar, SMC, and Cadet were assumed as starting concentrations. Therefore, the model runs may overpredict the distribution of the groundwater plume since it is expected that source area conditions will be reduced significantly in a short timeframe, especially for the NuStar source area.

The results of the modeling were also used to evaluate protection of the larger pumping centers in the project area, primarily City of Vancouver, Port of Vancouver, and CPU. Results of the modeling are included in Appendix B and are utilized in the sections below, as necessary. Groundwater modeling indicates that groundwater TCE and PCE concentrations in the intermediate zone are currently at levels that will not impact regional pumping wells in the vicinity (CPU, City of Vancouver, Port, etc.) above the MTCA Method B cleanup levels in the absence of EW-1 operation (i.e., turn the system off). This includes a conservative baseline scenario where no further source area actions are implemented for NuStar or SMC. Therefore, the source area remedies to be implemented will further reduce the available mass for migration into the intermediate zone and thus be highly protective of the regional pumping wells. This supports that the implementation of MNA is protective of known drinking water receptors.

9.4 EVALUATION OF CLEANUP ACTION ALTERNATIVES

As stated previously, MTCA established minimum requirements and procedures for selecting cleanup actions in WAC 173-340-360. The same standard and procedures were used in selection of both the Site remedies and remedies for the source areas. MTCA requires that all cleanup actions meet the threshold requirements that are part of the minimum requirements. Any alternatives that do not meet the threshold requirements are dropped from further consideration. This section uses the threshold requirements to screen the alternatives developed for the Site. Under MTCA, remediation alternatives must meet the following threshold requirements [(WAC 173-340-360(2)(a)]:

- Protection of human health and the environment
- Compliance with cleanup standards

- Compliance with ARARs
- Provision for compliance monitoring

Each alternative is evaluated individually against the threshold. Alternatives that do not meet the threshold requirements are not carried forward to the evaluation of other requirements [WAC 173-340-360(2)(b)]. The other requirements were defined in Section 6.0 and include:

- Use of Permanent Solutions
- Reasonable Restoration Timeframe
- Consideration of Public Concerns
- Prevent or Minimize Releases and Migration of Hazardous Substances in the Environment
- Degree to Which Cleanup Action Relies on Dilution/Dispersion

The following sections evaluate each of the individual alternatives against the threshold requirements and other criteria.

9.4.1 Alternative A – Source Control/Treatment and MNA

This alternative primarily consists of MNA and was developed as a supporting alternative to the source control and cleanup at the NuStar and SMC source areas to achieve RAOs. Although evaluated independently as an MNA alternative, this remedy assumes the source area preferred alternatives will be completed as described and are incorporated into this proposed alternative. Source control and cleanup at the NuStar site will include additional enhanced bioremediation (see Section 7.0). Source control and cleanup at the SMC site will include continued operation of the pump and treat system and implementation of institutional controls. The rate of pumping of the pump and treat system could be reduced to encompass the source area rather than the entire dissolved-phase plume (see Section 8.0).

Because the groundwater model already indicates that the Site plume is protective of current drinking water receptors (i.e., CPU, Port, COV), MNA can be applied as a remedy for the dissolved-phase plume concurrently with source control at the NuStar and SMC properties. Natural attenuation processes include a variety of physical, chemical, and biological processes that, under favorable conditions, act without human intervention to reduce the mass, toxicity, mobility, volume, or concentration of contaminants in groundwater. These *in situ* processes include biodegradation; dispersion; dilution; sorption; volatilization; and chemical or biological stabilization, transformation, and destruction of contaminants. Periodic monitoring is necessary to demonstrate that contaminant concentrations continue to decrease at a rate sufficient to ensure that they do not become a threat to human health or the environment. It is necessary to know what specific mechanism is responsible for the attenuation of organics so that the stability of the mechanism can be evaluated.

According to MTCA as described under WAC 173-340-370(7), MNA as a remediation alternative is most appropriate for sites with the following characteristics:

- Source control has been conducted to the maximum extent practicable;
- Leaving contaminants on the Site during the restoration timeframe does not pose an unacceptable threat to human health or the environment;
- There is evidence that natural biodegradation or chemical degradation is occurring and will continue to occur at a reasonable rate at the Site; and

- Appropriate monitoring is conducted to ensure that contaminant concentrations continue to decrease, the natural attenuation processes continue to occur, and human health and the environment are protected.

For the Site dissolved-phase groundwater plume, MNA technology would be applicable because:

- Various source control activities (e.g., interim actions at NuStar, Cadet, and SMC) have been completed that have reduced concentrations significantly in the source areas and throughout the dissolved-phase groundwater plume. Additional source treatment is recommended as described in Sections 7 and 8 for the NuStar and SMC properties, respectively. Source area treatment at NuStar includes additional enhanced bioremediation. Source area treatment at SMC includes continued operation of the pump and treat system at a rate sufficient to capture the source area (evaluated at a maximum rate of 1,250 gpm).
- Residual contamination does not pose a threat because potential receptors do not have direct contact with the contaminants remaining at the Site and the contamination does not pose a risk to human health or the environment because there is no complete exposure pathway. A MNA sampling program can be employed to ensure that assumptions for exposure are continually validated.
- There is evidence that natural attenuation is currently occurring and has significantly decreased contaminant concentrations. Specifically, biodegradation conditions have been documented near and beneath the NuStar facility. Groundwater concentrations of all contaminants at the Site have been steady or declining during the past monitoring period and are expected to continue to decline and ultimately achieve cleanup levels.
- Groundwater monitoring is required for the Site and has been conducted for all three source areas and the dissolved-phase groundwater plume. As part of the implementation of the FS remedies, a MNA sampling program will be developed and implemented. This will include establishing POCs and sampling methodology and criteria.
- Land use restrictions will be in place to protect potential exposure through direct contact or ingestion of groundwater that exceeds cleanup levels.
- The availability of the current groundwater pump and treat system provides a contingency element in the event that MNA is not proceeding as expected or an additional remedial action is desired to supplement MNA. This contingency will be included in the development of the MNA implementation plan, including criteria for shutting down and dismantling the GPTIA system.

The groundwater model was used to evaluate the applicability of MNA and to support the selection of MNA as the primary component to this alternative. Results of the modeling are included in Appendix B and are summarized below:

- Groundwater modeling indicates that groundwater TCE and PCE concentrations in the intermediate zone are currently at levels that will not impact regional pumping wells in the vicinity (CPU, City of Vancouver, Port, etc.) above the MTCA Method B cleanup levels in the absence of EW-1 operation (i.e., turn the system off). This includes a conservative baseline scenario where no further source area actions are implemented for NuStar or SMC. Therefore, the source area remedies to be implemented will further reduce the available mass for migration into the intermediate zone and thus be highly protective of the regional pumping wells. This supports that the implementation of MNA (with source control) is protective of known drinking water receptors.

- Additional source area remedial actions to be conducted at the NuStar facility include enhanced bioremediation. As discussed in Section 7.0, this remedial action is expected to reduce the NuStar source area to near or below the MTCA Method B cleanup levels for PCE and TCE within approximately 5 to 10 years. Groundwater modeling has shown that source removal at NuStar is not needed to be protective of intermediate zone groundwater, and that monitored natural attenuation can be implemented immediately. Source control, however, is proposed to shorten the shallow (source area) groundwater restoration timeframe.
- Groundwater modeling shows that if the SMC source area is reduced to an average TCE concentration of approximately 250 µg/L (referred to as the protective level in Section 8), source area shallow groundwater will not impact the intermediate zone above the MTCA Method B cleanup level. As discussed in Section 8.0, the reduction of the SMC source area groundwater concentrations to this protective level through operation of the groundwater pump and treat system is expected to take between 5 and 10 years.
- Based on the above, groundwater modeling indicates the intermediate USA zone will achieve the MTCA Method B cleanup levels at all POCs within 15 to 20 years, as long as source area treatment criteria are met. Figures 9-1 and 9-2 show the modeled concentrations remaining above the MTCA Method B cleanup level for PCE and TCE at Year 15 for the scenario in which EW-1 is pumping for 10 years to treat the SMC source area. Other model scenario results are included in Figures GM-1 through GM-54 in Appendix B.

The MNA approach will include a number of planning and reporting documents to support that MNA is meeting the RAOs. A comprehensive work plan would be prepared to outline methods for monitoring techniques and sampling events. The plan would define all POC sampling locations within the Site. The monitoring program would be developed with the objective of verifying the ongoing effectiveness of recovery of contaminated groundwater by natural processes. The monitoring would be used to evaluate contaminant concentrations relative to the cleanup levels established for the Site.

The estimated costs to implement the alternative is included in Appendix F. Estimated costs range from approximately $2.5M to $3.1M, which primarily includes monitoring requirements over an estimated 20-year timeframe (assumed starting from 2014), as well as planning documents for implementation of MNA. Costs associated with source control and cleanup at NuStar and SMC are not included with this alternative, as they are included as the preferred alternatives described in Sections 7 and 8.

9.4.1.1 Threshold Criteria

An evaluation of the source control and MNA remedial alternative indicates that it meets the threshold requirements, as summarized below:

- This alternative protects human health and the environment by removing COCs from the source areas and MNA reduces COCs to cleanup levels within a reasonable timeframe.

- This alternative complies with the MTCA cleanup standards by removing COCs from the source areas. Cleanup levels will be achieved in the intermediate zone in a reasonable timeframe.
- Numerical standard ARARs were incorporated into the cleanup level determination.
- This alternative provides for compliance monitoring, both in terms of performance monitoring during the source area remedies and conformation monitoring to monitor the long-term effectiveness of the remedies and MNA.

9.4.1.2 Use of Permanent Solutions

MNA is used for the dissolved-phase groundwater plume to achieve cleanup levels. Natural attenuation processes include a variety of physical, chemical, and biological processes that, under favorable conditions, act without human intervention to reduce the mass, toxicity, mobility, volume, or concentration of contaminants in groundwater. There is evidence that natural biodegradation or chemical degradation is occurring and will continue to occur at a reasonable rate at the Site. Therefore, MNA meets the requirement for a permanent solution.

9.4.1.3 Reasonable Restoration Timeframe

Groundwater modeling indicates the intermediate USA zone will achieve the MTCA Method B cleanup levels at all POCs within 15 to 20 years, as long as source area treatment criteria are met. This meets the reasonable timeframe criteria.

9.4.1.4 Consideration of Public Concerns

The proposed action would be submitted for public comment and concerns raised would be addressed prior to design and implementation. It is anticipated that potential concerns of the public could be addressed as appropriate. It is not expected that any public concerns that would prevent the implementation of this alternative would be received or could not otherwise be rectified.

9.4.1.5 Prevent or Minimize Releases and Migration of Hazardous Substances in the Environment

This alternative provides for removal of the most impacted zones; thus, it is effective at preventing or minimizing releases of hazardous substances. Groundwater modeling shows that even at current conditions (prior to additional source area remedies and MNA) public drinking water receptors will not be impacted above the MCLs.

9.4.1.6 Degree to Which Cleanup Action Relies on Dilution/Dispersion

Dilution and dispersion are part of an integral to the MNA remedy; however, the technology does not rely on these factors alone. MNA also utilizes such process as biodegradation, sorption, volatilization, and chemical or biological stabilization, transformation, and destruction of contaminants.

9.4.2 Alternative B – Source Control/Treatment and Pump and Treat

This alternative primarily consists of continued pump and treat and was developed as a supporting alternative to the source control and cleanup at the NuStar and SMC source areas to achieve RAOs. This remedy assumes the source area preferred alternatives will be completed as described; however, this alternative includes pump and treat beyond the time and flow rates required for source control. Source control and cleanup at the NuStar facility will include additional enhanced bioremediation (see Section 7.0). Source control and cleanup at the SMC property will include operation of the pump and treat system and implementation of institutional controls. The pump and treat system in this alternative is assumed to be operated at the current rate of 2,500 gpm and operated until MTCA Method B cleanup levels are achieved at all points of compliance in the intermediate USA zone.

Since the source controls are the same as those described for Alternative A, this alternative is primarily an evaluation of whether additional benefits are gained by continued operation of the pump and treat system to achieve cleanup levels in the intermediate zone versus implementation of MNA (i.e., active versus passive remedial action). The pump and treat system will be operated until cleanup levels are obtained at all POCs throughout the intermediate USA zone. The groundwater model was used to evaluate the effectiveness of the pump and treat system. Results of the modeling are included in Appendix B and are summarized below:

- Groundwater modeling indicates that groundwater TCE and PCE concentrations in the intermediate zone are currently at levels that will not impact regional pumping wells in the vicinity (CPU, City of Vancouver, Port, etc.) above the MTCA Method B cleanup levels in the absence of EW-1 operation (i.e., turn the system off). Thus any active alternative, such as pump and treat, is considered additionally conservative.
- Groundwater modeling shows that if the SMC source area is reduced to an average TCE concentration of approximately 250 µg/L (referred to as the protective level in Section 8), source area shallow groundwater will not impact the intermediate zone above the MTCA Method B cleanup level. As discussed in Section 8.0, the reduction of the SMC source area to this protective level through operation of the groundwater pump and treat system is expected to take between 5 and 10 years. This can be achieved at flow rates much lower than modeled for Alternative B.
- Groundwater modeling results show that after 5 to 10 years for completion of source area treatment (to meet the protective level of 250 µg/L), the continued operation of the pump and treat system to achieve MTCA Method B cleanup levels for TCE and PCE at all POCs will take another 5 to 10 years. When compared to Alternative A, the timeframe to achieve cleanup levels through GPTIA pumping at the current rate is similar. The additional 5 to 10 years of pumping does not appear to substantially impact cleanup; thus, pumping at the higher rate and for a longer period of time than would be required for source control only does not appear to have substantial benefit.

The pump and treat alternative will include a number of planning and reporting documents to support that the remedy is meeting the RAOs. A comprehensive work plan would be prepared that would outline the pump and treat operation plan, as well as methods for monitoring techniques and sampling events. The plan would define all POC sampling locations within the Site. The monitoring program would be developed with the objective of verifying the ongoing effectiveness of recovery of contaminated groundwater by operation of the pump and treat system. The monitoring would quantify the reduction in concentrations relative to the cleanup levels established for the Site.

The estimated costs to implement the alternative is included in Appendix F. Estimated costs range from approximately $4.7M to $6.8M, which primarily includes operation of the pump and treat system at the current pumping rate for a period of 10 to 15 years and monitoring requirements over an estimated 15-year timeframe (e.g., the midpoint between the low and high end estimates of restoration time), as well as planning documents for implementation of MNA. Costs associated with source control and cleanup at NuStar and SMC are not included with this alternative, as they are included as the preferred alternatives described in Sections 7 and 8. In addition, capital costs associated with the pump and treat system are not included as it has already been constructed as part of the Port's interim action and was allocated to that remedy.

9.4.2.1 Threshold Criteria

An evaluation of the pump and treat remedial alternative indicates that it meets the threshold requirements, as summarized below:

- This alternative protects human health and the environment by treating COCs in the source area and dissolved-phase groundwater plume via pump and treat.
- This alternative complies with the MTCA cleanup standards by treating COCs in the source area and dissolved-phase groundwater plume.
- Numerical standard ARARs were incorporated into the cleanup level determination.
- This alternative provides for compliance monitoring, both in terms of performance monitoring during the pump and treat remedy and conformation monitoring to monitor the long-term effectiveness of the remedy.

9.4.2.2 Use of Permanent Solutions

Additional pumping and treatment is used for the dissolved-phase groundwater plume to achieve cleanup levels and permanently removes VOC mass from the system. Therefore, this alternative meets the requirement for a permanent solution.

9.4.2.3 Reasonable Restoration Timeframe

Groundwater modeling indicates this would require operation of the pump and treat system for 10 to 20 years to meet cleanup standards. Given that there is no interim risk to potential receptors, this meets the reasonable timeframe criteria.

9.4.2.4 Consideration of Public Concerns

The proposed action would be submitted for public comment and concerns raised would be addressed prior to design and implementation. It is anticipated that potential concerns of the public could be addressed as appropriate. It is not expected that any public concerns that would prevent the implementation of this alternative would be received or could not otherwise be rectified.

9.4.2.5 Prevent or Minimize Releases and Migration of Hazardous Substances in the Environment

This alternative provides for treatment of the source areas and project area zones; thus, it is effective at preventing or minimizing releases of hazardous substances. Groundwater modeling shows that even at current conditions (prior to additional source area remedies) public drinking water receptors will not be impacted above the MCLs.

9.4.2.6 Degree to Which Cleanup Action Relies on Dilution/Dispersion

This alternative does not rely on dispersion or dilution. Active remediation will be implemented and operated until the cleanup levels are achieved.

9.5 GENERAL DISPROPORTIONATE COST ANALYSIS FOR GROUNDWATER

Costs are determined to be disproportionate to benefits if the incremental cost of a more expensive alternative over that of a lower cost alternative exceeds the incremental degree of benefits achieved by the more expensive alternative. As specified in WAC 173-340-360(3)(e) and (f), the disproportionate cost analysis includes evaluation criteria that are a mix of qualitative and quantitative factors. The primary evaluation criteria includes:

- Protectiveness
- Permanence
- Cost
- Long-term Effectiveness
- Short-term Risks
- Implementability
- Consideration of Public Concerns

A description of the evaluation criteria for analysis of disproportionate costs is provided in Sections 7.4 and 8.4. Each alternative was scored relative to the other alternatives. It is understood that remediation alternative ranking using relative criteria values is inherently subjective. Because the nature of the criteria is subjective, a qualitative or semi-quantitative evaluation based on currently available information and professional judgment was employed. A scale of zero (0) (least beneficial) to five (5) (most beneficial) was used for each criterion. Qualitative scoring for the criteria is appropriate and is typically conducted when the information to provide meaningful and defensible quantitative scoring is not available.

Table 9-2 presents an overall comparative summary of the two alternatives. Important differences and similarities between the alternatives are discussed below for each of the criteria.

9.5.1 Protectiveness

Current receptors (drinking water wells) are protected with Alternative A (MNA) and B (Pump and Treat). Alternative B is thought to provide a slightly greater level of protectiveness by incorporating a longer pump and treat timeframe into the dissolved-phase groundwater plume remedy, thus reducing the timeframe to achieve the MTCA cleanup levels.

9.5.2 Permanence

Alternatives A (MNA) and B (Pump and Treat) generally have similar permanence as they are both treating contaminants in the source area. However, Alternative A relies on MNA to ultimately reach cleanup levels. Alternative B is thought to provide a slightly greater level of permanence by incorporating a longer pump and treat timeframe into the dissolved-phase groundwater plume remedy, thus potentially reducing the timeframe to achieve the MTCA cleanup levels.

9.5.3 Long-Term Effectiveness

Alternatives A (MNA) and B (Pump and Treat) are similar with respect to long-term effectiveness. Each rely on remedial efforts to provide continued protection from the source areas and ultimately achieve cleanup levels in the dissolved-phase groundwater plume.

Alternative B, however, provides a slightly greater level of long-term effectiveness due to the complete removal of impacted groundwater through treatment, while Alternative A relies on the monitoring of natural processes. The effectiveness of both alternatives would be evaluated based on similar monitoring programs.

9.5.4 Short-Term Risks

There is little risk associated with Alternative A (MNA) as no construction or implementation is required and the ongoing measures of effectiveness (i.e. groundwater monitoring) are well established in the project area. There is also little risk associated with Alternative B (Pump and Treat), as the infrastructure has already been constructed and the operational process has already been implemented.

9.5.5 Implementability

Both alternatives are considered implementable and technically feasible. MNA (Alternative A) is very implementable and has been ongoing at the site for several years. Alternative B is also very implementable, as the current pump and treat system at SMC will be used and is operational and has no significant concerns. Since Alternative B uses infrastructure and mechanical equipment, with the potential for malfunction and maintenance, this technology is slightly less implementable than Alternative A.

9.5.6 Consideration of Public Concerns

The proposed actions would be submitted for public comment and concerns raised would be addressed prior to design and implementation. It is anticipated that potential concerns of the public could be addressed as appropriate. It is not expected that any public concerns that would prevent the implementation of the alternatives would be received or could not otherwise be rectified. Alternatives A and B are scored the same.

9.5.7 Cost

Estimated costs for each alternative are included in Appendix F. The estimated alternatives' completion costs are as follows:

Alternative A – Source Control/Treatment and MNA	\$2.5M-\$3.1M
Alternative B – Source Control/Treatment and Pump and Treat	\$4.7M-\$6.8M

Based on the cost estimate for each alternative, a relative score was assigned as is shown on Table 9-2. The costs are assigned independent of the other criteria such that the disproportionate costs can be considered as outlined below.

9.6 SCORING AND RANKING OF ALTERNATIVES

The scoring for each alternative, shown in Table 9-2, was conducted using a relative basis from 0 to 5 for each of the criteria. As discussed above, each of the alternatives was scored for each criterion based on the best professional judgment. Prior to evaluation of the disproportionate costs, the score for each alternative is as follows:

Alternative A – 26

Alternative B – 27

Costs are determined to be disproportionate to benefits if the incremental cost of a more expensive alternative over that of a lower cost alternative exceeds the incremental degree of benefits achieved by the more expensive alternative.

An evaluation of Alternative A (MNA) versus Alternative B (Pump and Treat) suggests that no significantly greater benefit is achieved through implementation of Alternative B. The timeframe for achieving cleanup of the dissolved-phase groundwater plume is similar, but it is suspected that a slight increase is gained by active operation of the pump and treat system as described for Alternative B. However, the reduction of risk and protection of human health and the environment is not any greater than Alternative A. In addition, both alternatives are considered protective, permanent, and implementable, and have little short-term risks or public concern issues. The cost to implement Alternative B over Alternative A is significantly higher, but does not achieve a higher incremental degree of benefit.

Thus, after consideration of the individual screening and comparative analysis, and the disproportionate cost analysis, the highest scored remedial alternative was Alternative A, Source Control/Treatment and Monitored Natural Attenuation. Alternative A was shown to be effective, reliable, implementable, and has little implementation risk.

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10. RECOMMENDED CLEANUP ACTIONS

As described previously, the feasibility evaluation primarily focused on contaminants in groundwater at the source areas and throughout the Site. However, all media (soil, groundwater, air, and sediment) have been addressed by previous remedial or interim actions or will be addressed by the current preferred remedial actions. Therefore, this FS Report constitutes the final evaluation of remedial actions for all media for all three sites, including the site-wide dissolved-phase groundwater plume.

The following summarizes the preferred cleanup actions for the NuStar source area, SMC source area, and the Site.

10.1 NUSTAR SOURCE AREA

Based on the overall evaluation in Sections 7.1 through 7.3, the recommended cleanup actions for the NuStar source area are SVE/Enhanced Bioremediation/Source Control. Together, these cleanup actions include the following technologies.

- Soil SVE:
  - Continued operation, inspection, and maintenance of the interim action SVE system;
  - Development of a soil management plan to ensure that proper controls are implemented during future activities at locations where impacted soils may be exposed;
  - Monitoring of the SVE vapor discharges;
  - Regular reporting of system operation and monitoring results; and
  - Post-remediation soil sampling to verify that soil cleanup levels are achieved.
- Groundwater Enhanced Bioremediation:
  - Injection of a vegetable-oil-based substrate in the shallow zone groundwater between the interim action injection area and the river;
  - Monitoring of groundwater concentrations to evaluate effectiveness of the cleanup action;
  - If necessary, conduct secondary injection to address residual impacts to groundwater;
  - Implementation of groundwater use restrictions (restrictive covenant, media management plan, or equivalent); and
  - Regular reporting of monitoring results.
- Sediment Source Control:
  - Groundwater source control actions as described above for groundwater cleanup actions;
  - Natural recovery of sediments as the groundwater source is eliminated; and
  - Baseline,during remediation and post-remediation sediment sampling to verify that sediment cleanup levels are achieved.

These cleanup actions were selected for the following reasons.

- The cleanup actions meet the threshold requirements: protecting human health and the environment, complying with cleanup standards and ARARs, and providing for compliance monitoring.
- The cleanup actions are the most permanent of the potential cleanup actions evaluated. The actions use permanent approaches to the maximum extent practicable to treat the source area and cleanup sediments.
- The restoration timeframe is the most reasonable of the cleanup actions evaluated.
- The cleanup actions address the potential for present and future releases or migration of hazardous substances by treating the source area.
- The cleanup actions address the source area risk by treatment.

The final design of the cleanup actions will be determined at the time of development of the cleanup action plan and will be based on the conditions present at the time of design.

10.2 SMC SOURCE AREA

Based on the overall evaluation in Section 8, the recommended cleanup action for the SMC source area is Pump and Treat and Institutional Controls. Together, these cleanup actions include the following technologies.

- Pump and Treat:
  - Continued operation, inspection, and maintenance of the interim action groundwater extraction and treatment system;
  - Development of an operation plan to ensure that the pump and treat system is operated in such a manner to maximize source area cleanup;
  - Monitoring of the source area groundwater wells to ensure cleanup is progressing in a reasonable timeframe to meet the “protective” level;
  - Groundwater monitoring incorporated into the project area MNA approach to verify that groundwater cleanup levels are achieved for the Site; and
  - Regular reporting of system operation and monitoring results.
- Institutional Controls:
  - Implementation of groundwater use restrictions (Restrictive Covenant, contaminated media management plan, or equivalent) for the SMC property to prevent shallow groundwater from being used and/or to prevent any other potential exposure to hazardous substances at the site;
  - Regular reporting of monitoring results to support institutional control requirements.

These cleanup actions were selected for the following reasons.

- The cleanup actions meet the threshold requirements: protecting human health and the environment, complying with cleanup standards and ARARs, and providing for compliance monitoring.

- The cleanup actions are the most permanent of the potential cleanup actions evaluated. The actions use permanent approaches to the maximum extent practicable to treat the source area.
- Restoration of the site will be achieved in a reasonable timeframe.
- The cleanup actions address the potential for present and future releases or migration of hazardous substances by treating the source area.
- The cleanup actions address the source area risk by treatment.

The final design of the cleanup actions will be determined at the time of development of the cleanup action plan and will be based on the conditions present at the time of design.

10.3 SITE

Based on the overall evaluation in Section 9, the recommended cleanup action for the Site is Source Control/Treatment and Monitored Natural Attenuation. This cleanup action includes the following technologies.

- Source Control/Treatment:
  - As described in Sections 10.1 and 10.2 above.
- MNA:
  - Development of a MNA implementation plan, which includes establishing points of compliance, sampling methodology, locations, and frequency, and MNA evaluation criteria;
  - Monitoring of the Site groundwater wells to verify that groundwater cleanup levels are achieved in a reasonable timeframe; and
  - Regular reporting of monitoring results.

This cleanup action was selected for the following reasons.

- The cleanup actions meet the threshold requirements: protecting human health and the environment, complying with cleanup standards and ARARs, and providing for compliance monitoring.
- There is evidence that natural biodegradation or chemical degradation is occurring and will continue to occur at a reasonable rate at the Site. Therefore, MNA meets the requirement for a permanent solution.
- Groundwater modeling indicates the intermediate USA zone will achieve cleanup levels at all POCs within 15 to 20 years, as long as source area treatment criteria are met. This meets the reasonable timeframe criteria.
- Groundwater modeling shows that even at current conditions (prior to additional source area remedies and MNA) public drinking water receptors will not be impacted above the MCLs.
- The cleanup actions address the potential for present and future releases or migration of hazardous substances by treating the source areas.

The final design of the cleanup action will be determined at the time of development of the cleanup action plan and will be based on the conditions present at the time of design.

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11. REFERENCES

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FIGURES

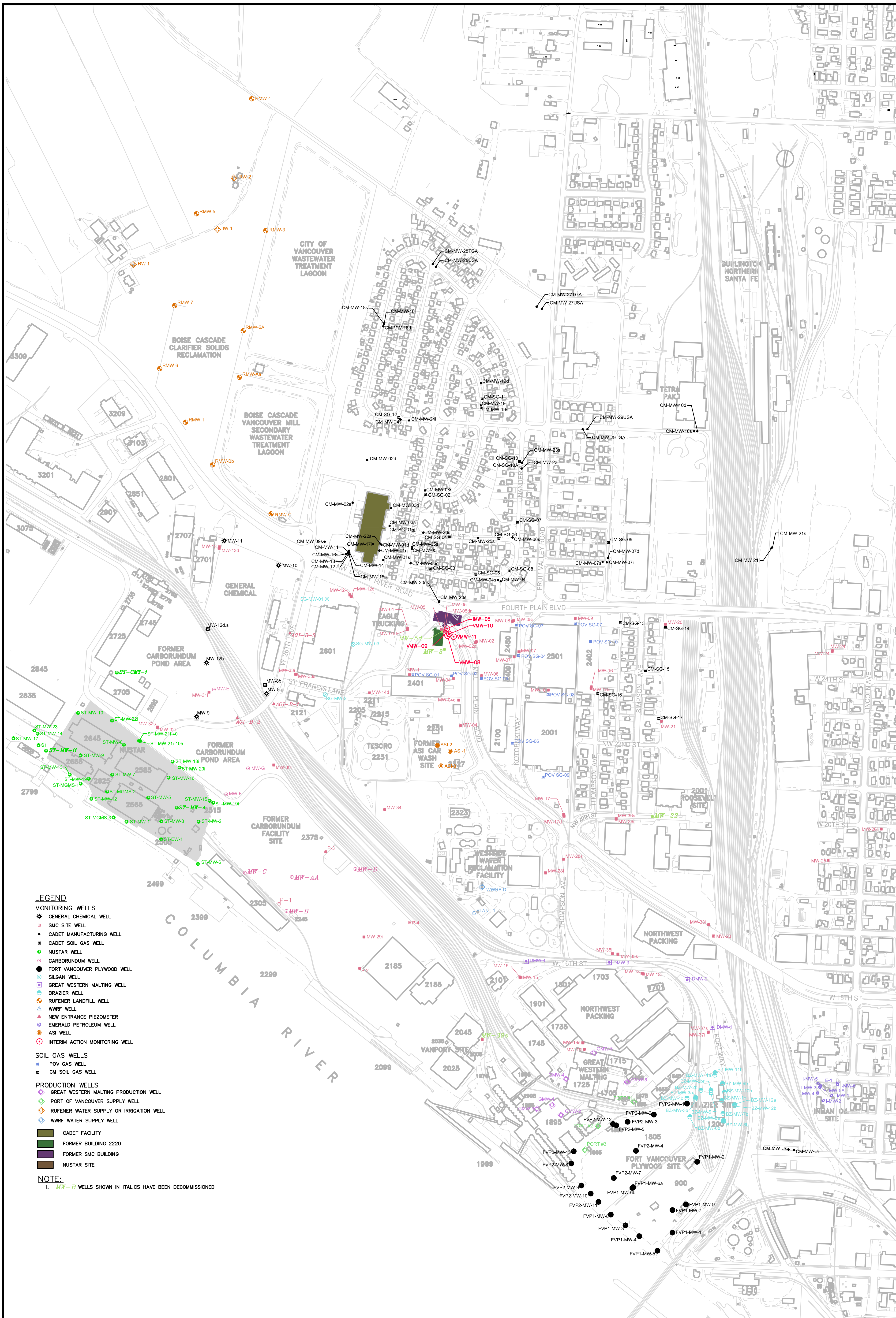
Figure 1-1
Project Area

Feasibility Study
NuStar, SMC, and Cadet
Vancouver, WA

Parametrix Date: 9/9/2014 File: P:\GIS\POV\MXD_PDF\Figures_01082014\Figure1-2_LeaseholdBoundaries.mxd

Figure 1-2
Leasehold Boundaries

Feasibility Study
NuStar, SMC, and Cadet
Vancouver, WA



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N

0 650'

SCALE IN FEET

Figure 1-3
Project Area Well Network

FEASIBILITY STUDY
NUSTAR, SMC AND CADET
VANCOUVER, WA

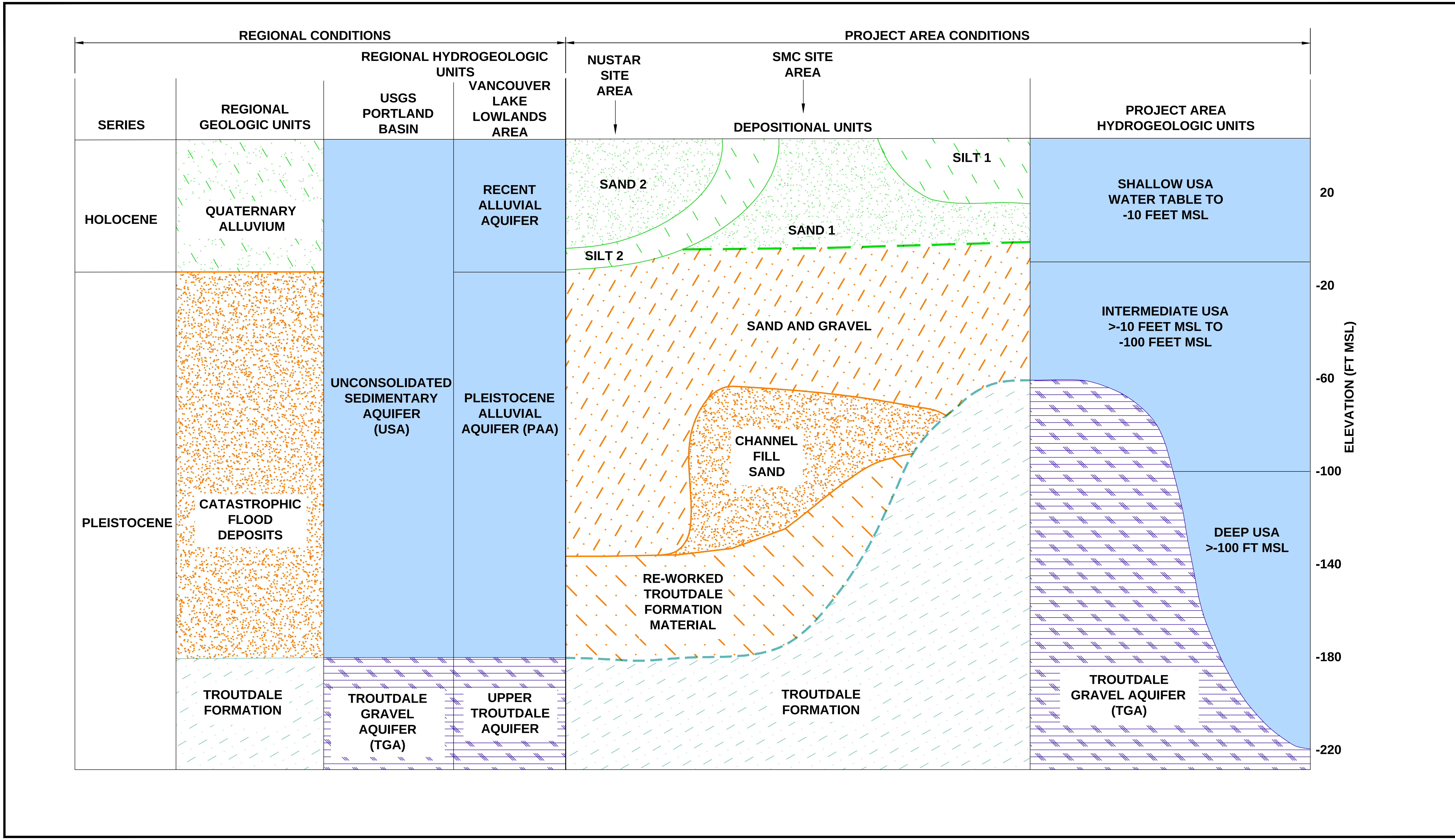

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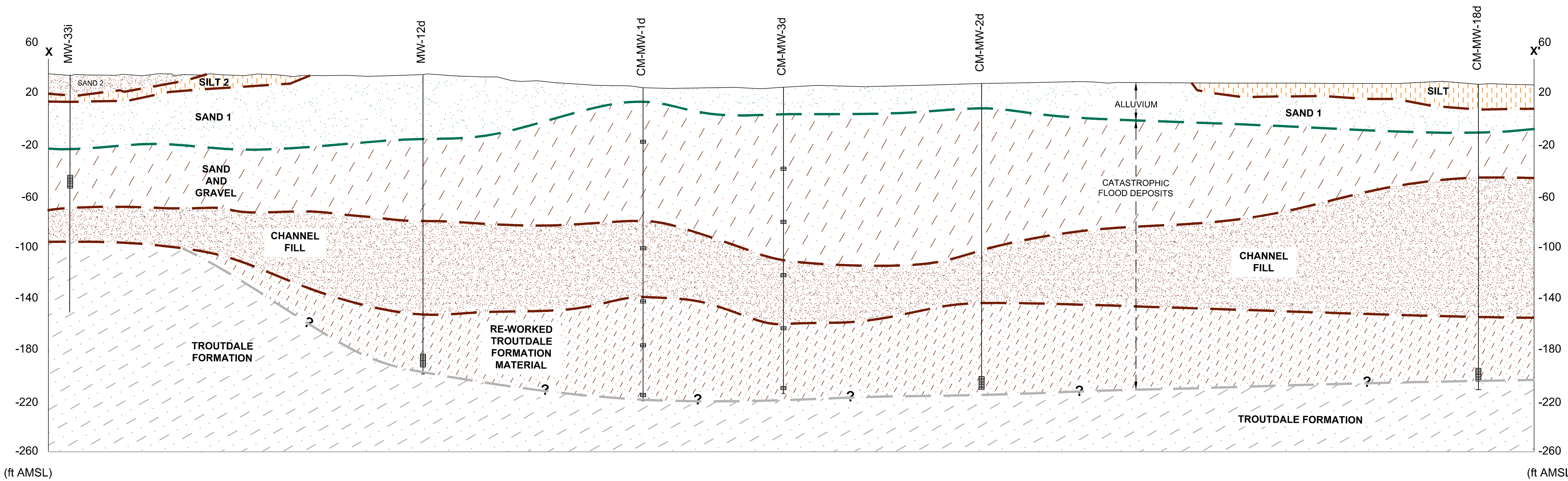
Figure 2-1
Regional and Project Area Geologic and Hydrologic Units

FEASIBILITY STUDY
NUSTAR, SMC, AND CADET
VANCOUVER, WA

Parametrix Date: 9/8/2014 Path: P:\GIS\POV\MXD_PDF\Figures_01082014\Figure2-2_CrossSectionOrientation_V2.mxd

Figure 2-2
Cross Section Orientations

Feasibility Study
NuStar, SMC, and Cadet
Vancouver, WA



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APPROXIMATE SCALE: HORIZONTAL 1"=200'
VERTICAL 1"=80'

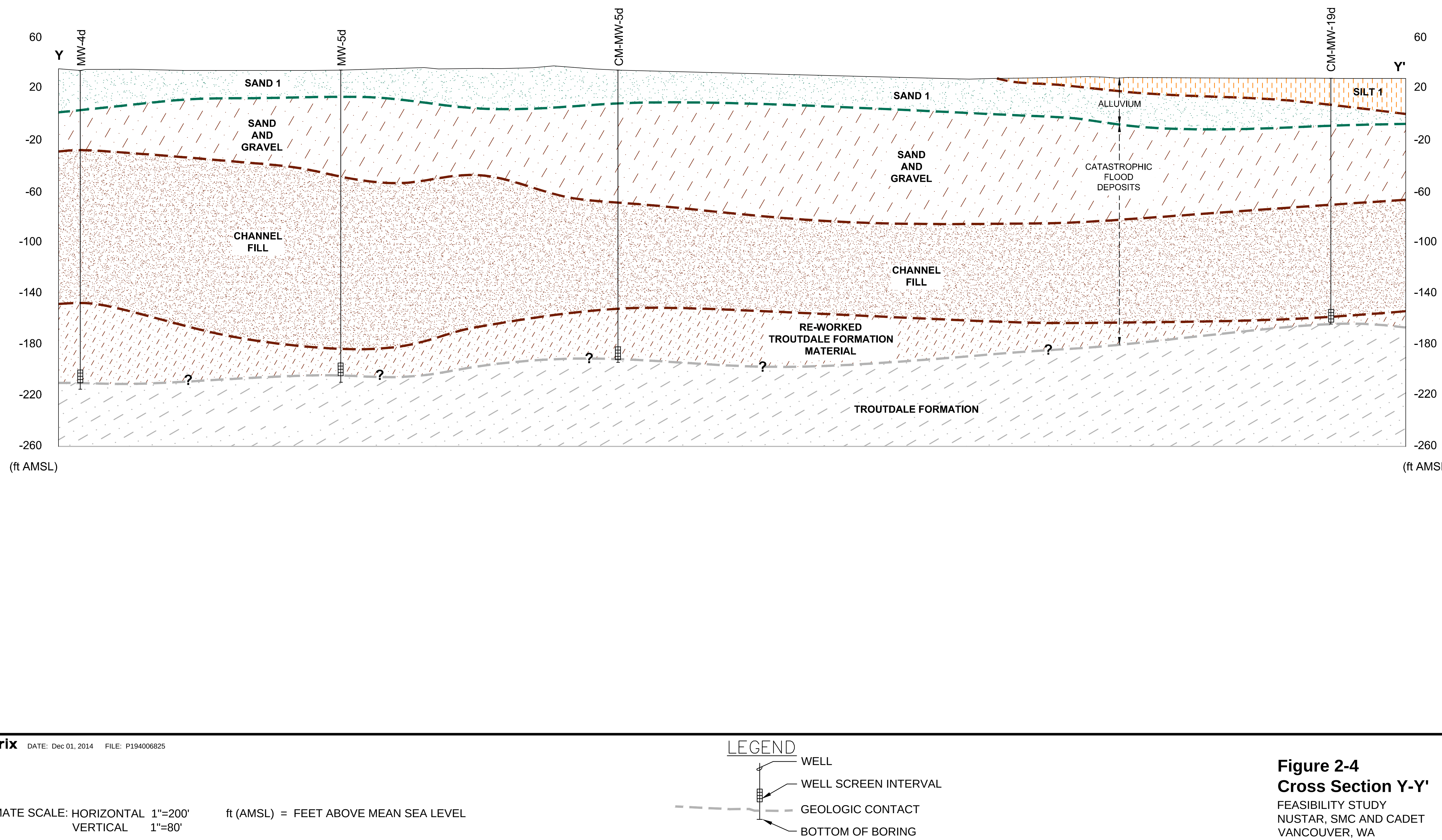
ft (AMSL) = FEET ABOVE MEAN SEA LEVEL

LEGEND

- WELL
- WELL SCREEN INTERVAL
- GEOLOGIC CONTACT
- BOTTOM OF BORING

Figure 2-3
Cross Section X-X'

FEASIBILITY STUDY
NUSTAR, SMC AND CADET
VANCOUVER, WA

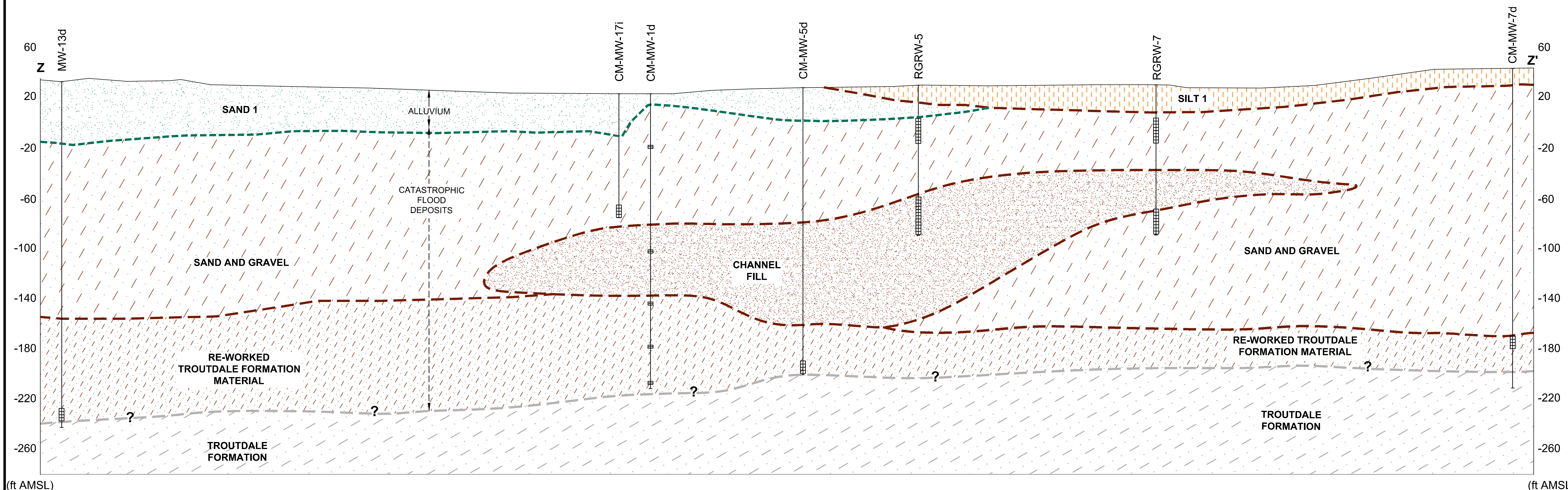


Parametrix DATE: Dec 01, 2014 FILE: P194006825

APPROXIMATE SCALE: HORIZONTAL 1"=200'
VERTICAL 1"=80'

ft (AMSL) = FEET ABOVE MEAN SEA LEVEL

Figure 2-4
Cross Section Y-Y'
FEASIBILITY STUDY
NUSTAR, SMC AND CADET
VANCOUVER, WA



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APPROXIMATE SCALE: HORIZONTAL 1"=200' VERTICAL 1"=80'

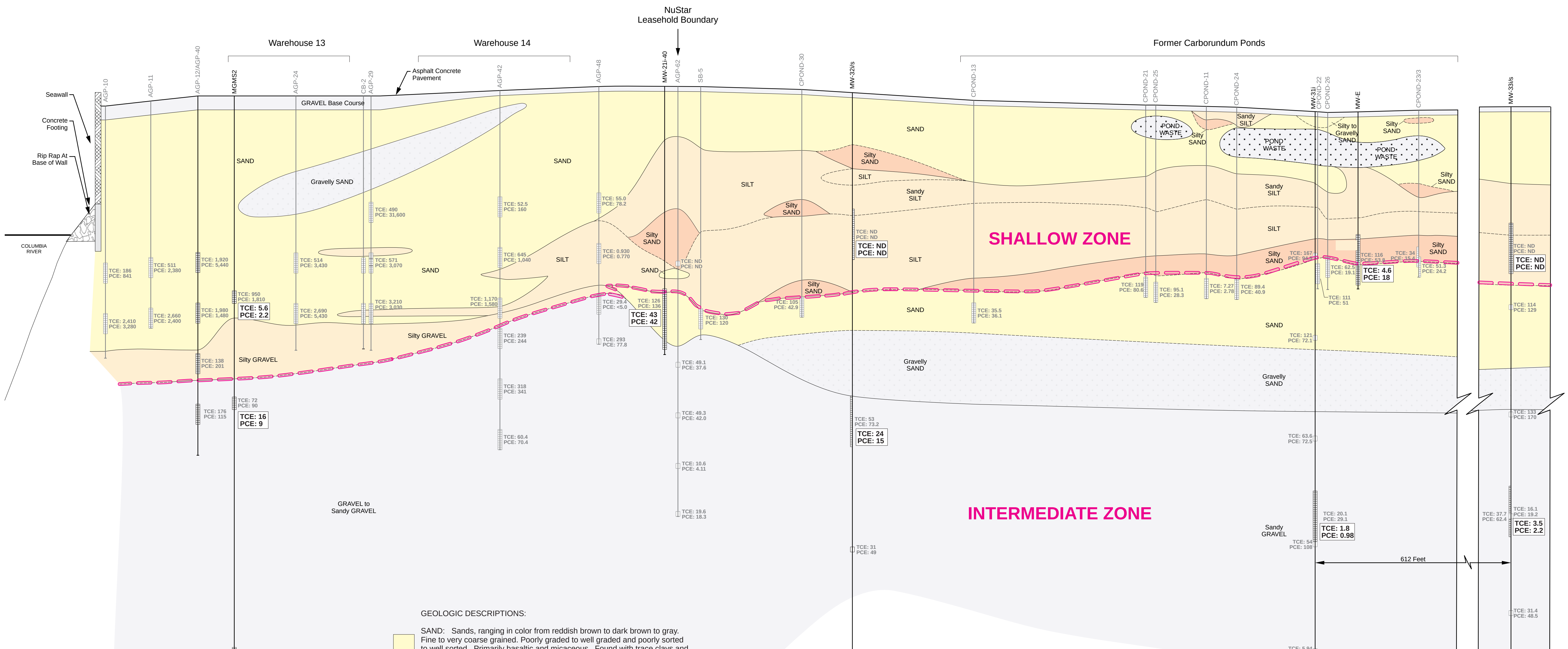
ft (AMSL) = FEET ABOVE MEAN SEA LEVEL

LEGEND

- WELL
- WELL SCREEN INTERVAL
- GEOLOGIC CONTACT
- BOTTOM OF BORING

Figure 2-5
Cross Section Z-Z'

FEASIBILITY STUDY
NUSTAR, SMC AND CADET
VANCOUVER, WA



GEOLOGIC DESCRIPTIONS:

SAND: Sands, ranging in color from reddish brown to dark brown to gray. Fine to very coarse grained. Poorly graded to well graded and poorly sorted to well sorted. Primarily basaltic and micaceous. Found with trace clays and gravels, and/or thin silt layers.

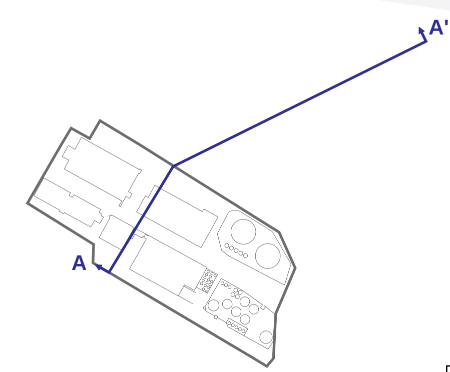
Silty SAND: Silty sands, ranging in color from dark yellowish brown to brown. Loose to medium stiff, with fine to coarse grained sands. Well graded. Micaceous with occasional gravels.

SILT: Silts, silts with sands, sandy silts, gravelly sandy silts and clayey silts. Color ranging from reds and tans, to grays, browns and black, frequently mottled. Soft to medium stiff, clayey silts ranging from soft to moderate plasticity. fine to coarse sands.

Gravelly SANDS: Gravelly sand to sand with gravel. Color ranging from reds to brown or black. Fine to coarse sands that are poorly graded to well graded. Clasts are well rounded to angular, up to six inches in diameter. Basaltic and micaceous with trace silts.

GRAVEL: Gravels with sand to sandy gravels. Color ranging from gray to black. Silty sandy matrix with trace clays. Fine to coarse grained, loose to partial cementation. Poorly graded to well graded. Clasts range from well rounded to angular. Basaltic with trace quartzite gravels.

POND WASTE



Cross Section Location

Approximate Horizontal Scale in Feet
0 100 200

0 20 40
Approximate Vertical Scale in Feet
Vertical Exaggeration x 5

Legend:

- Borehole
- TCE: 176 / PCE: 115 — Recent Trichloroethene (TCE) Concentration in µg/L; Recent Tetrachloroethene (PCE) Concentration in µg/L
- TCE: 176 / PCE: 115 — Historical TCE Concentration in µg/L; Historical PCE Concentration in µg/L
- Screened Interval
- Depth Discrete Sample Location

Sampling Notes:

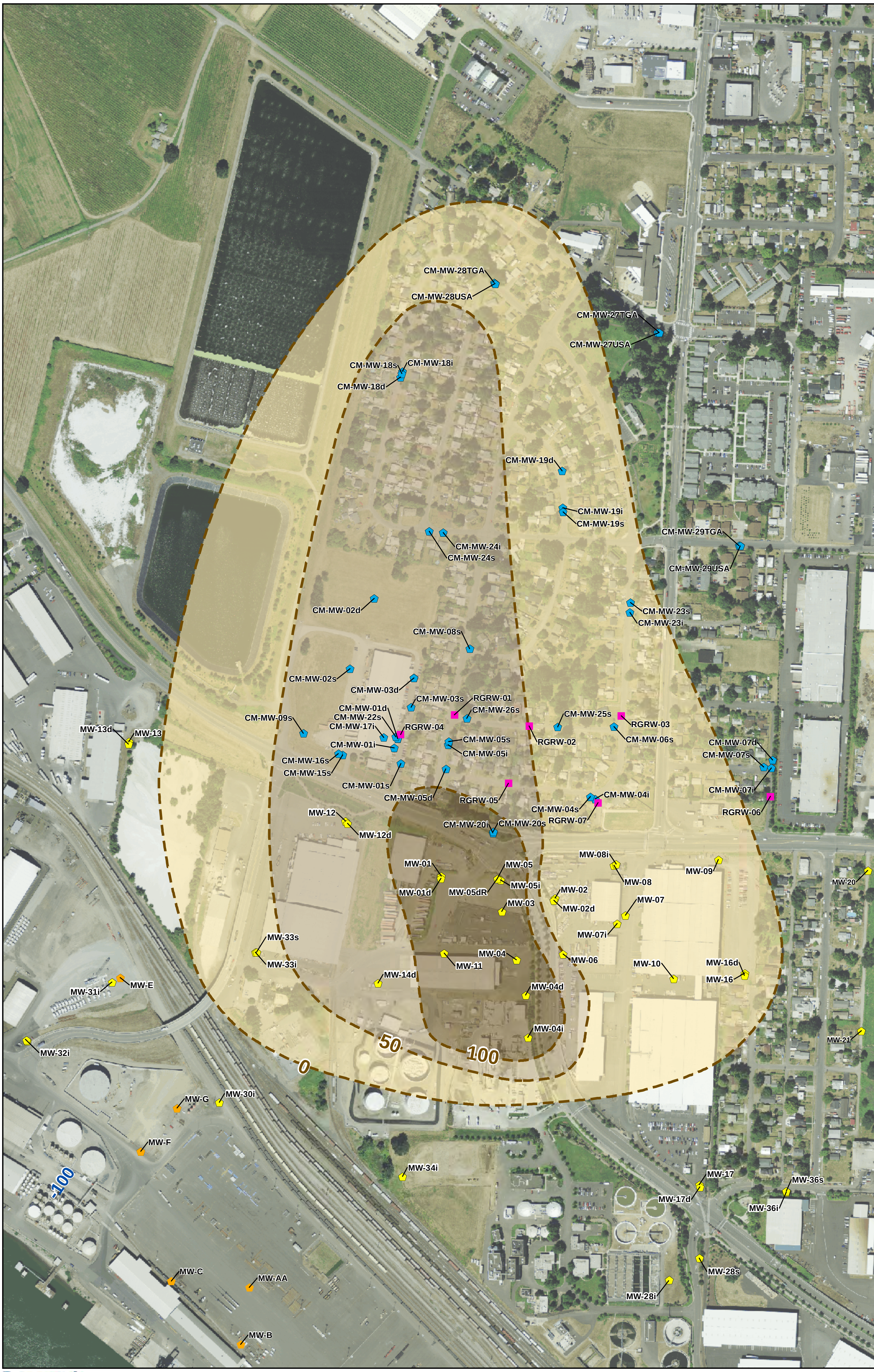
1. Historical Data (in grey):
   a. NuStar (AGP) data from 2006; "SB" boring data from March 2005.
   b. Off-facility well data from March 2006; "C-Pond" data collected by Parametrix in March 2005.
   c. Historical monitoring well data from March/June 2008.
   d. Boring CB-2 data from September 2010.
   e. Depth discreet data from POV wells MW-31i and MW33i/s are from January 2003 and July/August 2004, respectively.
2. Recent Data (in black; boxed):
   a. Monitoring well data from March 2013.
3. ND = Not detected (reporting limit of 0.5 µg/L unless otherwise specified).

NuStar Geologic Cross-Section A-A'

Feasibility Study
NuStar Terminals Services, Inc. Vancouver Facility
Vancouver, Washington

APEX
Apex Companies, LLC
3015 SW First Avenue
Portland, Oregon 97201

Project Number	1126-14	Figure
March 2014		2-6



Parametrix Date: 9/8/2014 File: P:\GIS\POV\MXD_PDF\Figures_01082014\Figure2-7_ChannelSandFillThickness.mxd

N

0 250 500

Scale in Feet

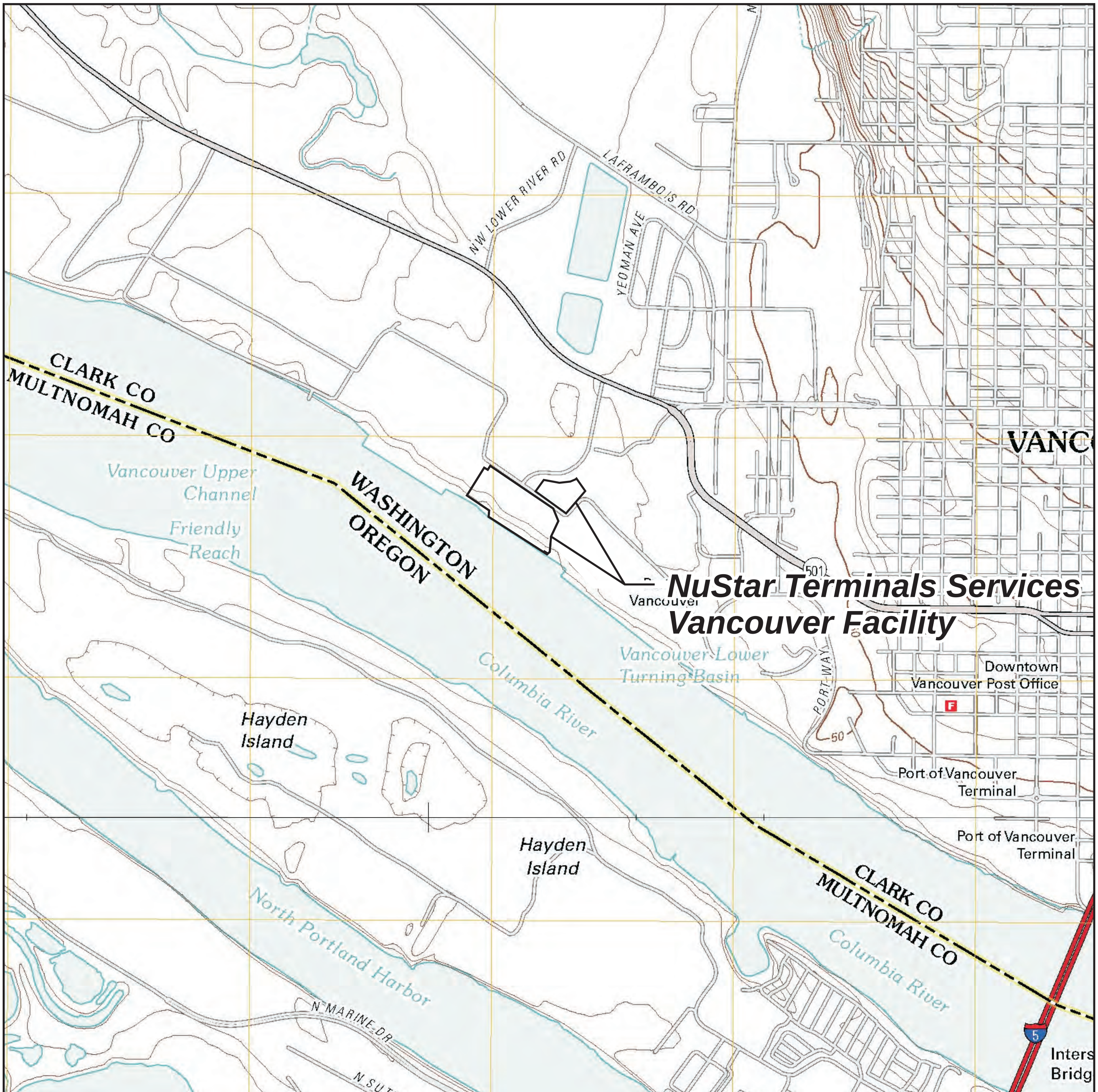
Thickness of Channel Fill Deposits in Feet

- 0
- 50
- 100

- SMC Site Well
- Cadet Manufacturing Well
- Recirculating Well
- Carborundum Well

Figure 2-7
Channel Sand Fill Thickness

Feasibility Study
NuStar, SMC, and Cadet
Vancouver, WA



Note: Base map prepared from USGS 7.5-minute quadrangles of Vancouver, WA-OR and Portland, OR-WA, dated 2011 as provided by USGS.gov.

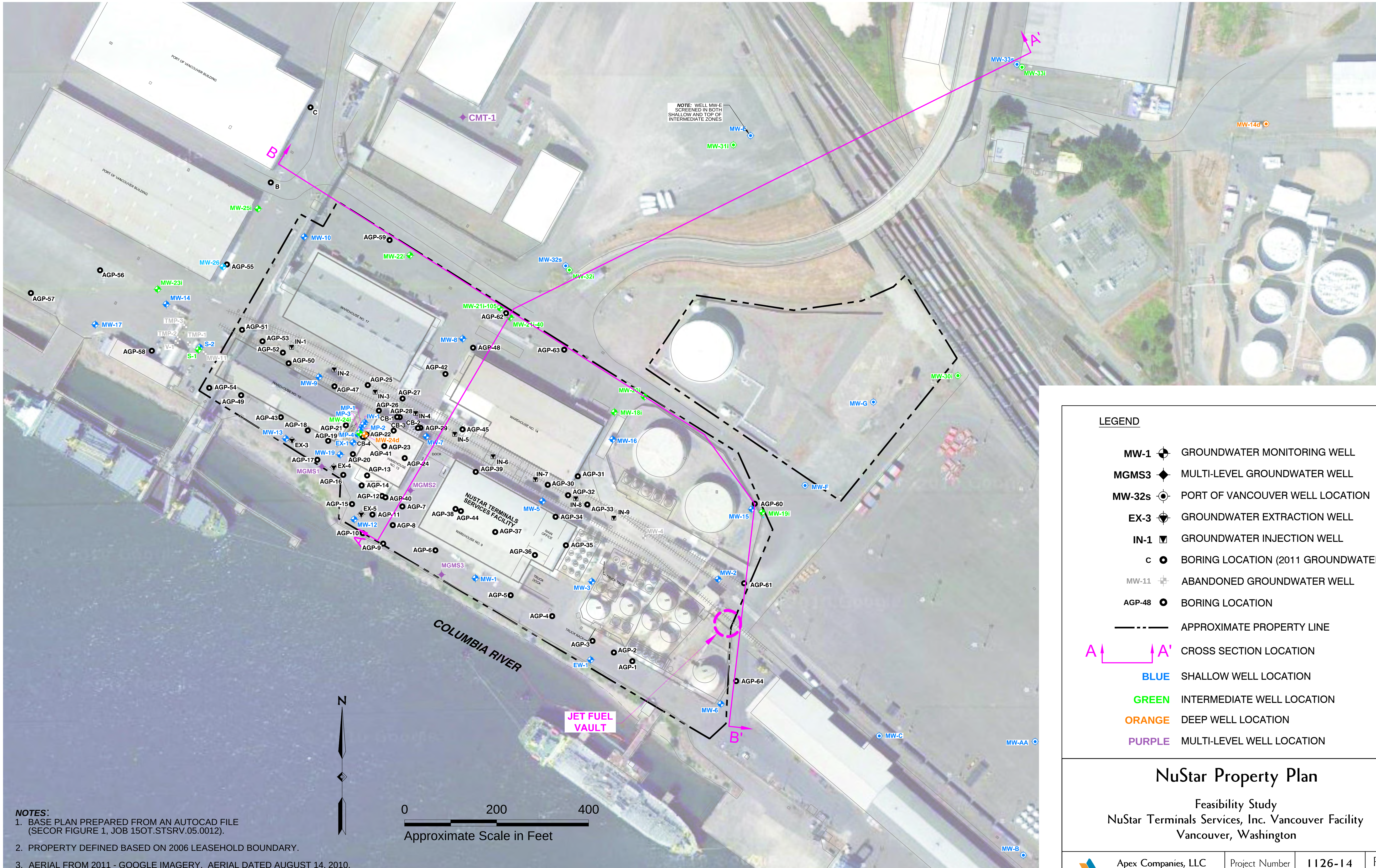
0 2,000 4,000
Approximate Scale in Feet

N

NuStar Facility Location Map

Feasibility Study
NuStar Terminals Services, Inc. Vancouver Facility
Vancouver, Washington

APEX	Apex Companies, LLC 3015 SW First Avenue Portland, Oregon 97201	Project Number: 1126-14 January 2014	Figure 2-8



NOTES:

1. BASE PLAN PREPARED FROM AN AUTOCAD FILE (SECOR FIGURE 1, JOB 15OT.STSRV.05.0012).
2. PROPERTY DEFINED BASED ON 2006 LEASEHOLD BOUNDARY.
3. AERIAL FROM 2011 - GOOGLE IMAGERY. AERIAL DATED AUGUST 14, 2010.

LEGEND

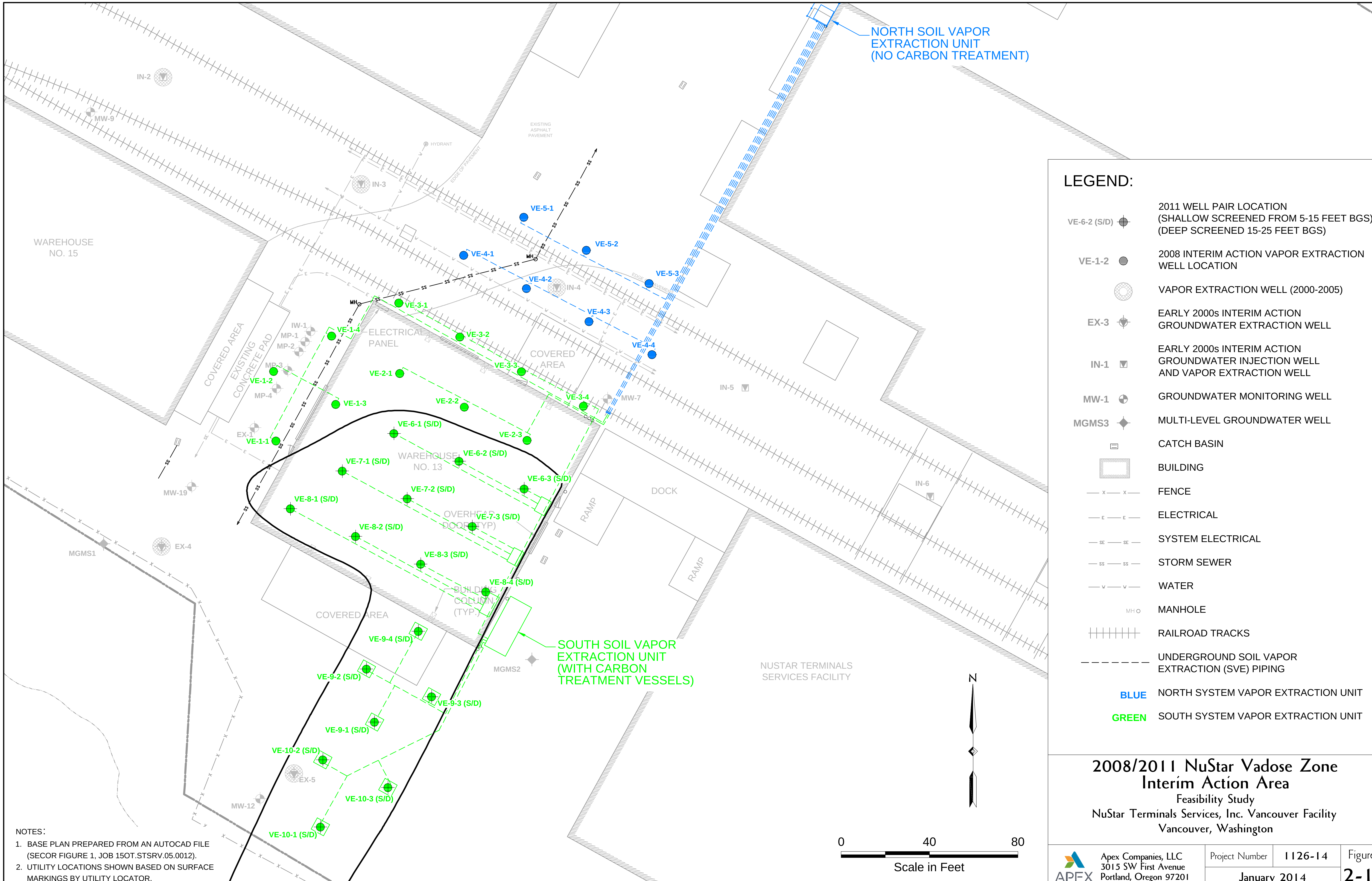
MW-1	GROUNDWATER MONITORING WELL
MGMS3	MULTI-LEVEL GROUNDWATER WELL
MW-32s	PORT OF VANCOUVER WELL LOCATION
EX-3	GROUNDWATER EXTRACTION WELL
IN-1	GROUNDWATER INJECTION WELL
C	BORING LOCATION (2011 GROUNDWATER INV.)
MW-11	ABANDONED GROUNDWATER WELL
AGP-48	BORING LOCATION
	APPROXIMATE PROPERTY LINE
A A'	CROSS SECTION LOCATION
BLUE	SHALLOW WELL LOCATION
GREEN	INTERMEDIATE WELL LOCATION
ORANGE	DEEP WELL LOCATION
PURPLE	MULTI-LEVEL WELL LOCATION

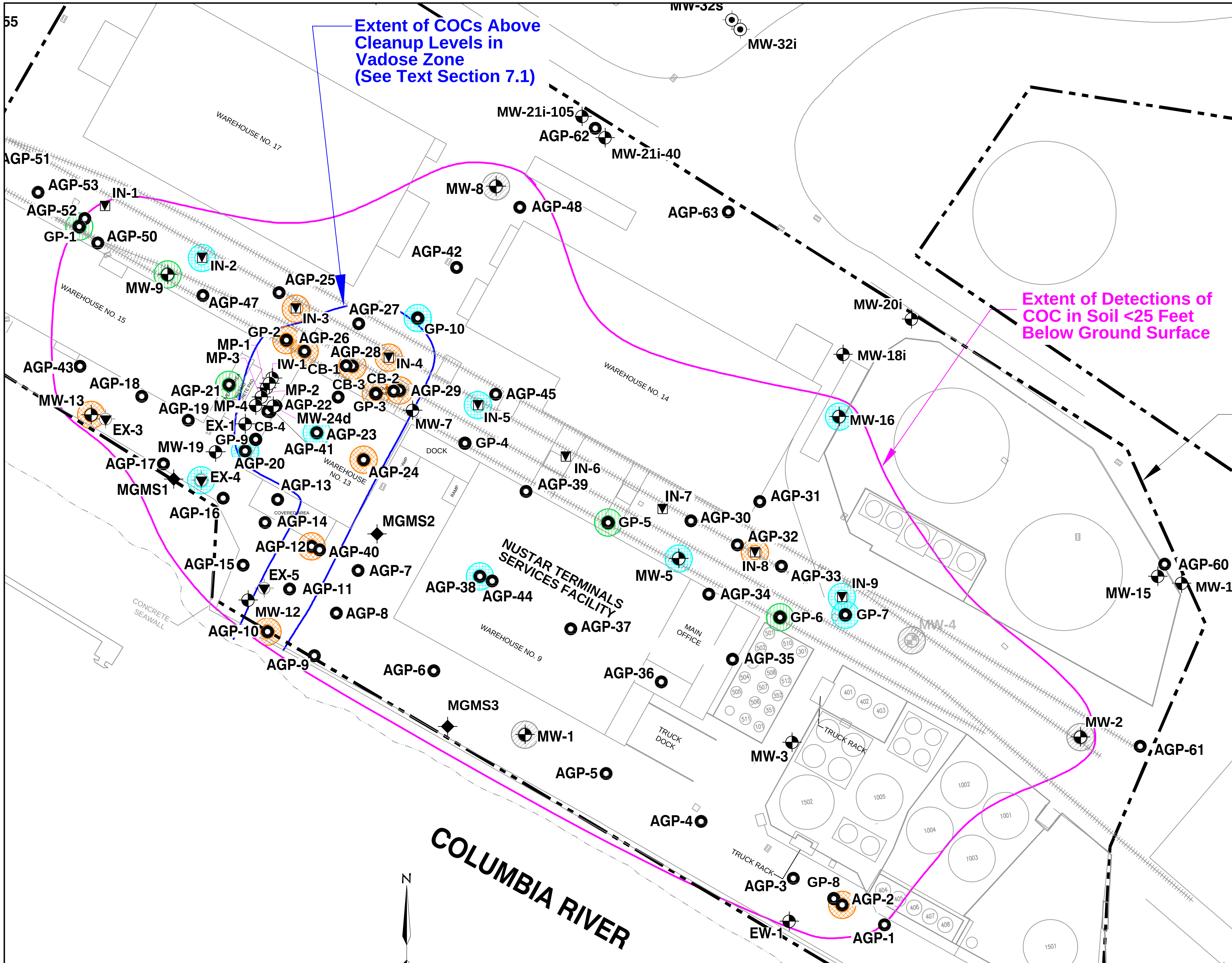
NuStar Property Plan

Feasibility Study
NuStar Terminals Services, Inc. Vancouver Facility
Vancouver, Washington

APEX — Apex Companies, LLC, 3015 SW First Avenue, Portland, Oregon 97201	Project Number	1126-14	Figure
	January 2014		2-9

MW-9
WAREHOUSE NO. 15
2008 GROUNDWATER/ SATURATED SOIL INTERIM ACTION AREA
ELECTRICAL PANEL
COVERED AREA
EXISTING CONCRETE PAD
COVERED AREA
MW-7
MW-13
EX-3
EX-1
MW-19
EX-4
MGMS1
WAREHOUSE NO. 13
OVERHEAD DOOR (TYP)
BUILDING COLUMN (TYP.)
COVERED AREA
DOCK
RAMP
RAMP
AREA INACCESSIBLE FOR DRILLING
NUSTAR TERMINALS SERVICES FACILITY
MGMS2
COLUMBIA RIVER
EX-5
MW-12
CONCRETE SEAWALL
TARGET GROUNDWATER INTERIM ACTION AREA
WAREHOUSE NO. 9
WAREHOUSE NO. 14
IN-6
IN-7
MW-5
MW-18i
MW-16
MAIN OFFICE
TRUCK DOCK
MGMS3
MW-1
N
0
50
100
Approximate Scale in Feet
LEGEND:
SOURCE AREA INJECTION POINT
STANDARD OIL SUBSTRATE INJECTION POINT
ANGLED INJECTION POINT
2008 INTERIM ACTION INJECTION POINT
EX-3 EARLY 2000s INTERIM ACTION GROUNDWATER EXTRACTION WELL
IN-1 EARLY 2000s INTERIM ACTION GROUNDWATER INJECTION WELL AND VAPOR EXTRACTION WELL
MW-1 GROUNDWATER MONITORING WELL
MGMS3 MULTI-LEVEL GROUNDWATER WELL
CATCH BASIN
BUILDING
FENCE
ELECTRICAL
SYSTEM ELECTRICAL
STORM SEWER
WATER
MANHOLE
RAILROAD TRACKS
NOTES:
1. BASE PLAN PREPARED FROM AN AUTOCAD FILE (SECOR FIGURE 1, JOB 15OT.STSRV.05.0012).
2. UTILITY LOCATIONS SHOWN BASED ON SURFACE MARKINGS BY UTILITY LOCATOR.
3. INJECTION LOCATIONS BASED ON FIELD MEASUREMENTS TO EXISTING SITE STRUCTURES.
2008/2011 NuStar Groundwater Interim Action Area
Feasibility Study
NuStar Terminals Services, Inc. Vancouver Facility
Vancouver, Washington
APEX
Apex Companies, LLC
3015 SW First Avenue
Portland, Oregon 97201
Project Number 1126-14
January 2014
Figure 2-10


NORTH SOIL VAPOR EXTRACTION UNIT (NO CARBON TREATMENT)
SOUTH SOIL VAPOR EXTRACTION UNIT (WITH CARBON TREATMENT VESSELS)
WAREHOUSE NO. 15
WAREHOUSE NO. 13
COVERED AREA
EXISTING CONCRETE PAD
ELECTRICAL PANEL
DOCK
RAMP
OVERHEAD DOOR (TYP)
BUILDING COLUMN (TYP)
NUSTAR TERMINALS SERVICES FACILITY
IN-2
IN-3
IN-4
IN-5
IN-6
MW-7
MW-9
MW-12
MW-19
MGMS1
MGMS2
EX-1
EX-4
EX-5
IW-1
MP-1
MP-2
MP-3
MP-4
VE-1-1
VE-1-2
VE-1-3
VE-1-4
VE-2-1
VE-2-2
VE-2-3
VE-3-1
VE-3-2
VE-3-3
VE-3-4
VE-4-1
VE-4-2
VE-4-3
VE-4-4
VE-5-1
VE-5-2
VE-5-3
VE-6-1 (S/D)
VE-6-2 (S/D)
VE-6-3 (S/D)
VE-7-1 (S/D)
VE-7-2 (S/D)
VE-7-3 (S/D)
VE-8-1 (S/D)
VE-8-2 (S/D)
VE-8-3 (S/D)
VE-8-4 (S/D)
VE-9-1 (S/D)
VE-9-2 (S/D)
VE-9-3 (S/D)
VE-9-4 (S/D)
VE-10-1 (S/D)
VE-10-2 (S/D)
VE-10-3 (S/D)
N
0
40
80
Scale in Feet
LEGEND:
VE-6-2 (S/D) 2011 WELL PAIR LOCATION (SHALLOW SCREENED FROM 5-15 FEET BGS) (DEEP SCREENED 15-25 FEET BGS)
VE-1-2 2008 INTERIM ACTION VAPOR EXTRACTION WELL LOCATION
VAPOR EXTRACTION WELL (2000-2005)
EX-3 EARLY 2000s INTERIM ACTION GROUNDWATER EXTRACTION WELL
IN-1 EARLY 2000s INTERIM ACTION GROUNDWATER INJECTION WELL AND VAPOR EXTRACTION WELL
MW-1 GROUNDWATER MONITORING WELL
MGMS3 MULTI-LEVEL GROUNDWATER WELL
CATCH BASIN
BUILDING
FENCE
ELECTRICAL
SYSTEM ELECTRICAL
STORM SEWER
WATER
MANHOLE
RAILROAD TRACKS
UNDERGROUND SOIL VAPOR EXTRACTION (SVE) PIPING
BLUE NORTH SYSTEM VAPOR EXTRACTION UNIT
GREEN SOUTH SYSTEM VAPOR EXTRACTION UNIT
NOTES:
1. BASE PLAN PREPARED FROM AN AUTOCAD FILE (SECOR FIGURE 1, JOB 15OT.STSRV.05.0012).
2. UTILITY LOCATIONS SHOWN BASED ON SURFACE MARKINGS BY UTILITY LOCATOR.
2008/2011 NuStar Vadose Zone Interim Action Area
Feasibility Study
NuStar Terminals Services, Inc. Vancouver Facility
Vancouver, Washington
APEX
Apex Companies, LLC
3015 SW First Avenue
Portland, Oregon 97201
Project Number 1126-14
January 2014
Figure 2-11



LEGEND

EX-3	GROUNDWATER EXTRACTION WELL
IN-1	GROUNDWATER INJECTION WELL
MW-1	GROUNDWATER MONITORING WELL
MGMS3	MULTI-LEVEL GROUNDWATER WELL
AGP-48	BORING LOCATION
MW-32s	PORT OF VANCOUVER WELL LOCATION
MW-11	ABANDONED GROUNDWATER WELL
	APPROXIMATE PROPERTY LINE
	>1.0 MG/KG TETRACHLOROETHENE (PCE)
	0.1-1.0 MG/KG PCE
	0.05-0.1 MG/KG PCE (0.05 MG/KG SOIL LEACHING TO DRINKING WATER STANDARD FOR PCE)
	<0.05 MG/KG PCE

NOTES:
1. BASE PLAN PREPARED FROM AN AUTOCAD FILE (SECOR FIGURE 1, JOB 15OT.STSRV.05.0012).
2. PROPERTY DEFINED BASED ON 2006 LEASEHOLD BOUNDARY.
3. COC = CHEMICAL OF CONCERN.

Extent of COCs Above Cleanup Levels in Vadose Zone Soil

Feasibility Study
NuStar Terminals Services, Inc. Vancouver Facility
Vancouver, Washington

APEX
Apex Companies, LLC
3015 SW First Avenue
Portland, Oregon 97201

Project Number 1126-14
March 2014
Figure 2-12

PCE in Shallow Zone 1Q 2008

PCE in Shallow Zone 1Q 2013

N

LEGEND:

- ◎ Swan Manufacturing (POV) Monitoring Well
- ⊙ ST Services (NuStar) Monitoring Well
- —··—·· Property Line

1.16 Concentration in Groundwater (µg/L)

NA Not Available; Well MW-26 Installed in 2011
*Groundwater data from boring AGP-55 are presented in 2008 figure to define the extent of Volatile Organic Compounds to the northwest. Well MW-26 was installed in 2011 at the same location as boring AGP-55.

- 5µg/L Isoconcentration Contour (MCL)
- 20µg/L Isoconcentration Contour (MCL)
- 200µg/L Isoconcentration Contour (MCL)
- 1,000µg/L Isoconcentration Contour (MCL)
- 10,000µg/L Isoconcentration Contour (MCL)

0 600 1,200
Approximate Scale in Feet

NOTE:

Base Map, Legend and Scale from S.S. Papadopulos & Associates, Inc. Expert Report of Dimitrios Vlassopoulos Port of Vancouver v. Cadet Manufacturing Company, May 2005

2008 and 2013 Isocontours of Tetrachloroethene (PCE) Concentrations in Shallow Zone Groundwater

Feasibility Study
NuStar Terminals Services, Inc. Vancouver Facility
Vancouver, Washington

APEX
Apex Companies, LLC
3015 SW First Avenue
Portland, Oregon 97201

Project Number	1126-14	Figure
March 2014		2-13

TCE in Shallow Zone 1Q 2008

TCE in Shallow Zone 1Q 2013

N

LEGEND:

- Swan Manufacturing (POV) Monitoring Well
- ST Services (NuStar) Monitoring Well
- Property Line

19.9 Concentration in Groundwater (µg/L)

NA Not Available; Well MW-26 Installed in 2011
*Groundwater data from boring AGP-55 are presented in 2008 figure to define the extent of Volatile Organic Compounds to the northwest. Well MW-26 was installed in 2011 at the same location as boring AGP-55.

- 4µg/L Isoconcentration Contour (MCL)
- 20µg/L Isoconcentration Contour (MCL)
- 200µg/L Isoconcentration Contour (MCL)
- 1,000µg/L Isoconcentration Contour (MCL)

NOTE:

Base Map, Legend and Scale from S.S. Papadopulos & Associates, Inc. Expert Report of Dimitrios Vlassopoulos Port of Vancouver v. Cadet Manufacturing Company, May 2005

2008 and 2013 Isocontours of Trichloroethene (TCE) Concentrations in Shallow Zone Groundwater

Feasibility Study
NuStar Terminals Services, Inc. Vancouver Facility
Vancouver, Washington

APEX
Apex Companies, LLC
3015 SW First Avenue
Portland, Oregon 97201

Project Number	1126-14	Figure
	March 2014	2-14

cDCE in Shallow Zone 1Q 2008

cDCE in Shallow Zone 1Q 2013

N

0 600 1,200
Approximate Scale in Feet

LEGEND:

◎ Swan Manufacturing (POV) Monitoring Well

⊙ ST Services (NuStar) Monitoring Well

—··—·· Property Line

5.75 Concentration in Groundwater (µg/L)

NA Not Available; Well MW-26 Installed in 2011
*Groundwater data from boring AGP-55 are presented in 2008 figure to define the extent of Volatile Organic Compounds to the northwest. Well MW-26 was installed in 2011 at the same location as boring AGP-55.

16µg/L Isoconcentration Contour (MCL)

200µg/L Isoconcentration Contour (MCL)

1,000µg/L Isoconcentration Contour (MCL)

NOTE:

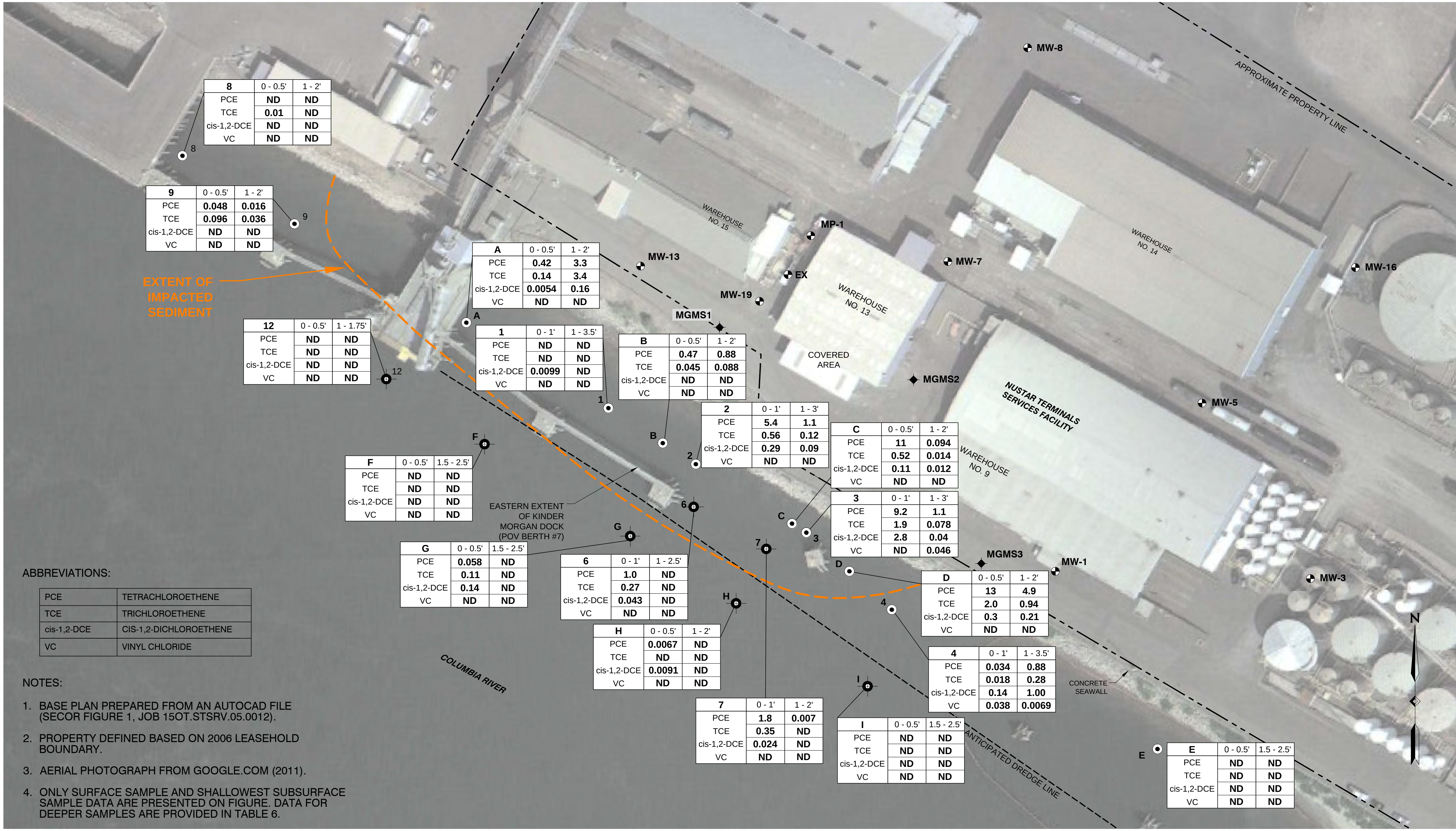
Base Map, Legend and Scale from S.S. Papadopulos & Associates, Inc. Expert Report of Dimitrios Vlassopoulos Port of Vancouver v. Cadet Manufacturing Company, May 2005

2008 and 2013 Isocontours of cis-1,2-Dichloroethene (cDCE) Concentrations in Shallow Zone Groundwater

Feasibility Study
NuStar Terminals Services, Inc. Vancouver Facility
Vancouver, Washington

APEX Apex Companies, LLC
3015 SW First Avenue
Portland, Oregon 97201

Project Number	1126-14	Figure
March 2014		2-15



8	0 - 0.5'	1 - 2'
PCE	ND	ND
TCE	0.01	ND
cis-1,2-DCE	ND	ND
VC	ND	ND

9	0 - 0.5'	1 - 2'
PCE	0.048	0.016
TCE	0.096	0.036
cis-1,2-DCE	ND	ND
VC	ND	ND

A	0 - 0.5'	1 - 2'
PCE	0.42	3.3
TCE	0.14	3.4
cis-1,2-DCE	0.0054	0.16
VC	ND	ND

12	0 - 0.5'	1 - 1.75'
PCE	ND	ND
TCE	ND	ND
cis-1,2-DCE	ND	ND
VC	ND	ND

1	0 - 1'	1 - 3.5'
PCE	ND	ND
TCE	ND	ND
cis-1,2-DCE	0.0099	ND
VC	ND	ND

B	0 - 0.5'	1 - 2'
PCE	0.47	0.88
TCE	0.045	0.088
cis-1,2-DCE	ND	ND
VC	ND	ND

2	0 - 1'	1 - 3'
PCE	5.4	1.1
TCE	0.56	0.12
cis-1,2-DCE	0.29	0.09
VC	ND	ND

C	0 - 0.5'	1 - 2'
PCE	11	0.094
TCE	0.52	0.014
cis-1,2-DCE	0.11	0.012
VC	ND	ND

F	0 - 0.5'	1.5 - 2.5'
PCE	ND	ND
TCE	ND	ND
cis-1,2-DCE	ND	ND
VC	ND	ND

3	0 - 1'	1 - 3'
PCE	9.2	1.1
TCE	1.9	0.078
cis-1,2-DCE	2.8	0.04
VC	ND	0.046

G	0 - 0.5'	1.5 - 2.5'
PCE	0.058	ND
TCE	0.11	ND
cis-1,2-DCE	0.14	ND
VC	ND	ND

6	0 - 1'	1 - 2.5'
PCE	1.0	ND
TCE	0.27	ND
cis-1,2-DCE	0.043	ND
VC	ND	ND

D	0 - 0.5'	1 - 2'
PCE	13	4.9
TCE	2.0	0.94
cis-1,2-DCE	0.3	0.21
VC	ND	ND

H	0 - 0.5'	1 - 2'
PCE	0.0067	ND
TCE	ND	ND
cis-1,2-DCE	0.0091	ND
VC	ND	ND

4	0 - 1'	1 - 3.5'
PCE	0.034	0.88
TCE	0.018	0.28
cis-1,2-DCE	0.14	1.00
VC	0.038	0.0069

7	0 - 1'	1 - 2'
PCE	1.8	0.007
TCE	0.35	ND
cis-1,2-DCE	0.024	ND
VC	ND	ND

I	0 - 0.5'	1.5 - 2.5'
PCE	ND	ND
TCE	ND	ND
cis-1,2-DCE	ND	ND
VC	ND	ND

E	0 - 0.5'	1.5 - 2.5'
PCE	ND	ND
TCE	ND	ND
cis-1,2-DCE	ND	ND
VC	ND	ND

ABBREVIATIONS:

PCE	TETRACHLOROETHENE
TCE	TRICHLOROETHENE
cis-1,2-DCE	CIS-1,2-DICHLOROETHENE
VC	VINYL CHLORIDE

NOTES:

1. BASE PLAN PREPARED FROM AN AUTOCAD FILE (SECOR FIGURE 1, JOB 15OT.STSRV.05.0012).
2. PROPERTY DEFINED BASED ON 2006 LEASEHOLD BOUNDARY.
3. AERIAL PHOTOGRAPH FROM GOOGLE.COM (2011).
4. ONLY SURFACE SAMPLE AND SHALLOWEST SUBSURFACE SAMPLE DATA ARE PRESENTED ON FIGURE. DATA FOR DEEPER SAMPLES ARE PROVIDED IN TABLE 6.

LEGEND

- A — SEDIMENT SAMPLING LOCATION - 2011 AND 2012 (INTERSECTS SHALLOW ZONE GROUNDWATER)
- F — SEDIMENT SAMPLING LOCATION - 2011 AND 2012 (INTERSECTS INTERMEDIATE ZONE GROUNDWATER)
- MW-12 — GROUNDWATER MONITORING WELL
- MGMS3 — MULTI-LEVEL GROUNDWATER WELL (40 FOOT SAMPLE INTERVAL)

A	0 - 0.5'	1 - 2'
PCE	0.42	3.3
TCE	0.14	3.4
cis-1,2-DCE	0.0054	0.16
VC	ND	ND

LOCATION ID

DEPTH OF SAMPLE

VOLATILE ORGANIC COMPOUNDS (VOCs) CONCENTRATION IN MG/KG

ANALYTE SAMPLED

NOTE: SAMPLES 1 THROUGH 7 BASED ON WET WEIGHT. THE OTHER SAMPLE'S RESULTS ARE BASED ON DRY WEIGHT.

0 100 200

Approximate Scale in Feet

Extent of VOC Impacts to Sediments

Feasibility Study
NuStar Terminals Services, Inc. Vancouver Facility
Vancouver, Washington

APEX

Apex Companies, LLC
3015 SW First Avenue
Portland, Oregon 97201

Project Number 1126-14

January 2014

Figure 2-16

Parametrix Date: 9/8/2014 Path: P:\GIS\POV\MXD_PDF\Figures_01082014\Figure2-17_TCE_Shallow4_Q1_2013_V2.mxd

N

0 250 500 750

Scale in Feet

MW-10 — Well Location Name
23 — Concentration Value (µg/l)

ND = Non-Detect
NS = Not sampled

- > 4 µg/L
- > 25 µg/L
- > 50 µg/L
- > 100 µg/L
- > 500 µg/L
- > 1000 µg/L

Figure 2-17
TCE Isoconcentrations in Shallow USA Zone Groundwater
1st Quarter 2013

Feasibility Study
NuStar, SMC, and Cadet
Vancouver, WA

Parametrix Date: 1/16/2014 Path: P:\GIS\POV\MXD_PDF\Figures_01082014\Figure2-18_PCE_Shallow5_Q1_2013.mxd

N

0 250 500 750

Scale in Feet

MW-10 — Well Location Name

23 — Concentration Value (µg/l)

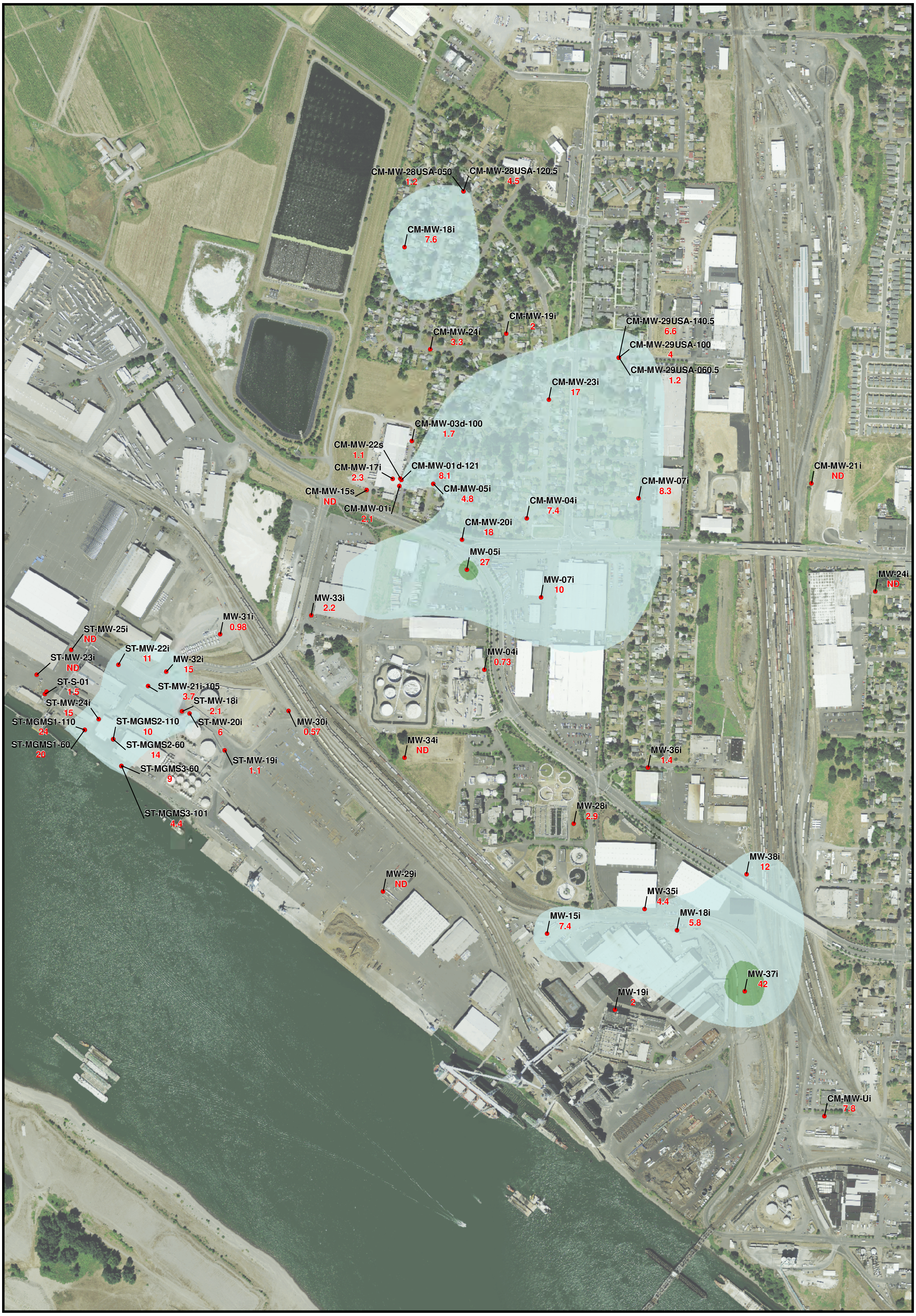
ND = Non-Detect

NS = Not sampled

- > 5 µg/L
- > 25 µg/L
- > 50 µg/L
- > 100 µg/L
- > 500 µg/L
- > 1000 µg/L

Figure 2-18
PCE Isoconcentrations in Shallow USA Zone Groundwater 1st Quarter 2013

Feasibility Study
NuStar, SMC, and Cadet
Vancouver, WA



Parametrix Date: 1/16/2014 Path: P:\GIS\POV\MXD_PDF\Figures_01082014\Figure2-19_TCE_Intermediate4_Q1_2013.mxd

N

0 250 500 750

Scale in Feet

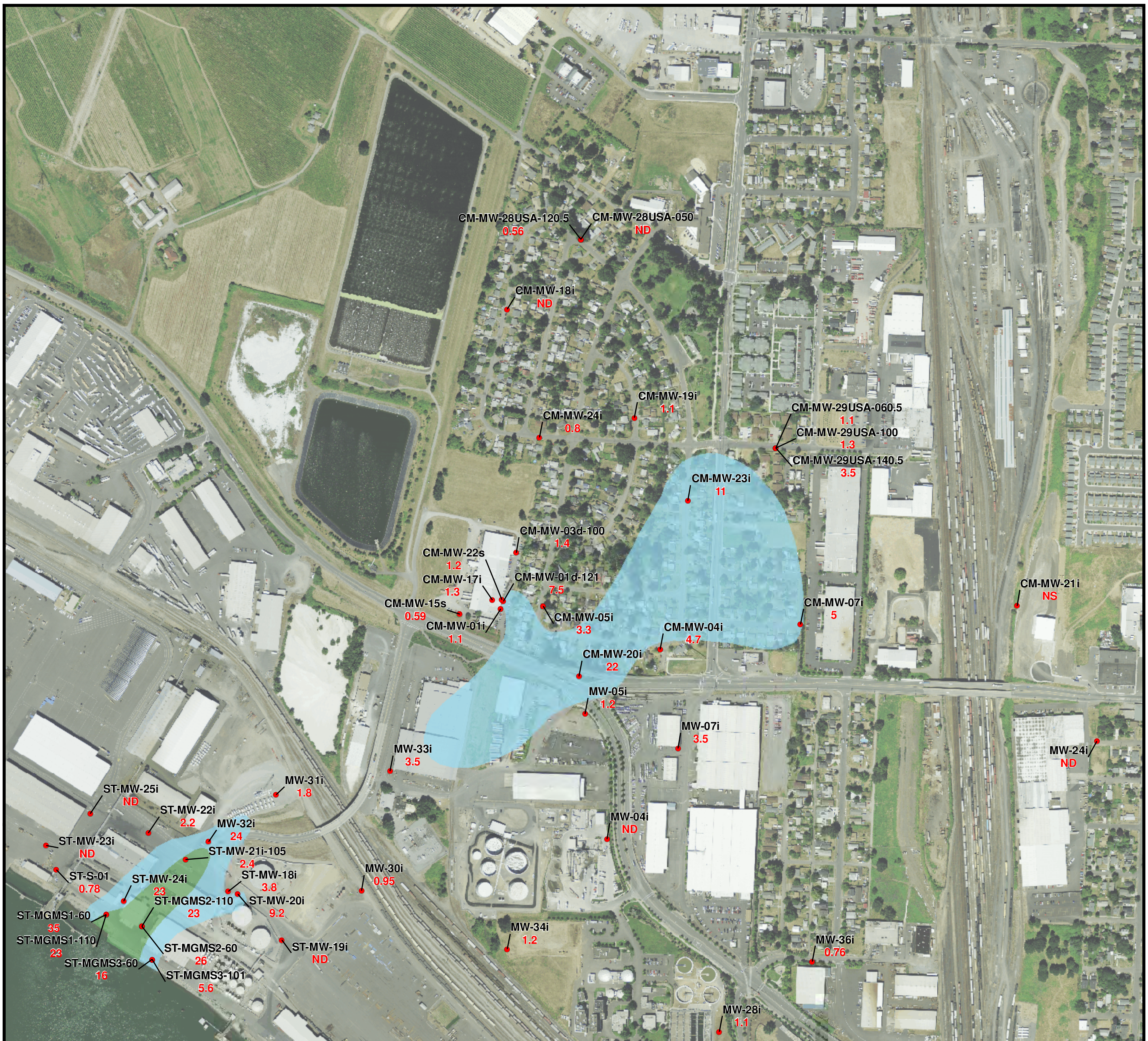
MW-10 — Well Location Name
23 — Concentration Value (µg/l)

ND = Non-Detect
NS = Not sampled

> 4 µg/L
> 25 µg/L

Figure 2-19
TCE Isoconcentrations in Intermediate USA Zone Groundwater 1st Quarter 2013

Feasibility Study
NuStar, SMC, and Cadet
Vancouver, WA



Parametrix Date: 1/16/2014 Path: P:\GIS\POV\MXD_PDF\Figures_01082014\Figure2-20_PCE_Intermediate5_Q1_2013.mxd

N

0 250 500 750

Scale in Feet

MW-10 — Well Location Name

23 — Concentration Value (µg/l)

ND = Non-Detect

NS = Not sampled

> 5 µg/L

> 25 µg/L

Figure 2-20
PCE Isoconcentrations in Intermediate USA Zone Groundwater 1st Quarter 2013

Feasibility Study
NuStar, SMC, and Cadet
Vancouver, WA

Parametrix Date: 1/16/2014 Path: P:\GIS\POV\MXD_PDF\Figures_01082014\Figure2-21_TCE_Deep4_Q1_2013.mxd

N

0 250 500 750

Scale in Feet

MW-10 — Well Location Name
23 — Concentration Value (µg/l)

ND = Non-Detect
NS = Not sampled

> 4 µg/L
> 25 µg/L

Figure 2-21
TCE Isoconcentrations in Deep USA Zone Groundwater 1st Quarter 2013

Feasibility Study
NuStar, SMC, and Cadet
Vancouver, WA

Parametrix Date: 1/16/2014 Path: P:\GIS\POV\MXD_PDF\Figures_01082014\Figure2-22_PCE_Deep5_Q1_2013.mxd

N

0 250 500 750

Scale in Feet

MW-10 — Well Location Name

23 — Concentration Value (µg/l)

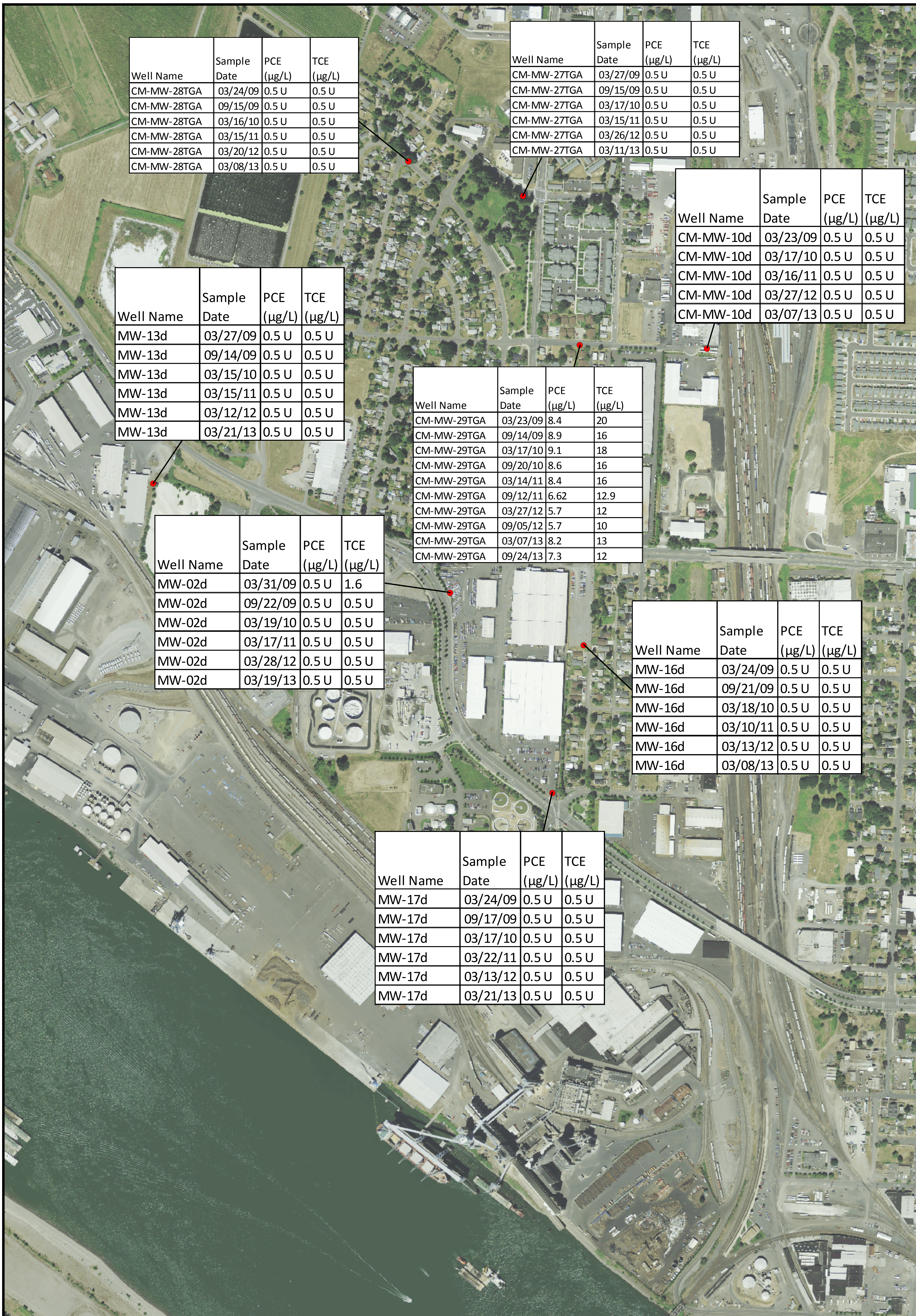
ND = Non-Detect

NS = Not sampled

> 5 µg/L

Figure 2-22
PCE Isoconcentrations in Deep USA Zone Groundwater
1st Quarter 2013

Feasibility Study
NuStar, SMC, and Cadet
Vancouver, WA



Well Name	Sample Date	PCE (µg/L)	TCE (µg/L)
CM-MW-28TGA	03/24/09	0.5 U	0.5 U
CM-MW-28TGA	09/15/09	0.5 U	0.5 U
CM-MW-28TGA	03/16/10	0.5 U	0.5 U
CM-MW-28TGA	03/15/11	0.5 U	0.5 U
CM-MW-28TGA	03/20/12	0.5 U	0.5 U
CM-MW-28TGA	03/08/13	0.5 U	0.5 U

Well Name	Sample Date	PCE (µg/L)	TCE (µg/L)
CM-MW-27TGA	03/27/09	0.5 U	0.5 U
CM-MW-27TGA	09/15/09	0.5 U	0.5 U
CM-MW-27TGA	03/17/10	0.5 U	0.5 U
CM-MW-27TGA	03/15/11	0.5 U	0.5 U
CM-MW-27TGA	03/26/12	0.5 U	0.5 U
CM-MW-27TGA	03/11/13	0.5 U	0.5 U

Well Name	Sample Date	PCE (µg/L)	TCE (µg/L)
CM-MW-10d	03/23/09	0.5 U	0.5 U
CM-MW-10d	03/17/10	0.5 U	0.5 U
CM-MW-10d	03/16/11	0.5 U	0.5 U
CM-MW-10d	03/27/12	0.5 U	0.5 U
CM-MW-10d	03/07/13	0.5 U	0.5 U

Well Name	Sample Date	PCE (µg/L)	TCE (µg/L)
MW-13d	03/27/09	0.5 U	0.5 U
MW-13d	09/14/09	0.5 U	0.5 U
MW-13d	03/15/10	0.5 U	0.5 U
MW-13d	03/15/11	0.5 U	0.5 U
MW-13d	03/12/12	0.5 U	0.5 U
MW-13d	03/21/13	0.5 U	0.5 U

Well Name	Sample Date	PCE (µg/L)	TCE (µg/L)
CM-MW-29TGA	03/23/09	8.4	20
CM-MW-29TGA	09/14/09	8.9	16
CM-MW-29TGA	03/17/10	9.1	18
CM-MW-29TGA	09/20/10	8.6	16
CM-MW-29TGA	03/14/11	8.4	16
CM-MW-29TGA	09/12/11	6.62	12.9
CM-MW-29TGA	03/27/12	5.7	12
CM-MW-29TGA	09/05/12	5.7	10
CM-MW-29TGA	03/07/13	8.2	13
CM-MW-29TGA	09/24/13	7.3	12

Well Name	Sample Date	PCE (µg/L)	TCE (µg/L)
MW-02d	03/31/09	0.5 U	1.6
MW-02d	09/22/09	0.5 U	0.5 U
MW-02d	03/19/10	0.5 U	0.5 U
MW-02d	03/17/11	0.5 U	0.5 U
MW-02d	03/28/12	0.5 U	0.5 U
MW-02d	03/19/13	0.5 U	0.5 U

Well Name	Sample Date	PCE (µg/L)	TCE (µg/L)
MW-16d	03/24/09	0.5 U	0.5 U
MW-16d	09/21/09	0.5 U	0.5 U
MW-16d	03/18/10	0.5 U	0.5 U
MW-16d	03/10/11	0.5 U	0.5 U
MW-16d	03/13/12	0.5 U	0.5 U
MW-16d	03/08/13	0.5 U	0.5 U

Well Name	Sample Date	PCE (µg/L)	TCE (µg/L)
MW-17d	03/24/09	0.5 U	0.5 U
MW-17d	09/17/09	0.5 U	0.5 U
MW-17d	03/17/10	0.5 U	0.5 U
MW-17d	03/22/11	0.5 U	0.5 U
MW-17d	03/13/12	0.5 U	0.5 U
MW-17d	03/21/13	0.5 U	0.5 U

Parametrix Date: 9/8/2014 Path: P:\GIS\POV\MXD_PDF\Figures_01082014\Figure2-23_TCE_PCEinTGA_Tables.mxd

N

0 250 500 750

Scale in Feet

● Monitoring Well Location

Figure 2-23
TCE and PCE Concentrations
In the TGA
2009-2013

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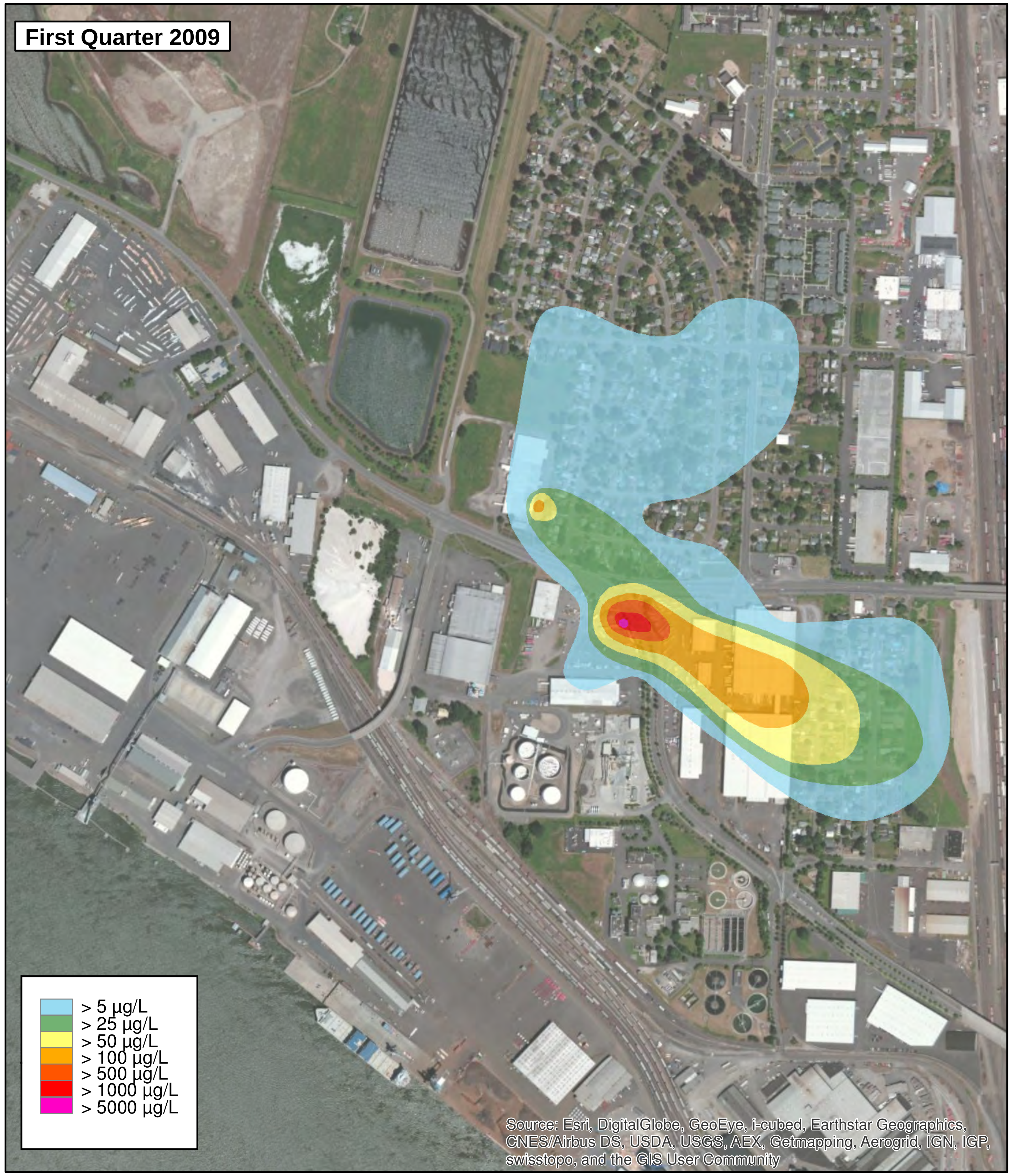

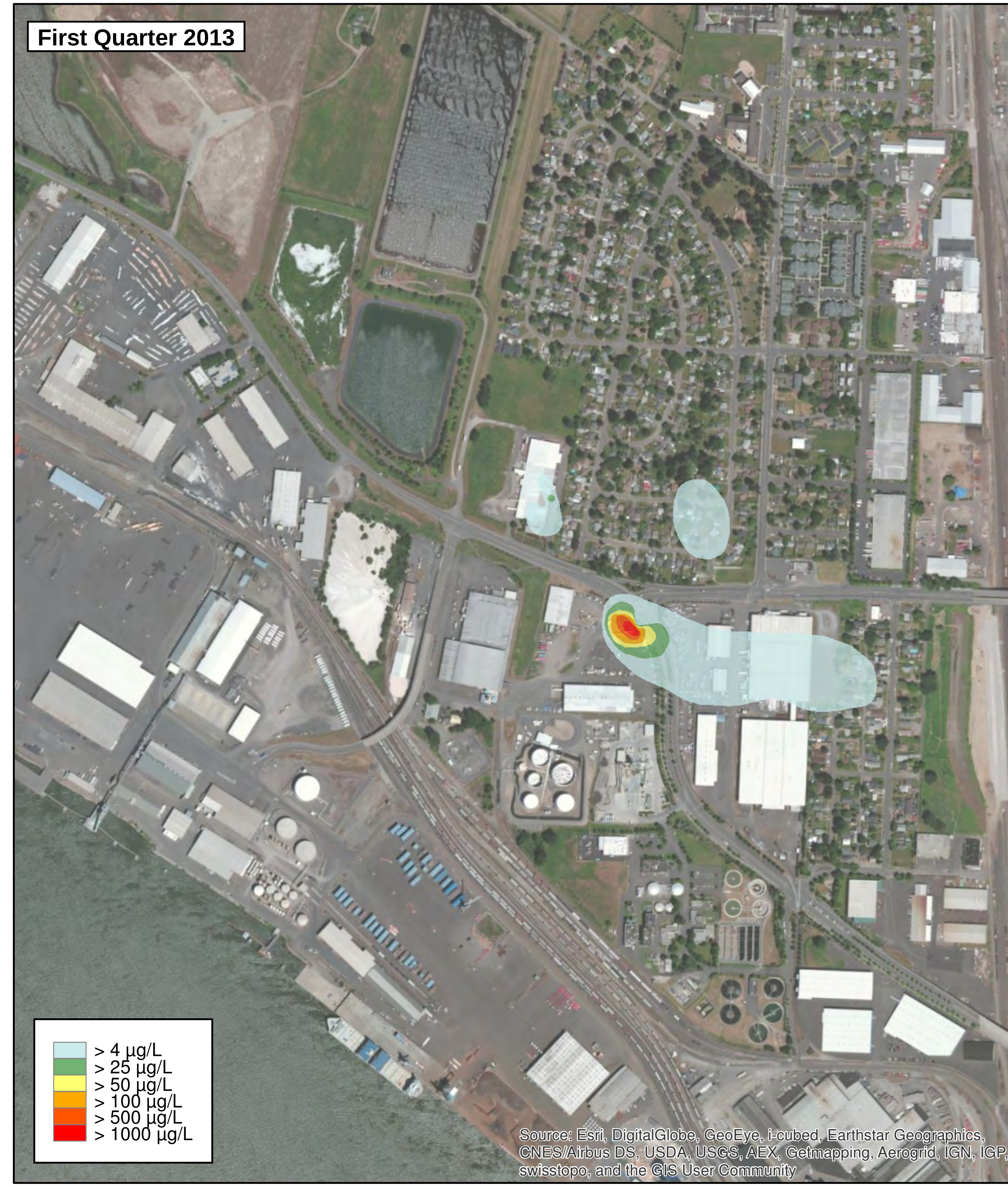

Parametrix Date: 9/8/2014 Path: P:\GIS\POV\MXD_PDF\Figures_01082014\Figure2-24_09-13_Q1_TCE_Shallow_V2.mxd

N

0 500 1,000
Feet

Figure 2-24
TCE Isoconcentrations in USA Shallow Zone
First Quarter 2009/First Quarter 2013

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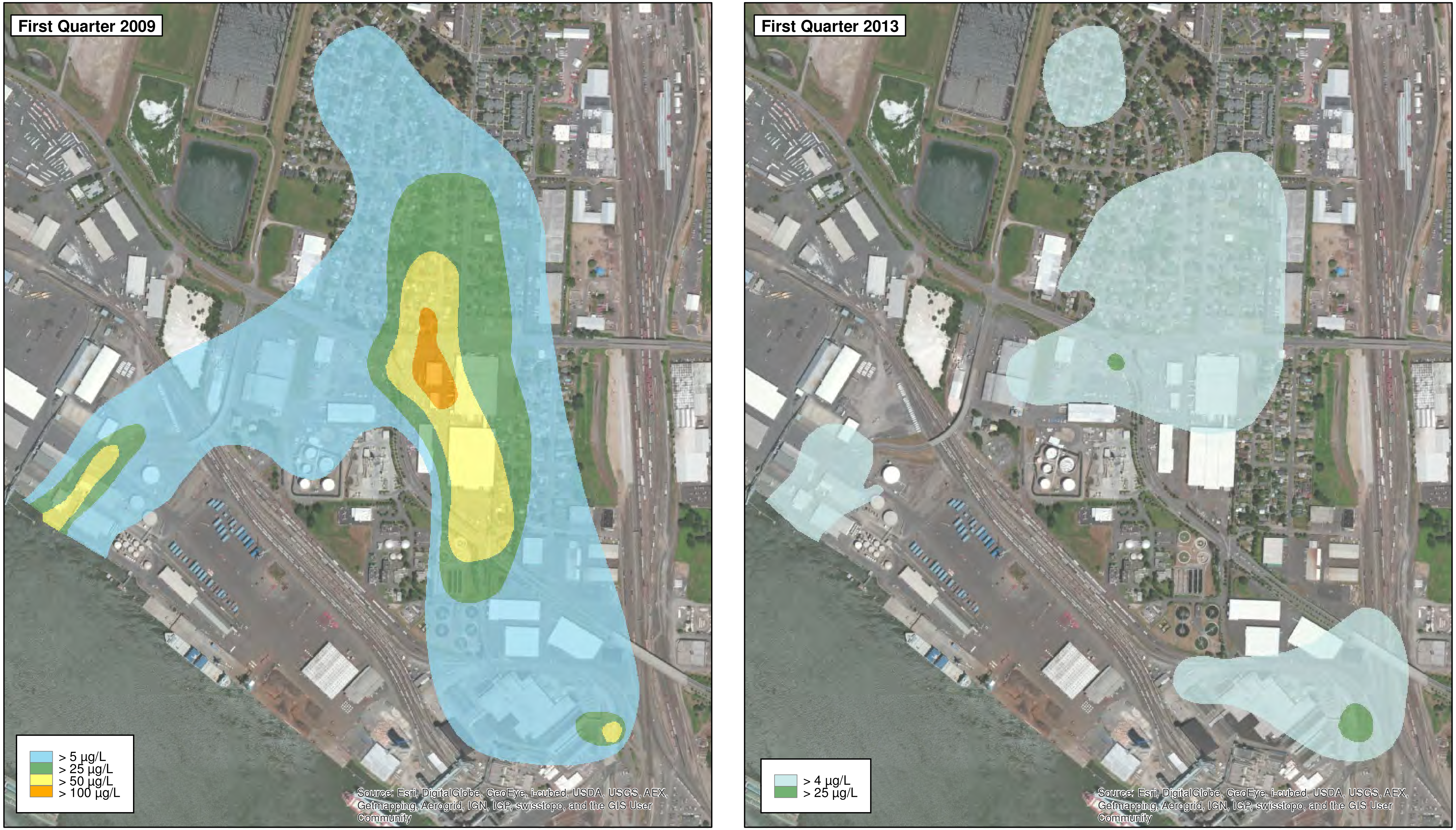
NuStar, SMC, and Cadet
Vancouver, WA



Parametrix Date: 1/16/2014 Path: P:\GIS\POV\MXD_PDF\Figures_01082014\Figure2-25_09-13_Q1_TCE_Intermediate.mxd

N

0 500 1,000
Feet

Figure 2-25
TCE Isoconcentrations in USA Intermediate Zone
First Quarter 2009/First Quarter 2013

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NuStar, SMC, and Cadet
Vancouver, WA

Parametrix Date: 1/16/2014 Path: P:\GIS\POV\MXD_PDF\Figures_01082014\Figure2-26_09-13_Q1_TCE_Deep.mxd

N

0 500 1,000
Feet

Figure 2-26
TCE Isoconcentrations in USA Deep Zone
First Quarter 2009/First Quarter 2013

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Vancouver, WA

PCE in Shallow Zone 1Q 2008

PCE in Shallow Zone 1Q 2013

N

LEGEND:

◎ Swan Manufacturing (POV) Monitoring Well

⊙ ST Services (NuStar) Monitoring Well

—··—·· Property Line

1.16 Concentration in Groundwater (µg/L)

NA Not Available; Well MW-26 Installed in 2011
*Groundwater data from boring AGP-55 are presented in 2008 figure to define the extent of Volatile Organic Compounds to the northwest. Well MW-26 was installed in 2011 at the same location as boring AGP-55.

5µg/L Isoconcentration Contour (MCL)

20µg/L Isoconcentration Contour (MCL)

200µg/L Isoconcentration Contour (MCL)

1,000µg/L Isoconcentration Contour (MCL)

10,000µg/L Isoconcentration Contour (MCL)

0 600 1,200
Approximate Scale in Feet

NOTE:

Base Map, Legend and Scale from S.S. Papadopulos & Associates, Inc. Expert Report of Dimitrios Vlassopoulos Port of Vancouver v. Cadet Manufacturing Company, May 2005

2008 and 2013 Isocontours of Tetrachloroethene (PCE) Concentrations in Shallow Zone Groundwater

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TCE in Shallow Zone 1Q 2008

TCE in Shallow Zone 1Q 2013

N

LEGEND:

◎ Swan Manufacturing (POV) Monitoring Well

⊙ ST Services (NuStar) Monitoring Well

—·-—·- Property Line

19.9 Concentration in Groundwater (µg/L)

NA Not Available; Well MW-26 Installed in 2011

*Groundwater data from boring AGP-55 are presented in 2008 figure to define the extent of Volatile Organic Compounds to the northwest. Well MW-26 was installed in 2011 at the same location as boring AGP-55.

4µg/L Isoconcentration Contour (MCL)

20µg/L Isoconcentration Contour (MCL)

200µg/L Isoconcentration Contour (MCL)

1,000µg/L Isoconcentration Contour (MCL)

NOTE:

Base Map, Legend and Scale from S.S. Papadopulos & Associates, Inc. Expert Report of Dimitrios Vlassopoulos Port of Vancouver v. Cadet Manufacturing Company, May 2005

2008 and 2013 Isocontours of Trichloroethene (TCE) Concentrations in Shallow Zone Groundwater

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NuStar Terminals Services, Inc. Vancouver Facility
Vancouver, Washington

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	March 2014		7-2

cDCE in Shallow Zone 1Q 2008

cDCE in Shallow Zone 1Q 2013

N

LEGEND:

◎	Swan Manufacturing (POV) Monitoring Well	5.75	Concentration in Groundwater (µg/L)
⊙	ST Services (NuStar) Monitoring Well	NA	Not Available; Well MW-26 Installed in 2011 *Groundwater data from boring AGP-55 are presented in 2008 figure to define the extent of Volatile Organic Compounds to the northwest. Well MW-26 was installed in 2011 at the same location as boring AGP-55.
—··—··	Property Line		
		(blue line)	16µg/L Isoconcentration Contour (MCL)
		(orange line)	200µg/L Isoconcentration Contour (MCL)
		(magenta line)	1,000µg/L Isoconcentration Contour (MCL)

0 600 1,200

Approximate Scale in Feet

NOTE:

Base Map, Legend and Scale from S.S. Papadopulos & Associates, Inc. Expert Report of Dimitrios Vlassopoulos Port of Vancouver v. Cadet Manufacturing Company, May 2005

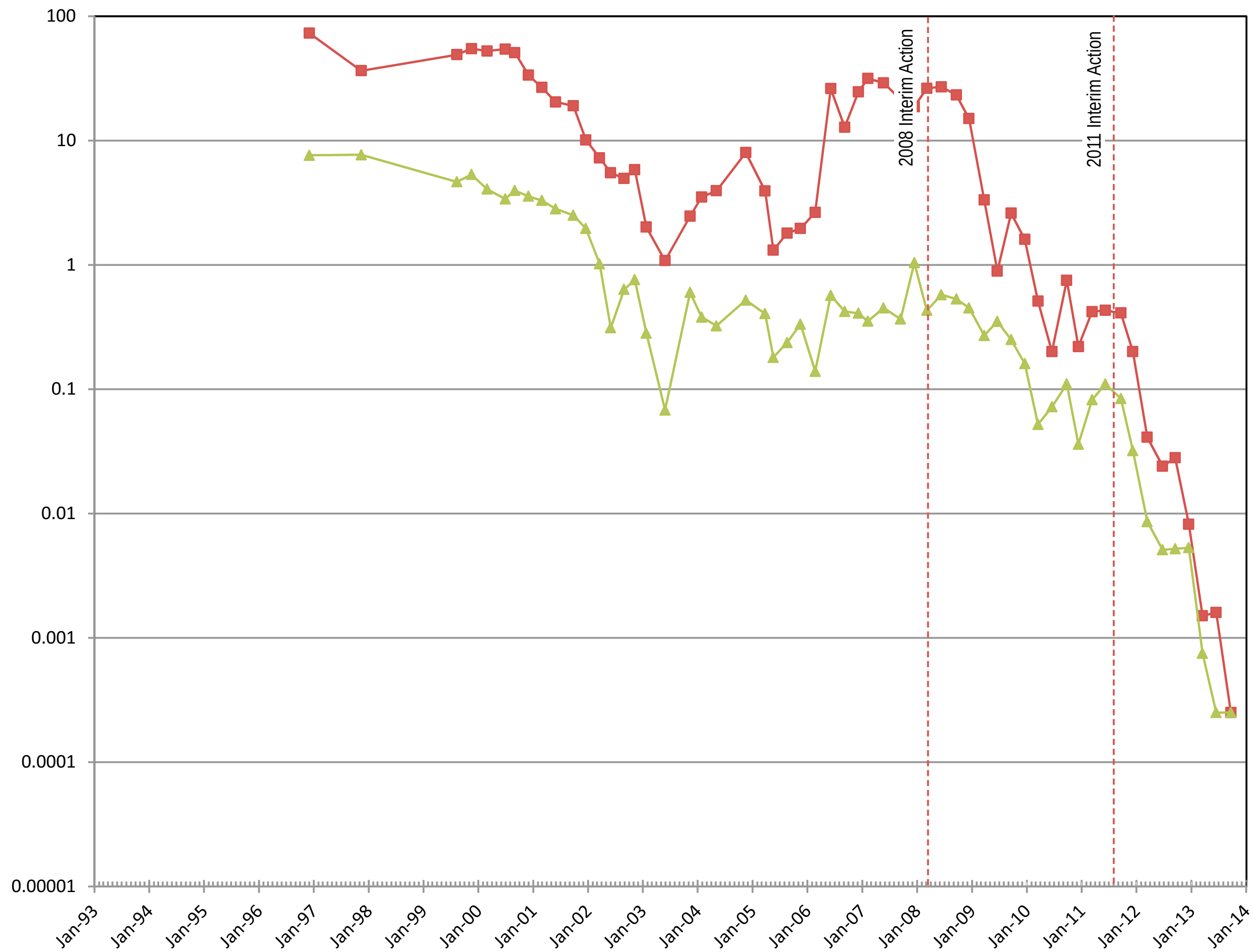
2008 and 2013 Isocontours of cis-1,2-Dichloroethene (cDCE) Concentrations in Shallow Zone Groundwater

Feasibility Study

NuStar Terminals Services, Inc. Vancouver Facility

Vancouver, Washington

APEX	Apex Companies, LLC 3015 SW First Avenue Portland, Oregon 97201	Project Number 1126-14 March 2014	Figure 7-3



Legend:

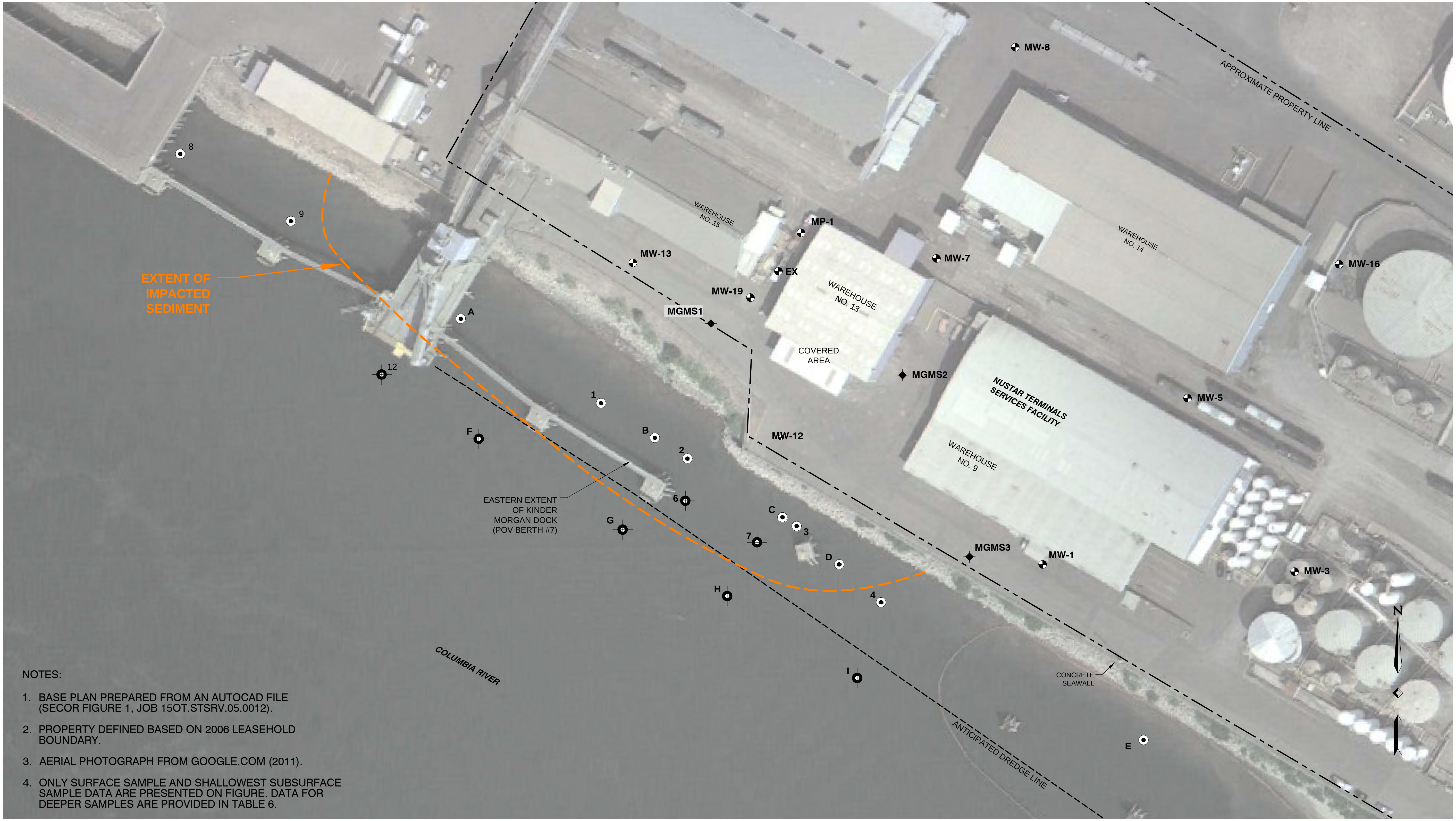
Tetrachloroethylene (PCE) Concentration in mg/L

Trichloroethylene (TCE) Concentration in mg/L

PCE/TCE Concentration Trends in Well MW-7

Feasibility Study
NuStar Terminals Services, Inc. Vancouver Facility
Vancouver, Washington

APEX — Apex Companies, LLC 3015 SW First Avenue Portland, Oregon 97201	Project Number	1126-14	Figure
	January 2014		7-4



NOTES:

1. BASE PLAN PREPARED FROM AN AUTOCAD FILE (SECOR FIGURE 1, JOB 15OT.STSRV.05.0012).
2. PROPERTY DEFINED BASED ON 2006 LEASEHOLD BOUNDARY.
3. AERIAL PHOTOGRAPH FROM GOOGLE.COM (2011).
4. ONLY SURFACE SAMPLE AND SHALLOWEST SUBSURFACE SAMPLE DATA ARE PRESENTED ON FIGURE. DATA FOR DEEPER SAMPLES ARE PROVIDED IN TABLE 6.

LEGEND

- A — SEDIMENT SAMPLING LOCATION - 2011 AND 2012 (INTERSECTS SHALLOW ZONE GROUNDWATER)
- F — SEDIMENT SAMPLING LOCATION - 2011 AND 2012 (INTERSECTS INTERMEDIATE ZONE GROUNDWATER)
- MW-12 — GROUNDWATER MONITORING WELL
- MGMS3 — MULTI-LEVEL GROUNDWATER WELL (40 FOOT SAMPLE INTERVAL)

0 100 200
Approximate Scale in Feet

Extent of VOC Impacts to Sediments

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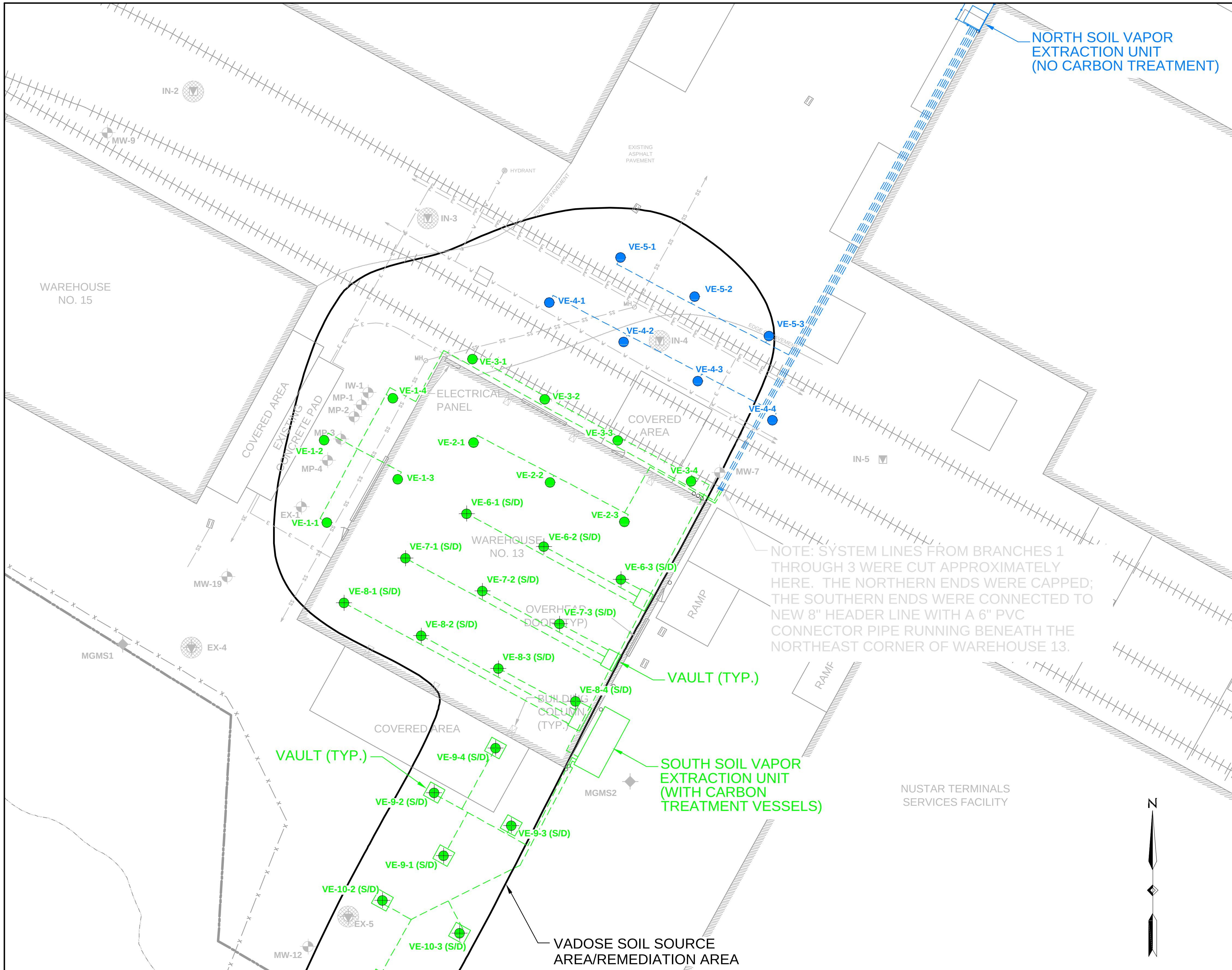
January 2014
Figure 7-5



LEGEND:

VE-6-2 (S/D)	2011 WELL PAIR LOCATION (SHALLOW SCREENED FROM 5-15 FEET BGS) (DEEP SCREENED 15-25 FEET BGS)
VE-1-2	2008 INTERIM ACTION VAPOR EXTRACTION WELL LOCATION
	VAPOR EXTRACTION WELL (2000-2005)
EX-3	EARLY 2000s INTERIM ACTION GROUNDWATER EXTRACTION WELL
IN-1	EARLY 2000s INTERIM ACTION GROUNDWATER INJECTION WELL AND VAPOR EXTRACTION WELL
MW-1	GROUNDWATER MONITORING WELL
MGMS3	MULTI-LEVEL GROUNDWATER WELL
	CATCH BASIN
	BUILDING
	FENCE
	ELECTRICAL
	SYSTEM ELECTRICAL
	STORM SEWER
	WATER
MH	MANHOLE
	RAILROAD TRACKS
	UNDERGROUND SOIL VAPOR EXTRACTION (SVE) PIPING
BLUE	NORTH VAPOR EXTRACTION UNIT
GREEN	SOUTH VAPOR EXTRACTION UNIT

NOTES:
1. BASE PLAN PREPARED FROM AN AUTOCAD FILE (SECOR FIGURE 1, JOB 15OT.STSRV.05.0012).
2. UTILITY LOCATIONS SHOWN BASED ON SURFACE MARKINGS BY UTILITY LOCATOR.

Interim Action SVE Layout

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Vancouver, Washington

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Project Number 1126-14
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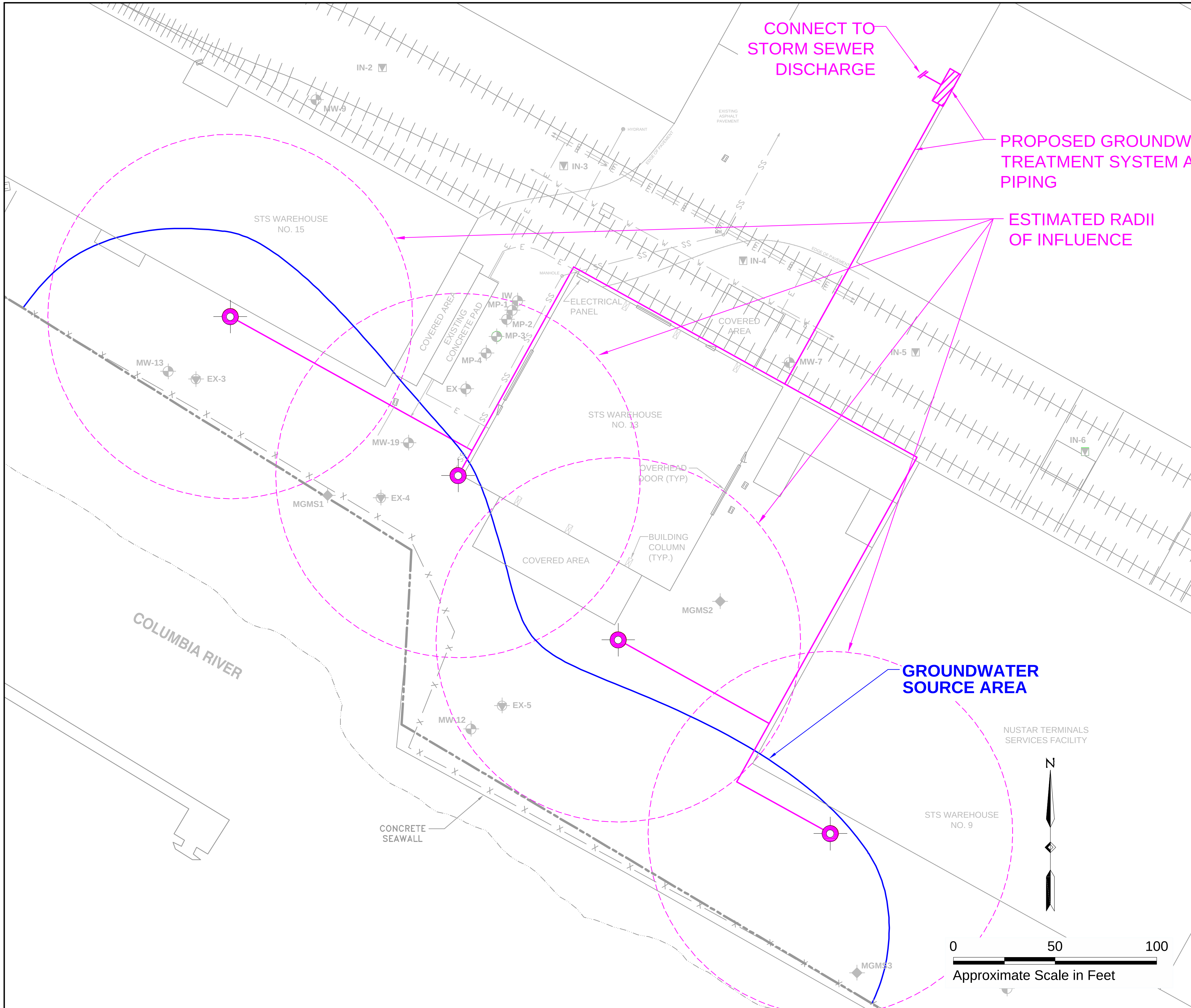
Figure 7-6



LEGEND:

- PROPOSED GROUNDWATER EXTRACTION WELL LOCATION
- EX-3 GROUNDWATER EXTRACTION WELL
- IN-1 GROUNDWATER INJECTION WELL
- MW-1 GROUNDWATER MONITORING WELL
- MGMS3 MULTI-LEVEL GROUNDWATER WELL

UTILITY LEGEND:

- E ELECTRICAL
- SS STORM SEWER
- W WATER

NOTES:
1. BASE PLAN PREPARED FROM AN AUTOCAD FILE (SECOR FIGURE 1, JOB 15OT.STSRV.05.0012).
2. UTILITY LOCATIONS SHOWN BASED ON SURFACE MARKINGS BY UTILITY LOCATOR.

Groundwater Hydraulic Containment

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LEGEND:

- ENHANCED BIOREMEDIATION INJECTION POINT
- 2011 INTERIM ACTION SOURCE AREA INJECTION POINT
- 2011 INTERIM ACTION STANDARD OIL SUBSTRATE INJECTION POINT
- 2011 INTERIM ACTION ANGLED INJECTION POINT
- 2008 INTERIM ACTION INJECTION POINT
- EX-3 EARLY 2000s INTERIM ACTION GROUNDWATER EXTRACTION WELL
- IN-1 EARLY 2000s INTERIM ACTION GROUNDWATER INJECTION WELL AND VAPOR EXTRACTION WELL
- MW-1 GROUNDWATER MONITORING WELL
- MGMS3 MULTI-LEVEL GROUNDWATER WELL
- CATCH BASIN
- BUILDING
- FENCE
- ELECTRICAL
- SYSTEM ELECTRICAL
- STORM SEWER
- WATER
- MANHOLE
- RAILROAD TRACKS

NOTES:

1. BASE PLAN PREPARED FROM AN AUTOCAD FILE (SECOR FIGURE 1, JOB 15OT.STSRV.05.0012).
2. UTILITY LOCATIONS SHOWN BASED ON SURFACE MARKINGS BY UTILITY LOCATOR.
3. INJECTION LOCATIONS BASED ON FIELD MEASUREMENTS TO EXISTING SITE STRUCTURES.

Enhanced Bioremediation Design

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Vancouver, Washington

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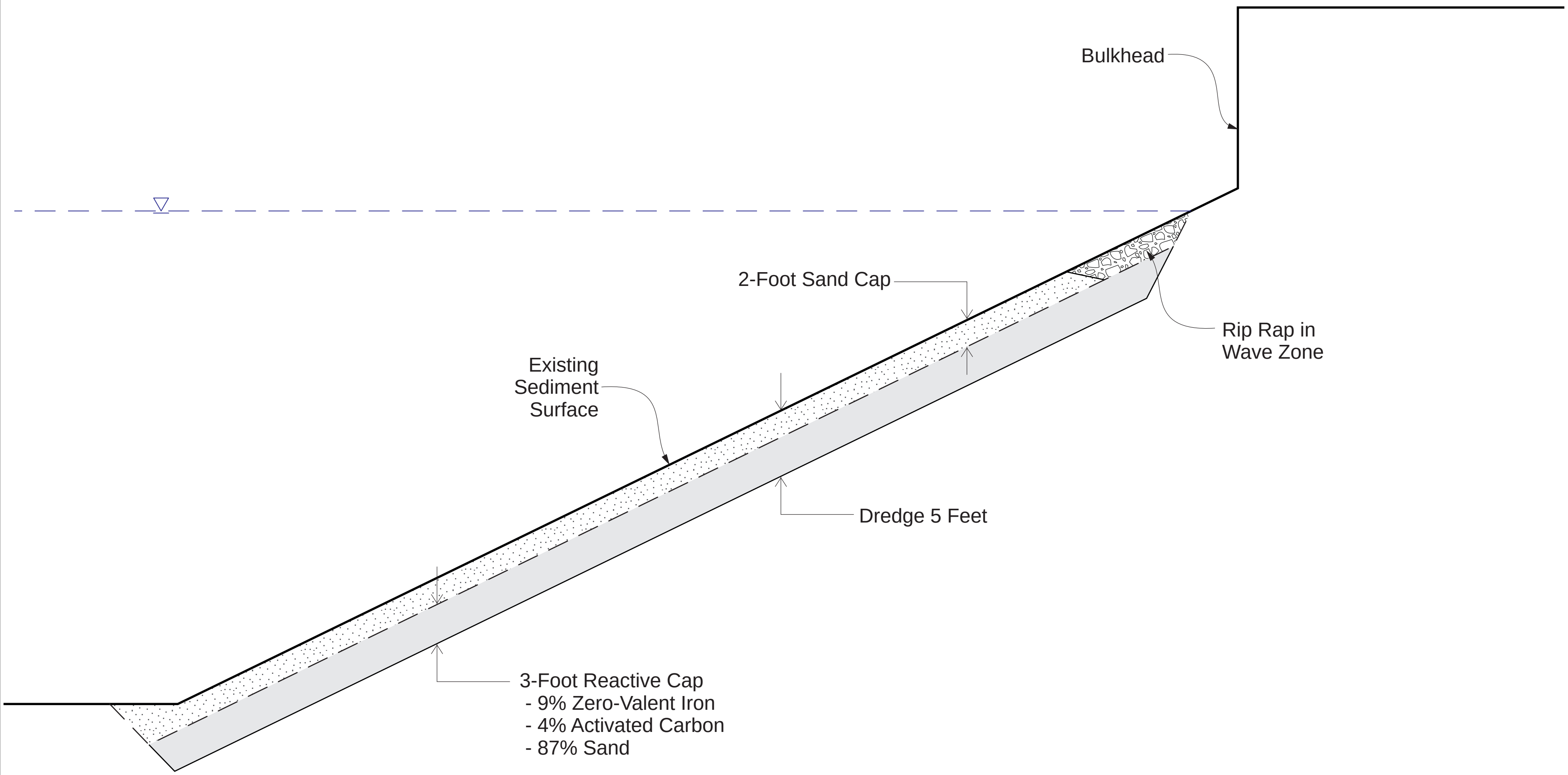
Project Number	1126-14	Figure
January 2014		7-8



Reactive Cap

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Vancouver, Washington

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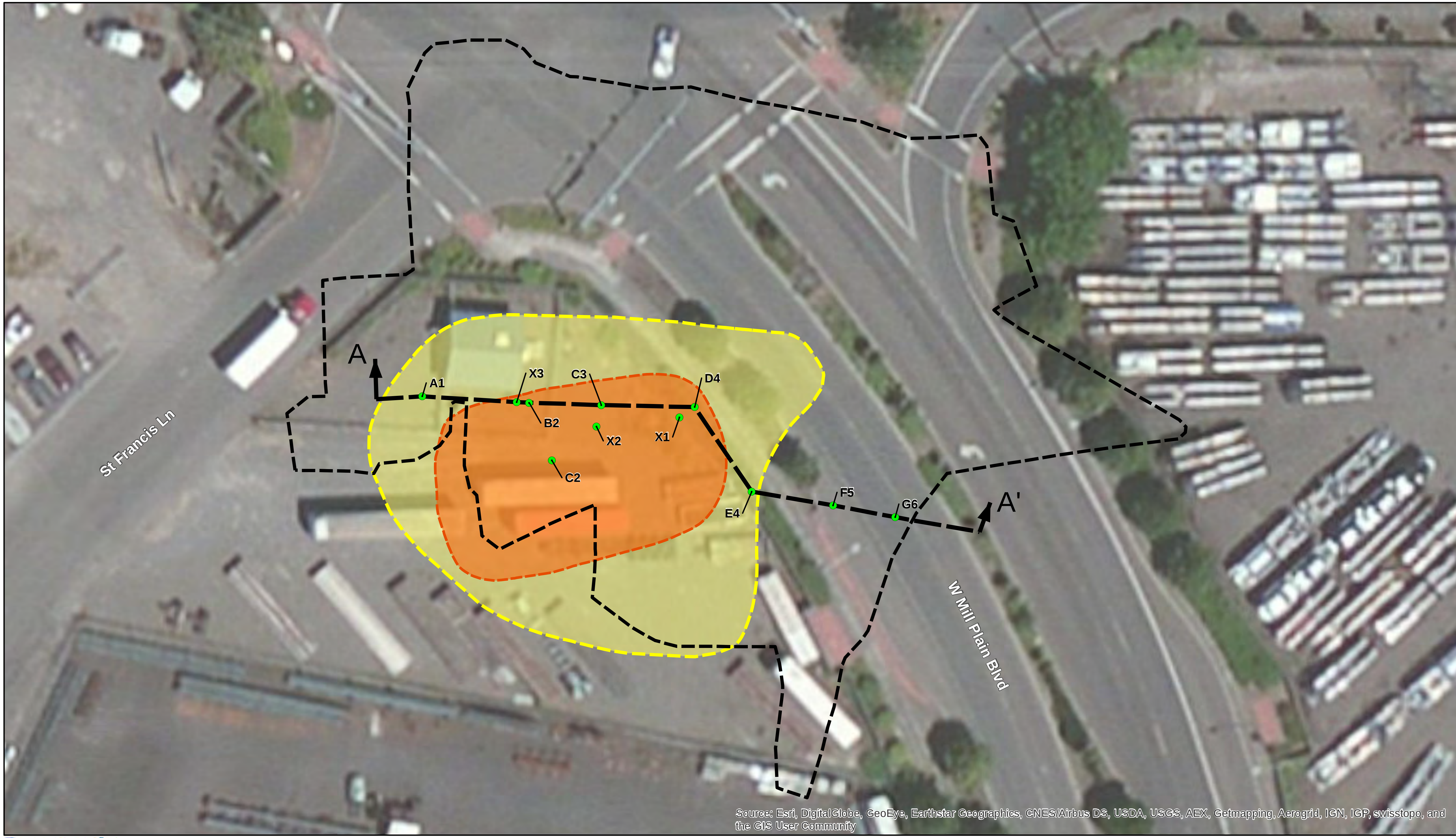
Project Number	1126-14	Figure
January 2014		7-9



Parametrix Date: 12/30/2014 Path: P:\GIS\POV\MXD_PDF\Figures_01082014\Figure8-1_ResidualSourceArea.mxd

N

0 50 100
Feet

- Borings Completed During the 2004 Fine-Grained Sand Layer Investigation
- Potential Extent of Residual Source Area
- Elevated Source Area*
- Extent of Former Excavation

**Based on historical soil conc. exceeding 10,000 µg/kg and groundwater exceeding 10,000 µg/L.*

Figure 8-1
Residual Source Area - SMC

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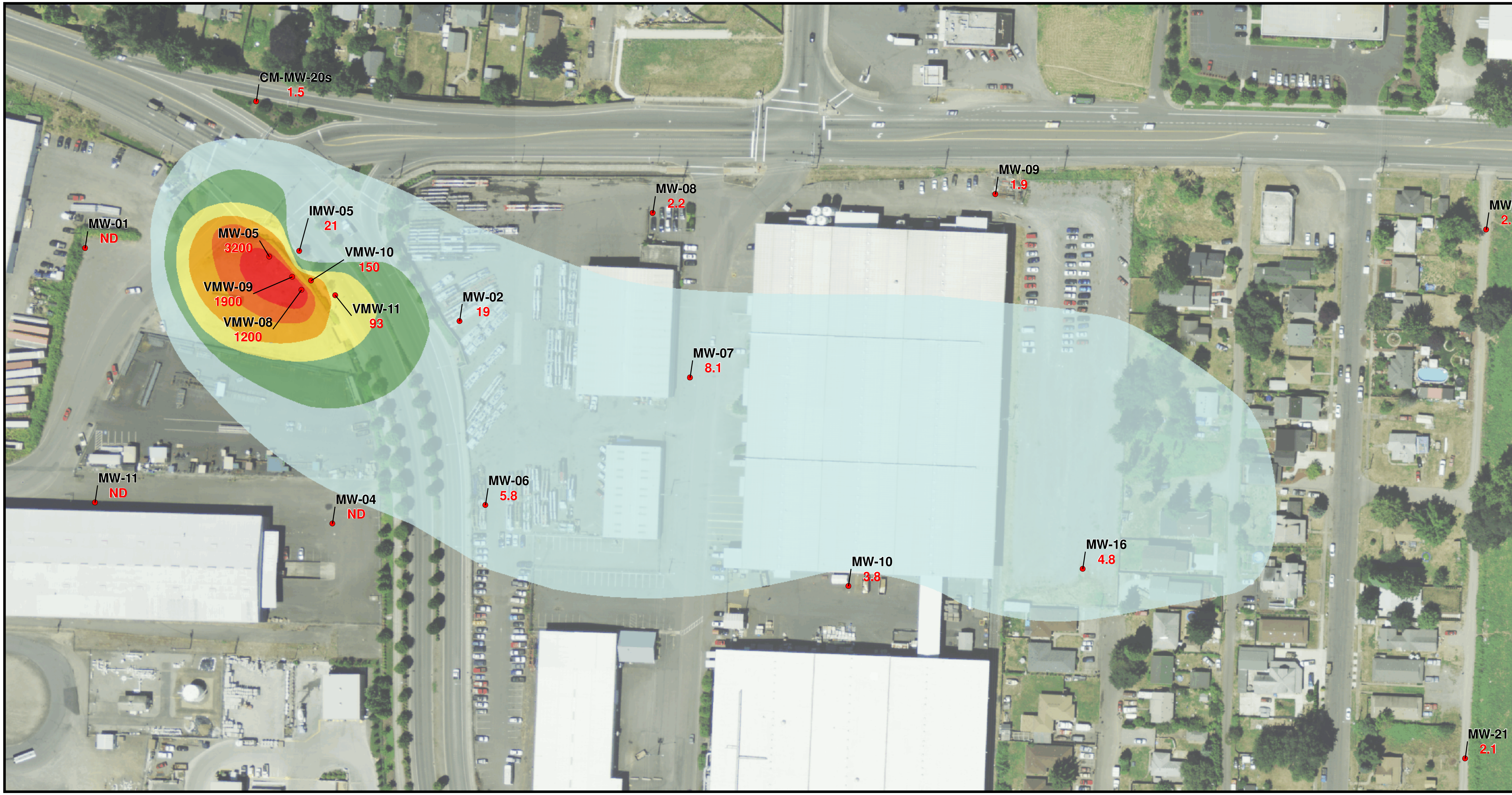
NuStar, SMC, and Cadet
Vancouver, WA



Parametrix Date: 2/27/2014 Path: P:\GIS\POV\MXD_PDF\Isoconcentrations\POV_Isoconcentrations_TCE_Shallow4_Q1_2013_source.mxd

N

MW-10 — Well Location Name
23 — Concentration Value (µg/l)

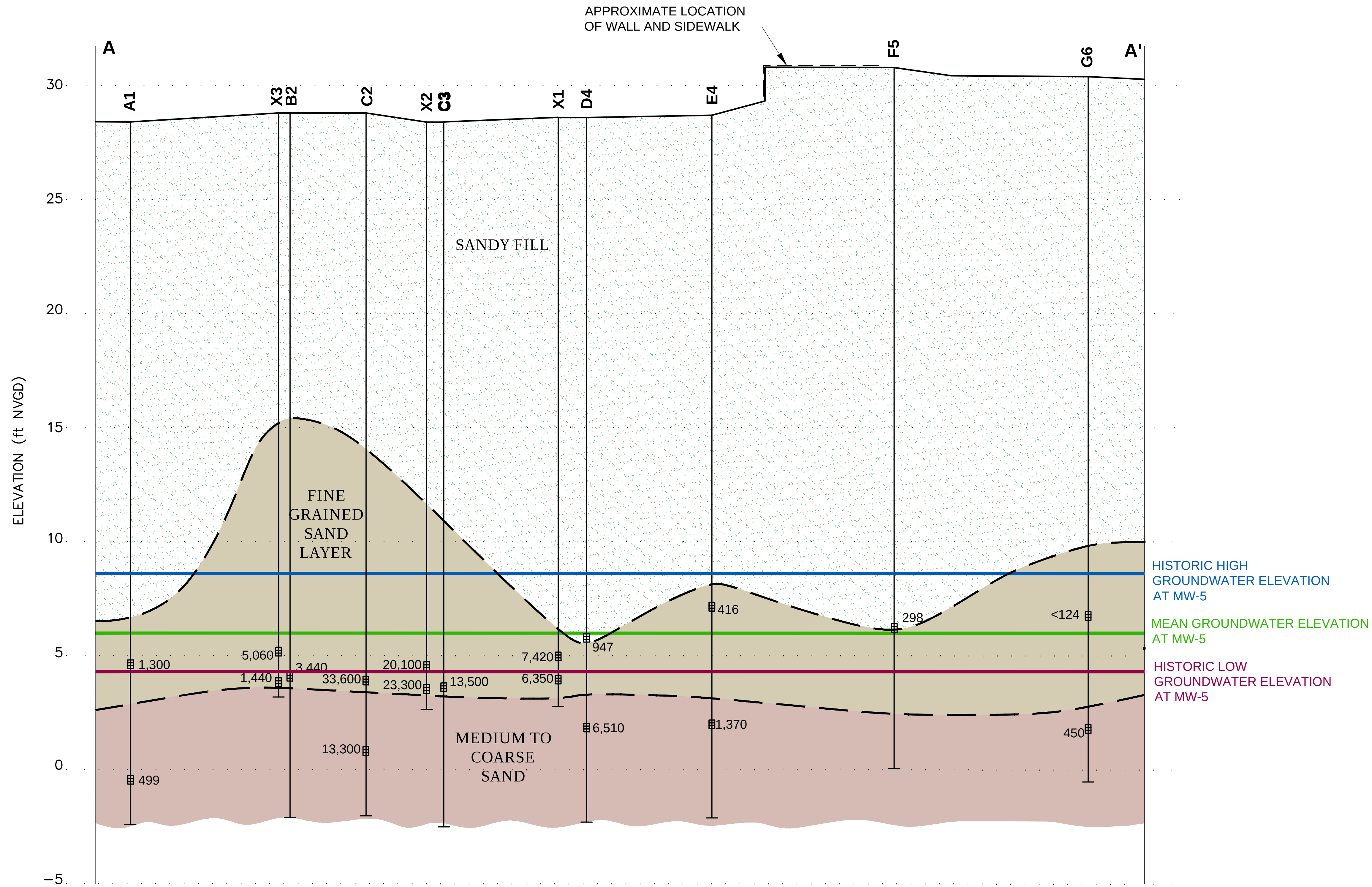
ND = Non-Detect
NS = Not sampled

Legend
> 4 µg/L
> 25 µg/L
> 50 µg/L
> 100 µg/L
> 500 µg/L
> 1000 µg/L

0 100 200 400 Feet

Figure 8-2
TCE Isoconcentrations in Shallow USA Zone Groundwater Near SMC Source Area 1st Quarter 2013

FEASIBILITY STUDY
NUSTAR, SMC AND CADET
VANCOUVER, WA



LEGEND

⊞ 1,300 TCE SOIL CONCENTRATION (µg/kg)

Parametrix DATE: 06/19/08 2:48pm FILE: P194006755

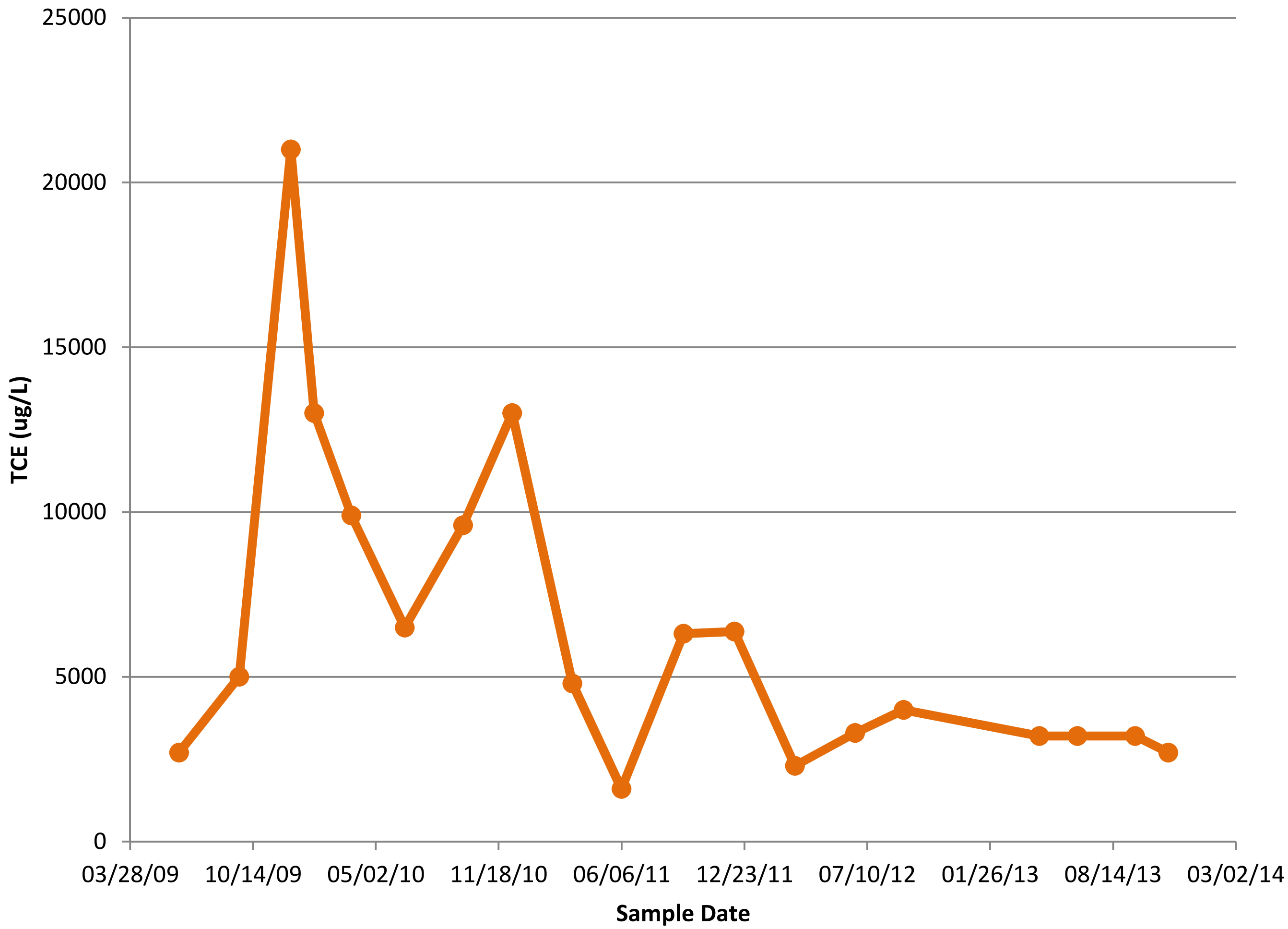
A1 - BORING IDENTIFICATION. BORINGS COMPLETED DURING THE 2004 FINE SAND LAYER INVESTIGATION.

HORIZONTAL SCALE: 1"=20'
VERTICAL SCALE : 1"=5'

Figure 8-3
SMC Source Area
Fine Grained Sand Layer

FEASIBILITY STUDY
NUSTAR, CADET AND SMC
VANCOUVER, WASHINGTON

Figure 8-4: Monitoring Well MW-05 TCE Trend



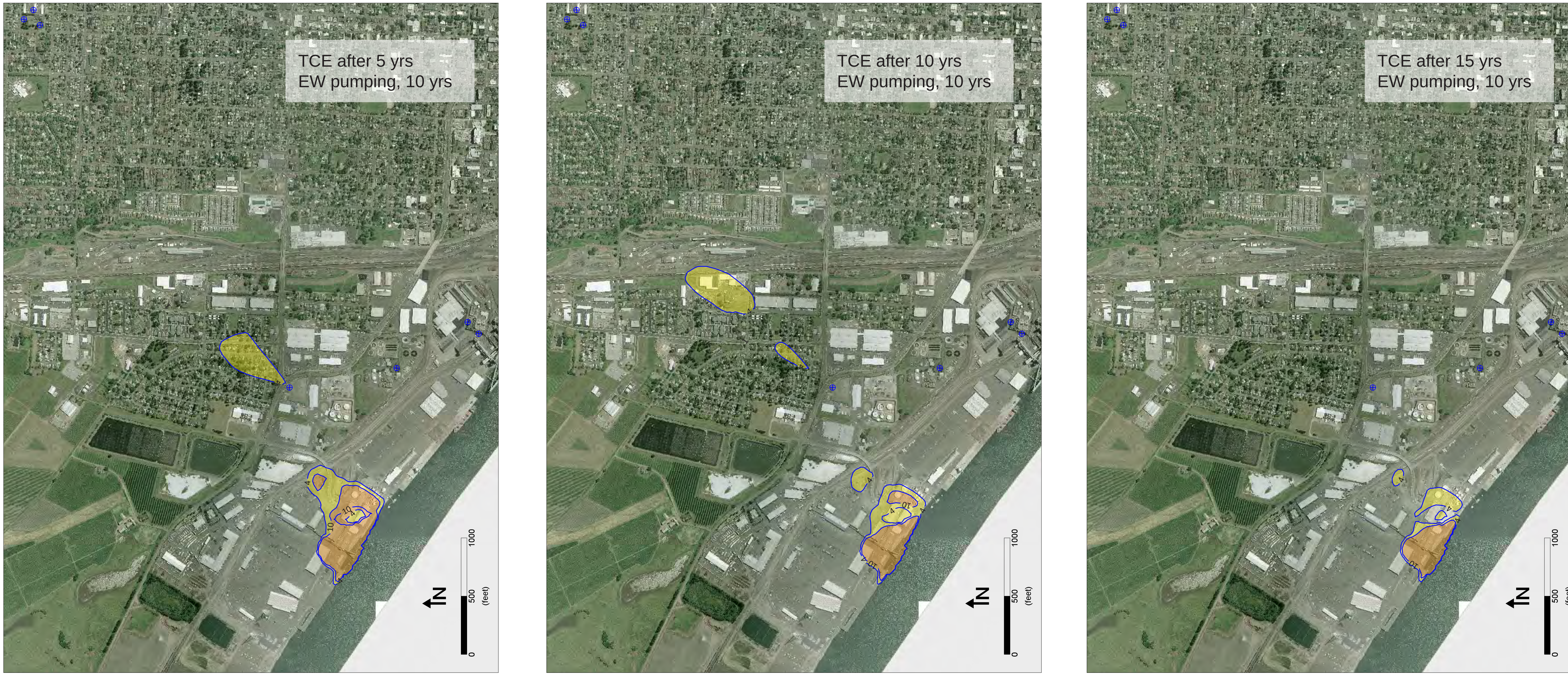


Figure 8-5
Modeled TCE Groundwater Concentrations Above Cleanup Level
Shallow Zone
Year 5, Year 10, Year 15
EW-1 Pumping for 10 Years

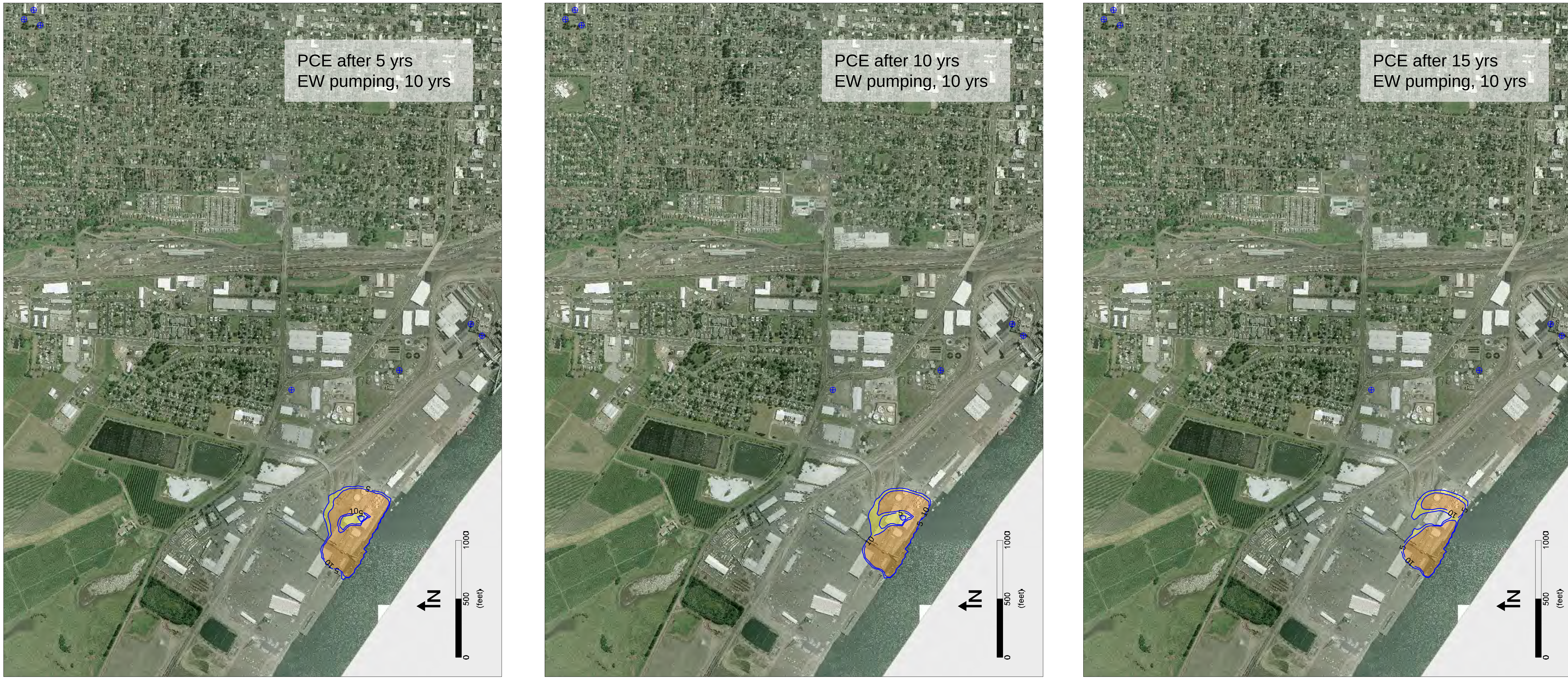
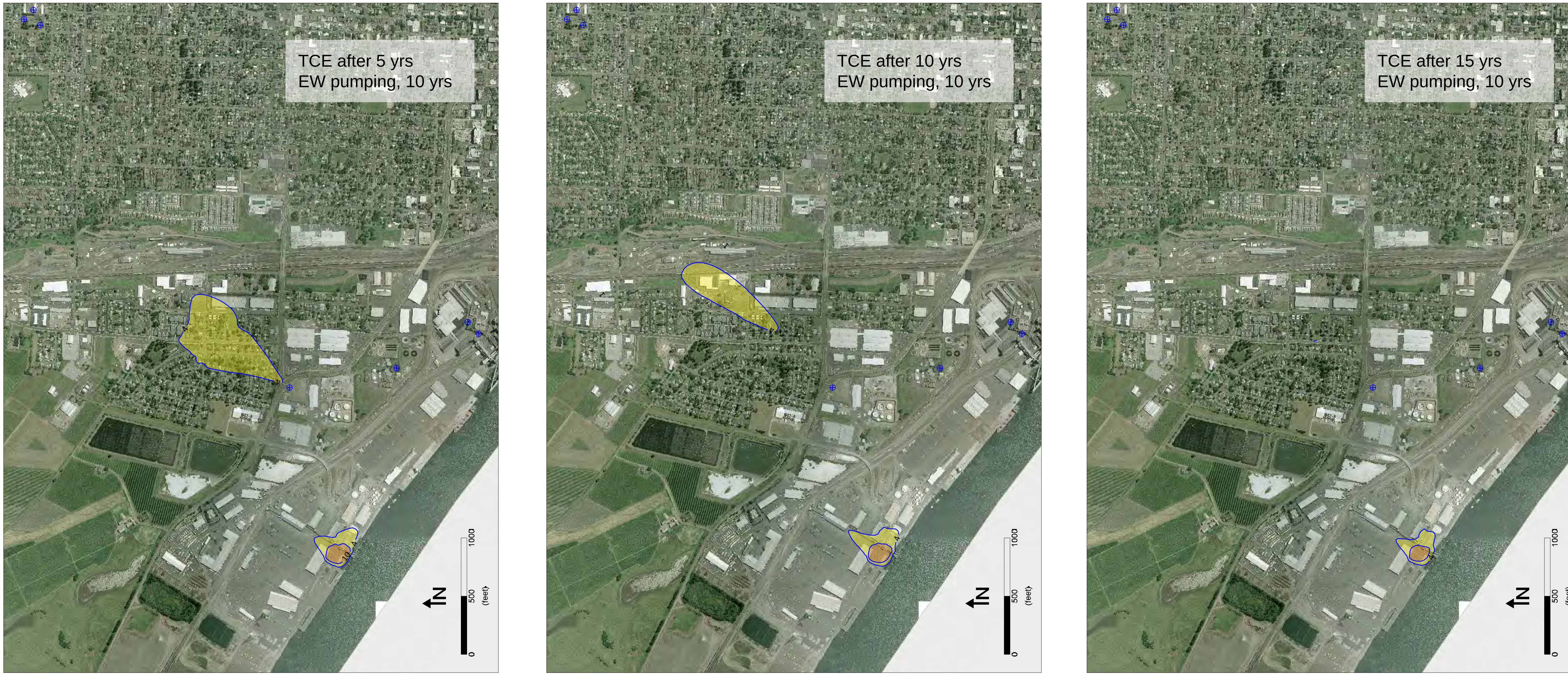


Figure 8-6
Modeled PCE Groundwater Concentrations Above Cleanup Level
Shallow Zone
Year 5, Year 10, Year 15
EW-1 Pumping for 10 Years



Parametrix 275-1940-006-0113-4995

Figure 9-1

Modeled TCE Groundwater Concentrations Above Cleanup Level

Intermediate Zone

Year 5, Year 10, Year 15

EW-1 Pumping for 10 Years

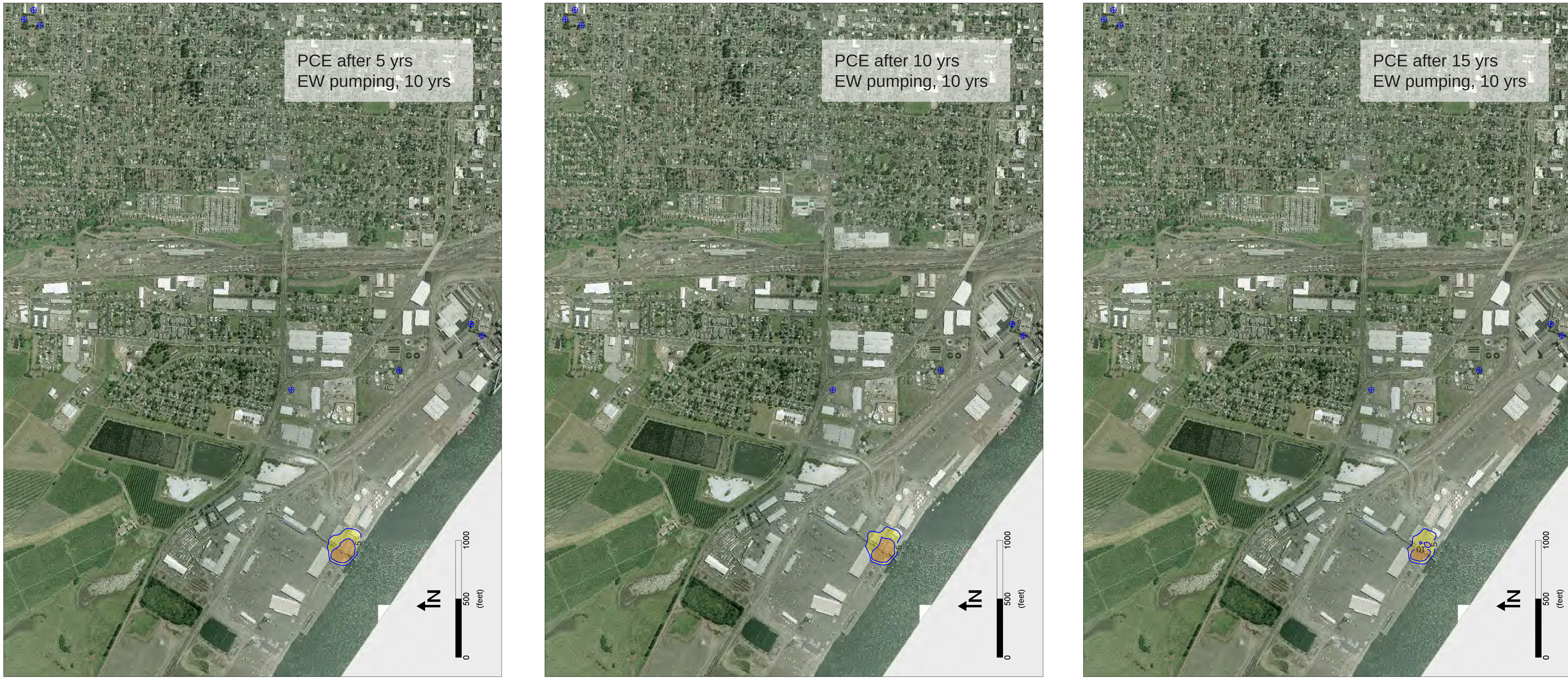


Figure 9-2

Modeled PCE Groundwater Concentrations Above Cleanup Level

Intermediate Zone

Year 5, Year 10, Year 15

EW-1 Pumping for 10 Years

TABLES

Table 4-1
Summary of Applicable or Relevant Federal and State Laws

Applicable Law	Reference Location	Corresponding Applicable Cleanup Levels (Y/N)
Federal		
The Clean Water Act (CWA)	33 U.S.C §1251 et seq.	Y
Safe Drinking Water Act (SDWA)	42 U.S.C §300f et seq.	N
National Toxics Rule	57 FR 60848; 40 CFR Part 131	Y
Resource Conservation and Recovery Act (RCRA)	42 U.S.C. §6901 et seq.	N
Federal Clean Air Act	42 U.S.C. §7401 et seq.	N
Endangered Species Act of 1973	16 U.S.C. §1531-1544, 87 Stat. 884	N
United States Fish and Wildlife Service (USFWS) Mitigation Policy	46 FR 7644	N
Sole Source Aquifer [Section 1424(3) of SDWA]	42 U.S.C §300f et seq., Public Law 93-523	N
The Fish and Wildlife Coordination Act of 1934	16 U.S.C. 661-667e	N
State		
State Environmental Policy Act (SEPA)	Chapter 43.21C RCW; WAC 197-11	N
Washington Water Pollution Control Act	Chapter 90.48 of RCW; WAC 173-201A	Y
Washington Hydraulic Code	Chapter 77.55 RCW; WAC 220-110	N
Washington State Clean Air Act	Chapter 70.94 RCW	N
Washington Solid Waste Management – Reduction and Recycling Act	Chapter 70.95 RCW; WAC 173-350	N
Washington Hazardous Waste Management Act	Chapter 70.105 RCW; WAC 173-303	N
Underground Injection Control (UIC) Program	Chapter 173-218 WAC	N
Compensatory Mitigation Policy for Aquatic Resources and Aquatic Resources Mitigation Act.	Chapters 75.46 and 90.74 RCW	N
Water Resources Act	Chapter 90.54 RCW	N
State Aquatic Lands Management Laws	Chapters 79.90 through 79.96 RCW; WAC 332-30	N
Growth Mangement Act	Chapters 36.70A, 36.70.A.150, and 36.70.A.200 RCW	N

Abbreviations:
1. U.S.C = United States Code.
2. FR = Federal Register.
3. RCW = Revised Code of Washington.
4. WAC = Washington Administrative Code.

Table 5-1
Cleanup Levels for Indicator Hazardous Substances
NuStar, SMC, and Cadet Site

		Cleanup Level Based on Receptor						
		Shallow Groundwater (µg/L)		Intermediate Groundwater (µg/L)	Soil (mg/kg)		Air (µg/m3)
Site	COC	Groundwater to Occupational Air [1]	Shallow Groundwater as Drinking Water[2]	Intermediate Zone GW as Drinking Water[2]	Direct Contact[3]	Leaching to Groundwater[4]	Direct Contact of Indoor Air[5]
NuStar	PCE	53.3	5	5	21,000	0.05	40
	TCE	4.76	4	4	1,800	0.03	2
	c-DCE	NA	16	16	7,000	0.35	NA
SMC	PCE	53.3	5	5	21,000	0.05	40
	TCE	4.76	4	4	1,800	0.03	2
	c-DCE	NA	NA	NA	7,000	0.35	NA

Abbreviations

1. Groundwater Protection of Indoor Air via Vapor Intrusion (Method C Industrial). Cleanup level derived using a Henry's Law Evaluation. Used for comparison check only.
2. Cleanup levels for TCE and cDCE from MTCA Method B published values (Ecology's CLARC database). Method B cleanup level for PCE exceeds the state of Washington MCL; therefore, the MCL is used.
3. Cleanup levels from MTCA Method C published values (Ecology's CLARC database).
4. Cleanup levels for PCE and TCE derived from Ecology's CLARC guidance document dated September 2012.
5. Cleanup levels from MTCA Method C published values (Ecology's CLARC database).
6. NA indicates CLARC value is not available and/or applicable.

Table 5-2
Sediment Cleanup Level Development
NuStar Vancouver Facility

		Human Health	Benthic Toxicity,	Higher Trophic	Sediment Screening Benchmarks from Oak Ridge National Laboratory Database (mg/kg) [8]			Dutch Sediment Screening Levels (mg/kg)[5]		Relevant Cleanup Level for Sediment (mg/kg)[1]	
Analyte	CAS Number	Risk-Based Levels[6]	Table VI, WAC 173-204-563[7]	Level Species Toxicity[6]	OSWER Ecotox Thresholds[2]	SD EPA R5 ESL Sediment[3]	EPA R3 BTAG Freshwater Sediment[4]	Target	Intervention	Sediment Cleanup Objective	Cleanup Screening Level
Dichloroethane, 1,1- (1,1-DCA)	75-34-3	NC	NV	NC		0.000575		0.02	15	0.02	15
Dichloroethene, 1,1- (1,1-DCE)	75-35-4	NC	NV	NC		0.0194	0.031	0.1	0.3	0.02	0.03
Dichloroethene, 1,2-cis (cis-DCE)	540-59-0	NC	NV	NC				0.2	1	0.2	1
Tetrachloroethene (PCE)	127-18-4	NC	NV	NC	0.53	0.99	0.468	0.002	4	0.5	1
Trichloroethene (TCE)	79-01-6	NC	NV	NC	1.6	0.112	0.0969	0.0078	2.5	0.1	1.6
Vinyl Chloride (VC)	75-01-4	NC	NV	NC		0.202		0.01	0.1	0.01	0.1

Notes:

1 Where screening level data are limited (≤ 1 Oak Ridge National Laboratory [ORNL] screening value), the Dutch sediment screening levels were used as relevent screening levels (i.e., for 1,1-DCA, cis-DCE, and VC). The target/intervention SQuiRT screening values were interpreted to be essentially analogous with the no effects/minor effects screening values that were selected from the published ORNL values. Sediment cleanup objective set at minimum of relevant standards; the cleanup screening level set at the maximum of the relevant standards.

2 Sediment Quality Benchmark method. OSWER (Office of Solid Waste and Emergency Response). 1996. Ecotox thresholds. U.S. Environmental Protection Agency. ECO Update 3 (2):1-12. (http://www.epa.gov/oswer/riskassessment/ecoup/pdf/v3no2.pdf)

3 The ESL reference database consists of Region 5 media-specific (soil, water, sediment, and air) Ecological Screening Levels (ESLs) for RCRA Appendix IX hazardous constituents. The ESLs are initial screening levels with which the site contaminant concentrations can be compared. The ESLs help to focus the investigation on those areas and chemicals that are most likely to pose an unacceptable risk to the environment. ESLs also impact the data requirements for the planning and implementation of field investigations. ESLs alone are not intended to serve as cleanup levels. See the August 2003 revision of the ESLs (formerly EDQLs) at http://www.epa.gov/reg5rcra/ca/ESL.pdf

4 The Region III Biological Technical Assistance Group (BTAG) Screening Benchmarks are values to be used for the evaluation of sampling data at Superfund sites. These values facilitate consistency in screening level ecological risk assessments throughout Region III. Additional toxicological information should be considered in Step 3 as provided by the Ecological Risk Assessment Guidance for Superfund (EPA, 1997). The tables include compounds for which benchmark values have been established or that are considered bioaccumulative compounds (identified in tables). For additional information on compounds for which no benchmarks are identified and the use of alternate values, please consult the BTAG FAQs specific to these subjects. The tables and FAQs are available at http://www.epa.gov/reg3hwmd/risk/eco/index.htm

5 Dutch Target/Intervention: E.M.J. Verbruggen, R.Posthmus and A.P. van Wezel, 2001. Ecotoxiological Serious Risk Concentrations for soil, sediment, and (ground)water: updated proposal for first series of compounds. Nat. Inst. Public Health and the Env., and subsequent updates as published elsewhere. Min. Housing, Spatial Plan, And hte Env., 2000. Annexes Circular on target values and intervention values for soil remedations.

6 NC = Not Calculated. Based on multiple lines of evidence (see Text), this pathway is not expected to control site risk.

7 NV = No Value

8 Sediment concentrations based on dry weight.

Table 5-3
Surface Water Cleanup Level Development
NuStar Vancouver Facility

Analyte	State Water Quality Criteria, WAC 173-201A[1]	Clean Water Act, Section 304 (µg/L)[1]			National Toxics Rule, 40 CFR 131 (µg/L)[1]			Minimum Environmental Screening Level (µg/L)[2]	Human Health, WAC 173-340-730(b)(iii), Standard Method B (µg/L)[1]	Human Health, Drinking Water (µg/L)[3]	Practical Quantition Limit (PQL) (µg/L)	Recommended Cleanup Level[4]	
		Freshwater Aquatic	Human Health, Water and Organism	Human Health, Organism Only	Freshwater Aquatic	Human Health, Water and Organism	Human Health, Organism Only					Cleanup Level (µg/L)	Basis
Chloroethane	NV	NV	NV	NV	NV	NV	NV	NV	NV	NV	0.5	0.5	PQL
1,1-Dichloroethane (1,1-DCA)	NV	NV	NV	NV	NV	NV	NV	47	NV	1,600	0.5	47	Environmental
1,2-Dichloroethane (1,2-DCA)	NV	NV	0.38	37	NV	0.38	99	100	59	0.48	0.5	0.5	PQL
1,1-Dichloroethylene (1,1-DCE)	NV	NV	330	7100	NV	0.057	3.2	25	23,000	7	0.5	3	Drinking Water[5]
cis-1,2-Dichloroethylene (cis-DCE)	NV	NV	NV	NV	NV	NV	NV	590	NV	16	0.5	8	Drinking Water[5]
Tetrachloroethylene (PCE)	NV	NV	0.69	3.3	NV	0.8	8.9	45	100	5	0.5	5	Drinking Water
1,1,1-Trichloroethane	NV	NV	NV	NV	NV	NV	NV	11	930,000	200	0.5	11	Environmental
Trichloroethylene (TCE)	NV	NV	2.5	30	NV	2.7	81	21	13	4	0.5	4	Drinking Water
Vinyl Chloride (VC)	NV	NV	0.025	2.4	NV	2	525	930	3.7	0.029	0.5	0.5	PQL

Notes:

1 CLARC Database. NV = No value.

2 From Table 5-4

3 Groundwater cleanup level from Table 5-1 and/or Ecology's CLARC database.

4 Minimum of relevant and appropriate criteria. State Water Quality Criteria, Clean Water Act, and National Toxics Rule not appropriate because either no value is available for the COCs, or because organism consumption assumptions are inconsistent with site characteristics. See further discussion in text.

5 Values for cis-DCE and 1,1-DCE adjusted downward per WAC 173-340-730(5)(a) to achieve total risk hazard index of one.

Table 5-4
Ecological Screening Benchmarks - Surface Water (Fresh)
Oak Ridge National Laboratory - Risk Assessment Information System, Ecological Benchmark Tool
http://rais.ornl.gov/tools/eco_search.php#88
Downloaded 9/5/13

Analyte	CAS Number	Canadian WQG Surface Water	EC20 Daphnids Surface Water	EC20 Fish Surface Water	EC25 Bass Population Surface Water	EPA R4 Acute Surface Water	EPA R4 Chronic Surface Water	LCV Aquatic Plants Surface Water	LCV Daphnids Surface Water	LCV Fish Surface Water	OSWER Tier II Secondary Surface Water	SW EPA R5 ESL Surface Water	SW EPA R6 FW Surface Water	Tier II SAV Surface Water	Tier II SCV Surface Water	EPA R3 BTAG Freshwater
		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Chloroethane	75-00-3															
Dichloroethane, 1,1-	75-34-3			8.22	1.59					14.7	0.047	0.047	5.13	0.83	0.047	0.047
Dichloroethane, 1,2-	107-06-2	0.1	11	29	1.26	11.8	2		15.2	41.4		0.91	6.3	8.8	0.91	0.1
Dichloroethylene, 1,2- (Mixed)	540-59-0			5.72		13.5	1.35			9.54			14	1.1	0.59	0.59
Dichloroethylene, 1,1-	75-35-4				0.447	3.03	0.303	798	4.72	2.8		0.065	3	0.45	0.025	0.025
Dichloroethylene, 1,2-trans-	156-60-5											0.97	22			0.97
Methylene Chloride	75-09-2	0.0981		0.41	1.26	19.3	1.93		42.7	108		0.94	22	26	2.2	0.0981
Toluene	108-88-3	0.002		0.026	0.2	1.75	0.175	245	25.2	1.27	0.13	0.253	2.9	0.12	0.0098	0.002
Trichloroethane, 1,1,1-	71-55-6	0.021	1.3	2.46	0.251	5.28	0.528	669		3.49	0.062	0.076	4.9	0.2	0.011	0.011
Tetrachloroethylene	127-18-4	0.11	0.51	0.5	0.05	0.528	0.084	816	0.75	0.84	0.12	0.045	0.79	0.83	0.098	0.111
Trichloroethylene	79-01-6	0.021		5.76	0.232				7.26	11.1	0.36	0.047	1.11	0.44	0.047	0.021
Vinyl Chloride	75-01-4											0.93	5.63			0.93

Table 7-1
Initial Screening of Technologies for Soil
NuStar Vancouver Facility

General Response Actions	Technology	Description	Screening Criteria			Screening Comments
			Effectiveness	Implementability	Cost	
NO ACTION	No Action	No Action	Not effective in achieving RAOs.	Easy to implement.	No capital or O&M costs incurred.	Does not meet threshold criteria. Retained as a comparison for other technologies.
INSTITUTIONAL CONTROLS	Deed Restrictions/ Soil Management Plan	Can prevent disturbance of any required soil cap or other engineering controls, address notification of Site hazards, and ensure proper controls are implemented during future Site activities. Protocols will be established for handling and managing contaminated soils during future Site work to protect workers, public health, and the environment.	Effective at regulating direct contact, but is not effective at preventing migration. Does not address risks associated with migration and does not address contaminant reduction.	Deed restrictions will require negotiation and agreement with affected property owners, but otherwise generally easy to implement.	Generally low costs associated with implementing various controls, except that deed restrictions may require compensation to affected property owners.	Institutional controls are useful technologies to address risks during cleanup and to address residuals remaining after primary cleanup.
	Monitoring	Laboratory analysis of soil samples.	Effective for documenting Site conditions to evaluate migration and current Site risks. Does not address contaminant reduction.	Moderately easy to implement. Collection of samples beneath structures more difficult.	Low to moderate costs for monitoring.	Applicable to document Site conditions and effectiveness of any treatment. Must be used in conjunction with other technologies.
ENGINEERING CONTROLS	Access Restrictions	Use of fencing, signs, or other controls to limit access to impacted soils.	Effective at preventing direct contact, but is not effective at preventing migration. Does not address risks associated with vapor intrusion and does not address contaminant reduction.	Site is already a controlled space, and limiting worker access to impacted area is not feasible.	Low costs associated with implementing controls.	Not retained since not practical for the impacted soil area (incompatible with current site use) and does not address migration.
	Control of Building HVAC System	Use HVAC system to maintain positive pressure in buildings.	May be effective in preventing migration of volatile contaminants from soil into indoor air as long as a pressure differential is maintained between building and subsurface soil. Does not address migration to other media or contaminant reduction. Generally used in conjunction with other engineering controls.	Can be easy to implement in buildings with existing HVAC systems. Not applicable to most of impacted area (warehouses with large open bays and no HVAC systems).	Low costs associated with implementing these controls. Operational costs include additional heating/cooling of outdoor air.	Not retained as not applicable to current Site structures. Could be re-considered if new structures placed over impacted soil areas.
	Vapor Barrier	Installation of low-permeability barriers beneath structures to prevent vapor intrusion. Alternatively, can place sealants on floor slabs or paved surfaces.	Effective in preventing migration of volatile contaminants from soil into indoor air. Does not address contaminant reduction.	Easy to implement for new building construction. Existing buildings are slab on grade or asphalt concrete pavement. Products readily available for sealing these surfaces.	Moderate cost for vapor barriers and surface sealing.	Technology retained for potential use in conjunction with other technologies.
	Sub-Slab Depressurization or Sub-Floor Venting	Installation of sub-slab venting systems or suction pits to create negative pressures beneath structures to prevent vapor migration to ambient air. Vapors are collected in the suction pit or venting pipes below the building and vented to the outside of the building, either passively or with fans.	Effective in preventing migration of subsurface volatile contaminants from soil into ambient air. Does not address contaminant reduction.	Easy to implement for new building construction. Materials and construction methods are readily available. However, inconsistent with current site conditions (low habitation and well ventilated warehouse structures).	Moderate costs for retrofitting existing structures.	Not retained as not applicable to current Site structures. Could be re-considered if new structures placed over impacted soil areas. Vapor barrier retained as representative engineering control technology.
CONTAINMENT	Capping	Installation of cap (e.g., soil, asphalt, impermeable liner) over impacted soils to prevent direct contact or leaching to groundwater.	Effective at preventing direct contact with contaminated soils but this is not a complete pathway of significance. Can be effective in reducing vapor migration (addressed by vapor barrier above). Low-permeability caps can reduce rainwater infiltration thereby reducing the potential for contaminants leaching from soil.	Much of impacted soil area currently capped by pavement (preventing direct contact). Easy to implement new caps as needed if redevelopment occurs.	No cost to implement within currently capped areas. Marginal costs to implement capping in new development is low.	Not retained given that direct contact not a substantive pathway of concern, vapor migration protection is represented by vapor barrier technology above, and does not address leaching from soil in the zone of groundwater fluctuation.
REMOVAL/OFF-SITE DISPOSAL	Excavation	Excavate contaminated soils with subsequent treatment or off-site disposal.	Effective for removing source material from site. Addresses direct exposure pathways, vapor intrusion, and migration by reducing contaminant concentrations and mass. May also improve groundwater conditions as potential for leaching is reduced.	Implementation involves conventional construction equipment and methods. Difficult to implement in areas with limited access (i.e., under buildings, rail-lines, utility corridors). Some soil located at depths of 25 to 30 feet. Requires subsequent treatment or disposal of hazardous waste.	High costs due to required soil volumes and interference with structures.	Source area soils are primarily located under buildings or other Site infrastructure, thus excavation is difficult to implement. Generates large quantity of hazardous waste that would require treatment and/or disposal. The high costs associated with this technology do not provide adequate benefit over other technologies.
	Off-site Disposal	Off-site disposal at licensed landfill. Soils would require characterization to determine type of disposal facility (hazardous or non-hazardous).	Disposal in a controlled landfill is effective for containing contaminated soils and reducing risks associated with direct exposure.	Implementation involves transportation of contaminanted soils on public roads for potentially long distances. The nearest permitted hazardous waste landfill is located in Arlington, OR (150 miles one way).	High costs for hazardous waste disposal.	Excavation not retained as technology so disposal is not applicable.

Please refer to note at end of table.

Table 7-1
Initial Screening of Technologies for Soil
NuStar Vancouver Facility

General Response Actions	Technology	Description	Screening Criteria			Screening Comments
			Effectiveness	Implementability	Cost	
IN SITU PHYSICAL/ CHEMICAL/ THERMAL TREATMENT	Soil Vapor Extraction (SVE)	SVE involves extraction of vapors from the vadose zone using system of vertical wells or horizontal vents and vacuum pumps/blowers. Treatment of the discharge may be required and carbon adsorption technologies are included in this approach to address the vapor stream; for chlorinated VOCs, treatment is typically achieved using carbon adsorption.	Highly effective at removing volatile organic compounds (VOCs) from unsaturated soils and controlling vapor migration into buildings. Soil conditions at the site are amenable to vapor extraction.	Uses well-established technologies and access is available. Operation of interim action demonstrated implementability at this site.	Moderate capital and O&M costs. Treatment system already exists.	Technology is currently being used as an interim action. Technology is retained.
	Electrokinetic Separation	Application of a low-intensity direct current through the soil between electrodes that are divided into a cathode array and an anode array. This mobilizes charged species, causing ions and water to move toward the electrodes.	Effective for removing inorganic ions and polor organics from saturated soil. Most effective in low-permeability soils (particularly clays).	Requires significant power supply and not suitable for use in inhabited areas during implementation. Would require saturation of shallow soils (not suitable beneath building).	High implementation cost.	Not suitable to Site conditions and not compatible with COIs (i.e., non-polar organics).
	Fracturing	Development of cracks in low-permeability or overconsolidated soils to create passageways that increase the effectiveness of other *in situ* processes and extraction technologies.	Effective in conjunction with other technologies (e.g., vapor extraction) in deep, fine-grained or consolidated soils. Not effective with shallow soil.	Specialized equipment and personnel needed to safely implement.	Moderate implementation cost.	Not suitable for shallow sandy/silty soil at site. Previous experience at Site suggests fracturing not required for effective vapor migration.
	Chemical Oxidation	Chemically converts hazardous contaminants to less toxic compounds. Effective in destroying organic contaminants and oxidizing inorganic contaminants to less toxic/less mobile forms. Can include oxidant chemicals such as peroxides, permanganates, or ozone.	Can be highly effective at destruction of organic contaminants. Can be difficult to achieve full coverage (contact between oxidant and COIs), particularly in unsaturated soils. May not be suitable for use beneath structures.	Equipment and vendors are readily available. Implementation beneath building would require care to prevent settling (and potential damage to building). Delivery difficult in unsaturated soils.	High implementation cost.	Technology not retained because of difficulty in delivery in unsaturated soil and high cost.
	Soil Flushing	Water (or water containing an additive to enhance contaminant solubility) is circulated through the soil to desorb contaminants, recovered, and treated. Single-well implementation can involve injection followed by removal (such as via vacuum truck).	Less effective for organic contaminants and would require groundwater extraction/treatment operation. Can be effective at removing bound separate-phase liquids from vicinity of well (less suited to widespread impacts).	Difficult to maintain control of amended water. Inefficient process for unsaturated soils.	High implementation cost.	Not retained because less suitable to Site contaminants (volatile organics), less effective in shallow unsaturated zone, would require significant infrastructure for water extraction and treatment.
	Solidification/ Stabilization/ Vitrification	Contaminants are physically bound or enclosed within a stabilized mass (solidification and vitrification), or chemical reactions are induced between the stabilizing agent and contaminants to reduce their mobility (stabilization).	Most suitable to inorganic contaminants.	Not suitable for use in inhabited areas during implementation. May not be suitable for use beneath building. Volatilization of organics would need to be controlled during implementation.	High implementation cost.	Not retained because less suitable to Site contaminants and Site conditions compromise effectiveness. More cost-effective methods of addressing volatile contaminants are available.
	Thermally-Enhanced Removal	High-energy injection (steam/hot air, electrical resistance, electromagnetic, fiber optic, radio frequency) is used to increase the recovery rate of semi-volatile or non-volatile compounds to facilitate extraction (enhanced volatilization or decreased viscosity).	Most suitable to semi-volatile organic contaminants or viscous compounds that are not otherwise extractable with vapor extraction or fluid extraction technologies.	Generally used in conjunction with SVE system or other recovery system (i.e., groundwater extraction). Has high energy requirements.	High implementation cost.	Not retained because less suitable for Site contaminants and high cost.
IN SITU BIOLOGICAL TREATMENT	Bioventing	Bioventing involves inducing air or oxygen flow in the unsaturated zone to promote biodegradation of hydrocarbons and VOCs. Applications include injection of air or oxygen into subsurface, or extraction of air at rates lower than SVE.	Would be less efficient for degradation of chlorinated solvents (reductive dechlorination is an anaerobic process).	This technology may interfere with anaerobic degradation of chlorinated solvents. Requires air emission testing and modeling to determine if off-gas treatment is required. Air injection would need to be coupled with extraction to maintain control of fugitive VOC emissions. Low air volume recovery rates would require larger number of extraction points.	Moderate capital and O&M costs.	Would not efficiently promote degradation of chlorinated solvents.

Please refer to note at end of table.

Table 7-1
Initial Screening of Technologies for Soil
NuStar Vancouver Facility

General Response Actions	Technology	Description	Screening Criteria			Screening Comments
			Effectiveness	Implementability	Cost	
IN SITU BIOLOGICAL TREATMENT—CONTINUED	Enhanced Bioremediation (Bioaugmentation, Biostimulation)	Adding nutrients, electron acceptor, or other amendments to enhance bioremediation.	Effective in saturated soils with addition of suitable amendments. Treatment of vadose zone soils requires means of providing adequate soil moisture.	Difficult to maintain in thick unsaturated soil profile (particularly with contaminants concentrated in lenses of relatively fine-grained soil). Being implemented as groundwater technology that would also address saturated soil.	Moderate costs depending on number of injection events required.	Not suitable for shallow unsaturated soil. Further evaluated as groundwater technology that would also address saturated soil.
	Land Treatment	Combination of aeration (tilling) and amendments to enhance bioremediation in surface soils.	Effective for organic contaminants in shallow soil that can be degraded aerobically.	Common agricultural equipment can be used to process shallow soil. Less efficient for chlorinated solvent hydrocarbons (degraded anaerobically). Requires open land that is not available at the site.	Low to moderate implementation cost.	Not retained because incompatible with Site contamination, structures, or depth to contaminants.
	Monitored Natural Attenuation	Using natural processes to reduce contaminant concentrations to acceptable levels. Process is closely monitored to verify exposures are acceptable prior to concentrations reaching acceptable levels.	May be effective, especially in areas of low concentrations. Not efficient for source areas; other technologies will likely be required.	Easy to implement. Monitoring of unsaturated soil would require repeated intrusive sampling events. Likely will require significant timeframe to reach cleanup goals.	Moderate costs for monitoring.	May be applicable to address residual low-concentration contamination not efficiently addressed by active remediation.
	Phytoremediation	Phytoremediation is a process that uses plants to remove, transfer, stabilize, and destroy contaminants in soil or sediment.	Can be effective at removing a variety of organic and inorganic compounds from soil through plant uptake in vicinity of roots (rhizosphere).	Requires significant land area suitable for large plants. Contamination must be accessible to plant root zones. Large variety of COIs may not all be addressed by compatible plant species.	Moderate implementation cost.	Not retained because incompatible with Site use and depth to contaminants. Unlikely to be effective for all COIs.
EX SITU PHYSICAL/ CHEMICAL/ THERMAL TREATMENT	Chemical Extraction	Excavated soil is mixed with an extractant, which dissolves the contaminants. The resultant solution is placed in a separator to remove the contaminant/extractant mixture for treatment.	Most suitable to removal of semi-volatile and inorganic contamination from excavated soil. Less effective in fine-grained soils.	Can be effective in removing most organic contaminants from soil. Difficult to remove all contaminant/extractant mixture from soil—would likely require finish treatment. Requires area for soil treatment or transport to off-site facility. Extractant fluid would need subsequent treatment process or disposal.	Moderate to high implementation cost.	Not retained because excavation technology was not retained.
	Dehalogenation	Reagents are added to soils contaminated with halogenated organics to remove halogen molecules.	Effective at detoxifying halogenated organic compounds in excavated soil. Less effective in fine-grained soils.	Requires area for soil treatment or transport to off-site facility. Risks associated with handling of reagents.	Moderate to high implementation cost.	Not retained because excavation technology was not retained.
	Incineration	High temperatures are used to combust (in the presence of oxygen) organic constituents in hazardous wastes.	Effective at removing organic contaminants from excavated soil.	Requires transport to off-site facility (long-distance interstate transport—nearest facility in Nebraska, distance of 1,200 miles).	High implementation cost.	Not retained because excavation technology was not retained.
	Soil Washing	Contaminants are separated from the excavated soil with wash-water augmented with additives to help remove organics.	Most suitable for semi-volatile organics or inorganic contamination.	Requires area for soil treatment or transport to off-site facility. Resultant fluid would need subsequent treatment process or disposal.	Moderate to high implementation cost.	Not retained because excavation technology was not retained.
	Solar Detoxification	Contaminants are destroyed by photochemical and thermal reactions using ultraviolet energy in sunlight or artificial UV light. Usually involves application of catalyst agent.	Can be effective at treating a variety of organic compounds. Most effective when used with catalyst agent (e.g., titanium dioxide).	Implementation with sunlight limited by availability (not effective during nighttime and limited effectiveness in cloudy/wet seasons). Requires area for treatment or transport to off-site facility.	Low to moderate implementation cost.	Not retained because excavation technology was not retained.
	Thermal Desorption/ Pyrolysis/ Hot Gas Decontamination	Waste soils are heated to either volatilize (desorption and hot gas) or to anaerobically decompose (pyrolysis) organic contaminants. Off-gas is collected and treated.	Effective at removing organic materials from excavated soil (particularly volatile organics). Pyrolysis generally used for semi-volatiles or pesticide wastes.	Requires transport to off-site treatment facility. Treatment of chlorinated hydrocarbons difficult (may generate acid in off-gas). Off-gas treatment required.	Moderate to high implementation cost.	Not retained because excavation technology was not retained.

Please refer to note at end of table.

Table 7-1
Initial Screening of Technologies for Soil
NuStar Vancouver Facility

General Response Actions	Technology	Description	Screening Criteria			Screening Comments
			Effectiveness	Implementability	Cost	
EX SITU PHYSICAL/ CHEMICAL/ THERMAL TREATMENT—CONTINUED	Separation	Separation techniques concentrate contaminated solids through physical, magnetic, and/or chemical means. These processes remove solid-phase contaminants from the soil matrix.	Effective only for removal of solids with distinct physical characteristics (size, composition, etc.).	Commercial equipment available for separation by size (sieving) or for removing iron (magnetic removal).	Low to moderate cost.	Not retained because excavation technology was not retained. Not compatible with Site COIs.
EX SITU BIOLOGICAL TREATMENT	Biopiles	Excavated soils are mixed with soil amendments and placed in aboveground enclosures and aerated with blowers or vacuum pumps.	Effective for removal of organic contaminants from excavated soil. Most effective with control of moisture, heat, nutrients, oxygen, and pH to enhance biodegradation.	Requires area for soil treatment or transport to off-site facility. May generate leachate that would need to be collected and managed.	Low to moderate cost.	Land use requirements are not compatible with Site use. Not retained because excavation technology was not retained.
	Composting	Excavated soil is mixed with bulking agents and organic amendments to promote microbial activity.	Effective for removal of organic contaminants from excavated soil. Most effective with control of moisture, heat, nutrients, oxygen, and pH to enhance biodegradation.	Requires area for soil treatment or transport to off-site facility. May generate leachate that would need to be collected and managed.	Low to moderate cost.	Land use requirements are not compatible with Site use. Not retained because excavation technology was not retained.
	Landfarming	Excavated soil is placed in lined beds and periodically tilled to aerate the soil.	Effective at removing organic contaminants from excavated soil.	Requires area for soil treatment or transport to off-site facility. Common agricultural equipment can be used to process soil in treatment beds.	Low to moderate cost.	Chlorinated hydrocarbons would require long-term treatment and frequent handling; land use requirements are not compatible with anticipated future Site use; aerobic environment less effective for biological treatment of chlorinated hydrocarbons. Not retained because excavation technology was not retained.
	Slurry Phase Biological Treatment	An aqueous slurry of soil, sediment, or sludge with water and other additives is mixed to keep solids suspended and microorganisms in contact with the soil contaminants. When complete, the slurry is dewatered and the soil is disposed of.	Can be effective at treating a variety of organic compounds.	Requires area for soil treatment or transport to off-site facility. Slurry dewatering generates water that requires treatment or disposal.	Moderate to high implementation cost.	Handling of slurry and wastewater is complicated and expensive; land use requirements are not compatible with Site use. Not retained because excavation technology was not retained.

Note:
1. Shading indicates technology has been eliminated from consideration.

Table 7-2
Initial Screening of Technologies for Groundwater
NuStar Vancouver Facility

General Response Actions	Technology	Description	Screening Criteria			Screening Comments
			Effectiveness	Implementability	Cost	
NO ACTION	No Action	No Action	Not effective in achieving RAOs.	Easy to implement.	No capital or O&M costs incurred.	Does not meet threshold criteria. Retained as a comparison for other technologies.
INSTITUTIONAL CONTROLS	Groundwater Use Restrictions	Restricted use of Shallow Zone and Intermediate Zone groundwater.	Effective at preventing direct contact, but is not effective at preventing migration. Does not address risks associated with vapor intrusion and does not address contaminant reduction.	May require deed restrictions to prevent off-site and on-site groundwater use. No planned use of on-site groundwater.	Low costs associated with implementing restrictions (off-site deed restrictions could require significant compensation).	Applicable technology used in conjunction with other technologies.
	Monitoring	Laboratory analyses of groundwater samples.	Effective for documenting Site conditions to evaluate migration and current Site risks. Does not address contaminant reduction.	Easy to implement. On-site and off-site monitoring wells already exist.	Low to moderate costs for monitoring.	Applicable to document Site conditions and effectiveness of any treatment.
ENGINEERING CONTROLS	Control of Building HVAC System	Use HVAC system to maintain positive pressure in buildings.	May be effective in preventing migration of volatile contaminants from shallow groundwater into indoor air as long as a pressure differential is maintained between building and subsurface soil. Does not address contaminant reduction. Generally used in conjunction with other engineering controls.	Can be easy to implement in buildings with existing HVAC systems. Not applicable to most of impacted area (warehouses with open bays).	Low costs associated with implementing these controls. Operational costs include additional heating of outdoor air.	Not retained as not applicable to current Site structures. Could be re-considered if new structures placed over impacted groundwater areas.
	Vapor Barrier	Installation of low-permeable barriers beneath buildings to prevent vapor intrusion.	Effective in preventing migration of volatile contaminants from shallow groundwater into indoor air. Does not address contaminant reduction.	Easy to implement for new building construction. Existing buildings are slab on grade or asphalt concrete pavement. Products readily available for sealing these surfaces.	Moderate cost for vapor barriers and surface sealing.	Technology retained for potential use in conjunction with other technologies.
	Sub-Slab Depressurization or Sub-Floor Venting	Installation of sub-slab or sub-floor venting systems or suction pits to create negative pressures beneath structures to prevent vapor migration to ambient air. Vapors are collected in the suction pit or venting pipes below the building and vented to the outside of the building, either passively or with fans.	Effective in preventing migration of subsurface volatile contaminants from groundwater into ambient air. Does not address contaminant reduction.	Easy to implement for new building construction. Materials and construction methods are readily available. However, inconsistent with current site conditions (low habitation and well ventilated warehouse structures).	Moderate costs for retrofitting existing structures.	Not retained as not applicable to current Site structures. Could be re-considered if new structures placed over impacted soil areas. Vapor barrier retained as representative engineering control technology.
	Alternative Water Supply	Develop new water supply in uncontaminated area to provide potable water in the areas of impact.	Effective in preventing use of contaminated groundwater. No contaminant reduction. Does not address risks associated with vapor intrusion. Does not address requirement to protect drinking water supply.	Conventional construction, requires local and WRD approvals.	High capital costs, low to moderate O&M costs.	Not retained as viable technology. Site groundwater not used. Does not address off-site use of groundwater as drinking water or requirement to protect drinking water supply. High cost.
	Wellhead Treatment	Treatment at individual impacted water supply wells with use of *Ex-Situ* Physical/Chemical/Thermal treatment technology.	Effective in reducing contaminant concentrations in groundwater prior to use. Does not address risks associated with vapor intrusion. No groundwater pumping is anticipated at the Facility.	No groundwater pumping is anticipated at the Facility. Treatment units for large-scale municipal systems would be difficult to implement. Requires ongoing testing and system maintenance to remain effective.	High capital costs and O&M costs for municipal-scale treatment system.	No groundwater pumping is anticipated at Facility. A potential municipal treatment unit would involve many responsible parties, require significant treatment volumes, and would be cost prohibitive. Does not address requirement to protect drinking water supply. Technology not retained.
CONTAINMENT	Vertical Barrier	Installation of vertical barriers (e.g., sheet piling, soil-bentonite slurry wall, grout, etc.) to prevent migration of groundwater contamination.	Effective at preventing lateral migration. Requires keying into underlying confining unit. Hydraulic control often necessary as supplemental measure to achieve containment. Cannot prevent downward migration.	Difficult to implement, particularly given depth to groundwater and overall size of groundwater plume. Additionally, groundwater in the Shallow and Intermediate Zones have different flow directions, so multiple barriers would be required to contain all groundwater. Site lacks suitable confining unit at reasonable depth. Some Site contaminants have specific gravity greater than 1 (sinkers). Specialized equipment required for construction.	High capital costs, low to moderate O&M.	Not practical for deep groundwater, would need to extend below deepest potential impact to prevent lateral migration beneath barrier. Several more cost-effective technologies are available. Technology not retained.
	Pumping / Hydraulic Containment	Extraction well(s) with submersible pumps to lower the water table and create hydraulic gradients that direct contaminant migration into the extraction well. Extracted groundwater would require treatment before discharge (see *Ex-Situ* Physical/Chemical/ Thermal Treatment).	Effective in porous soils for preventing further contaminant migration. May also be used in conjunction with other technologies. Not efficient for removal of contaminant mass.	Existing monitoring wells could be utilized, although new wells likely needed to achieve full capture of plume. Discharge of treated water would need to be permitted.	Moderate to high capital costs. New extraction wells may be required. Moderate to high O&M costs.	Retained as applicable technology to control groundwater flow. Could be combined with other technologies to address otherwise saturated soil (wihtin the cone of depression).

Please refer to note at end of table.

Table 7-2
Initial Screening of Technologies for Groundwater
NuStar Vancouver Facility

General Response Actions	Technology	Description	Screening Criteria			Screening Comments
			Effectiveness	Implementability	Cost	
REMOVAL/DISCHARGE	Pumping (Pump & Treat)	Extraction well(s) with submersible pumps to remove contaminated groundwater with goal of plume reduction and aquifer restoration. Treatment of extracted groundwater likely required before discharge (see *Ex-Situ* Physical/Chemical/ Thermal Treatment).	Effective in porous soils for preventing contaminant migration and removing contaminants from extracted groundwater, but is inefficient at source reduction. May also be used in conjunction with other technologies to address previously saturated soils.	Existing monitoring wells could be utilized, although new wells likely needed to achieve objectives of plume reduction/aquifer restoration. Discharge of treated water would need to be permitted.	Moderate to high capital costs, if new extraction wells required. Moderate to high O&M costs.	Not retained because inefficient at mass removal. Technology retained above as groundwater control process.
	Subsurface Drains	Trench or horizontal boring filled with porous media—gravity drains to sump/pump. Treatment of extracted groundwater likely required before discharge (see Ex-Situ Physical/Chemical/Thermal Treatment).	Effective for shallow groundwater at preventing contaminant migration. Not effective for impacted deeper groundwater. May also be used in conjunction with other technologies.	Not practical to install at groundwater depths at site.	Moderate to high capital and O&M costs.	Not retained since groundwater depth greater than appropriate for subsurface drains.
	Discharge to Sewer / Surface Water	Discharge of water (which may require treatment) into surface water, storm sewer, or sanitary sewer.	Effective for disposal of extracted groundwater. Treatment of water may be necessary prior to disposal.	State and federal legislation regulate discharge into river. NPDES permit required to discharge treated water into the Columbia River. Local permit needed to discharge to sewer system.	Moderate cost to transport treated water to river. Permitting and associated negotiations could incur moderate costs.	Applicable for discharge of extracted groundwater.
	Discharge to Reinjection Wells	Discharge of water (which may require treatment) into aquifer by reinjection wells.	Moderate effectiveness, depending upon whether injection wells can be adequately located to prevent plume spreading.	Underground injection control permit required for reinjection.	Moderate to high capital and O&M costs for reinjection wells.	Applicable for discharge of extracted groundwater. UIC permit required for injection wells (treatment needed to meet UIC discharge requirements).
	Reuse	Reuse of treated water for non-potable use such as irrigation or wetland enhancement.	Effective for treated, extracted groundwater.	A suitable use would need to be identified that can accommodate a steady flow rate in all seasons and within reasonable proximity.	Low to high costs depending upon storage and pumping requirements, and length of discharge piping.	No identified potential use suitable for flow rate expected from extraction system.
EX SITU PHYSICAL/ CHEMICAL/ THERMAL TREATMENT	Adsorption	Concentrating solutes on the surface of a sorbent material, such as activated carbon, to remove the solute from the bulk liquid.	Highly effective at removing many organic compounds from extracted water stream.	Applicable for treatment of Site contaminants in extracted water. Treatment equipment is readily available.	Moderate capital and O&M costs.	Applicable for treatment of extracted water.
	Air Stripping	Volatile organics are partitioned from extracted groundwater by increasing surface area exposed to air.	Highly effective at removing many VOCs from extracted water stream. May require treatment of vapor effluent.	Applicable for treatment of Site contaminants in extracted water. Treatment equipment is readily available. Requires air emission testing and modeling to determine if off-gas treatment is required.	Low to moderate capital and O&M costs. Higher costs if off-gas treatment needed.	Applicable for treatment of extracted water.
	Separation/ Reverse Osmosis	Extracted groundwater is forced through a selectively permeable membrane under pressure. Water is allowed to pass through the membrane while contaminants are trapped.	Highly effective at removing many contaminants from the extracted water stream.	Applicable for treatment of Site contaminants in extracted water. Treatment equipment is readily available.	High capital and O&M costs.	Not retained since more cost-effective treatment methods exist for removal of Site contaminants from water.
	Ultraviolet (UV) Oxidation	Ultraviolet radiation is used to destroy organic contaminants as water flows through treatment cell.	Effective at removing many organic contaminants from the extracted water stream.	Applicable for treatment of Site contaminants in extracted water. Treatment equipment is readily available.	High capital and O&M costs.	Not retained since more cost-effective treatment methods exist for removal of Site contaminants from water.
	Sprinkler Irrigation	Contaminated water is distributed through a pressurized sprinkler irrigation system (generally onto a highly porous media), allowing transfer of VOCs from aqueous phase to vapor phase.	Effective at removing many organic contaminants from the extracted water stream. Simpler system than more aggressive treatment technologies (such as air stripping).	Applicable for treatment of Site contaminants in extracted water, but requires significant treatment system area.	Low to moderate capital and O&M costs.	Not retained since land use not compatible with Site conditions.
	Ion Exchange	Ion exchange removes ions from the aqueous phase by exchange with counter ions on the exchange medium.	Effective for treatment of inorganic contaminants.	Treatment equipment is readily available.	Moderate to high capital and O&M costs.	Not compatible with Site contaminants.
	Precipitation/ Coagulation/ Flocculation	This process transforms dissolved contaminants into an insoluble solid, facilitating the contaminant's subsequent removal from the liquid phase by sedimentation or filtration.	Effective for treatment of inorganic contaminants.	Treatment equipment is readily available.	Moderate to high capital and O&M costs.	Not compatible with Site contaminants.

Please refer to note at end of table.

Table 7-2
Initial Screening of Technologies for Groundwater
NuStar Vancouver Facility

General Response Actions	Technology	Description	Screening Criteria: Effectiveness	Screening Criteria: Implementability	Screening Criteria: Cost	Screening Comments
EX SITU BIOLOGICAL TREATMENT	Bioreactors / Trickling Filter	Contaminants in extracted groundwater are put into contact with microorganisms in attached or suspended growth biological reactors.	Effective at removing many organic contaminants from the extracted water stream. May be less effective during cold weather. May not reach treatment goals without follow-up polishing treatment.	Difficult to maintain effectiveness with variable operating parameters (i.e., influent concentrations, ambient concentrations). Requires significant area for reactors. Would require significant maintenance.	Moderate capital costs and moderate to high O&M costs	Not retained since required space not suitable for Site conditions.
	Constructed Wetlands	Utilizes natural geochemical and biological processes inherent in an artificial wetland ecosystem to remove contaminants from extracted groundwater.	Highly effective at removing many organic and inorganic contaminants from the extracted water stream.	Requires large land area to implement. May introduce attractive nuisance hazard for local wildlife.	Moderate to high capital costs. Low O&M costs.	Not retained since land use not compatible with Site conditions.
IN SITU BIOLOGICAL TREATMENT	Enhanced Bioremediation (Bioaugmentation, Biostimulation)	Adding nutrients, electron acceptor, or other amendments to enhance bioremediation. Addition of specific microbial cultures can be included if indigenous species not suitable for complete degradation of COIs.	Effective with addition of suitable amendments. Strategic placement of amendments can be effective in conjunction with other technologies. Treating source-area concentrations (NAPLs) requires significantly longer time to complete. Has been demonstrated as an affective technology at the Site.	Equipment and technology for direct injection are readily available. Amendments for stimulating reductive dechlorination are commercially available.	Low to moderate costs depending on number of injection events required.	Applicable technology for Site contaminants. Currently is being used as an interim action with demonstrated effectiveness.
	Monitored Natural Attenuation	Using natural processes to reduce contaminant concentrations to acceptable levels. Process is closely monitored to verify exposures are acceptable prior to concentrations reaching acceptable levels.	May be effective, especially in areas of low concentrations (near plume boundaries), but is dependant upon Site conditions. Not effective for source areas; other technologies will likely be required.	Easy to implement. Monitoring wells already exist. Likely will require significant timeframe to reach cleanup goals.	Low costs for monitoring.	Applicable technology for portions of plume with low contaminant concentrations.
	Phytoremediation	Phytoremediation is a process that uses plants to remove, transfer, stabilize, and destroy contaminants.	Can be effective at removing a variety of organic and inorganic compounds from contaminated groundwater through plant uptake.	Requires significant land area suitable for large plants. Contamination must be accessible to plant root zones.	Moderate implementation cost.	Not retained because incompatible with Site conditions and depth to groundwater.
IN SITU PHYSICAL/ CHEMICAL/ THERMAL TREATMENT	Aeration / Air Sparging	Increasing the contact between water and air to enhance volatilization. Air sparging involves injecting air into saturated matrices.	Effective for volatile contamination. May require shallow vapor extraction to prevent uncontrolled vapor migration. Oxygen input is incompatible with anaerobic degredation of HVOCs.	Equipment and technology for air sparging are readily available. Vapor mitigation would likely be required. Most effective in areas of high concentrations.	Moderate capital and O&M costs for air sparging. High capital and O&M costs with addition of SVE system to control vapors (although SVE system already installed at most impacted source area)	Not suitable for low-concentration extent of plume. Technology not retained because would be detrimental to anaerobic biodegredation that has been demonstrated to be successful at the site.
	Multi-Phase Extraction (MPE)	MPE provides simultaneous extraction of soil vapor, contaminated groundwater, and NAPL using single vacuum pump, multiple in-well pumps, or bioslurping.	Effective for source removal at Site with moderate to low soil permeability. Also effective for treating impacted groundwater in the source area.	Equipment and technology for MPE are readily available. Treatment of recovered soil vapors and groundwater would be required prior to discharge.	Moderate to high capital and O&M costs. Higher costs if vapor treatment needed.	Relatively high cost. Inefficient approach for moderately high hydraulic conductivity at the site.
	Steam Flushing/ Steam Stripping	Steam is injected into the contaminated aquifer to vaporize less volatile organics.	Used in conjunction with vapor recovery. May be effective for increasing usability of SVE for low-volatility compounds.	Equipment and technology are readily available. Treatment of recovered vapors would likely be required.	High capital costs.	Not retained since not beneficial to removal of Site COIs.
	Chemical Oxidation	Chemically converts hazardous contaminants to less toxic compounds. Effective in destroying organic contaminants (including LNAPL) and oxidizing inorganic contaminants to less toxic/less mobile forms. Can include oxidant chemicals such as peroxides, permanganates, or ozone.	Effective in destroying organic contaminants (including free product) and oxidizing inorganic contaminants to less toxic/less mobile forms. Difficult to provide adequate coverage in subsurface. May cause settling in organic soils. Most applicable to source-area concentrations or NAPLs.	Equipment and vendors are readily available. Less efficient at addressing diffuse concentrations of Site COIs.	High implementation costs (potentially requiring multiple applications).	Not retained since inefficient for diffuse contaminant plume and no specific source area (NAPLs) identified.
	Passive/Reactive Treatment Walls	Barriers placed across groundwater movement that allows passage of water while facilitating degradation or removal of contaminants.	Can be effective in the remediation of dissolved-phase VOC contamination. May not be suitable for source area remediation. Not cost-effective for very wide or deep plumes. Iron filings have been demonstrated to be effective at removal of HVOCs.	Depth of shallow aquifer would require installation by drilled methods (rather than open excavation). Specialty equipment needed for installation. Barrier materials readily available (iron and sand). Existing subsurface structures (tied-back bulkhead along seawall) would interfere with installation.	High costs for installation. Moderate costs for performance and compliance monitoring, and periodic maintenance.	Not practical for large perimeter of diffuse contaminant plume and would not address residual source area (only applicable to migrating contaminants).

Note:
1. Shading indicates technology has been eliminated from consideration.

Table 7-3
Initial Screening of Technologies for Sediment
NuStar Vancouver Facility

General Response Action	Technology	Description	Screening Criteria: Effectiveness	Screening Criteria: Implementability	Screening Criteria: Cost	Screening Comments
NO ACTION	No Action	No Action	Not effective in achieving RAOs	Easy to Implement	No capital or O&M costs incurred	Does not meet threshold criteria, but required to be retained
INSTITUTIONAL AND ENGINEERING CONTROLS	Legal Restrictions, Regulations, and Covenants	May include restrictions such as: deed restrictions, easements, and covenants, attached to property-related documents; physical barriers such as fences; and legal bans or controls of activities (i.e., fishing).	Can be effective at controlling human exposures, but less effective (or not effective) at controlling ecological exposures. Is not effective at controlling or reducing migration. Most suitable for use in conjuction with other active technologies. Enforcement in commercial/publicly accessible waterway is difficult.	Likely to require acceptance and cooperation of multiple parties (including Native American tribes and public agencies) to implement.	Low	Not retained because technology does not address ecological exposures and marginally effective at addressing human health exposures.
	Sediment Management Plan	Development and publication of protocols for handling and managing contaminated sediments during future work to protect workers, public health, ecological exposures, and the environment.	Effective for management of contaminated sediments. Not effective at preventing human or ecological exposures without other active technologies.	Easy to implement. Likely to require review by multiple parties (including Native American tribes and public agencies).	Low	Potentially applicable in conjunction with other technologies and/or to address residual contamination.
	Signage/Notifications/Advisories	Posting of signs and/or distribution of notifications regarding health concerns in area of contamination.	Can be effective at reducing human exposures via public education, but not effective at controlling ecological exposures. Is not effective at controlling or reducing migration. Most suitable for use in conjuction with other active technologies. Enforcement in publicly accessible waterway is difficult.	Easy to implement.	Low	Potentially applicable in conjunction with other technologies and/or to address residual contamination.
	Monitoring	Laboratory analysis of samples collected from sediment or pore-water.	Effective for documenting site conditions and exposure risks, evaluating migration and naturally occuring processes, and effectiveness of remediation actions. Does not address contaminant reduction or receptor exposures.	Easy to implement.	Low	Potentially applicable in conjunction with other technologies.
SOURCE CONTROL	Groundwater Source Cleanup	Any of several groundwater source cleanups as described in Table 7-2 that eliminates ongoing flux of contaminated groundwater through sediments.	Effective in eliminating contaminant migration from the source area to river sediments. Would require natural degradation of residual contaminants in soil outside source area and in sediments.	Implementation would be relatively easy as the best overall groundwater cleanup action would be selected following the rules and guidance.	Marginal costs would be low as the source area cleanup would be implemented for groundwater cleanup.	Potentially applicable if used in conjunction with MNR or other sedimnet remedy.
	Vertical Barrier	Installation of vertical barriers (e.g., sheet piling, soil-bentonite slurry wall, grout, frozen ground, etc.) to prevent migration of groundwater contamination to river sediments.	Effective at preventing lateral migration. Requires keying into underlying confining unit to prevent migration underneath the barrier. Hydraulic control often necessary as supplemental measure to achieve containment. Would not prevent downward migration. Relies on natural attenuation of residual contaminants in sediments.	Difficult to implement, particularly given depth to groundwater and overall size of groundwater plume. Site lacks suitable confining unit to key into. Technology would not address soil wedge between the barrier wall and the sediment which would act as an ongoing source to sediments. Difficult to install near the seawall due to physical obstructions (i.e., tiebacks). Specialized equipment required for construction.	High capital costs, low to moderate O&M.	Not retained due to significant remaining residual source material, implementation difficulties, and high cost.
	Permeable Reactive Barrier (PRB)	A permeable barrier is installed across the flowpath of the grondwater plume allowing water to flow freely through the wall. Permeable reactive barriers allow the passage of groundwater while probhibiting the passage of contaminants by adding amendments such as zero-valent metals, sorbents, microbes, etc. As groundwater moves through the wall it reacts with the amendments and reductive dechlorination occurs (i.e. producing chloride and non-toxic chemicals).	Effective in limiting lateral contaminant migration from the source area to river sediments. Would require natural degradation of residual contaminants between PRB and sediments.	Not practical to install on river side of top of bank (work below high water would require low-water construction window, significant permitting, and could affect seawall integrity) and upland construction would need to avoid seawall tiebacks to maintain structural integrity of the wall; therefore, there would remain a wedge of soil containing VOCs on the riverside of the PRB that could act as an ongoing source of VOCs. As treatment wall ages it may lose its reactive capacity and require replacement of active medium. Construction of the wall would also be complicated by the installation occurring under an active terminal road with subsurface shoreline and docking infrastructure present.	High capital costs, moderate to high O&M depending upon rate in which wall pores clog with metal salts, biological organisms, etc.	Potentially applicable to prevent further migration from the source area but would not address existing contamination between barrier wall and sediments. Constructability issues would compromise the effectiveness of the wall due to the location of the wall. Retained as representative reactive barrier technology.
	Ice Wall Barrier	Installation of a "wall" of ice probes directly into sediment that would then be cooled with a refridgeration device until adjacent sediment is frozen. This technique is generally used to create a frozen wall to cut off water and isolate sediments for remediation using other technologies. It could potentially be used to prevent groundwater migration from source to river sediments.	The effectiveness of this technology for use as a barrier wall is uncertain as information on similar use of this technology is not available in the literature. Would need to be maintained until source area migration would no longer affect sediments.	Difficult to implement as probes would need to be installed directly into the shoreline area of the Columbia River. Would likely be difficult to obtain permit from Army Corps of Engineers/Washington Division of Natural Resources as technology would involve afffecting the temperature, if only locally, of Columbia River surface water.	High Capital costs, potentially high O&M.	Not retained as this variation on the vertical barrier has greater cost and greater uncertainty with respect to effectiveness.
CONTAINMENT	Cap	Installation of an engineered cap over impacted sediment. Could include: sand cap; sand and clay cap; armored cap; or composite materials cap.	Most effective for contaminants with low-solubility and high sorption (i.e., chemicals likely to remain bound to sediment). Sources to sediments primarily related to migration in groundwater, so cap not effective. Unprotected caps may not be effective in potential scour areas from river currents or propeller wash.	Generally uses proven technologies. Access to site somewhat limited by dock structures. Capping near shipping channel can be problematic.	Moderate	Not retained as cap material would quickly become impacted from migration of contaminated groundwater.
	Reactive Cap	Installation of an engineered cap containing reactive additives (e.g., adsorptive or reactive materials such as activated carbon or zero-valent metals) over impacted sediment. Reactive layers would be placed in the lower portion of the cap to treat groundwater passing through the cap. The upper portion would consist of habitat material or armoring, as appropriate.	The cap would provide immediate protection with a clean layer at the surface. The lower portion of the cap would treat groundwater and sequester the contaminants below the biologically active depth. The cap would have a limited life determined by the layer thickness/additive quantity and contaminant mass flux. May require source control to be effective in the long term.	Reactive caps are relatively new technology and there is limited experience with installation, effectiveness, and longevity. It it difficult to esimate the useful life of a reactive cap.	Moderate to High	Although there is large uncertainty related to the life of the cap, it is retained as a representative containment technology.

Please refer to note at end of table.

Table 7-3
Initial Screening of Technologies for Sediment
NuStar Vancouver Facility

General Response Action	Technology	Description	Screening Criteria: Effectiveness	Screening Criteria: Implementability	Screening Criteria: Cost	Screening Comments
REMOVAL AND DISPOSAL	Dredging	Mechanical removal of contaminated sediments. Could include: mechanical dredging, hydraulic dredging, or land-based excavation (either submerged or behind coffer dam).	Effective in removing impacted sediments. Significant effort may be needed to minimize sediment resuspension. Likely impractical to remove all impacted sediment and residual contamination will require management. Would not be effective with ongoing source contribution in the absence of source control action (ongoing migration would re-contaminate sediments).	Dredging equipment is readily available, but implementation requires signficant permitting and preparatory work. May require contaminant barrier during dredging activities. Hydraulic dredging would also require dewatering facility. Signicant quantities of riprap are present in the area of concern.	Moderate	Potentially applicable for short-term removal of impacted sediment. Needs to be combined with a source control remedy for VOC-containing groundwater for long-term success.
	Off-Site Disposal	Off-site disposal of dredged/excavated sediment at a permitted disposal facility (e.g., landfill). Selection of disposal facility dependent upon characterization of wastes.	Effective at removing source material from cleanup area and placement in a managed waste facility. Addresses direct exposure pathways and migration by removing contaminant mass from site.	Implementation involves transportation of contaminated sediment on public roads for potentially long distances. Transportation by truck requires elimination of free liquids from sediment.	Moderate to High	Not a stand alone technology. Applicable for handling of dredged/excavated sediments.
	Onsite Upland Landfill	Construction of a permitted upland landfill facility at the Site for the disposal of the dredged/excavated sediments. Would require suitable area and acceptance by permitting agencies.	Effective at removing source material from cleanup area and placement in a self-managed waste facility. Addresses direct exposure pathways and migration by removing contaminant mass from cleanup area. Would require ongoing maintenance of landfill.	On-site landfill incompatible with current site use, and permitting would be difficult.	Moderate to High	Not retained because it is not compatible with current site use.
	Confined Aquatic Disposal (CAD)	Disposal area is excavated in open water or utilizes existing low spots in the river. The disposal cell is then filled with the dredged/excavated sediment and covered with clean material (i.e., capped).	Effective at removing source material from cleanup area and placement in a self-managed waste facility. Addresses direct exposure pathways and migration by removing contaminant mass from cleanup area. Placement and design of CAD facility must account for potential soluble contamination migration. Would require ongoing maintenance of disposal facility.	Potential for increased releases during disposal. Mitigation would be required. Significant permitting effort would be required and acceptance by regional stakeholders. Would require long-term monitoring and maintenance. May require navigation restrictions.	High	Not retained because has higher costs than other disposal methods (i.e., off-site landfill), has higher risks during and after implementation, and it is unlikely that it would be permitted. Is more suitable to larger removal volumes.
	Confined Disposal Facility (CDF)	A disposal facility built specifically for the disposal of dredged sediment. Sediment is placed in CDF and physically separated from waterway (cap/barrier).	Effective at removing source material from cleanup area and placement in a self-managed waste facility. Addresses direct exposure pathways and migration by removing contaminant mass from cleanup area. Placement and design of CDF facility must account for potential soluble contamination migration. Would require ongoing maintenance of disposal facility.	Potential for increased releases during disposal. Mitigation would be required. Significant permitting effort would be required and acceptance by regional stakeholders. Would require long-term monitoring and maintenance.	High	Not retained because has higher costs than other disposal methods (i.e., off-site landfill) and has higher risks during and after implementation, and it is unlikely that it would be permitted. Is more suitable to larger removal volumes.

Please refer to note at end of table.

Table 7-3
Initial Screening of Technologies for Sediment
NuStar Vancouver Facility

			Screening Criteria			
General Response Action	Technology	Description	Effectiveness	Implementability	Cost	Screening Comments
IN-SITU PHYSICAL/ CHEMICAL TREATMENT	Chemical Oxidation	Includes the application of chemical oxidants for the purpose of remediating contaminated sediments. Generally involves reduction/oxidation (redox) reactions that chemically convert hazardous contaminants to less toxic or less mobile forms.	Can be highly effective at destruction of organic contaminants. Can be difficult to achieve full coverage (contact between oxidant and COI). Would not be effective with ongoing source contribution in the absence of source control action. Insufficient evidence exists that in-situ oxidation would be effective in shallow sediments.	Would be difficult to get full coverage of oxidant in sediment. Could be implemented as slurry but would require significant containment effort (such as installation of sheet piling). Less suitable for shallow sediments as application difficult to separate from free water zone and multiple injection/mixing points would be needed. Care would be needed to prevent secondary impacts (such as from mobilized metals) during oxidation.	Moderate to High	Not retained because it would be difficult to ensure adequate coverage and has high implementation risks. Lower-cost options exist for short-term management during source control.
	Sediment Flushing	Circulation of water or an aqueous solution through the contaminated sediment to desorb contaminants. The circulated water is then recovered and treated.	Bench scale tests at other sites have shown to be effective. Less effective for organic contaminants and would require an upland treatment operation.	Would be difficult to get full coverage of solution through sediment. Less suitable for shallow sediments as application difficult to separate from free water zone and multiple injection/mixing points would be needed.	Moderate to High	Technology not retained as implementation risks are high and other more suitable technologies are available.
	Solidification/Stabilization	Contaminants are physically bound or enclosed in a stabilized mass (solidification) or chemical reactions are induced between the reagent and contaminants to reduce their mobility (stabilization).	Most suitable to inorganic contaminants. Reduction of material permeability would likely cause migration from source area to migrate to different area. Resultant sediments may not provide suitable ecological habitat.	Less suited to volatile organic contamination. High-energy solidification would be inefficient (or impractical) with saturated sediments.	Moderate to High	Not retained because it may cause migration from source area to impact larger area by changing flow paths. High-energy technologies incompatible with site conditions.
	Electrokinetic Separation	Application of a low-intensity direct current through the sediment between electrodes (cathode array and anode array). This mobilizes charged ion species causing movement toward the electrodes.	Effective at removing inorganic ions and some polar organics from saturated soil. No demonstrated application to sediment treatment.	Requires significant electrical power and would have high implementation risks in standing water. Would be difficult to control in shallow sediments.	Moderate to High	Not retained because technology incompatible with site contaminants and has high implementation risks.
	Electrochemical Oxidation	Technology for degrading organic contaminants in situ by applying an electrical current across electrodes placed in the subsurface to ionize oxidizing species (i.e., metal ions) and cause oxidation of the COI.	Laboratory bench scale tests suggest technology could be effective for organics. Application in sediments is untested and would be experimental.	Requires significant electrical power and would have high implementation risks in standing water. Would be difficult to control in shallow sediments.	Moderate to High	Not retained because it is an unproven technology and has high implementation risks.
	Activated Carbon Amendment	Activated carbon (e.g., GAC) is blended into sediments to increase sorptive capacity of sediment and reduce bioavailability of organic contaminants.	Could effectively reduce VOC concentrations in sediment pore-water. Carbon would have a limited adsorptive capacity and would not be suitable for long-term treatment with ongoing source. Most effective with low concentrations of organic contaminants.	Blending of carbon into sediment would require disturbance of sediment and would potentially cause significant resuspension during implementation. If blended into cover layer, is similar to the reactive barrier cap as described above.	Low to Moderate	Potentially applicable to short-term management of VOCs in sediment during implementation of source control action. Essentially same as reactive cap, so not retained as separate technology.
IN-SITU BIOLOGICAL TREATMENT	Enhanced Bioremediation	Addition of nutrients, electron acceptors, or other amendments to sediment to enhance bioremediation.	Effective in saturated soil/sediment with addition of suitable amendments. Degradation of chlorinated ethenes is most effective anaerobically. Process is relatively slow and sufficient residence time may not be available in shallow sediment. May not be possible to adequately create anaerobic conditions.	Blending of amendments into sediment would require disturbance of sediment and would potentially cause significant resuspension.	Low to Moderate	Not retained because aerobic environment not suitable for degradation of site COI. Limited area for treatment in shallow sediments would compromise effectiveness - not suitable for site conditions.
	Phytoremediation	The process of using plants to remove, transfer, stabilize and/or destroy contaminants in soil or sediment.	Can be effective at removing a variety of organic and inorganic compounds from soil/sediment through plant uptake in the plant rhizosphere. Unlikely to be effective in significant water depth (no compatible plant selection).	Would require planting of suitable plants for site conditions, or changing of site conditions to accommodate plants (such as the construction of an engineered wetlands). Would not be compatible with current site use.	Moderate to High	Not retained because incompatible with site conditions.
IN-SITU NATURAL PROCESSES	Monitored Natural Recovery	Naturally occurring physical processes (advection, desorption, dispersion, diffusion, dilution, resuspension, sedimentation, and volatilization), and biological processes (biodegradation, reductive dechlorination). Process is monitored to verify exposures.	Likely to be effective if the source to sediments (contaminated groundwater flux) is addressed. Flushing and dispersion followed by chemical degradation the likley primary mechanisms. Naturally occuring sedimentation may reduce exposures in areas of deposition (would require demonstration of long-term deposition at site).	Easy to implement. Monitoring of COI concentrations in sediments would require long-term monitoring. May require significant timeframe to reach cleanup goals (depending primarily on source reduction actions).	Low	Applicable to addressing low-level contamination, particularly in conjunction with source-control action. VOCs expected to naturally attenuate relatively quickly in absence of ongoing source. The presence of chlorinated VOC degradation products in site sediments, indicates that natural attenuation may already be occuring.

Please refer to note at end of table.

Table 7-3
Initial Screening of Technologies for Sediment
NuStar Vancouver Facility

General Response Action	Technology	Description	Screening Criteria			Screening Comments
			Effectiveness	Implementability	Cost	
EX-SITU PHYSICAL/ CHEMICAL TREATMENT	Dewatering	Removal of water from dredged/excavated sediment (such as to facilitate disposal). Methods may include passive dewatering on barges, dewatering in a constructed lagoon, geotextile tubes (filters), filter presses or other mechanical dewatering methods, or dewatering by adding chemical reagents or adsorptive materials.	Various methods can be effectively used (selected based on site conditions and degree of dewatering needed) to remove water from dredged/excavated sediment. Debris may need to be removed from sediment prior to dewatering. Resultant water may need to be treated prior to disposal.	Barge dewatering would require ensuring water quality impacts are minimized. Lagoon dewatering incompatible with site conditions (inadequate area for lagoon), and geotextile dewatering would also require significant staging area - both of these methods could require significant time to complete. Mechanical dewatering requires regular equipment maintenance but has significantly shorter residence time than passive methods. Air quality standards for site workers may be affected by open-air dewatering methods. Bench testing may be needed to define specific parameters for dewatering operation.	Moderate	Not a stand-alone technology. Retained as potentially applicable for use in conjuction with other technologies such as preparation of dredged/excavated sediments for disposal.
	Separation	Use of physical means to separate sandier sediments (which would have less contamination) for beneficial reuse.	Can be effective in reducing volume of contaminated sediment requiring disposal. Not effective with sediments with high concentrations or high organic content.	Commercial equipment is available for separation (i.e., sieves). Separated sand may be available for potential beneficial use (would require verification testing and identification of potential use). Bench scale testing may be needed to define specific operating parameters.	Low to Moderate	Sediments previously identified to have high organic content. Not retained because the impacted material removed would primarily consist of finer sediments.
	Sediment Washing	Contaminants are separated from the dredged/excavated sediment with wash water augmented with additives to help remove contamination.	Most suitable for semi-volatile organics or inorganic contamination.	Elutriate would require treatment and disposal, which could significantly increase the overall cost of treatment. Bench-scale testing would be required during design. Requires staging area for treatment or transport to off-site facility. Air quality standards may be affected by open-air treatment methods.	Moderate	Not retained because technology has little value for treatment of VOCs.
	Chemical Oxidation	Includes the application of chemical oxidants for the purpose of remediating contaminated sediments. Generally involves reduction/oxidation (redox) reactions that chemically convert hazardous contaminants to less toxic or less mobile forms.	Can be highly effective at destruction of organic contaminants. May not be cost effective for high contaminant concentrations or high organic sediments due to large amounts of oxidizing agent required. Less efficient for low concentrations compared to other technologies.	Risks associated with handling of oxidant in above-ground application. Bench-scale testing would be required during design. Requires staging area for treatment or transport to off-site facility. Air quality standards for site workers may be affected by open-air treatment methods.	High	Not retained because technology has relatively high implementation risk to workers and equally effective lower cost technologies are available.
	Dehalogenation	Reagents are added to sediment contaminated with halogenated organics to strip halogen molecules (i.e., chlorines).	Effective at detoxifying halogenated organic compounds in dredged/excavated sediment. Less effective in fine-grained sediment.	May generate secondary waste streams (air, water, and sludge), which will require treatment and disposal and could significantly increase the overall cost of treatment. Bench-scale testing would be required during design. Air quality standards may be affected by open-air treatment methods.	High	Not retained because other equally effective technologies are available without significant costs and secondary waste streams.
	Chemical Extraction	Dredged/excavated sediment is mixed with an extractant (e.g., acid or solvent), which dissolves the contaminants. The resultant solution is placed in a separator to remove the contaminant/extractant mixture for treatment.	Most suitable to semi-volatile or inorganic contamination. Less effective in fine-grained soil/sediment.	Difficult to remove all contaminant/extractant from sediment - would likely require finish treatment. Elutriate would require treatment and disposal, which could significantly increase the overall cost of treatment. Bench-scale testing would be required during design. Requires staging area for treatment or transport to off-site facility. Air quality standards may be affected by open-air treatment methods.	High	Not retained because technology has little value for treatment of VOCs.
	Solidification/Stabilization	Contaminants are physically bound or enclosed in a stabilized mass (solidification) or chemical reactions are induced between the stabilizing agent and contaminants to reduce their mobility (stabilization). Methods may include the addition of Portland cement, lime, kiln dust, pozzolan, sorbent clay (i.e., bentonite), and proprietary reagents.	Can be effective at reducing mobility of contaminants (most suitable to inorganics) or solidifying for disposal.	Would need to be significantly dewatered prior to solidification. Requires staging area for treatment or transport to off-site facility. Air quality standards for site/occupational workers may be affected by open-air dewatering methods.	Low	Not retained because likely would still require landfill disposal and dewatering technologies already retained.
	Solar Detoxification	Contaminants are destroyed by photochemical and thermal reactions using ultraviolet energy in sunlight or artificial UV light. Usually involves application of catalyst agent.	Can be effective at treating a variety of organic compounds. Most effective when used with a catalyst agent (i.e., titanium dioxide).	Implementation with sunlight limited by availability (not effective during nighttime and limited effectiveness during cloudy/wet seasons). Requires staging area for treatment or transport to off-site facility. Air quality standards for site/occupational workers may be affected by open-air treatment methods.	Low	Not retained beause adequate space is not available at the site.

Please refer to note at end of table.

Table 7-3
Initial Screening of Technologies for Sediment
NuStar Vancouver Facility

General Response Action	Technology	Description	Screening Criteria			Screening Comments
			Effectiveness	Implementability	Cost	
EX-SITU BIOLOGICAL TREATMENT	Land Treatment/ Landfarming	Land treatment reduces contaminant concentrations through biological processes. Dredged/excavated sediment is placed in controlled cells and manipulated as necessary to improve biological conditions (such as by tilling to aerate sediment).	Effective at removing organic contamination from sediment.	Requires area for soil treatment or transport to an off-site facility. Requires dewatering of sediment, and controls likely to be needed for contaminant migration from runoff. Bench-scale testing would be required to define operating parameters. Air quality standards may be affected by open-air treatment methods.	Low to Moderate	Not retained beause adequate space is not available at the site.
	Composting	Reduces contaminant concentrations through composting. Dredged/excavated sediment is mixed with bulking agents and organic amendments to promote microbial activity.	Effective at removing organic contamination from sediment. Most effective with control of moisture, heat, nutrients, oxygen, and pH to enhance biodegradation.	Requires area for soil treatment or transport to an off-site facility. Requires dewatering of sediment, and controls likely to be needed for contaminant migration from runoff and leachate. Bench-scale testing would be required to define operating parameters. Air quality standards may be affected by open-air treatment methods.	Low to Moderate	Not retained beause technology has little value for treatment of VOCs and is incompatible with current site use.
	Biopiles	Reduces contaminant concentrations through treatment of sediment in biopiles. Sediment is mixed with soil amendments, placed in aboveground enclosures, and aerated with blowers or vacuum pumps.	Effective at removing organic contamination from sediment. Most effective with control of moisture, heat, nutrients, oxygen, and pH to enhance biodegradation.	Requires area for soil treatment or transport to an off-site facility. Requires dewatering of sediment, and controls likely to be needed for contaminant migration from runoff and leachate. Bench-scale testing would be required to define operating parameters. Air quality standards may be affected by open-air treatment methods.	Low to Moderate	Not retained beause adequate space is not available at the site and addition of amendments would have little value for treatment of VOCs.
	Slurry-phase Biological Treatment	An aqueous slurry of sediment with water and other additives is mixed to keep solids suspended and microorganisms in contact with the soil contaminants. When complete, the slurry is dewatered and the treated soil/sediment is disposed of.	Can be effective at treating a variety of organic compounds.	Requires area for treatment cell or transport to an off-site facility. Slurry dewatering generates liquid waste stream that will require treatment or disposal. Bench-scale testing would be required to define operating parameters. Air quality standards may be affected by open-air treatment methods.	Moderate	Not retained because incompatible with site conditions.
EX-SITU THERMAL TREATMENT	Incineration	High temperatures are used to combust (in the presence of oxygen) organic constituents in hazardous wastes.	High temperatures result in generally complete deomposition of organic chemicals. Effective across wide range of sediment characteristics. Not effective for metals.	Requires air pollution control device. Nearest existing, permitted facility is more than 700 miles from the site. Involves high energy consumption.	Very High	Significant cost for transportation and treatment. Other less expensive technologies available. Most suitable to high concentrations or highly toxic contamination.
	Thermal Desorption/ Pyrolysis/ Hot Gas Decontamination	Waste soils are heated to either volatilize (desorption and hot gas) or to anaerobically decompose (pyrolysis) organic contaminants. Off-gas is collected and treated.	Effective at removing organic materials from excavated soil (particularly volatile organics). Pyrolysis generally used for semi-volatiles or pesticide wastes.	Requires transport to off-site treatment facility. Treatment of chlorinated hydrocarbons difficult (may generate acid in off-gas). Off-gas treatment required.	Moderate to High	Significant cost for transportation and treatment. Little value for treatment of VOCs.

Note:
1. Shading indicates technologies that have been eliminated from consideration.

Table 7-4.1
Cleanup Action Alternative Cost Estimate - Soil Vapor Extraction
NuStar Vancouver Facility

Present Worth Costs @ 5%

Cost Item	Unit Cost		Units		Extension	Notes
System Construction	$0				$0	No additional construction; use existing interim action system
SVE System O&M						
System inspection/maintenance (Yrs 1-3)	$750	/month	36	months	$25,000	Based on actual costs from interim action system
Vapor carbon consumption	$9,240	/year	3	years	$25,200	Based on actual costs from interim action system
				Subtotal	$50,200	
Closure						
Soil verification sampling	$10,000	/each	1	event	$8,600	Present value; conduct in year 3
System Decommissioning	$5,000	/each	1	event	$4,319	Present value; conduct in year 3
SVE Well abandonment	$1,400	/well	34	wells	$41,119	Present value; conduct in year 3
				Subtotal	$54,038	
Engineering						
System and Project Management	$540	/month	36	months	$18,000	4 hr/mo at $135/hr during 3-year operational period
Closure report (Year 3)	$15,000	/lump sum	1	each	$13,000	Present value; conduct in year 3
				Subtotal	$31,000	
System monitoring and reporting						
Sampling (Yrs 1-3)	$1,000	/month	36	months	$33,400	Present value; assume conducted in conjunction with sytem inspection/maintenance.
Operation Reporting	$500	/month	36	months	$16,700	Present value
				Subtotal	$50,100	
			10% Contingency		$18,500	
			Ecology Oversight		$9,540	20% of engineering and reporting costs
			Total Project Cost		$213,000	

Table 7-4.2
Cleanup Action Alternative Cost Estimate - Groundwater Hydraulic Containment
NuStar Vancouver Facility

Present Worth Costs @ 5%

Cost Item	Unit Cost		Units		Extension	Notes
Groundwater Extraction and Treatment (4 wells @ 40 gpm each)						
Groundwater Containment System						
System Construction						
Extraction well installation	$400	/foot	200	feet	$80,000	Engineering judgment
Trenching/piping/backfill	$23	/foot	900	feet	$21,000	Engineering judgment
Pumps and controls	$7,500	/each	4	units	$30,000	Engineering judgment
Control panel and elec. supply	$24,000	/lump sum	1	each	$24,000	Assumes power available nearby; engineering judgment
Ancillary system components	$10,000	/lump sum	1	each	$10,000	Engineering judgment
Carbon vessels	$6,000	/each	4	units	$24,000	Engineering judgment
IDW soil disposal (H)	$450	/ton	5.5	tons	$2,500	Assumed haz soil from borings; engineering judgment
IDW soil disposal (NH)	$37	/ton	170	tons	$6,300	Assumed non-haz soil from trenching; engineering judgment
IDW groundwater disposal	$10,000	/lump sum	1	each	$10,000	Engineering judgment
System compound	$25	/sf	400	sf	$10,000	Engineering judgment
Discharge point connection	$25,000	/lump sum	1	each	$25,000	Assumes connection to storm sewer; engineering judgment
System install labor and oversight	$2,750	/day	24	days	$66,000	Engineering judgment
				Subtotal	$308,800	
Groundwater System O&M						
Carbon replacement	$32,500	/year (avg)	30	years	$499,000	$91,000 Yr 1; $68,000 Yr 2; $45,000 Yr 3; $23,000/yr Yr 4-30; engineering judgment
System sampling and reporting	$1,800	/month	360	months	$335,300	Includes NPDES reporting; present value; engineering judgment
Routine system maintenance	$700	/month	360	months	$130,400	Present value; engineering judgment
Major system maintenance	$20,000	/3 Years	10	events	$97,500	Present value; engineering judgment
				Subtotal	$1,062,000	
			Total Groundwater System		$1,370,000	
Groundwater Monitoring and Reporting						
Quarterly groundwater monitoring	$58,200	/year	2	year	$113,600	Semi-annual reporting; based on site experience; present value
Semi-annual groundwater monitoring	$22,800	/year	3	years	$56,300	Semi-annual reporting; based on site experience; present value
Annual groundwater monitoring	$11,400	/year	45	years	$158,800	Annual reporting; based on site experience; present value
			Total Monitoring Costs		$328,700	
Closure						
Closure report	$15,000	/lump sum	1	each	$3,000	Present value; conduct in year 30
System Decommissioning	$5,000	/each	1	event	$1,200	Present value; conduct in year 30
Pumping well abandonment	$5,000	/well	3	wells	$3,500	Present value; conduct in year 30
			Total Closure Costs		$7,700	
Engineering						
Aquifer pump test	$12,000	/lump sum	1	each	$12,000	Engineering judgment
Startup, design, permits, PM	$134	/hour	300	hours	$40,200	Engineering judgment
Construction report	$15,000	/lump sum	1	each	$15,000	Engineering judgment
			Total Engineering Costs		$67,200	
			15% Contingency		$266,000	
			Ecology Oversight		$79,780	20% of engineering/report costs
			Total Project Cost		$2,110,000	

Table 7-4.3
Cleanup Action Alternative Cost Estimate - Groundwater Enhanced Bioremediation
NuStar Vancouver Facility

Present Worth Costs @ 5%

Cost Item	Unit Cost		Units		Extension	Notes
Enhanced Bioremediation						
Substrate Injection						
Injectant material	$1.72	/pound	81,800	pounds	$140,700	Including shipping; current rate
Probe injections/equipment	$850	/probe	72	probes	$61,200	Based on Interim Action implementation
Oversight	$1,250	/day	29	days	$36,250	Based on Interim Action implementation
		Total Enhanced Bioremediation Injection			$238,150	
Contingency Followup Injection (Interim Action area; Year 4)						
Injectant material	$1.72	/pound	30,300	pounds	$42,900	15% of total groundwater treatment area; present value
Probe injections/equipment	$850	/probe	25	probes	$17,500	Based on Interim Action implementation; present value
Oversight	$1,250	/day	10	days	$10,300	Based on Interim Action implementation; present value
			Total Followup Injection		$70,700	
Groundwater Monitoring and Reporting						
Quarterly groundwater monitoring	$58,200	/year	2	year	$113,600	Semi-annual reporting; prior experience; present value
Semi-annual groundwater monitoring	$22,800	/year	8	years	$133,700	Semi-annual reporting; prior experience; present value
			Total Engineering Costs		$247,300	
Engineering						
Startup, design, permits, PM	$134	/hour	150	hours	$20,100	Engineering judgment
Construction report	$15,000	/lump sum	1	each	$15,000	Engineering judgment
Closure report (Year 10)	$15,000	/lump sum	1	each	$9,000	Engineering judgment; present value
			Total Ancillary Costs		$44,100	
			5% Contingency		$30,000	
			Ecology Oversight		$58,280	20% of engineering/report costs
			Total Project Cost		$689,000	

Table 7-4.4
Cleanup Action Alternative Cost Estimate - Sediment Source Control
NuStar Vancouver Facility

Present Worth Costs @ 5%

Cost Item	Unit Cost		Units		Extension	Notes
Capital Costs						
None					$0	Source control part of groundwater cleanup alternative
Operation/Maintenance						
None					$0	Source control part of groundwater cleanup alternative
Engineering, Sampling, and Reporting (Year 3 and Year 7)						
Sediment Sampling	$46,000	/ls	2	each	$72,500	Prior experience; present value
Sediment Analysis	$150	/sample	20	samples	$4,800	Prior experience; present value
Closure Report	$20,000	/ls	1	ls	$14,300	Engineering judgment; present value
	Total Engineering and Construction Management				$91,600	
			25% Contingency		$22,900	
			Ecology Oversight		$18,300	20% of engineering/report costs
			Total Project Cost		$132,800	

Table 7-4.5
Cleanup Action Alternative Cost Estimate - Sediment Reactive Cap
NuStar Vancouver Facility

Present Worth Costs @ 5%

Cost Item	Unit Cost		Units		Extension	Notes
Pre-Construction						
Work Plan	1%		$2,576,600		$25,800	Including construction work plans, TDP, QAPP, CQCP, EPP, HASP, and WQMCCP. Assume 1% of direct capital costs (exlcuding disposal).
Mobilization	20%		$2,576,600		$515,400	Assume 20% of direct capital costs (excluding disposal); engineering judgment
Site Preparation	1%		$3,876,200		$38,800	Site preparation and sediment transloading area prep. Assumed 1% direct capital costs based on professional judgment.
			Total Pre-Construction		$580,000	
Dredging						
Open Water Dredging	$19	/cy	7,300	cy	$138,700	Means; Prof. judgement; 0.9 acre x 5 feet; no overdredge
Obstructed Dredging (Wharf)	$56	/cy	4,100	cy	$229,600	Means; Prof. judgement; 0.5 acre x 5 feet; no overdredge
Debris allowance	1%		$368,300		$3,683	Based on professional experience, assume 1% of dredging cost
Dredging verification	4%		$2,021,583		$80,863	Bathymetric surveys and sampling. Assume 4% of other direct dredging costs based on professional judgment.
Water Quality Control Measures	1	ls	$350,000	each	$350,000	Assume $150k plus $50k/week based on professional judgment.
Sediment Offload/Amend/Disposal	$114	/cy	$11,400	cy	$1,299,600	Means; Professional Experience; Similar Projects. Includes amendment (solidification), transport, and upland disposal.
			Total Dredging		$2,102,500	
Capping						
Base material (sand)	$13.50	/ton	8,700	tons	$117,450	Means; Prof. Experience; 1.4 acres x 3 feet; 1.6 tons/cy - in place (less amendment volume)
Amendment material (carbon)	$1,500	/ton	270	tons	$405,000	10% of mix volume; 0.4 tons/cy
Amendment material (ZVI)	$455	/ton	1,360	tons	$618,800	10% of mix volume; 2.0 tons/cy
Clean sand cap	$13.5	/ton	7,200	tons	$97,200	Means; Prof. Experience; 1.4 acres x 2 feet; 1.6 tons/cy - in place
Amendment mixing	$22.6	/cy	6,700	cy	$151,353	Means
Cap Placement	$18	/ton	17,530	tons	$315,540	Means; Prof experience
Capping verification	4%		$1,705,343		$68,300	Bathymetric surveys and sampling. Assume 4% of other direct capping costs based on professional judgment.
			Total Followup Injection		$1,773,700	
Other Contractor Costs						
Contractor Overhead	4%		$3,876,200		$155,100	Based on professional experience, assume 4% of construction costs
Bonding/Insurance	5%		$3,876,200		$193,900	Assume 5% of construction costs based on professional judgment.
			Total Other Contractor Costs		$349,000	
Engineering and Construction Management						
Design/permitting	$200,000	/ls	1	ls	$200,000	Engineering judgment
Engineering Support	$2,400	/wk	6	weeks	$14,400	Construction time for dredge and cap based on professional judgment - dredging: 1,500 cy/day open; 500 cy/day obstructed; capping: 900 cy/day; assume mix cap material while dredging
Construction Management/Oversight	$9,300	/wk	6	weeks	$55,800	Based on professional judgment, unit rate includes 2 at 45 hr/wk at $90/hr plus 1 at 8 hr/wk at $150/hr.
Water Quality Monitoring	$18,000	/wk	6	weeks	$108,000	Unit rate assumed based on professional judgment.
Reporting	$50,000	/ls	1	ls	$50,000	Unit rate assumed based on professional judgment.
			Total Engineering and Construction Management		$429,000	
Sampling and Reporting (Year 7)						
Sediment Sampling	$46,000	/ls	1	each	$39,800	Prior experience; present value
Sediment Analysis	$150	/sample	15	samples	$2,000	Prior experience; present value
Closure Report	$20,000	/ls	1	ls	$17,300	Engineering judgment; present value
			Total Sampling and Reporting		$59,100	
			25% Contingency		$1,323,000	
			Ecology Oversight		$97,620	20% of engineering/report costs
			Total Project Cost		$6,720,000	

Table 8-1
Initial Screening and Evaluation of Technologies for Soil
SMC Source Area, Vancouver, WA

General Response Actions	Technology	Description	Screening Criteria: Effectiveness	Screening Criteria: Implementability	Screening Criteria: Cost	Screening Comments
NO ACTION	None	No Action	Not effective in achieving RAOs.	Easy to implement.	No capital or O&M costs incurred.	Does not meet threshold criteria.
INSTITUTIONAL CONTROLS	Deed Restrictions/ Soil Management Plan/Signage	Can prevent disturbance of any required soil cap or other engineering controls, address notification of Site hazards, and ensure proper controls are implemented during future Site activities. Protocols will be established for handling and managing contaminated soils during future Site work to protect workers, public health, and the environment.	Effective at regulating direct contact, but is not effective at preventing migration. Does not address risks associated with migration and does not address contaminant reduction.	Deed restrictions require negotiation and agreement with affected property owners. However, Port owns the property so controls are easily implementable.	Low costs associated with implementing soil management plan.	Institutional controls are useful technologies to address risks during cleanup and to address residuals remaining after primary cleanup.
	Monitoring	Laboratory analysis of soil samples.	Effective for documenting Site conditions to evaluate migration and current Site risks. Does not address contaminant reduction.	Moderately easy to implement. Collection of samples beneath structures more difficult.	Low to moderate costs for monitoring.	Applicable to document Site conditions and effectiveness of any treatment. Must be used in conjunction with other technologies.
ENGINEERING CONTROLS	Access Restrictions	Use of fencing or other controls to limit access to impacted soils.	Effective at preventing direct contact, but is not effective at preventing migration. Does not address contaminant reduction.	Limiting access to area procludes potential future development.	Low costs associated with implementing controls.	Retain for potential use, but likely used in conjunction with other technologies.
	Control of Building HVAC System	Use HVAC system to maintain positive pressure in buildings.	May be effective in preventing migration of volatile contaminants from soil into indoor air as long as a pressure differential is maintained between building and subsurface soil. Does not address migration to other media or contaminant reduction. Generally used in conjunction with other engineering controls.	Can be easy to implement in buildings with existing HVAC systems. No current structures at site.	Low costs associated with implementing these controls. Operational costs include additional heating of outdoor air.	There are no current site structures; thus, not applicable.
	Vapor Barriers	Installation of low-permeability barriers beneath structures to prevent vapor intrusion. Alternatively, can place sealants on floor slabs or paved surfaces.	Effective in preventing migration of volatile contaminants from soil into indoor air. Does not address contaminant reduction.	Easy to implement for new building construction. Products readily available. There are no current structures.	Moderate cost for vapor barriers and surface sealing.	There are no current site structures; thus, not applicable.
	Sub-Slab Depressurization or Sub-Floor Venting	Installation of sub-slab venting systems or suction pits to create negative pressures beneath structures to prevent vapor migration to ambient air. Vapors are collected in the suction pit or venting pipes below the building and vented to the outside of the building, either passively or with fans.	Effective in preventing migration of subsurface volatile contaminants from soil into ambient air. Does not address contaminant reduction.	Easy to implement for new building construction. Existing buildings could be retrofitted. Materials and construction methods are readily available. Generally most suitable for buildings with slab-on-grade floors.	Moderate costs for system installation.	There are no current site structures; thus, not applicable.
CONTAINMENT	Capping	Installation of cap (e.g., soil, asphalt, impermeable liner) over impacted soils.	Effective at preventing direct contact to contaminated soils. May be effective in controlling volatilization to indoor air and outdoor air depending on construction (addressed by vapor barrier technology). Low-permeability caps can reduce rainwater infiltration thereby reducing the potential for contaminants leaching from soil.	Much of impacted soil area currently capped by gravel (preventing direct contact). Easy to implement new caps as needed if redevelopment occurs.	No cost to implement within currently capped areas. Marginal costs to implement capping in new development is low.	Retain this technology for potential use, but must be used in conjunction with other technologies.

Please refer to note at end of table.

Table 8-1
Initial Screening and Evaluation of Technologies for Soil
SMC Source Area, Vancouver, WA

General Response Actions	Technology	Description	Screening Criteria: Effectiveness	Screening Criteria: Implementability	Screening Criteria: Cost	Screening Comments
REMOVAL/OFF-SITE DISPOSAL	Excavation	Excavate contaminated soils with off-site disposal.	Effective for removing source material from site. Addresses direct exposure pathways, vapor intrusion, and migration by reducing contaminant concentrations and mass. May also improve groundwater conditions as potential for leaching is reduced. Significant excavation was already completed as an initial action.	Implementation involves conventional construction equipment and methods. Difficult to implement in areas with limited access (i.e., under buildings, rail-lines, utility corridors). Soil contamination left in-place at the site is relatively deep and much is below the groundwater table, which would complicate any further excavation.	High costs due to required soil volumes, depth, and groundwater table.	Source area soils are primarily located at and below the water table, thus excavation is extremely difficult to implement.
	Off-site Disposal	Off-site disposal at licensed landfill. Soils would require characterization to determine type of disposal facility (hazardous or non-hazardous).	Effective for containing contaminated soils and reducing risks associated with direct exposure.	Implementation involves transportation of contaminanted soils on public roads for potentially long distances. The nearest permitted hazardous waste landfill is located in Arlington, OR (140 miles away).	Moderate to high costs depending upon soil volumes.	Excavation not retained as technology so disposal is not applicable.
IN SITU PHYSICAL/ CHEMICAL/ THERMAL TREATMENT	Soil Vapor Extraction (SVE)	SVE involves extraction of vapors from the vadose zone using system of vertical wells or horizontal vents and vacuum pumps/blowers. Treatment of the discharge may be required; for chlorinated VOCs, treatment is typically achieved using carbon adsorption.	Highly effective at removing volatile organic compounds (VOCs) from unsaturated soils and controlling vapor migration into buildings. Less effective in fine-grained soil.	Applicable for treatment of volatile Site contaminants. Would require installation of new well points and associated infrastructure. Would be most effective when used in conjunction with air sparging technology for groundwater.	Moderate to high capital and O&M costs.	Technology is applicable to Site conditions.
	Electrokinetic Separation	Application of a low-intensity direct current through the soil between electrodes that are divided into a cathode array and an anode array. This mobilizes charged species, causing ions and water to move toward the electrodes.	Effective for removing inorganic ions and polor organics from saturated soil. Most effective in low-permeability soils (particularly clays).	Requires significant power supply and not suitable for use in inhabited areas during implementation. Would require saturation of shallow soils.	High implementation cost.	Not suitable to Site conditions and not compatible with COIs (i.e., non-polar organics).
	Fracturing	Development of cracks in low-permeability or overconsolidated soils to create passageways that increase the effectiveness of other *in situ* processes and extraction technologies.	Effective in conjunction with other technologies (e.g., vapor extraction) in deep, fine-grained or consolidated soils. Not effective with shallow soil.	Specialized equipment and personnel needed to safely implement.	Moderate implementation cost.	Not suitable for shallow sandy/silty soil at site.

Please refer to note at end of table.

Table 8-1
Initial Screening and Evaluation of Technologies for Soil
SMC Source Area, Vancouver, WA

General Response Actions	Technology	Description	Screening Criteria: Effectiveness	Screening Criteria: Implementability	Screening Criteria: Cost	Screening Comments
	Chemical Oxidation	Chemically converts hazardous contaminants to less toxic compounds. Effective in destroying organic contaminants and oxidizing inorganic contaminants to less toxic/less mobile forms. Can include oxidant chemicals such as peroxides, permanganates, or ozone.	Can be highly effective at destruction of organic contaminants. Can be difficult to achieve full coverage (contact between oxidant and COIs), particularly in unsaturated soils.	Equipment and vendors are readily available. Delivery difficult in unsaturated soils.	High implementation cost.	Technology retained.
	Soil Flushing	Water (or water containing an additive to enhance contaminant solubility) is circulated through the soil to desorb contaminants, recovered, and treated. Single-well implementation can involve injection followed by removal (such as via vacuum truck).	Less effective for organic contaminants and would require groundwater extraction/treatment operation. Can be effective at removing bound separate-phase liquids from vicinity of well (less suited to widespread impacts).	Difficult to maintain control of amended water. Inefficient process for unsaturated soils.	High implementation cost.	Not retained because less suitable to Site contaminants (volatile organics), less effective in shallow unsaturated zone.
	Solidification/ Stabilization/ Vitrification	Contaminants are physically bound or enclosed within a stabilized mass (solidification and vitrification), or chemical reactions are induced between the stabilizing agent and contaminants to reduce their mobility (stabilization).	Most suitable to inorganic contaminants.	Not suitable for use in inhabited areas during implementation. Volatilization of organics would need to be controlled during implementation.	High implementation cost.	Not retained because less suitable to Site contaminants and Site conditions compromise effectiveness. More cost-effective methods of addressing volatile contaminants are available.
	Thermally-Enhanced Removal	High-energy injection (steam/hot air, electrical resistance, electromagnetic, fiber optic, radio frequency) is used to increase the recovery rate of semi-volatile or non-volatile compounds to facilitate extraction (enhanced volatilization or decreased viscosity).	Most suitable to semi-volatile organic contaminants or viscous compounds that are not otherwise extractable with vapor extraction or fluid extraction technologies.	Generally used in conjunction with SVE system or other recovery system (i.e., groundwater extraction). Has high energy requirements.	High implementation cost.	Not retained because less suitable for Site contaminants and high cost.
IN SITU BIOLOGICAL TREATMENT	Bioventing	Bioventing involves inducing air or oxygen flow in the unsaturated zone to promote biodegradation of hydrocarbons and VOCs. Applications include injection of air or oxygen into subsurface, or extraction of air at rates lower than SVE. Due to concerns with uncontrolled migration of VOCs associated with air injections, only air extraction applications will be considered for the site.	Effective in reducing contaminant concentrations in unsaturated soils. As with SVE, effectiveness can be limited by short-circuiting. Less effective for chlorinated solvent hydrocarbons (typically biodegrade anaerobically).	This technology may interfere with anaerobic degradation of chlorinated solvents. Requires air emission testing and modeling to determine if off-gas treatment is required.	Moderate capital and O&M costs.	Would not efficiently promote degradation of chlorinated solvents.
IN SITU BIOLOGICAL TREATMENT—CONTINUED	Enhanced Bioremediation (Bioaugmentation, Biostimulation)	Adding nutrients, electron acceptor, or other amendments to enhance bioremediation.	Effective in saturated soils with addition of suitable amendments. Strategic placement of amendments can be effective in conjunction with other technologies. Treatment of vadose zone soils requires means of providing adequate soil moisture.	Temporary injection points would be used;no permanent injection infrastructure exists. The implementability of the technology has been positively demonstrated.	Low to moderate costs depending on number of injection events required.	Not suitable for shallow unsaturated soil. Retained as groundwater technology that would also address saturated soil.
	Land Treatment	Combination of aeration (tilling) and amendments to enhance bioremediation in surface soils.	Effective for organic contaminants in shallow soil that can be degraded aerobically.	Common agricultural equipment can be used to process shallow soil. Less efficient for chlorinated solvent hydrocarbons (degraded anaerobically).	Low to moderate implementation cost.	Not retained because incompatible with Site contamination, structures, or depth to contaminants.
	Monitored Natural Attenuation	Using natural processes to reduce contaminant concentrations to acceptable levels. Process is closely monitored to verify exposures are acceptable prior to concentrations reaching acceptable levels.	May be effective, especially in areas of low concentrations, but is dependant upon Site conditions. Not efficient for source areas; other technologies will likely be required.	Easy to implement. Monitoring of unsaturated soil would require repeated intrusive sampling events. Likely will require significant timeframe to reach cleanup goals.	Moderate costs for monitoring.	May be applicable to address residual low-concentration contamination not efficiently addressed by active remediation.
	Phytoremediation	Phytoremediation is a process that uses plants to remove, transfer, stabilize, and destroy contaminants in soil or sediment.	Can be effective at removing a variety of organic and inorganic compounds from soil through plant uptake in vicinity of roots (rhizosphere).	Requires significant land area suitable for large plants. Contamination must be accessible to plant root zones. Large variety of COIs may not all be addressed by compatible plant species.	Moderate implementation cost.	Not retained because incompatible with Site use. Unlikely to be effective for all COIs.

Please refer to note at end of table.

Table 8-1
Initial Screening and Evaluation of Technologies for Soil
SMC Source Area, Vancouver, WA

General Response Actions	Technology	Description	Screening Criteria: Effectiveness	Screening Criteria: Implementability	Screening Criteria: Cost	Screening Comments
EX SITU PHYSICAL/ CHEMICAL/ THERMAL TREATMENT	Chemical Extraction	Excavated soil is mixed with an extractant, which dissolves the contaminants. The resultant solution is placed in a separator to remove the contaminant/extractant mixture for treatment.	Most suitable to removal of semi-volatile and inorganic contamination from excavated soil. Less effective in fine-grained soils.	Can be effective in removing most organic contaminants from soil. Difficult to remove all contaminant/extractant mixture from soil—would likely require finish treatment. Requires area for soil treatment or transport to off-site facility. Extractant fluid would need subsequent treatment process or disposal.	Moderate to high implementation cost.	Not retained because excavation technology was not retained.
	Dehalogenation	Reagents are added to soils contaminated with halogenated organics to remove halogen molecules.	Effective at detoxifying halogenated organic compounds in excavated soil. Less effective in fine-grained soils.	Requires area for soil treatment or transport to off-site facility. Risks associated with handling of reagents.	Moderate to high implementation cost.	Not retained because excavation technology was not retained.
	Incineration	High temperatures are used to combust (in the presence of oxygen) organic constituents in hazardous wastes.	Effective at removing organic contaminants from excavated soil.	Requires transport to off-site facility.	High implementation cost.	Not retained because excavation technology was not retained.
	Soil Washing	Contaminants are separated from the excavated soil with wash-water augmented with additives to help remove organics.	Most suitable for semi-volatile organics or inorganic contamination.	Requires area for soil treatment or transport to off-site facility. Resultant fluid would need subsequent treatment process or disposal.	Moderate to high implementation cost.	Not retained because excavation technology was not retained.
	Solar Detoxification	Contaminants are destroyed by photochemical and thermal reactions using ultraviolet energy in sunlight or artificial UV light. Usually involves application of catalyst agent.	Can be effective at treating a variety of organic compounds. Most effective when used with catalyst agent (e.g., titanium dioxide).	Implementation with sunlight limited by availability (not effective during nighttime and limited effectiveness in cloudy/wet seasons). Requires area for treatment or transport to off-site facility.	Low to moderate implementation cost.	Not retained because excavation technology was not retained.
	Thermal Desorption/ Pyrolysis/ Hot Gas Decontamination	Waste soils are heated to either volatilize (desorption and hot gas) or to anaerobically decompose (pyrolysis) organic contaminants. Off-gas is collected and treated.	Effective at removing organic materials from excavated soil (particularly volatile organics). Pyrolysis generally used for semi-volatiles or pesticide wastes.	Requires transport to off-site treatment facility. Treatment of chlorinated hydrocarbons difficult (may generate acid in off-gas). Off-gas treatment required.	Moderate to high implementation cost.	Not retained because excavation technology was not retained.
	Separation	Separation techniques concentrate contaminated solids through physical, magnetic, and/or chemical means. These processes remove solid-phase contaminants from the soil matrix.	Effective only for removal of solids with distinct physical characteristics (size, composition, etc.).	Commercial equipment available for separation by size (sieving) or for removing iron (magnetic removal).	Low to moderate cost.	Not compatible with Site COIs.
EX SITU BIOLOGICAL TREATMENT	Biopiles	Excavated soils are mixed with soil amendments and placed in aboveground enclosures and aerated with blowers or vacuum pumps.	Effective for removal of organic contaminants from excavated soil. Most effective with control of moisture, heat, nutrients, oxygen, and pH to enhance biodegradation.	Requires area for soil treatment or transport to off-site facility. May generate leachate that would need to be collected and managed.	Low to moderate cost.	Not retained because excavation technology was not retained.
	Composting	Excavated soil is mixed with bulking agents and organic amendments to promote microbial activity.	Effective for removal of organic contaminants from excavated soil. Most effective with control of moisture, heat, nutrients, oxygen, and pH to enhance biodegradation.	Requires area for soil treatment or transport to off-site facility. May generate leachate that would need to be collected and managed.	Low to moderate cost.	Not retained because excavation technology was not retained.
	Landfarming	Excavated soil is placed in lined beds and periodically tilled to aerate the soil.	Effective at removing organic contaminants from excavated soil.	Requires area for soil treatment or transport to off-site facility. Common agricultural equipment can be used to process soil in treatment beds.	Low to moderate cost.	Not retained because excavation technology was not retained.
	Slurry Phase Biological Treatment	An aqueous slurry of soil, sediment, or sludge with water and other additives is mixed to keep solids suspended and microorganisms in contact with the soil contaminants. When complete, the slurry is dewatered and the soil is disposed of.	Can be effective at treating a variety of organic compounds.	Requires area for soil treatment or transport to off-site facility. Slurry dewatering generates water that requires treatment or disposal.	Moderate to high implementation cost.	Not retained because excavation technology was not retained.

Note:

1. Shading indicates technology has been eliminated from consideration.

Table 8-2
Initial Screening and Evaluation of Technologies for Groundwater
SMC Source Area, Vancouver, WA

General Response Actions	Technology	Description	Screening Criteria: Effectiveness	Screening Criteria: Implementability	Screening Criteria: Cost	Screening Comments
NO ACTION	None	No Action	Not effective in achieving RAOs.	Easy to implement.	No capital or O&M costs incurred.	Does not meet threshold criteria.
INSTITUTIONAL CONTROLS	Groundwater Use Restrictions	Restricted use of Any Zone groundwater.	Effective at preventing direct contact, but is not effective at preventing migration. Does not address risks associated with vapor intrusion (future building) and does not address contaminant reduction.	May require deed restrictions to prevent off-site and on-site groundwater use. No planned use of on-site groundwater.	Low costs associated with implementing restrictions (off-site deed restrictions could require significant compensation).	Applicable technology used in conjunction with other technologies.
	Monitoring	Laboratory analyses of groundwater samples.	Effective for documenting Site conditions to evaluate migration and current Site risks. Does not address contaminant reduction.	Easy to implement. On-site and off-site monitoring wells already exist.	Low to moderate costs for monitoring.	Applicable to document Site conditions and effectiveness of any treatment.
ENGINEERING CONTROLS	Control of Building HVAC System	Use HVAC system to maintain positive pressure in buildings.	May be effective in preventing migration of volatile contaminants from shallow groundwater into indoor air as long as a pressure differential is maintained between building and subsurface soil. Does not address contaminant reduction. Generally used in conjunction with other engineering controls.	Can be easy to implement in buildings with existing HVAC systems.	Low costs associated with implementing these controls. Operational costs include additional heating of outdoor air.	Potential for future site structures.Technology retained for potential use in conjunction with other technologies.
	Vapor Barriers	Installation of low-permeable barriers beneath buildings to prevent vapor intrusion.	Effective in preventing migration of volatile contaminants from shallow groundwater into indoor air. Does not address contaminant reduction.	Easy to implement for new building construction. Some protection from existing slab-on-grade construction - improvement would require sealing floor from top surface.	Moderate cost for surface application. High cost for sub-floor installation (removal and replacement of slab floor).	Technology retained for potential use in conjunction with other technologies.
	Sub-Slab Depressurization or Sub-Floor Venting	Installation of sub-slab or sub-floor venting systems or suction pits to create negative pressures beneath structures to prevent vapor migration to ambient air. Vapors are collected in the suction pit or venting pipes below the building and vented to the outside of the building, either passively or with fans.	Effective in preventing migration of subsurface volatile contaminants from groundwater into ambient air. Does not address contaminant reduction.	Easy to implement for new building construction. Existing buildings can be retrofitted. Materials and construction methods are readily available. Generally most suitable for buildings with slab-on-grade floors.	Moderate costs for retrofitting existing structures - would require cutting slab floor to install vapor pits.	Applicable technology for addressing vapor migration to indoor air. Retained for use in conjunction with other technologies
	Alternative Water Supply	Develop new water supply in uncontaminated area to provide potable water in the areas of impact.	Effective in preventing use of contaminated groundwater. No contaminant reduction. Does not address risks associated with vapor intrusion (future building).	Conventional construction, requires local and WRD approvals.	High capital costs, low to moderate O&M costs.	Not retained as viable technology. Site groundwater not used. Does not address off-site use of groundwater as drinking water.
	Wellhead Treatment	Treatment at individual impacted water supply wells with use of *Ex-Situ* Physical/Chemical/Thermal treatment technology.	Effective in reducing contaminant concentrations in groundwater prior to use. Does not address risks associated with vapor intrusion (future building). No groundwater pumping is anticipated at the site.	An extraction well is already in use at the site as part of the interim action. Treatment units for large-scale municipal systems would be difficult to implement. Requires ongoing testing and system maintenance to remain effective.	High capital costs and O&M costs for municipal-scale treatment system.	An extraction is already in use at the site as part of the interim action. A potential municipal treatment unit would involve many responsible parties, require significant treatment volumes, and would be cost prohibitive. Technology not retained. .

Please refer to note at end of table.

Table 8-2
Initial Screening and Evaluation of Technologies for Groundwater
SMC Source Area, Vancouver, WA

General Response Actions	Technology	Description	Screening Criteria: Effectiveness	Screening Criteria: Implementability	Screening Criteria: Cost	Screening Comments
CONTAINMENT	Vertical Barrier	Installation of vertical barriers (e.g., sheet piling, soil-bentonite slurry wall, grout, etc.) to prevent migration of groundwater contamination.	Effective at preventing lateral migration. Requires keying into underlying confining unit. Hydraulic control often necessary as supplemental measure to achieve containment. Cannot prevent downward migration.	Difficult to implement, particularly given depth to groundwater and overall size of groundwater plume. Additionally, groundwater in the Shallow and Intermediate Zones have different flow directions, so multiple barriers would be required to contain all groundwater. Site lacks suitable confining unit at reasonable depth. Some Site contaminants have specific gravity greater than 1 (sinkers). Specialized equipment required for construction.	High capital costs, low to moderate O&M.	Not practical for source area groundwater, no signficant confining unit to prevent lateral migration beneath barrier. Several more cost-effective technologies are available. Technology not retained.
	Pumping / Hydraulic Containment	Extraction well(s) with submersible pumps to lower the water table and create hydraulic gradients that direct contaminant migration into the extraction well. Extracted groundwater would require treatment before discharge (see *Ex-Situ* Physical/Chemical/ Thermal Treatment).	Effective in porous soils for preventing further contaminant migration. May also be used in conjunction with other technologies.	Implementable; pumping rate, depth of extraction well, and design can be tailered to capture zone requirements. Discharge of treated water would need to be permitted.	Moderate to high capital costs. Extraction well and associated infrastructure would be required. Moderate to high O&M costs.	Retained as applicable technology in Pump and Treat (below).
REMOVAL/DISCHARGE	Pumping (Pump & Treat)	Extraction well(s) with submersible pumps to remove contaminated groundwater with goal of plume reduction and aquifer restoration. Treatment of extracted groundwater likely required before discharge (see *Ex-Situ* Physical/Chemical/ Thermal Treatment).	Effective in porous soils for preventing contaminant migration and removing contaminants from extracted groundwater. May also be used in conjunction with other technologies.	Extraction well already in place and operational. Modifcation to target source area may be required. Discharge of treated water currently permitted.	Extraction well already in place and operational. Moderate to high O&M costs.	Applicable technology for Site conditions. Currently is being used as an interim action.
	Subsurface Drains	Trench or horizontal boring filled with porous media— gravity drains to sump/pump. Treatment of extracted groundwater likely required before discharge (see Ex-Situ Physical/Chemical/Thermal Treatment).	Effective for shallow groundwater at preventing contaminant migration. Not effective for impacted deeper groundwater. May also be used in conjunction with other technologies.	Not practical to install at groundwater depths.	Moderate to high capital and O&M costs.	Not retained since groundwater depth greater than appropriate for subsurface drains.
	Discharge to Sewer / Surface Water	Discharge of water (which may require treatment) into surface water, storm sewer, or sanitary sewer.	Effective for disposal of extracted groundwater. Already in use at site. Treatment of water (physical and chemical) is also in existence prior to disposal.	State and federal legislation regulate discharge into river. NPDES permit (already obtained) required to discharge treated water into the Columbia River.	Moderate cost to transport treated water to river. Infrastructure has already been constructed for the Pump and Treat interim action.	Applicable for discharge of extracted groundwater. Currently is being used as part of an interim action.
	Discharge to Reinjection Wells	Discharge of water (which may require treatment) into aquifer by reinjection wells.	Moderate effectiveness, depending upon whether injection wells can be adequately located to prevent plume spreading.	Underground injection control permit required for reinjection.	Moderate to high capital and O&M costs for reinjection wells.	Applicable for discharge of extracted groundwater. UIC permit required for injection wells (treatment needed to meet UIC discharge requirements).
	Reuse	Reuse of treated water for non-potable use such as irrigation or wetland enhancement.	Effective for treated, extracted groundwater.	A suitable use would need to be identified that can accommodate a steady flow rate in all seasons and within reasonable proximity.	Low to high costs depending upon storage and pumping requirements, and length of discharge piping.	No identified potential use suitable for flow rate expected from extraction system.
	Excavation	Excavate contaminated soils with off-site disposal.	Effective for removing source material from site. Addresses direct exposure pathways, vapor intrusion, and migration by reducing contaminant concentrations and mass. May also improve groundwater conditions as potential for leaching is reduced. Significant excavation was already completed as an initial action.	Implementation involves conventional construction equipment and methods. Difficult to implement in areas with limited access (i.e., under buildings, rail-lines, utility corridors). Soil contamination left in-place at the site is relatively deep and much is below the groundwater table, which would complicate any further excavation.	High costs due to required soil volumes, depth, and groundwater table.	Source area soils are primarily located at and below the water table, thus excavation is extremely difficult to implement.

Please refer to note at end of table.

Table 8-2
Initial Screening and Evaluation of Technologies for Groundwater
SMC Source Area, Vancouver, WA

General Response Actions	Technology	Description	Screening Criteria: Effectiveness	Screening Criteria: Implementability	Screening Criteria: Cost	Screening Comments
EX SITU PHYSICAL/ CHEMICAL/ THERMAL TREATMENT	Adsorption	Concentrating solutes on the surface of a sorbent material, such as activated carbon, to remove the solute from the bulk liquid.	Highly effective at removing many organic compounds from extracted water stream.	Applicable for treatment of Site contaminants in extracted water. Treatment equipment is readily available.	Moderate capital and O&M costs.	Applicable for treatment of extracted water.
	Air Stripping	Volatile organics are partitioned from extracted groundwater by increasing surface area exposed to air.	Highly effective at removing many VOCs from extracted water stream. May require treatment of vapor effluent.	Applicable for treatment of Site contaminants in extracted water. Treatment equipment is readily available. Requires air emission testing and modeling to determine if off-gas treatment is required.	Low to moderate capital and O&M costs. Higher costs if off-gas treatment needed.	Applicable for treatment of extracted water. Currently is being used as part of an interim action. Infrastructure is present.
	Separation/ Reverse Osmosis	Extracted groundwater is forced through a selectively permeable membrane under pressure. Water is allowed to pass through the membrane while contaminants are trapped.	Highly effective at removing many contaminants from the extracted water stream.	Applicable for treatment of Site contaminants in extracted water. Treatment equipment is readily available.	High capital and O&M costs.	Not retained since more cost-effective treatment methods exist for removal of Site contaminants from water.
	Ultraviolet (UV) Oxidation	Ultraviolet radiation is used to destroy organic contaminants as water flows through treatment cell.	Effective at removing many organic contaminants from the extracted water stream.	Applicable for treatment of Site contaminants in extracted water. Treatment equipment is readily available.	High capital and O&M costs.	Not retained since more cost-effective treatment methods exist for removal of Site contaminants from water.
	Sprinkler Irrigation	Contaminated water is distributed through a pressurized sprinkler irrigation system (generally onto a highly porous media), allowing transfer of VOCs from aqueous phase to vapor phase.	Effective at removing many organic contaminants from the extracted water stream. Simpler system than more aggressive treatment technologies (such as air stripping).	Applicable for treatment of Site contaminants in extracted water, but requires significant treatment system area.	Low to moderate capital and O&M costs.	Not retained since land use not compatible with Site conditions.
	Ion Exchange	Ion exchange removes ions from the aqueous phase by exchange with counter ions on the exchange medium.	Effective for treatment of inorganic contaminants.	Treatment equipment is readily available.	Moderate to high capital and O&M costs.	Not compatible with Site contaminants.
	Precipitation/ Coagulation/ Flocculation	This process transforms dissolved contaminants into an insoluble solid, facilitating the contaminant's subsequent removal from the liquid phase by sedimentation or filtration.	Effective for treatment of inorganic contaminants.	Treatment equipment is readily available.	Moderate to high capital and O&M costs.	Not compatible with Site contaminants.
EX SITU BIOLOGICAL TREATMENT	Bioreactors / Trickling Filter	Contaminants in extracted groundwater are put into contact with microorganisms in attached or suspended growth biological reactors.	Effective at removing many organic contaminants from the extracted water stream. May be less effective during cold weather. May not reach treatment goals without follow-up polishing treatment.	Difficult to maintain effectiveness with variable operating parameters (i.e., influent concentrations, ambient concentrations). Requires significant area for reactors. Would require significant maintenance.	Moderate capital costs and moderate to high O&M costs	Not retained since more cost-effective treatment methods exist for removal of Site contaminants from water.
	Constructed Wetlands	Utilizes natural geochemical and biological processes inherent in an artificial wetland ecosystem to remove contaminants from extracted groundwater.	Highly effective at removing many organic and inorganic contaminants from the extracted water stream.	Requires large land area to implement. May introduce attractive nuisance hazard for local wildlife.	Moderate to high capital costs. Low O&M costs. Would require signficant land area availability and pumping distances.	Not retained since land use not compatible with Site conditions.
IN SITU BIOLOGICAL TREATMENT	Enhanced Bioremediation (Bioaugmentation, Biostimulation)	Adding nutrients, electron acceptor, or other amendments to enhance bioremediation. Addition of specific microbial cultures can be included if indigenous species not suitable for complete degradation of COIs.	Effective with addition of suitable amendments. Strategic placement of amendments can be effective in conjunction with other technologies. Treating source-area concentrations requires significantly longer time to complete. Has been demonstrated as an effective technology at nearby sites.	Equipment and technology for direct injection are readily available. Amendments for stimulating reductive dechlorination are commercially available.	Low to moderate costs depending on number of injection events required.	Applicable technology for Site contaminants.

Please refer to note at end of table.

Table 8-2
Initial Screening and Evaluation of Technologies for Groundwater
SMC Source Area, Vancouver, WA

General Response Actions	Technology	Description	Screening Criteria: Effectiveness	Screening Criteria: Implementability	Screening Criteria: Cost	Screening Comments
	Monitored Natural Attenuation	Using natural processes to reduce contaminant concentrations to acceptable levels. Process is closely monitored to verify exposures are acceptable prior to concentrations reaching acceptable levels.	May be effective, especially in areas of low concentrations (near plume boundaries), but not effective for high concentrations, such as at the source area. Other technologies will likely be required.	Easy to implement. Monitoring wells already exist. Likely would require significant timeframe to reach cleanup goals.	Low costs for monitoring.	Not retained since not suitable for source area contamination.
	Phytoremediation	Phytoremediation is a process that uses plants to remove, transfer, stabilize, and destroy contaminants.	Can be effective at removing a variety of organic and inorganic compounds from contaminated groundwater through plant uptake.	Requires significant land area suitable for large plants. Contamination must be accessible to plant root zones.	Moderate implementation cost.	Not retained because incompatible with Site conditions or deep contamination.
IN SITU PHYSICAL/ CHEMICAL/ THERMAL TREATMENT	Aeration / Air Sparging	Increasing the contact between water and air to enhance volatilization. Air sparging involves injecting air into saturated matrices.	Effective for volatile contamination. Use in conjunction with shallow vapor extraction to prevent uncontrolled vapor migration.	Equipment and technology for air sparging are readilly available.	Moderate to high capital costs. Low O&M costs.	Applicable technology for source area contaminants.
	Multi-Phase Extraction (MPE)	MPE provides simultaneous extraction of soil vapor, contaminated groundwater, and NAPL using single vacuum pump, multiple in-well pumps, or bioslurping.	Effective for source removal at Site with moderate to low soil permeability. Also effective for treating impacted groundwater in the source area.	Equipment and technology for MPE are readily available. Treatment of recovered soil vapors and groundwater would be required prior to discharge.	Moderate to high capital and O&M costs. Higher costs if vapor treatment needed.	Relatively high cost. Inefficient approach for moderately high hydraulic conductivity at the site.
	Steam Flushing/ Steam Stripping	Steam is injected into the contaminated aquifer to vaporize less volatile organics.	Used in conjunction with vapor recovery. May be effective for increasing usability of SVE for low-volatility compounds.	Equipment and technology are readily available. Treatment of recovered vapors would likely be required.	High capital costs.	Not retained since not beneficial to removal of Site COIs.
	Chemical Oxidation	Chemically converts hazardous contaminants to less toxic compounds. Effective in destroying organic contaminants (including LNAPL) and oxidizing inorganic contaminants to less toxic/less mobile forms. Can include oxidant chemicals such as peroxides, permanganates, or ozone.	Effective in destroying organic contaminants (including free product) and oxidizing inorganic contaminants to less toxic/less mobile forms. Difficult to provide adequate coverage in subsurface. May cause settling in organic soils. Most applicable to source-area concentrations or NAPLs.	Equipment and vendors are readily available. Less efficient at addressing diffuse concentrations of Site COIs.	High implementation costs (potentially requiring multiple applications).	Applicable technology for source area contaminants.
	Passive/Reactive Treatment Walls	Barriers placed across groundwater movement that allows passage of water while facilitating degradation or removal of contaminants.	Can be effective in the remediation of dissolved-phase VOC contamination. May not be suitable for source area remediation. Not cost-effective for very wide or deep plumes. Iron filings have been demonstrated to be effective at removal of HVOCs.	Depth of shallow aquifer would require installation by drilled methods (rather than open excavation). Specialty equipment needed for installation. Barrier materials readily available (iron and sand).	High costs for installation. Moderate costs for performance and compliance monitoring, and periodic maintenance.	Not practical for source area groundwater, no signficant confining unit to prevent lateral migration beneath barrier. Several more cost-effective technologies are available. Technology not retained.

Note:
1. Shading indicates technology has been eliminated from consideration.

Table 8-3: Comparative Analysis of Remedial Alternatives for the SMC Source Area

Alternative		Selection Criteria** Protectiveness	Permanence	Long-term Effectiveness	Implementability	Short-Term Risk	Public Concerns	Sum	Cost Effectiveness*
Alternative A:	MNA (Source Area only)	Not protective of human health or the environment; does not reduce risks or attain cleanup standards RAOs not met.	No control over future uses; does not prevent exposure.	Not effective.	Can be implemented.	No agency acceptance, specifically Ecology. Does not meet goals of POV.	The neighborhood has witnessed several interim actions since discovery, and there is great concern regarding the contamination. MNA does not address public concern.		$234,000
	Score	**1**	**1**	**1**	**5**	**1**	**1**	**10**	**3**
Alternative B:	Remedial Excavation of Source Area	Meets effectiveness criteria by preventing potential exposure to contaminants. Direct removal at one time. Places soil in a permitted landfill.	High reliability due to excavation and off-site disposal of the impacted soil. Soil is placed at a permitted landfill.	Effectively removes the impacted soil and disposes off-site. However, this is direct removal at one time, with no long-term monitoring.	Excavation is a common method and disposal options exist. However, groundwater will be encountered. Dewatering and shoring will be required, and extracted water needs to be treated before discharging. Site access is limited. Clean overburden needs to be stockpiled, and space is limited.	High incremental implementation risk. There is increased risk to excavation workers to implement this alternative. There is potential that de-watering can not occur. The exact volume to excavate is not known. Potential impacts from soil contaminants to the surrounding community and environment can be minimized through implementation of BMPs specified in a CMMP. Confirmation sampling will need to be conducted to confirm that remedial excation achives site RAOs.	This alternative addresses public concern by actively removing the source and disposing the contamination off-site.		$875,000
	Score	**3**	**4**	**3**	**2**	**2**	**4**	**18**	**1**
Alternative C:	Air Sparging and Soil Vapor Extraction	This is a very effective technique for removing volatile organic compounds from groundwater. However, soil at the site has very low permeability, and the radius of influence (ROI) for each well would be small.	AS/SVE systems have proven reliable in extracting volatile organic compounds from groundwater. The Port would have to maintain the AS/SVE system until the site can be closed, and Ecology determines an NFA. This technique includes some risk of rebound.	Proven to be a very effective technique. However, long-term maintanence is necessary, and there is some risk of rebound after the system is shut off.	Requires design, engineering, and more consultation with regulatory agencies. Easy to implement on currently mostly vacant site. However, the source area is a thin layer, with low permeability, and groundwater will be encountered. Exact placement of wells is necessary for success. Requires long-term system operation and maintenance.	Minimum risk to construction workers. Potential impacts from soil contaminants to the surrounding community and environment can be minimized through implementation of BMPs specified in a CMMP.There is a risk of placing the AS wells in the wrong location due to several factors: depth and elevation of the fine grain sand layer (source area) is not precisely known; the source area layer is thin; and, this layer has low permeability, making the radius of influence small.	This technique addresses public concern. It is an effective remedial action that the public has witnessed at the Cadet site.		$219,200
		3	**3**	**3**	**3**	**2**	**4**	**18**	**3**
Alternative D:	In-Situ Substrate Injection	Meets effectiveness criteria by reducing contaminants in place. However this alternative needs to be designed with site conditions in mind, to maintain its effectiveness.	Capable of achieving high treatment efficiencies (>90%) for VOC compounds such as TCE. Other organics are amenable to partial degradation as an aid to subsequent bioremediation. This technique includes some risk of rebound.	This techinque requires design and engineering specific to the site conditions. If the agent can be injected into the fine-grain sand layer, and dispersed horizontally, this alternative can be effective long term. However, there are some risks.	Requires design, engineering, and more consultation with regulatory agencies. Easy to implement on currently mostly vacant site, however the key to successful implementation will be to inject the agent into the fine-grain sand layer, and to get it dispersed horizontally. Requires subsequent injections.	Minimal risk to construction workers. Potential impacts from soil contaminants to the surrounding community and environment can be minimized through implementation of BMPs specified in a CMMP. There is a risk of placing the injection wells in the wrong location due to several factors: depth and elevation of the fine grain sand layer (source area) is not precisely known; the source area layer is thin; and, this layer has low permeability, making the radius of influence small.	This technique addresses public concern by actively treating the contamination, over the long-term.		$350,000
		3	**3**	**3**	**3**	**3**	**4**	**19**	**2**
Alternative E:	Pump and Treat and MNA	Meets effectiveness criteria by preventing potential exposure to contaminants. Has proven very effective in the dispersed plume since start up in June 2009. However, not as effective in the source area. This alternative requires continued operation over a longer time period than the others. This technique should prove relatively effective in the source area	Pump and Treat is a reliable technology. This system has been, and continues to be, effective in the dispersed plume. It is a proven technology with long-term benefits. There is potential for rebound to occur once the system is shut off.	This technique has proven to be very effective in the dispersed plume since start up in June 2009, however, not as effective in the source area. Over a longer time period, this technique should prove effective in the source area.	The Pump & Treat system has already been implemented for cleanup of the dispersed plume, as an interim action. Therefore, only routine O&M needs to occur. Ongoing costs generally only include O&M. MNA can be easily implemented after operation ceases.	Little incremental implementation risk as the system has already been designed, constructed, and is currently operational. There is potential that the source area may not clean up as fast as modelling suggests.	This technique addresses public concern by actively treating the contamination, over the long-term. The public has witnessed this system in action, cleaning up the contamination in the dissolved plume.		$500K - $1M
		4	**4**	**4**	**5**	**4**	**4**	**25**	**3**

Criteria

Protectiveness
The overall protectiveness of human health and the environment, including the degree to which existing risks are reduced, time required to reduce risk at the facility and attain cleanup standards, on-site and off-site risks resulting from implementing the alternative, and improvement of the overall environmental quality.

Permanence
The degree to which the alternative permanently reduces the toxicity, mobility or volume of hazardous substances, including the adequacy of the alternative in destroying the hazardous substances, the reduction or elimination of hazardous substance releases and sources of releases, the degree of irreversibility of waste treatment process, and the characteristics and quantity of treatment residuals generated.

Cost
The cost to implement the alternative, including the cost of construction, the net present value of any long-term costs, and agency oversight costs that are cost recoverable. Long-term costs include operation and maintenance costs, monitoring costs, equipment replacement costs, and the cost of maintaining institutional controls. Cost estimates for treatment technologies shall describe pretreatment, analytical, labor, and waste management costs. The design life of the cleanup action shall be estimated and the cost of replacement or repair of major elements shall be included in the cost estimate.

Long-Term Effectiveness
This includes the degree of certainty that the alternative will be successful, the reliability of the alternative during the period of time hazardous substances are expected to remain on-site at concentrations that exceed cleanup levels, the magnitude of residual risk with the alternative in place, and the effectiveness of controls required to manage treatment residues or remaining wastes. The following types of cleanup action components may be used as a guide, in descending order, when assessing the relative degree of long-term effectiveness: Reuse or recycling; destruction or detoxification; immobilization or solidification; on-site or offsite disposal in and engineered, lined and monitored facility; on-site isolation or containment with attendant engineering controls; and institutional controls and monitoring.

Short-term Risks
The risk to human health and the environment associated with the alternative during construction and implementation, and the effectiveness of measures that will be taken to manage such risks.

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

Consideration of Public Concerns
Whether the community has concerns regarding the alternative and, if so, the extent to which the alternative addresses those concerns. This process includes concerns from individuals, community groups, local governments, tribes, federal and state agencies, or any other organization that may have an interest in or knowledge of the site.

Criteria Scoring

1 - Does not satisfy the criterion
2 - Marginally satisfies the criterion
3 - Partially satisfies the criterion
4 - Mostly satisfies the criterion
5 - Completely satisfies the criterion

* Costs excludes those items common to the alternatives, including long-term monitoring.

Table 9-1
Initial Screening and Evaluation of Technologies for Groundwater
Dissolved-Phase Plume, Vancouver, WA

General Response Actions	Technology	Description	Screening Criteria: Effectiveness	Screening Criteria: Implementability	Screening Criteria: Cost	Screening Comments
NO ACTION	None	No Action	Not effective in achieving RAOs.	Easy to implement.	No capital or O&M costs incurred.	Does not meet threshold criteria.
INSTITUTIONAL CONTROLS	Groundwater Use Restrictions	Restricted use of Shallow Zone and Intermediate Zone groundwater.	Effective at preventing direct contact, but is not effective at preventing migration. Does not address contaminant reduction.	May require deed restrictions to prevent off-site and on-site groundwater use.	Low to moderate costs associated with implementing restrictions (off-site deed restrictions could require significant compensation).	Applicable technology used in conjunction with other technologies.
	Monitoring	Laboratory analyses of groundwater samples.	Effective for documenting plume conditions to evaluate migration and current risks. Does not address contaminant reduction.	Easy to implement. Monitoring well network already exists.	Low to moderate costs for monitoring.	Applicable to document plume conditions and effectiveness of any treatment.
ENGINEERING CONTROLS	Control of Building HVAC System	Use HVAC system to maintain positive pressure in buildings.	May be effective in preventing migration of volatile contaminants from shallow groundwater into indoor air as long as a pressure differential is maintained between building and subsurface soil. Does not address contaminant reduction. Generally used in conjunction with other engineering controls.	Can be easy to implement in buildings with existing HVAC systems.	Low costs associated with implementing these controls in individual buildings; however, to install in numerous buildings would incur high costs.	Not applicable to dissolved-phase plume. Does not address contaminant reduction. Not retained as viable technology.
	Vapor Barriers	Installation of low-permeable barriers beneath buildings to prevent vapor intrusion.	Effective in preventing migration of volatile contaminants from shallow groundwater into indoor air. Does not address contaminant reduction.	Easy to implement for new building construction. Some protection from existing slab-on-grade construction - improvement would require sealing floor from top surface (including removal/replacement of finish floor surface), which is not feasible for the all building overlying dissolved-phase plume.	Moderate cost for individual building surface application. High cost for sub-floor installation (removal and replacement of slab floor). High costs for area overlying dissolved-phase plume.	Not applicable to dissolved-phase plume. Does not address contaminant reduction. Not retained as viable technology.
	Sub-Slab Depressurization or Sub-Floor Venting	Installation of sub-slab or sub-floor venting systems or suction pits to create negative pressures beneath structures to prevent vapor migration to ambient air. Vapors are collected in the suction pit or venting pipes below the building and vented to the outside of the building, either passively or with fans.	Effective in preventing migration of subsurface volatile contaminants from groundwater into ambient air. Does not address contaminant reduction.	Easy to implement for new building construction. Existing buildings could be retrofitted. Materials and construction methods are readily available. Generally most suitable for buildings with slab-on-grade floors. Not feasible for area overlying dissolved-phase plume.	Moderate costs for retrofitting individual existing structures - would require cutting slab floor to install vapor pits. High costs for retrofitting structures overlying dissolved-phase plume.	Not applicable to dissolved-phase plume. Does not address contaminant reduction. Not retained as viable technology.
	Alternative Water Supply	Develop new water supply in uncontaminated area to provide potable water in the areas of impact.	Effective in preventing use of contaminated groundwater. No contaminant reduction.	Conventional construction, requires local and WRD approvals.	High capital costs, low to moderate O&M costs.	Not retained as viable technology. No contaminant reduction and very high costs.
	Wellhead Treatment	Treatment at individual impacted water supply wells with use of *Ex-Situ* Physical/Chemical/Thermal treatment technology.	Effective in reducing contaminant concentrations in groundwater prior to use. Currently in use at Great Western Malting as part of initial actions.	Treatment units for large-scale municipal systems would be difficult to implement. Requires ongoing testing and system maintenance to remain effective.	High capital costs and O&M costs for municipal-scale treatment system.	An extraction ssytem is already in use at the site as part of the interim action. A potential municipal treatment unit would involve many responsible parties, require significant treatment volumes, and would be cost prohibitive. Technology not retained. .
CONTAINMENT	Vertical Barrier	Installation of vertical barriers (e.g., sheet piling, soil-bentonite slurry wall, grout, etc.) to prevent migration of groundwater contamination.	Effective at preventing lateral migration. Requires keying into underlying confining unit. Hydraulic control often necessary as supplemental measure to achieve containment. Cannot prevent downward migration.	Difficult to implement, particularly given depth to groundwater and overall size of groundwater plume. Additionally, groundwater in the Shallow and Intermediate Zones have different flow directions, so multiple barriers would be required to contain all groundwater. Site lacks suitable confining unit at reasonable depth. Some Site contaminants have specific gravity greater than 1 (sinkers). Specialized equipment required for construction. Not feasible for the entireity of the site.	High capital costs, low to moderate O&M.	Not practical for dissolved-phase plume area. Several more cost-effective technologies are available. Technology not retained.

Table 9-1
Initial Screening and Evaluation of Technologies for Groundwater
Dissolved-Phase Plume, Vancouver, WA

	Pumping / Hydraulic Containment	Extraction well(s) with submersible pumps to lower the water table and create hydraulic gradients that direct contaminant migration into the extraction well. Extracted groundwater would require treatment before discharge (see *Ex-Situ* Physical/Chemical/ Thermal Treatment).	Effective in porous soils for preventing further contaminant migration. May also be used in conjunction with other technologies. Not efficient for removal of contaminant mass.	Extraction well already in place at the SMC source area, and is currently operational. Achieves containment of dissolved-phase plume. Discharge of treated water currently permitted.	Extraction well already in place at SMC source area, and operational. Additional extraction wells may be considered. Moderate to high O&M costs.	Applicable technology for dissolved-phase plume. Currently is being used as an interim action at SMC source area and achives containment of dissolved-phase plume.
REMOVAL/DISCHARGE	Pumping (Pump & Treat)	Extraction well(s) with submersible pumps to remove contaminated groundwater with goal of plume reduction and aquifer restoration. Treatment of extracted groundwater likely required before discharge (see *Ex-Situ* Physical/Chemical/ Thermal Treatment).	Effective in porous soils for preventing contaminant migration and removing contaminants from extracted groundwater. Less effective for achievement of cleanup of source areas. May also be used in conjunction with other technologies.	Extraction well already in place at the SMC source area, and is currently operational. Achieves containment of dissolved-phase plume. Discharge of treated water currently permitted.	Extraction well already in place at SMC source area, and operational. Moderate to high O&M costs.	Applicable technology for dissolved-phase plume. Currently is being used as an interim action at SMC source area and achives containment of dissolved-phase plume.
	Subsurface Drains	Trench or horizontal boring filled with porous media— gravity drains to sump/pump. Treatment of extracted groundwater likely required before discharge (see Ex-Situ Physical/Chemical/Thermal Treatment).	Effective for shallow groundwater at preventing contaminant migration. Not effective for impacted deeper groundwater. May also be used in conjunction with other technologies.	Not practical to install at groundwater depths or for the entire area of the dissolved-phase plume.	Moderate to high capital and O&M costs.	Not retained due to area of dissolved-phase plume. Additionally, groundwater depth is greater than appropriate for subsurface drains.
	Discharge to Sewer / Surface Water	Discharge of water (which may require treatment) into surface water, storm sewer, or sanitary sewer.	Effective for disposal of extracted groundwater. Already in use at site for discharge of treated water to the Columbia River. Treatment of water (physical or chemical) required prior to discharge.	State and federal legislation regulate discharge into river. NPDES permit (already obtained) required to discharge treated water into the Columbia River.	Moderate cost to transport treated water to river. Infrastructure has already been constructed for the SMC extraction well interim action.	Applicable for discharge of extracted groundwater. Currently is being used as part of an interim action.
	Discharge to Reinjection Wells	Discharge of water (which may require treatment) into aquifer by reinjection wells.	Moderate effectiveness, depending upon whether injection wells can be adequately located to prevent plume spreading.	Underground injection control permit required for reinjection.	Moderate to high capital and O&M costs for reinjection wells.	Applicable for discharge of extracted groundwater. UIC permit required for injection wells (treatment needed to meet UIC discharge requirements).
	Reuse	Reuse of treated water for non-potable use such as irrigation or wetland enhancement.	Effective for treated, extracted groundwater.	A suitable use would need to be identified that can accommodate a steady flow rate in all seasons and within reasonable proximity.	Low to high costs depending upon storage and pumping requirements, and length of discharge piping.	No identified potential use suitable for flow rate expected from extraction system.
EX SITU PHYSICAL/ CHEMICAL/ THERMAL TREATMENT	Adsorption	Concentrating solutes on the surface of a sorbent material, such as activated carbon, to remove the solute from the bulk liquid.	Highly effective at removing many organic compounds from extracted water stream. However, may not be capable of processing the flow rate/volume from the extraction well(s)	Applicable for treatment of dissolved-phase contaminants in extracted water. Treatment equipment is readily available.	Moderate capital and O&M costs.	Not suitable for flow rate/volume expected from extraction system.
	Air Stripping	Volatile organics are partitioned from extracted groundwater by increasing surface area exposed to air.	Highly effective at removing many VOCs from extracted water stream. May require treatment of vapor effluent.	Applicable for treatment of dissolved-phase contaminants in extracted water. Treatment equipment is readily available. Requires air emission testing and modeling to determine if off-gas treatment is required.	Low to moderate capital and O&M costs. Higher costs if off-gas treatment needed.	Applicable for treatment of extracted water. Currently is being used as part of an interim action at SMC source area.
	Separation/ Reverse Osmosis	Extracted groundwater is forced through a selectively permeable membrane under pressure. Water is allowed to pass through the membrane while contaminants are trapped.	Highly effective at removing many contaminants from the extracted water stream.	Applicable for treatment of dissolved-phase contaminants in extracted water. Treatment equipment is readily available.	High capital and O&M costs.	Not retained since more cost-effective treatment methods exist for removal of contaminants from dissolved-phase plume.
	Ultraviolet (UV) Oxidation	Ultraviolet radiation is used to destroy organic contaminants as water flows through treatment cell.	Effective at removing many organic contaminants from the extracted water stream.	Applicable for treatment of dissolved-phase contaminants in extracted water. Treatment equipment is readily available.	High capital and O&M costs.	Not retained since more cost-effective treatment methods exist for removal of contaminants from dissolved-phase plume.
	Sprinkler Irrigation	Contaminated water is distributed through a pressurized sprinkler irrigation system (generally onto a highly porous media), allowing transfer of VOCs from aqueous phase to vapor phase.	Effective at removing many organic contaminants from the extracted water stream. Simpler system than more aggressive treatment technologies (such as air stripping).	Applicable for treatment of site contaminants in extracted water, but requires significant treatment system area.	Low to moderate capital and O&M costs.	Not retained since land use not compatible with site conditions.
	Ion Exchange	Ion exchange removes ions from the aqueous phase by exchange with counter ions on the exchange medium.	Effective for treatment of inorganic contaminants.	Treatment equipment is readily available.	Moderate to high capital and O&M costs.	Not compatible with dissolved-phase plume contaminants.

Table 9-1
Initial Screening and Evaluation of Technologies for Groundwater
Dissolved-Phase Plume, Vancouver, WA

	Precipitation/ Coagulation/ Flocculation	This process transforms dissolved contaminants into an insoluble solid, facilitating the contaminant's subsequent removal from the liquid phase by sedimentation or filtration.	Effective for treatment of inorganic contaminants.	Treatment equipment is readily available.	Moderate to high capital and O&M costs.	Not compatible with dissolved-phase plume contaminants.
EX SITU BIOLOGICAL TREATMENT	Bioreactors / Trickling Filter	Contaminants in extracted groundwater are put into contact with microorganisms in attached or suspended growth biological reactors.	Effective at removing many organic contaminants from the extracted water stream. May be less effective during cold weather. May not reach treatment goals without follow-up polishing treatment.	Difficult to maintain effectiveness with variable operating parameters (i.e., influent concentrations, ambient concentrations). Requires significant area for reactors. Would require significant maintenance.	Moderate capital costs and moderate to high O&M costs	Not retained since may require further treatment, and may not be effective during cold weather.
	Constructed Wetlands	Utilizes natural geochemical and biological processes inherent in an artificial wetland ecosystem to remove contaminants from extracted groundwater.	Highly effective at removing many organic and inorganic contaminants from the extracted water stream.	Requires large land area to implement. May introduce attractive nuisance hazard for local wildlife.	Moderate to high capital costs. Low O&M costs.	Applicable technology for dissolved-phase plume contaminants. Sufficient space may be available, but located significantly away from existing infrastructure.
IN SITU BIOLOGICAL TREATMENT	Enhanced Bioremediation (Bioaugmentation, Biostimulation)	Adding nutrients, electron acceptor, or other amendments to enhance bioremediation. Addition of specific microbial cultures can be included if indigenous species not suitable for complete degradation of COIs.	Effective with addition of suitable amendments. Strategic placement of amendments can be effective in conjunction with other technologies. Treating source-area concentrations requires significantly longer time to complete. Has been demonstrated as an affective technology at nearby sites.	Equipment and technology for direct injection are readily available. Amendments for stimulating reductive dechlorination are commercially available.	Low to high costs depending on number of injection events required. Area of dissolved-phase plume would incur very high costs.	Not practical for dissolved-phase plume area. Several more cost-effective technologies are available. Technology not retained.
	Monitored Natural Attenuation	Using natural processes to reduce contaminant concentrations to acceptable levels. Process is closely monitored to verify exposures are acceptable prior to concentrations reaching acceptable levels.	May be effective, especially in areas of low concentrations (near plume boundaries), but not effective for high concentrations, such as at the source areas. Other technologies will likely be required.	Easy to implement. Monitoring well system already exists. Likely would require significant timeframe to reach cleanup goals.	Low costs for monitoring.	Retained as an applicable technology. May be most effective in conjunction with other technologies to reduce concentrations.
	Phytoremediation	Phytoremediation is a process that uses plants to remove, transfer, stabilize, and destroy contaminants.	Can be effective at removing a variety of organic and inorganic compounds from contaminated groundwater through plant uptake.	Requires significant land area suitable for large plants. Contamination must be accessible to plant root zones.	Moderate implementation cost.	Not retained because incompatible with site conditions or deep contamination.
IN SITU PHYSICAL/ CHEMICAL/ THERMAL TREATMENT	Aeration / Air Sparging	Increasing the contact between water and air to enhance volatilization. Air sparging involves injecting air into saturated matrices.	Effective for volatile contamination. Use in conjunction with shallow vapor extraction to prevent uncontrolled vapor migration. Has been demonstrated as an affective technology at nearby Cadet source area.	Equipment and technology for air sparging are readily available.	Typically, moderate to high capital costs. Low O&M costs. High costs for the total area overlying the dissolved-phase plume.	Not practical for dissolved-phase plume area. Several more cost-effective technologies are available. Technology not retained.
	Multi-Phase Extraction (MPE)	MPE provides simultaneous extraction of soil vapor, contaminated groundwater, and NAPL using single vacuum pump, multiple in-well pumps, or bioslurping.	Effective for source removal at sites with moderate to low soil permeability. Also effective for treating impacted groundwater in the source area. Not efficient for removal of plume.	Equipment and technology for MPE are readily available. Treatment of recovered soil vapors and groundwater would be required prior to discharge.	Moderate to high capital and O&M costs. Higher costs if vapor treatment needed.	Not practical for dissolved-phase plume area. Several more cost-effective technologies are available. Technology not retained.
	Steam Flushing/ Steam Stripping	Steam is injected into the contaminated aquifer to vaporize less volatile organics.	Used in conjunction with vapor recovery. May be effective for increasing usability of SVE for low-volatility compounds.	Equipment and technology are readily available. Treatment of recovered vapors would likely be required.	High capital costs.	Not practical for dissolved-phase plume area. Several more cost-effective technologies are available. Technology not retained.
	Chemical Oxidation	Chemically converts hazardous contaminants to less toxic compounds. Effective in destroying organic contaminants (including LNAPL) and oxidizing inorganic contaminants to less toxic/less mobile forms. Can include oxidant chemicals such as peroxides, permanganates, or ozone.	Effective in destroying organic contaminants (including free product) and oxidizing inorganic contaminants to less toxic/less mobile forms. Difficult to provide adequate coverage in subsurface. May cause settling in organic soils. Most applicable to source-area concentrations or NAPLs.	Equipment and vendors are readily available. Less efficient at addressing diffuse concentrations of Site COIs.	High implementation costs (potentially requiring multiple applications).	Not practical for dissolved-phase plume area. Several more cost-effective technologies are available. Technology not retained.

Table 9-1
Initial Screening and Evaluation of Technologies for Groundwater
Dissolved-Phase Plume, Vancouver, WA

	Passive/Reactive Treatment Walls	Barriers placed across groundwater movement that allows passage of water while facilitating degradation or removal of contaminants.	Can be effective in the remediation of dissolved-phase VOC contamination. May not be suitable for source area remediation. Not cost-effective for very wide or deep plumes. Iron filings have been demonstrated to be effective at removal of HVOCs.	Depth of shallow aquifer would require installation by drilled methods (rather than open excavation). Specialty equipment needed for installation. Barrier materials readily available (iron and sand).	High costs for installation. Moderate costs for performance and compliance monitoring, and periodic maintenance.	Not practical for the area overlying the dissolved-phase plume. Would need to extend below deepest potential impact to prevent lateral migration beneath barrier. Several more cost-effective technologies are available. Technology not retained.

Note:

1. Shading indicates technology has been eliminated from consideration.

Table 9-2: Comparative Analysis of Remedial Alternatives for the Dissolved-Phase Groundwater Plume

Alternative		Selection Criteria**						Sum	Cost Effectiveness
		Protectiveness	Permanence	Long-term Effectiveness	Implementability	Short-Term Risk	Public Concerns		
Alternative A:	Source Control and MNA	Meets protectiveness criteria by treating source area contaminants. Current receptors (drinking water wells) are protected through source conrol, then MNA to cleanup levels.	High reliability due to source area control. P&T can remain as backup contingency. MNA program implemented to ensure permanance.	Effectively removes the most impacted groundwater (source area). MNA is effective once source areas reduced.	Existing source area remedial actions are implementable. MNA can be easily implemented and incorporated into the sampling program. P&T maintained as contingency.	Some risk due to uncertainty of source area effectiveness. Robust sampling required to confirm that remedial actions achieve RAOs and MNA is implemented.	Little percieved public concerns. This alternative addresses public concern by actively removing the source areas and implmentating a long-term MNA plan.		$2.5M-$3.1M
	Score	4	4	4	5	4	5	26	5
Alternative B:	Source Control and Pump and Treat	Meets protectiveness criteria by treating source area contaminants. Current receptors (drinking water wells) are protected through P&T to cleanup levels.	High reliability due to source area control. P&T will be operational until cleanup levels met. MNA implemented to ensure permanance.	P&T proven to be a very effective technique. System operational until cleanup levels met. Long-term maintanence is necessary.	Existing source area remedial actions are implementable. P&T currently exists and is operational. P&T has some potential maintenance issues.	Some risk due to uncertainty of source area effectiveness. P&T is currently operational, so little risk of typical construction issues. Robust sampling required to confirm that remedial actions achieve RAOs.	Little percieved public concern. Public has been receptive of P&T and its operating success.		$4.5M-$6.8M
	Score	5	5	4	4	4	5	27	3

Criteria

Protectiveness
The overall protectiveness of human health and the environment, including the degree to which existing risks are reduced, time required to reduce risk at the facility and attain cleanup standards, on-site and off-site risks resulting from implementing the alternative, and improvement of the overall environmental quality.

Permanence
The degree to which the alternative permanently reduces the toxicity, mobility or volume of hazardous substances, including the adequacy of the alternative in destroying the hazardous substances, the reduction or elimination of hazardous substance releases and sources of releases, the degree of irreversibility of waste treatment process, and the characteristics and quantity of treatment residuals generated.

Cost
The cost to implement the alternative, including the cost of construction, the net present value of any long-term costs, and agency oversight costs that are cost recoverable. Long-term costs include operation and maintenance costs, monitoring costs, equipment replacement costs, and the cost of maintaining institutional controls. Cost estimates for treatment technologies shall describe pretreatment, analytical, labor, and waste management costs. The design life of the cleanup action shall be estimated and the cost of replacement or repair of major elements shall be included in the cost estimate.

Long-Term Effectiveness
This includes the degree of certainty that the alternative will be successful, the reliability of the alternative during the period of time hazardous substances are expected to remain on-site at concentrations that exceed cleanup levels, the magnitude of residual risk with the alternative in place, and the effectiveness of controls required to manage treatment residues or remaining wastes. The following types of cleanup action components may be used as a guide, in descending order, when assessing the relative degree of long-term effectiveness: Reuse or recycling; destruction or detoxification; immobilization or solidification; on-site or offsite disposal in and engineered, lined and monitored facility; on-site isolation or containment with attendant engineering controls; and institutional controls and monitoring.

Short-term Risks
The risk to human health and the environment associated with the alternative during construction and implementation, and the effectiveness of measures that will be taken to manage such risks.

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

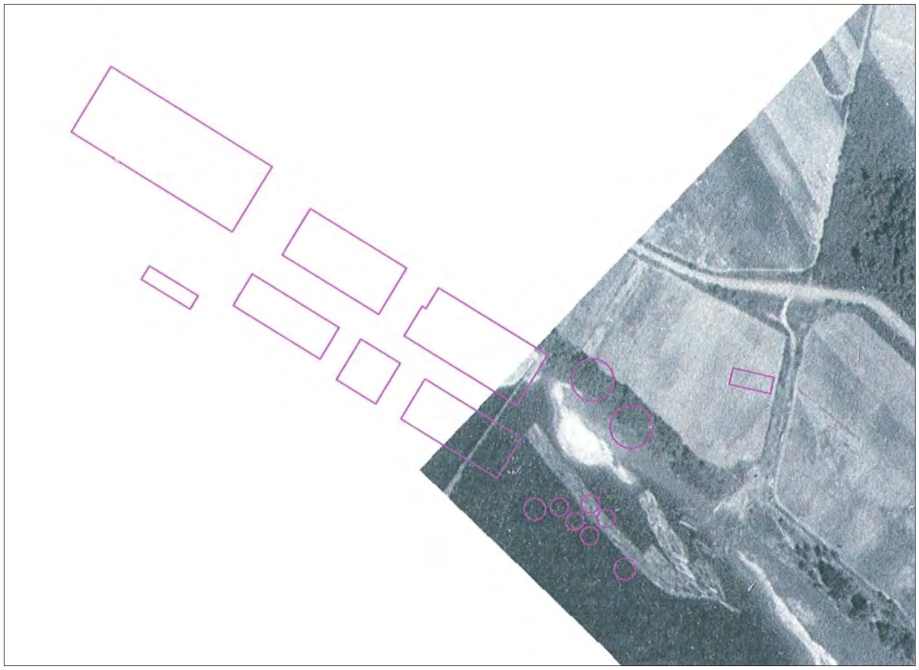
Consideration of Public Concerns
Whether the community has concerns regarding the alternative and, if so, the extent to which the alternative addresses those concerns. This process includes concerns from individuals, community groups, local governments, tribes, federal and state agencies, or any other organization that may have an interest in or knowledge of the site.

Criteria Scoring

1 - Does not satisfy the criterion
2 - Marginally satisfies the criterion
3 - Partially satisfies the criterion
4 - Mostly satisfies the criterion
5 - Completely satisfies the criterion

APPENDIX A

NuStar Aerial Photos



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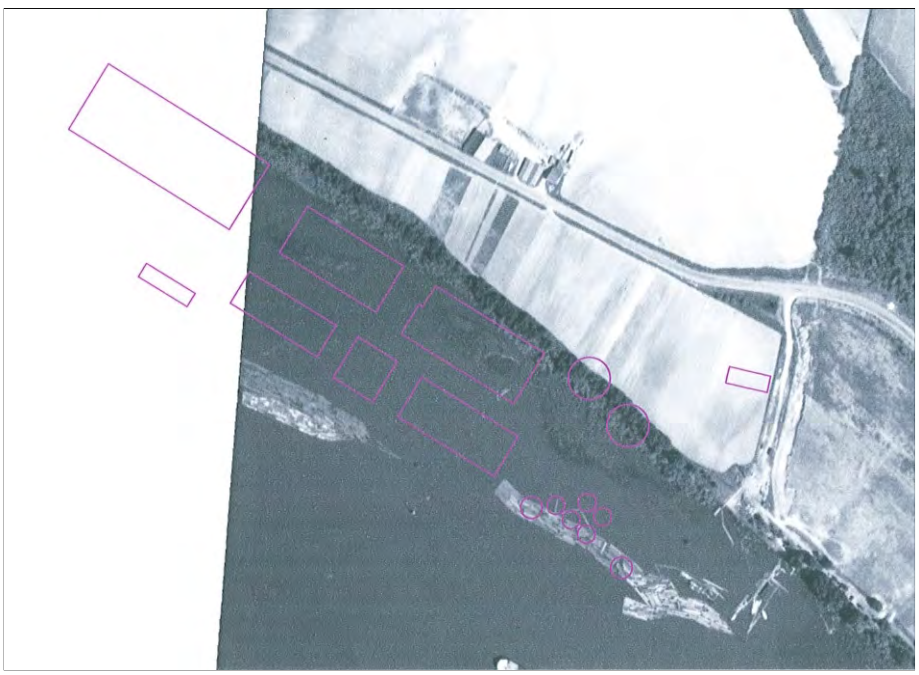
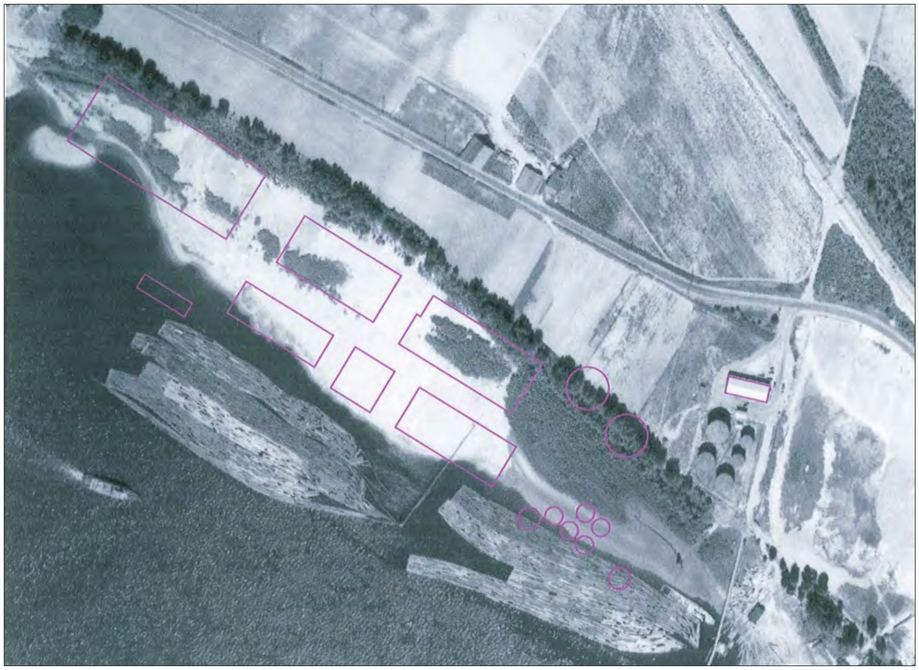


1939

1935 and 1939 Aerial Photographs

Revised Remedial Investigation Report
NuStar Terminals Services, Inc. Vancouver Facility
Vancouver, Washington

Ash Creek Associates, Inc. Environmental and Geotechnical Consultants	Project Number	1126-09	Figure
	October 2009		A-1



1940

1948

1940 and 1948 Aerial Photographs

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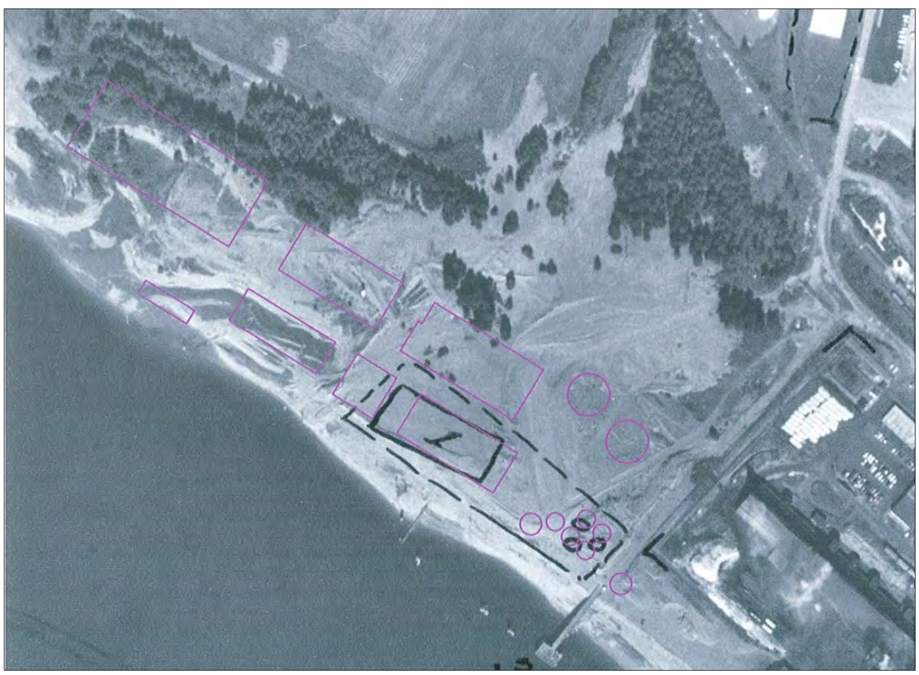
NuStar Terminals Services, Inc. Vancouver Facility
Vancouver, Washington

Ash Creek Associates, Inc.
Environmental and Geotechnical Consultants

Project Number	1126-09	Figure
October 2009		A-2

1956

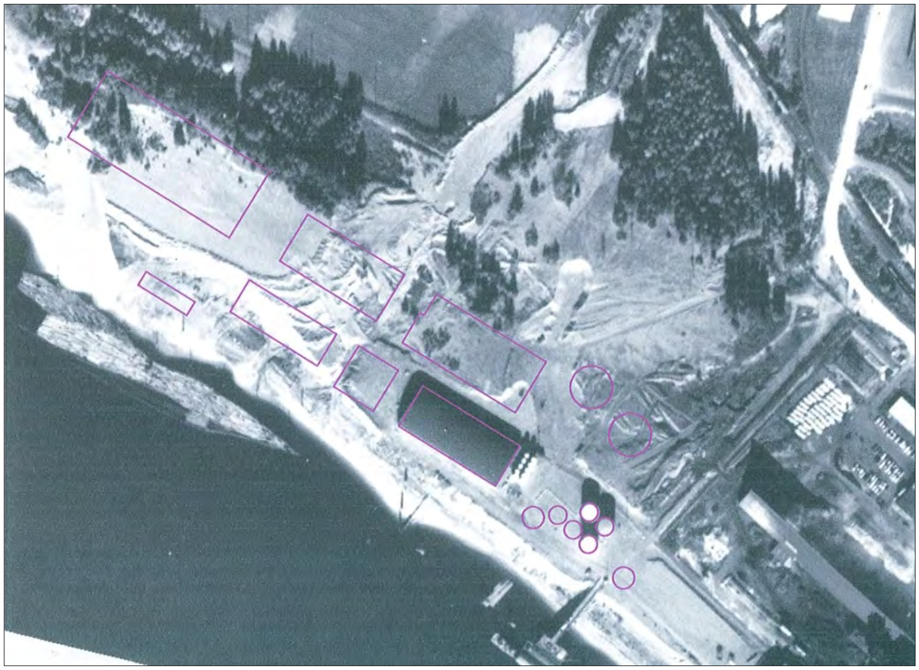


1959

1956 and 1959 Aerial Photographs

Revised Remedial Investigation Report
NuStar Terminals Services, Inc. Vancouver Facility
Vancouver, Washington

Ash Creek Associates, Inc. Environmental and Geotechnical Consultants	Project Number	1126-09	Figure A-3
	October 2009		



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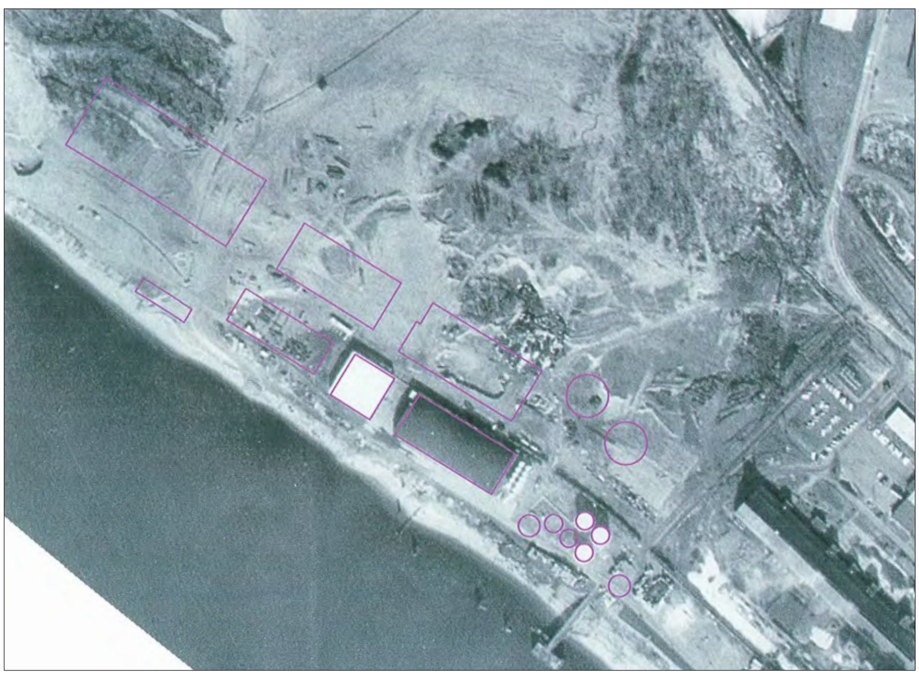

1966

1961 and 1966 Aerial Photographs

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Ash Creek Associates, Inc. Environmental and Geotechnical Consultants	Project Number	1126-09	Figure
	October 2009		A-4

1967

1971

1967 and 1971 Aerial Photographs

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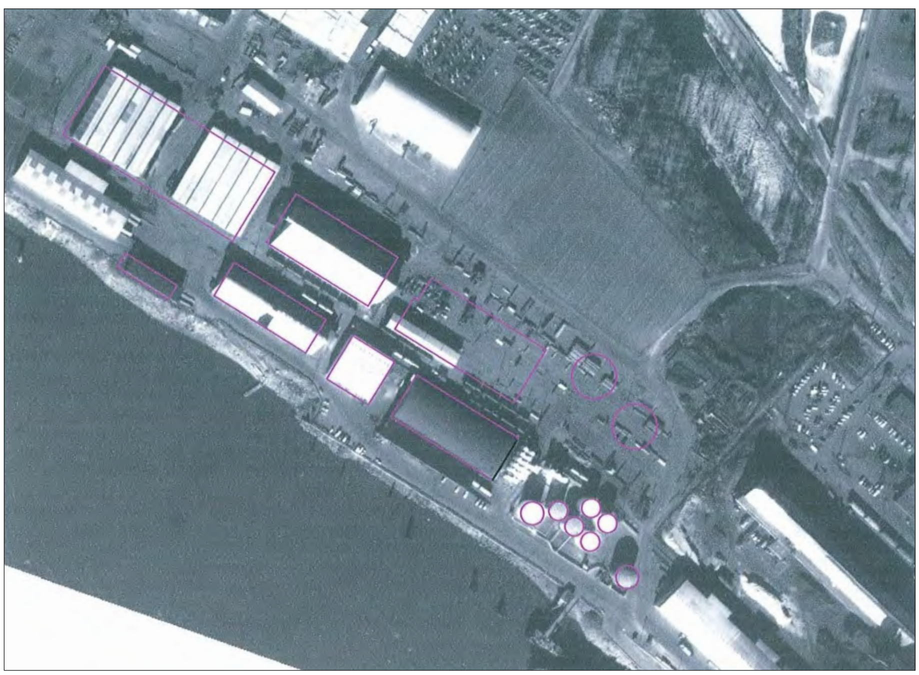
Ash Creek Associates, Inc. Environmental and Geotechnical Consultants	Project Number	1126-09	Figure
	October 2009		A-5

1974



1980

N

1974 and 1980 Aerial Photographs

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Vancouver, Washington

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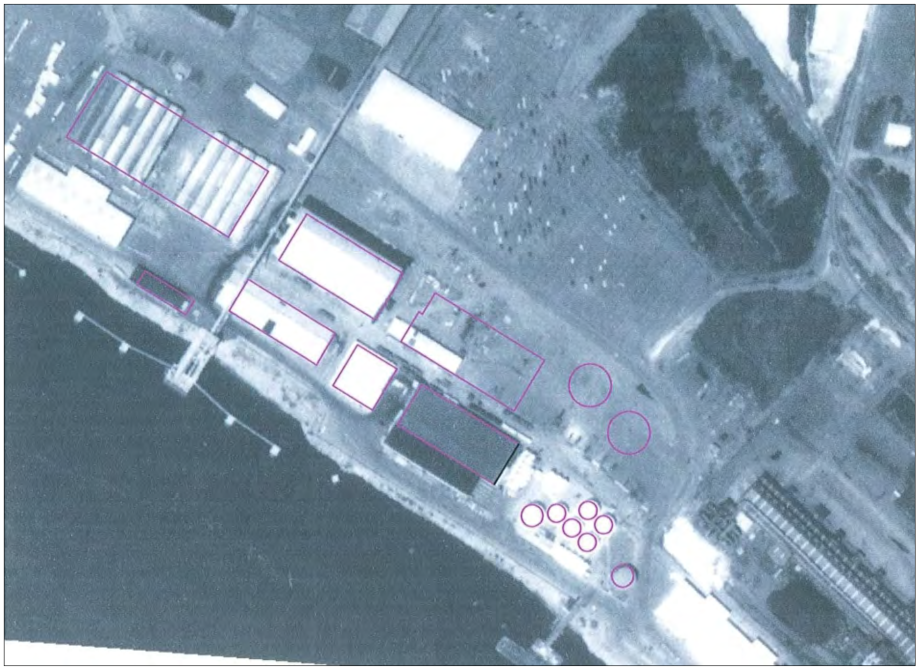

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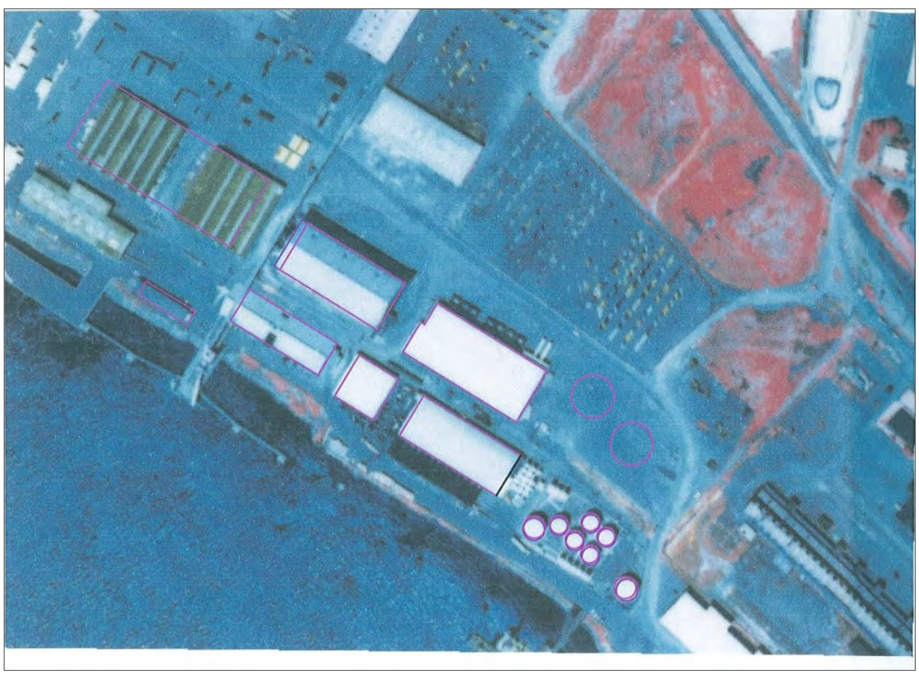

1990

1983 and 1990 Aerial Photographs

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Ash Creek Associates, Inc.
Environmental and Geotechnical Consultants

Project Number	1126-09	Figure
October 2009		A-7

1998

2002

1998 and 2002 Aerial Photographs

Revised Remedial Investigation Report
NuStar Terminals Services, Inc. Vancouver Facility
Vancouver, Washington

Ash Creek Associates, Inc. Environmental and Geotechnical Consultants	Project Number	1126-09	Figure
	October 2009		A-8

APPENDIX B

Groundwater Model Results

GROUNDWATER MODELING
Feasibility Study
NuStar, Cadet, and SMC

The following presents the significant assumptions, scenarios evaluated, and results associated with the groundwater modeling effort prepared for the feasibility study (FS) regarding the NuStar, Cadet, and SMC site. Background information and a description of the groundwater model used in this analysis is described in Section 3 of the FS.

A detailed description of the groundwater flow model used in the FS evaluation is provided in the Groundwater Model Summary Report (Parametrix, 2004). Further validation of the flow model was completed using weekly averages of river stage and pumping rates as described in the Interim Action Summary Report (Parametrix 2011). The flow model has been utilized in conjunction with a transport model to evaluate remediation scenarios in this FS; the fate and transport parameters utilized in the transport model are detailed herein.

PUMP STRESSES

Due to presence of flat groundwater gradients, high transmissivities, and the recharge characteristics associated with the unconsolidated sedimentary aquifer (USA) in the model area, pumping stresses greatly influence the flow of groundwater. The transport model utilizes the flow model results; consequently, pumping stress assumptions applied to the model strongly influence contaminant transport results.

Water supply well pumping stresses (withdrawal rates) for a 25 year period from 2012 through 2037 were established. The sources and basis for the pumping stresses applied to the groundwater model used for the FS are described below.

<u>City of Vancouver supply wells</u>

Annual production projections (pumping rates) for City of Vancouver (COV) Water Stations 1, 3, and 4 for a 25 year period (2012 through 2037) were developed. Production rate projections for these three COV water stations, which are located in the active model area, are shown on Table B-1. The projected annual production rates were developed in November 2011 and involved communications with COV representatives regarding anticipated future rates at that time.

<u>Clark Public Utilities South Lake Wellfield</u>

Annual production projections for pumping in the PAA (a.k.a., the USA; see Figure 2-1 of the FS Report) at Clark Public Utilities (CPU) South Lake Wellfield are based on projected water demands as presented in CPU's *Phase 1 Report for Water Right Application G2-29981 South Lake PAA Wellfield*, dated March 2012. Two USA production projections are presented in this report and are based on if production from the deeper sand and gravel aquifer (SGA) is operated at their full water right or one-half of their full water right. It is not clear if long-term pumping the SGA at the South Lake Wellfield at the full water right is sustainable. For the FS modeling effort, projected average annual PAA (USA) supply needs were based on the more conservative assumption that the SGA will be operated at one-half of the full water right. Table B-2 is a copy of Table 2 from the CPU's March 2012 Phase 1 Report presenting average annual PAA supply needs used in the groundwater model.

Great Western Malting

Annual production projections for the two Great Western Malting (GWM) production wells were based on pump rate data obtained from GWM for the period August 2009 to April 2012.

Port of Vancouver

Annual production projections for the two POV supply wells located just east of GWM was based on pump rate data obtained from POV for the period of September 2011 to April 2012.

Westside Wastewater Reclamation Facility

Annual production projections for the small supply well located at COV's Westside Wastewater Reclamation Facility was based on historic rate of 93 gallon per minute (gpm). This rate is consistent with review of pump rates for the period of May 2009 to October 2002.

Clark Public Utilities Co-Generation Plant

Annual production projections for the two supply wells located at CPU's co-generation plant was based on data obtained from CPU for the year 2011

SMC Site Extraction Well

The extraction well (designated EW-1) located at the former SMC site was simulated to be pumping at a constant rate of 2,500 gpm. As described below, the operation period of EW-1 was varied (1 year from 2013, 5 years from 2013, and 10 years from 2013) depending on the scenario being considered.

SOURCE AREAS

The concentration and size of source areas, which represents contaminant mass, influence the resulting distribution (migration) from the defined sources. The Cadet site, former SMC site, and NuStar site source areas were simulated as described below. The starting concentrations at all three source areas were based on first quarter 2013 (1Q13) trichloroethylene (TCE) and tetrachloroethylene (PCE) isoconcentration maps.

TCE and PCE plume concentrations and distribution in the USA were also based on 1Q13 isoconcentrations. A combination of data and digitized points along the contours shown on the 1Q13 isoconcentration maps was used to closely reflect both data and isoconcentration interpretation.

Cadet

The Cadet source was based on 1Q13 TCE and PCE isoconcentrations produced by Parametrix. The source area was simulated as a non-constant source that reduced in concentration over time due to just advection.

SMC

The SMC source was based on a depletion rate associated with the trend line shown on Figure B-1. This depletion rate was applied while well EW-1 operated. When EW-1 was not operating (off), the SMC source was simulated as a non-constant source that reduced in concentration over time due to just advection.

The six shallow wells in the SMC source area represent the best available data source regarding contaminant (TCE) concentrations (remnant source contaminant mass) overtime. Following pumping of EW-1, TCE concentrations in the shallow wells declined notably at start of EW-1 pumping, but more recently have been variable, which complicates the understanding of the rate of mass source reduction. TCE concentrations vary at each of the six shallow wells with concentrations at MW-5 consistently the highest detected since commencement of EW-1 pumping. Analysis indicates that source area concentrations appear to fluctuate with water table elevation. The residual source area is generally the size of the 50 foot by 50 foot model cell. Various methods were considered and evaluated in the modeling effort. The observed contaminant depletion at MW-05 was determined to best represent a conservative approach for modeling the SMC source area contaminant mass reduction in response to EW-1 pumping. A depletion constant (Kd) of 40 was applied for model periods when EW-1 was off to simulate reduction of the source over time due to just advection.

NuStar

The NuStar source was simulated as a non-constant source that reduced in concentration over time due to just advection. The starting concentration for the NuStar source area was based on 1Q13 TCE and PCE isoconcentrations produced by Apex. The modeling assumes that no further cleanup of the source area in the shallow zone would be conducted; because additional cleanup is proposed, the results of this modeling effort are conservative.

FATE AND TRANSPORT PARAMETER ASSUMPTIONS

Mass transport was simulated using MT3D99: A Modular Three-Dimensional Transport Model for Simulation of Advection, Dispersion, and Chemical Reactions of Contaminants in Groundwater Systems (SSPA 1999). MT3D99 simulates mass transport within the model area by utilizing the flow distribution generated by MODFLOW to calculate a velocity distribution for the model area. The partial differential transport equation is then solved by MT3D99. For the groundwater model, the transport equation was solved using the generalized conjugate gradient method (Zhang and Wang 1998). The input data array files were generated using ModIME (SSPA 1996) and computer programs coded in FORTRAN and written for this study to translate hydrogeologic data into the required MT3D99 input arrays. Use of dedicated programs allows for greater flexibility and more rigorous data analysis than is typically provided by 'off-the-shelf' MODFLOW pre- and post-processor packages.

Parameters that are considered in the mass transport model are boundary conditions, porosity, dispersion, and retardation. The Groundwater Model Summary Report (Parametrix 2004) evaluated these parameters which are described below and have been applied in the FS mass transport modeling effort.

Boundary Conditions

Because the chemical properties of PCE and TCE are similar and their movement with groundwater is similar, the transport model treats these chemicals in a similar manner and is designed to predict the movement of both of these chlorinated solvents. The applied mass transport model assumes that chlorinated solvents do not enter the project area from other sources outside the model area. Therefore, zero mass flux conditions were assigned to the perimeter of the transport model area. Concentration conditions were assigned to model cells in the SMC, Cadet, and NuStar source areas to simulate the known presence of residual chlorinated solvents in these areas as described in the previous section.

Porosity

Effective porosity controls the seepage velocity; total porosity determines the volume of water available for solute storage in a model cell. Effective porosity is that portion of total porosity that conveys flow. Therefore, dead zones and blocked pore spaces do not contribute to effective porosity. For a very coarse grain matrix, such as the USA, the large pore spaces are not easily blocked, and dead zones are unlikely. Therefore, for this model, no distinction was made between effective porosity and total porosity. A value of 0.30 was used for porosity in all model layers throughout the model area. This value may be slightly high for the fine-grain alluvium, but this just has the effect of slightly reducing the contaminant transport velocity.

Dispersion

Dispersion refers to the reduction in concentration along a flowpath, which is primarily due to non-uniform velocity distributions in the porous media. A value of three feet was used for longitudinal dispersivity in all model layers throughout the model area (Zheng and Bennett 2002). Transverse and vertical dispersivities were taken as 0.3 and 0.03 feet, respectively, based on literature values (Zheng and Bennett 2002) of the ratio among longitudinal, transverse, and vertical dispersivities.

Retardation

Retardation refers to the tendency of many contaminants to travel slower than the groundwater flow rate. This is largely due to the interaction between contaminants and the aquifer matrix. Retardation factors of 1 (no retardation), 2, 3, 4, and 6 were tested during the 2004 modeling effort (Parametrix 2004). Higher retardation factors indicate that the contaminant interacts more strongly with the aquifer matrix and therefore has a slower velocity with respect to the groundwater velocity. The 2004 modeling effort found that at higher retardation rates, the predicted concentration at the GWM wells was reduced due to the slower mass transport of contaminants into the total volume of water pumped at the GWM wells. The 2004 modeling effort found that predicted concentrations were closest to the observed concentrations at GWM production well 5 (the GWM well with the highest observed and predicted concentration of TCE) when a retardation factor of 1 (no retardation) was used. This was not considered realistic because some retardation is expected. Assuming no retardation is also not conservative with respect to cleanup time frame because it would predict a shorter cleanup time. To be more realistic and more conservative, a retardation factor of 2 was used. This retardation rate is similar to the retardation rate derived from MTCA default parameters, which would be 1.5 using an estimated bulk density of 1.5 kg/L and a porosity of 0.3. Given the uncertainty in bulk density and porosity, retardation factors of 1.5 or 2 are equally defensible.

SCENARIOS MODELED

Using the pump stress and source area assumptions described above, future TCE and PCE concentration distributions were analyzed for the following scenarios:

1. Pumping of EW-1 stops in 1 year (2014). This represents a baseline scenario or a no action scenario.
2. Pumping of EW-1 stops in 5 years (2018).
3. Pumping of EW-1 stops in 10 years (2028).

The resulting distribution of TCE and PCE for the above three scenarios were then generated for the following time periods:

- Year 5 (2018)
- Year 10 (2023)
- Year 15 (2028)

Results are presented as iscoconcentration maps for the model layer representing the shallow zone (model layer 1), the top of the Intermediate USA zone (model layer 4), and the top of the deep zone (model layer 9). See model results below.

For the SMC source area, the model was also used to evaluate a SMC source concentration in the shallow silts that would be protective of the Intermediate USA zone. For this analysis, a constant TCE source was applied to the SMC source area and the maximum resulting concentration in model layer 3 after 20 years was examined. This analysis found that a SMC source area TCE concentration of 243 micrograms per liter (µg/L) results in a maximum TCE concentration of 4 µg/L (MTCA Method B Cleanup Level). Log-linear analysis of the trend line shown on Figure B-1 found that the best estimate for MW-5 to reach a concentration of 250 µg/L is 6 years with an upper end estimate of 10 years. Consequently, this suggests that operation of EW-1 needs to continue for at least 5 years and possibly up to 10 years to reach concentrations in the SMC source area that are protective of the intermediate USA. This timeframe was the basis of the scenarios evaluated and shown in the model results below.

MODEL RESULTS

The results of the three scenarios modeled are presented as isoconcentrations maps. The TCE isoconcentration maps show 4 µg/L, and 10 µg/L isoconcentration lines. The PCE isconcentrations maps show 5 µg/L, and 10 µg/L isoconcentration lines. The 10 µg/L isoconcentration identifies where higher concentrations (at or above 10 µg/L) are present. The 4 µg/L for TCE and the 5 µg/L isoconcentration lines represent the cleanup level for TCE and PCE, respectively.

For each of the three scenarios considered, the resulting TCE and PCE distributions after 5 years (representing year 2018), after 10 years (representing year 2023), and 15 years (representing year 2028) were generated for the shallow zone (model layer 1), intermediate USA (model layer 4), and the deep USA (model layer 9). Figures GM-1 through GM-54 present these isoconcentrations maps and are organized beginning with PCE results for 1 year EW-1 pumping and shallow zone after 5 years, 10 years and 15 years (Figures GM-1 to GM-3) followed by TCE for 1 year EW-1 pumping and shallow zone after 5 years, 10 years, and 15 years (Figures GM-4 to GM-6), then PCE results for 1 year EW-1 pumping and intermediate zone after 5 years, 10 years, and 15 years, and so on through the various scenarios. Overall, the model results indicate that TCE and PCE originating from the SMC source area migrates toward the northeast and appears to be pulled toward COV water station 3. The scenario in which EW-1 is shutdown in 1 year results in the highest concentrations in the three zones evaluated. Table B-3 presents a comparison of:

1. EW-1 stops in 5 years results with EW-1 stops in 10 years results, and
2. EW-1 stops in 1 year results with EW-1 stops in 10 years results for both TCE and PCE and the three time periods evaluated (5, 10 ,and 15 years).

Table B-3 indicates that the resulting TCE and PCE distributions for EW-1 stops in 5 years and stops in 10 years are similar with distributions being slightly smaller for EW-1 stops in 10 years. The lowest concentrations result in the EW-1 stops in 10 years scenario. The results also indicate that the greatest distribution changes for the scenarios considered occur in the area northeast of the SMC site.

Groundwater Flow

The model predicts that groundwater flow is toward EW-1 in the intermediate zone within the Project Area, but that it has a more localized influence in the shallow zone and variable influence in the deeper zone due to river stage and depositional features in these units. The model predicts intermediate zone groundwater flow towards EW-1 from the Columbia River in the area extending from the western end of Terminal 3 to at least the area near Great Western Malting. The eastern area of capture generally extends to the BNSF railway lines. The northern extent of capture extends generally up to the northern property line of the Cadet facility. Due to their close proximity to the river, the GWM and POV supply wells form their own smaller capture zone within the larger EW-1 capture zone. As comparison, annualized groundwater elevation data collected in the Project Area shows a consistent steep gradient towards EW-1 to a distance approximately 600 feet southwest of EW-1 extending at least 1800 feet northeast of EW-1. Although the gradients vary significantly based on river stage and at times the gradients are towards the river beneath the NuStar facility, on an annualized basis the data suggest an area of relatively flat or low gradient from the Columbia River to well MW-31i and between GWM and EW-1 (Ash Creek Associates, 2012).

The model predicted flow towards EW-1 in the shallow zone is less extensive and slower than those predicted in the intermediate zone due to lower hydraulic conductivity and depositional features particularly in the area toward and along the river (overbank deposits), and the fact that EW-1 is producing from the intermediate zone. Flow paths in the deep zone are similar to those predicted in the intermediate zone, but even more constrained due to depositional features (primarily variation in the depth of the TF formation), generally lower transmissivity, and less influence as EW-1 is pumping from the upper section of the intermediate zone.

As initially documented in the Groundwater Model Summary Report (Parametrix 2004), production rates at GWM and adjacent POV wells have declined over time while production rates at COV WS 1 and 3 have increased. Projected future water demands at COV WS 1 and 3 (Table B-1) along with future pumping of CPU's South Lake Wellfield PAA wells (Table B-2) were included in the model simulation. The combination of lower production rates of GWM and POV supply wells with the projected future water demands at COV and CPU wells effectively reduces the capture zone produced by the GWM and POV wells such that it no longer includes the three source areas.

As noted above, the results indicate that even if EW-1 was turned off now (2014), migration of VOCs will be toward the northeast in both the shallow and intermediate zones. This flow direction differs from the previously observed pre-GPTIA flow direction which was controlled by pumping at GWM. As described in the remedial investigation reports for Cadet (Parametrix 2010) and SMC (Parametrix 2009), pre-GPTIA flow in the shallow zone at Cadet and SMC was initially toward the east and then toward the southeast. A similar flow pattern was present in the intermediate; initially to the east/southeast, and then to the south toward GWM production wells. Based on the pumping rate projections assumed in the groundwater model, flow in both the shallow and intermediate zone in the area of the Cadet and SMC sites are now controlled by pumping stresses associated with COV Water Station 3 and future CPU South Lake PAA wells when EW-1 is off.

Comparison of EW-1 pumping stops in 1 year results with EW-1 stops in 10 years was examined as this highlights the end points of the three scenarios considered. The resulting distributions for PCE and TCE for this comparison differ most notably for the intermediate zone. For both PCE and TCE in the shallow zone, the area at and near the NuStar source area are similar indicating that pumping of EW-1 has no direct influence on the shallow zone in the NuStar source area. This is due to the presence of the lower permeability overbank silt deposits associated with the natural river channel that has been filled. Higher PCE and TCE concentrations are present in the SMC source area in the shallow zone for the EW-1 stops in 1 year scenario compared with EW-1 stops in 10 years results indicating that EW-1 has a notable influence on the SMC source. For both the EW-1 stops in 5 years and 10 years scenarios, no TCE isoconcentrations greater than 4 µg/L that have migrated from SMC source are present at year 15 (2028).

Model results indicate that deep zone PCE and TCE distributions tend to be similar to intermediate zone distributions but have overall smaller distributions and lower concentrations. The model results do suggest that contaminants are pulled downward in the USA as they migrate to the northeast. This may be caused by the depth of the production zones of the COV Water Station 3 wells (i.e., well screen intervals) as simulated by the flow model.

Examination of the resulting model scenario isoconcentration figures in terms of cleanup levels for PCE and TCE indicates it will take longer to achieve cleanup levels beyond the source areas for TCE than PCE.

Table B-4 presents brief descriptions regarding model results that show isoconcentrations at or above cleanup levels beyond the SMC and NuStar source areas. Yellow highlighting is used to identify a result that indicates this condition. For PCE there is only one result (EW-1 stops pumping in 1 year at 5 years for the intermediate zone) that indicates PCE concentrations at or above its cleanup level would result beyond a source area. The opposite is observed for TCE. There are only two scenarios that result in TCE isoconcentrations that are not at or above its cleanup level beyond a source area. These two scenarios are both for the 15 year time period for EW-1 stopping at 5 years and at 10 years and are for the shallow, intermediate, and deep zones.

Examination of the results for the three scenarios modeled indicates that pumping EW-1 needs to continue for at least 5 more years (until year 2018) but may not be longer than 10 years to achieve cleanup levels in the shallow and intermediate zone. However, for TCE, model results do indicate that concentrations at or below the TCE cleanup level will not be achieved until year 2028 (15 years) beyond the SMC and NuStar source areas. It should be noted again that the assumptions utilized for the NuStar source area assumes that no further cleanup actions in the source area would occur; because additional cleanup of the source area is proposed and anticipated to mitigate the source area to below MTCA levels in 5 to 7 years, the results of the modeling will significantly over predict the actual concentrations beyond the NuStar source area. As indicated above, model analysis indicates that TCE concentrations in the SMC source area that are protective of the intermediate zone would result within 10 years beyond 2013 of EW-1 pumping. Model results also indicate that PCE and TCE concentrations above cleanup levels do not migrate from the NuStar site after 10 years.

<u>Concentration of TCE/PCE at COV wells Under Modeled Scenarios</u>

The groundwater model was used to evaluate whether the dissolved-phase groundwater plume has the potential to impact pumping wells in the vicinity under different remedial action scenarios. As noted above, based on the pumping rate projections assumed in the groundwater model, flow in both the shallow, intermediate, and deep zones in the area of the Cadet and SMC sites are now controlled by pumping stresses associated with COV Water Station 3 and future CPU South Lake PAA wells when EW-1 is off. Review of the model isoconcentration results indicate that COV Water Station 3 is a potential receptor of PCE and TCE migrating from the known source areas.

COV Water Station 3 is located adjacent to the intersection of NW Washington Street and W 42nd Street; approximately 1.42 miles northeast of SMC site extraction well EW-1. The water station consists of three wells that are approximately 270 feet deep. The three production wells are located within approximately 100 feet of each other. Figure B-2 shows the approximate location of the three COV Water Station wells and their designation used in the model.

Based on the production schedules (Tables B-1 and B-2) the annual production volume of CPU's South Lake PAA wells is more than 10 times lower than COV's WS 3 wells until year 2019. A notable production increase for the CPU's PAA wells occurs in year 2019 resulting in COV's WS 3 annual production volume being slightly more than 2 times greater. This difference slowly declines from 2021 to 2028. During the modeled period, pumping at COV WS 1 increases even more dramatically. The combination of the assumed pumping stress over time as applied in the model (based on Tables B-1 and B-2) results in COV water station 3 being the contaminant receptor from the known source areas over future pumping at

CPU South Lake PAA wells. Ultimately, projected production rates associated CPU South Lake PAA wells ramp up faster than COV WS 3. By around year 2031 CPU PAA annual production rate surpasses COV WS 3 rate and based on projected rates presented in Table B-2. CPU PAA wells will ultimately control flow in the Vancouver Lake lowlands area. However, by that time contaminants associated with the source areas will have been significantly reduced.

Based on the three scenarios modeled, Table B-5 presents the maximum PCE and TCE concentrations to reach COV Water Station 3 wells and time of the occurrence. Model results indicate that PCE and TCE migrate initially to more westerly wells COV3a and COV3c and then arrive at more easterly well COV3b several years later. Consistent with this behavior, the concentrations projected to arrive at COV3b are lower than projected for the two other wells. As indicated on Table B-5, the maximum PCE and TCE concentrations projected to arrive at COV Water Station 3 wells are below drinking water maximum contaminant levels and MTCA cleanup levels. Projected PCE concentrations are also below state reporting limits for analysis of VOCs in drinking water samples.

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Figure B-1

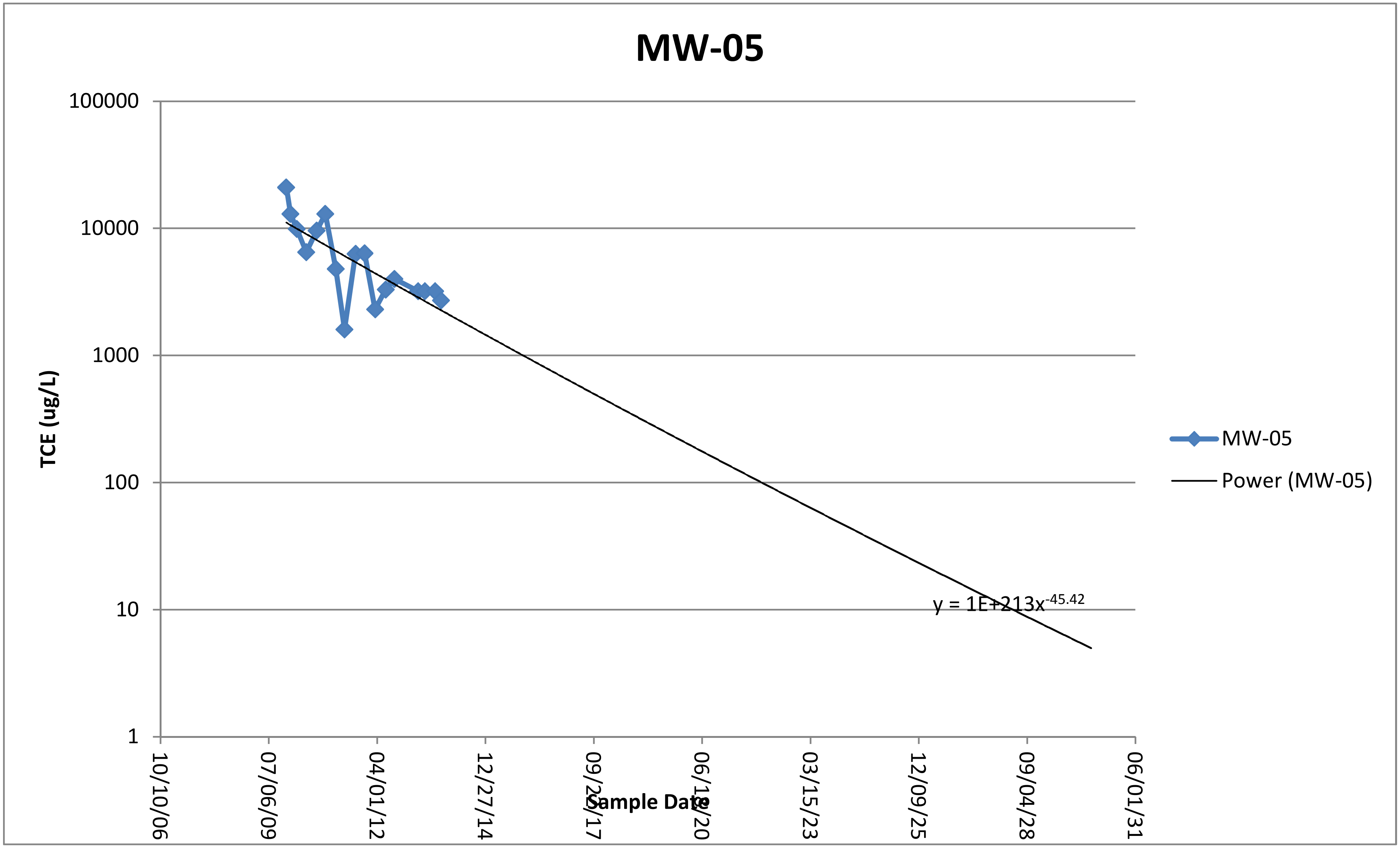

MW-05
100000
10000
1000
100
10
1
TCE (ug/L)
10/10/06
07/06/09
04/01/12
12/27/14
09/22/17
06/18/20
03/15/23
12/09/25
09/04/28
06/01/31
Sample Date
y = 1E+213x-45.42
MW-05
Power (MW-05)

Figure B-2

Table B-1: City of Vancouver Water Station 1, 3, and 4 Production Projections
Port of Vancouver Treatment System Evaluation Modeling Effort

year	2007 WMP ADD$_1$		Actual Production$_2$	Projected % increase$_5$	Proposed Projected Production$_3$	Proposed Projected % increase$_3$	Percent of Total Production$_4$			Percent of Total Production for WS 1, 3, and 4	Annual Production			Total Annual Production of WS 1, 3, and 4
	daily production	annual production	annual production		annual production		WS 1	WS 3	WS 4		WS 1	WS 3	WS 4	
	gallons per day	gallons	gallons		gallons						gallons	gallons	gallons	gallons
2004	27,303,212	9,965,672,380	10,032,036,000				21.7	11.5	13.7	46.9	2,181,135,000	1,153,603,000	1,372,170,000	4,706,908,000
2005	27,687,930	10,106,094,450	9,568,956,500				17.9	13.8	7.0	38.7	2,144,894,000	1,246,706,000	973,635,500	4,365,235,500
2006	28,578,502	10,431,153,230	10,252,391,000				21.5	12.7	12.3	46.5	2,203,240,000	1,298,748,000	1,264,330,000	4,766,318,000
2007	29,474,861	10,758,324,265	9,926,689,000				23.1	15.7	10.2	49.0	2,288,324,000	1,555,918,000	1,014,210,000	4,858,452,000
2008	30,370,509	11,085,235,785	9,662,033,000				28.7	16.5	11.1	56.3	2,770,730,000	1,591,568,000	1,074,963,000	5,437,261,000
2009	31,273,093	11,414,678,945	9,410,734,000				21.2	16.3	22.6	60.1	1,990,713,000	1,535,464,000	2,125,467,000	5,651,644,000
2010	32,180,954	11,746,048,210	8,504,224,000				18.2	15.1	20.6	53.9	1,543,768,000	1,287,925,000	1,747,640,000	4,579,333,000
2011	34,694,986	12,663,669,890	8,950,493,000		8,950,493,000		23.2	8.3	17.7	49.2	2,076,514,376	742,890,919	1,584,237,261	4,403,642,556
2012	35,316,463	12,890,508,995			9,000,000,000		22.5	14.2	35.0	71.7	2,025,000,000	1,278,000,000	3,150,000,000	6,453,000,000
2013	35,943,279	13,119,296,835		1.77%	9,000,000,000		22.5	14.2	36.0	72.7	2,025,000,000	1,278,000,000	3,240,000,000	6,543,000,000
2014	36,577,350	13,350,732,750		1.76%	9,000,000,000		22.5	14.2	37.0	73.7	2,025,000,000	1,278,000,000	3,330,000,000	6,633,000,000
2015	37,217,645	13,584,440,425		1.75%	9,108,000,000	1.20%	22.5	14.2	38.0	74.7	2,049,300,000	1,293,336,000	3,461,040,000	6,803,676,000
2016	37,864,698	13,820,614,770		1.74%	9,217,296,000	1.20%	22.5	14.5	39.0	76.0	2,073,891,600	1,336,507,920	3,594,745,440	7,005,144,960
2017	38,519,187	14,059,503,255		1.73%	9,327,903,552	1.20%	23.0	14.7	40.0	77.7	2,145,417,817	1,371,201,822	3,731,161,421	7,247,781,060
2018	39,180,417	14,300,852,205		1.72%	9,439,838,395	1.20%	23.0	14.9	40.5	78.4	2,171,162,831	1,406,535,921	3,823,134,550	7,400,833,301
2019	39,848,836	14,544,825,140		1.71%	9,553,116,455	1.20%	23.5	15.2	40.0	78.7	2,244,982,367	1,452,073,701	3,821,246,582	7,518,302,650
2020	40,524,503	14,791,443,595		1.70%	9,667,753,853	1.20%	23.5	15.4	39.5	78.4	2,271,922,155	1,488,834,093	3,818,762,772	7,579,519,021
2021	41,207,616	15,040,779,840		1.69%	9,783,766,899	1.20%	25.0	15.6	39.0	79.6	2,445,941,725	1,526,267,636	3,815,669,091	7,787,878,452
2022	41,897,786	15,292,691,890		1.67%	9,901,172,102	1.20%	25.0	15.8	38.5	79.3	2,475,293,025	1,564,385,192	3,811,951,259	7,851,629,477
2023	42,574,518	15,539,699,070		1.62%	10,019,986,167	1.20%	27.0	16.0	38.0	81.0	2,705,396,265	1,603,197,787	3,807,594,743	8,116,188,795
2024	43,280,400	15,797,346,000		1.66%	10,140,226,001	1.20%	29.0	16.2	37.5	82.7	2,940,665,540	1,642,716,612	3,802,584,750	8,385,966,903
2025	43,993,406	16,057,593,190		1.65%	10,261,908,713	1.20%	30.0	16.4	37.3	83.7	3,078,572,614	1,682,953,029	3,827,691,950	8,589,217,593
2026	44,715,253	16,321,067,345		1.64%	10,385,051,618	1.20%	31.0	16.6	36.9	84.5	3,219,366,001	1,723,918,569	3,832,084,047	8,775,368,617
2027					10,509,672,237	1.20%	32.0	16.8	36.5	85.3	3,363,095,116	1,765,624,936	3,836,030,367	8,964,750,418
2028					10,635,788,304	1.20%	33.0	17.0	36.0	86.0	3,509,810,140	1,808,084,012	3,828,883,789	9,146,777,941
2029					10,763,417,764	1.20%	34.0	17.0	35.7	86.7	3,659,562,040	1,829,781,020	3,842,540,142	9,331,883,201
2030					10,892,578,777	1.20%	35.0	17.0	35.3	87.3	3,812,402,572	1,851,738,392	3,845,080,308	9,509,221,272
2031					11,023,289,722	1.20%	36.0	16.3	35.0	87.3	3,968,384,300	1,796,796,225	3,858,151,403	9,623,331,927
2032					11,155,569,199	1.20%	37.0	16.0	34.5	87.5	4,127,560,604	1,784,891,072	3,848,671,374	9,761,123,049
2033					11,289,436,029	1.20%	38.0	15.8	34.0	87.8	4,289,985,691	1,783,730,893	3,838,408,250	9,912,124,834
2034					11,424,909,261	1.20%	39.0	15.5	33.5	88.0	4,455,714,612	1,770,860,936	3,827,344,603	10,053,920,150
2036					11,562,008,173	1.20%	40.0	15.2	33.0	88.2	4,624,803,269	1,757,425,242	3,815,462,697	10,197,691,208
2037					11,700,752,271	1.20%	41.0	14.9	32.5	88.4	4,797,308,431	1,743,412,088	3,802,744,488	10,343,465,007
								Water right annual load:			7,263,704,438	2,207,924,334	3,914,432,478	

(1): Total system average day demand by pressure zone - medium range. As presented on Table 2-16 in 2007 WMP
(2): Based on COV monthly production tables.
(3): Based on information provided by Tyler Clary w/ COV 11/27 emails.
(4) Based on COV monthly production tables. Note 2011 based on usage up to end of August
(5): Represents annual increase based on 2007 WMP projection.
Indicates years with actual data.

Table B-2 - Water Demand and Supply Projections for CLARK, Battle Ground, and Ridgefield (2011 through 2060)
SGA Operated at One-Half Full Water Right (4,950 ac-ft/yr)

	[illegible]				[illegible]				[illegible]			[illegible]	
Year	CPU (mgd)	Battle Ground (mgd)	Ridgefield (mgd)	Total Demand (mgd)	CPU Lower Unit (mgd)	CPU Pioneer and Mountain View Glass (mgd)	Battle Ground (mgd)	Ridgefield (mgd)	CPU Fill-up/in Rivers (mgd)	South Lake SGA (mgd)	South Lake FAA (mgd)	Peak FAA Supply Needed (gpm)	[illegible] Annual FAA Supply Needed (ac-ft/yr)
2011	12.08	1.50	0.63	14.21	5.50	4.92	1.50	0.63	0.00	1.66	0.00	0	0
2012	12.35	1.55	0.70	14.59	5.39	4.96	1.55	0.70	0.00	2.00	0.00	0	0
2013	12.61	1.59	0.78	14.98	5.28	5.00	1.59	0.78	0.00	2.32	0.00	23	3
2014	12.88	1.64	0.86	15.38	5.18	5.08	1.64	0.86	0.00	2.57	0.06	476	64
2015	13.14	1.69	0.96	15.79	5.07	5.18	1.69	0.96	0.00	2.77	0.12	871	130
2016	13.41	1.74	1.08	16.23	4.97	5.29	1.74	1.08	0.00	2.95	0.20	1,274	228
2017	13.68	1.79	1.20	16.67	4.87	5.39	1.79	1.20	0.00	3.13	0.29	1,672	326
2018	13.94	1.85	1.34	17.13	4.77	5.50	1.85	1.34	0.00	3.29	0.37	2,048	418
2019	14.21	1.90	1.50	17.61	4.68	2.66	1.90	1.50	0.84	4.38	1.65	5,608	1,847
2020	14.48	1.96	1.68	18.12	4.59	2.66	1.96	1.68	1.09	4.42	1.72	5,776	1,925
2021	14.74	2.02	1.88	18.63	4.49	2.66	2.02	1.68	1.36	4.53	1.89	6,193	2,117
2022	15.01	2.08	2.10	19.19	4.40	2.66	2.08	1.68	1.66	4.63	2.07	6,620	2,313
2023	15.27	2.14	2.36	19.76	4.32	2.66	2.14	1.68	1.99	4.74	2.23	7,027	2,501
2024	15.54	2.20	2.64	20.38	4.23	2.65	2.20	1.68	2.35	4.83	2.41	7,444	2,705
2025	15.77	2.27	2.85	20.89	4.15	2.66	2.27	1.68	2.64	4.89	2.59	7,795	2,898
2026	16.01	2.34	2.96	21.31	4.06	2.66	2.34	1.68	2.84	4.93	2.79	8,157	3,120
2027	16.25	2.41	3.09	21.75	3.98	2.66	2.41	1.68	3.05	4.96	3.00	8,514	3,359
2028	16.49	2.48	3.22	22.19	3.90	2.66	2.48	1.68	3.26	4.98	3.21	8,866	3,595
2029	16.74	2.55	3.35	22.64	3.82	2.66	2.55	1.68	3.48	4.99	3.44	9,227	3,848
2030	16.99	2.63	3.49	23.11	3.75	2.66	2.63	1.68	3.71	5.01	3.66	9,584	4,100
2031	17.26	2.71	3.63	23.61	3.67	2.66	2.71	1.68	3.95	5.01	3.91	9,971	4,382
2032	17.54	2.79	3.74	24.07	3.60	2.66	2.79	1.68	4.15	5.01	4.17	10,352	4,666
2033	17.81	2.87	3.85	24.54	3.53	2.66	2.87	1.68	4.35	5.01	4.42	10,729	4,945
2034	18.08	2.96	3.97	25.01	3.46	2.66	2.96	1.68	4.57	5.01	4.66	11,100	5,221
2035	18.35	3.05	4.09	25.49	3.39	2.66	3.05	1.68	4.78	5.01	4.90	11,466	5,494
2036	18.63	3.14	4.21	25.98	3.32	2.66	3.14	1.68	5.01	5.01	5.14	11,828	5,762
2037	18.90	3.24	4.34	26.47	3.25	2.66	3.24	1.68	5.23	5.01	5.38	12,184	6,027
2038	19.17	3.33	4.47	26.97	3.19	2.66	3.33	1.68	5.47	5.01	5.61	12,535	6,288
2039	19.45	3.43	4.60	27.48	3.12	2.66	3.43	1.68	5.71	5.01	5.84	12,881	6,545
2040	19.72	3.54	4.74	28.00	3.06	2.66	3.54	1.68	5.96	5.01	6.07	13,222	6,798
2041	20.04	3.64	4.88	28.56	3.00	2.66	3.64	1.68	6.21	5.01	6.34	13,624	7,096
2042	20.35	3.75	5.00	29.11	2.94	2.66	3.69	1.68	6.44	5.01	6.66	14,112	7,459
2043	20.67	3.86	5.13	29.66	2.88	2.66	3.69	1.68	6.68	5.01	7.03	14,673	7,876
2044	20.99	3.98	5.26	30.23	2.82	2.66	3.69	1.68	7.22	5.01	7.11	14,798	7,969
2045	21.31	4.10	5.39	30.79	2.77	2.66	3.69	1.68	7.59	5.01	7.37	15,179	8,252
2046	21.62	4.22	5.52	31.37	2.71	2.66	3.69	1.68	7.97	5.01	7.62	15,554	8,531
2047	21.94	4.35	5.66	31.95	2.66	2.72	3.69	1.68	8.30	5.01	7.86	15,925	8,806
2048	22.26	4.48	5.80	32.54	2.60	2.78	3.69	1.68	8.64	5.01	8.10	16,289	9,077
2049	22.57	4.61	5.95	33.14	2.55	2.84	3.69	1.68	8.98	5.01	8.34	16,649	9,344
2050	22.89	4.75	6.10	33.74	2.50	2.93	3.69	1.68	9.31	5.01	8.58	17,002	9,607
2051	23.26	4.89	6.25	34.40	2.45	3.05	3.69	1.68	9.62	5.01	8.86	17,426	9,922
2052	23.62	5.04	6.41	35.07	2.40	3.17	3.69	1.68	9.66	5.01	9.41	18,260	10,542
2053	23.99	5.19	6.53	35.72	2.35	3.28	3.69	1.68	9.79	5.01	9.86	18,938	11,046
2054	24.36	5.35	6.67	36.37	2.31	3.34	3.69	1.68	9.87	5.01	10.43	19,790	11,678
2055	24.73	5.51	6.80	37.03	2.26	3.40	3.69	1.68	9.95	5.01	10.99	20,646	12,314
2056	25.09	5.67	6.93	37.70	2.22	3.45	3.69	1.68	9.94	5.01	11.65	21,652	13,062
2057	25.46	5.84	7.07	38.38	2.17	3.51	3.69	1.68	9.97	5.01	12.29	22,599	13,766
2058	25.83	6.02	7.22	39.06	2.13	3.53	3.69	1.68	10.01	5.01	12.96	23,614	14,520
2059	26.19	6.20	7.36	39.75	2.09	3.53	3.69	1.68	10.01	5.01	13.70	24,718	15,340
2060	26.56	6.39	7.51	40.45	2.04	3.53	3.69	1.68	10.01	5.01	14.44	25,833	16,169

Table B-3: Model Scenarios Comparison Matrix

Time Period Represented	PCE EW-1 Pumping 5 years - Shallow (Layer 1)	PCE EW-1 Pumping 10 years - Shallow (Layer 1)	TCE EW-1 Pumping 5 years - Shallow (Layer 1)	TCE EW-1 Pumping 10 years - Shallow (Layer 1)	Comments
	PCE		TCE		
5 years	Same distribution.		Same distribution.		Same distribution results as simulation conditions are the same.
10 years	Similar distribution. Slightly smaller for 10 years particularly NE of SMC. NuStar area same.		Very similar distribution. Slightly smaller for 10 years particularly NE of SMC. NuStar area same.		Slightly smaller but similar PCE and TCE distributions result in 10 years due to 5 more years of pumping that are associated with the 10 years scenario.
15 years	Similar distribution. Slightly smaller for 10 years particularly NE of SMC. NuStar area same.		Very similar distribution. Slightly smaller for 10 years particularly NE of SMC. NuStar area same.		Slightly smaller but similar PCE and TCE distributions result in 10 years due to 5 more years of pumping that are associated with the 10 years scenario.

Time Period Represented	PCE EW-1 Pumping 5 years - Intermediate (Layer 4)	PCE EW-1 Pumping 10 years - Intermediate (Layer 4)	TCE EW-1 Pumping 5 years - Intermediate (Layer 4)	TCE EW-1 Pumping 10 years - Intermediate (Layer 4)	Comments
5 years	Same distribution.		Same distribution.		Same distribution results as simulation conditions are the same.
10 years	Similar distribution. Slightly smaller for 10 years.		Very similar distribution. Slightly smaller for 10 years.		Slightly smaller but similar PCE and TCE distributions result in 10 years due to 5 more years of pumping that are associated with the 10 years scenario.
15 years	Similar distribution. Slightly smaller for 10 years.		Very similar distribution. Slightly smaller for 10 years.		Slightly smaller but similar PCE and TCE distributions result in 10 years due to 5 more years of pumping that are associated with the 10 years scenario.

Time Period Represented	PCE EW-1 Pumping 1 year - Shallow (Layer 1)	PCE EW-1 Pumping 10 years - Shallow (Layer 1)	TCE EW-1 Pumping 1 year - Shallow (Layer 1)	TCE EW-1 Pumping 10 years - Shallow (Layer 1)	Comments
5 years	Same distribution.		NuStar area similar. Larger plume area for 1 year NE of SMC with large 4 ug/L area.		Comparisons notes NuStar area remains similar between the two scenarios but a larger plume area for both TCE and PCE is present NE of SMC in 1 year scenario.
10 years	Similar distribution. Slightly smaller for 10 years.		NuStar area similar. Larger plume area for 1 year NE of SMC with a notably large 4 ug/L area.		Comparisons notes NuStar area remains similar between the two scenarios but a larger plume area for both TCE and PCE is present NE of SMC in 1 year scenario.
15 years	Similar distribution. Slightly smaller for 10 years.		NuStar area similar. Larger plume area for 1 year NE of SMC. 4 ug/L isocon present in 1 year but not in 10 year.		Comparisons notes NuStar area remains similar between the two scenarios but a larger and for a PCE substantially lager plume area is present NE of SMC in 1 year scenario.

Time Period Represented	PCE EW-1 Pumping 1 year - Intermediate (Layer 4)	PCE EW-1 Pumping 10 years - Intermediate (Layer 4)	TCE EW-1 Pumping 1 year - Intermediate (Layer 4)	TCE EW-1 Pumping 10 years - Intermediate (Layer 4)	Comments
5 years	Overall similar but larger distribution in 1 year particularly between Cadet and SMC. Small 5 ug/L iscon NE of SMC that is not present in 10 year. NuStar area fairly similar.		Overall similar distribution but larger for 1 year scenario. A 10 ug/L iscocon is present NE of SMC in 1 year but not in 10 year. Larger 4 ug/L isocon area NE of SMC in 1 year. Nustar area generally similar.		Comparisons notes NuStar area remains similar between the two scenarios but a larger plume area for both TCE and PCE is present NE of SMC in 1 year scenario.
10 years	Notably larger plume area for 1 year. NuStar area notably smaller area in 10 year. This is the biggest observed comparison difference in the NuStar area for the scenarios compared.		Larger plume area for 1 year NE of SMC with a larger 4 ug/L area NE of SMC. Similar isocon distribution in NuStar area.		Comparisons note that NuStar area remains similar between the two scenarios for TCE but not PCE. For both TCE and PCE alarger plume area is present in 1 year scenario.
15 years	Notably larger plume area for 1 year. Similar at NuStar source area.		Larger plume area for 1 year NE of SMC. No 4 ug/L isocon area NE of SMC in 10 year. Similar isocon distribution in NuStar area.		Comparisons notes NuStar area remains similar between the two scenarios a larger plume area for both TCE and PCE. For PCE the resulting isocon is for both scenario is only associated with the NuStar source. The PCE isocon area is notably larger in the 1 year scenario compared with 10 year scenario.

Time Period Represented	PCE EW-1 Pumping 5 years - Deep (Layer 9)	PCE EW-1 Pumping 10 years - Deep (Layer 9)	TCE EW-1 Pumping 5 years - Deep (Layer 9)	TCE EW-1 Pumping 10 years - Deep (Layer 9)	Comments
5 years	No 5 ug/L or greater isocon.		Same distribution. 4 ug/L isocon present.		Same distribution results as simulation conditions are the same.
10 years	No 5 ug/L or greater isocon.		Very similar distribution. Slightly smaller for 10 years. Isocons not near EW-1.		Slightly smaller but similar PCE and TCE distributions result in 10 years due to 5 more years of pumping that are associated with the 10 years scenario.
15 years	No 5 ug/L or greater isocon.		Large 1 ug/L isocon present NE of SMC and Cadet sites is not present for EW-1 stops in 10 years. Isocons not near EW-1.		Slightly smaller but similar PCE and TCE distributions result in 10 years due to 5 more years of pumping that are associated with the 10 years scenario.

Time Period Represented	PCE EW-1 Pumping 1 year - Deep (Layer 9)	PCE EW-1 Pumping 10 years - Deep (Layer 9)	TCE EW-1 Pumping 1 year - Deep (Layer 9)	TCE EW-1 Pumping 10 years - Deep (Layer 9)	Comments
5 years	No 5 ug/L or greater isocon.		Overall similar distribution but larger for 1 year scenario. A 10 ug/L isocon is present NE of SMC in 1 year but not in 10 year. Larger 4 ug/L isocon area NE of SMC in 1 year. Nustar area smaller.		Comparisons notes NuStar area remains similar between the two scenarios but a larger plume area for both TCE and PCE is present NE of SMC in 1 year scenario.
10 years	No 5 ug/L or greater isocon.		Larger plume area for 1 year NE of SMC with a larger 4 ug/L area NE of SMC. Similar isocon distribution in NuStar area but bends more toward EW-1 in 10 year scenario.		Comparisons note that NuStar area remains similar between the two scenarios for TCE and PCE. For both TCE and PCE a larger plume area is present in 1 year scenario.
15 years	No 5 ug/L or greater isocon.		Much larger plume area for 1 year NE of SMC that includes a 4 ug/L isocon. In 10 year scenario the 1 and 4 ug/L isocons NE of SMC site are not present. Similar isocon distribution in NuStar area but 10 year scenario bends more		Comparisons notes NuStar area remains similar between the two scenarios; a larger plume area for both TCE and PCE. For both TCE and PCE, isocons NE of SMC are not present in the 10 year scenario.

Table B-4: Cleanup Level Evaluation

Shallow Zone	PCE - Cleanup Level 5 ug/L			TCE - Cleanup Level 4 ug/L		
Time Period Represented	PCE EW-1 Pumping 1 year - Shallow (Layer 1)	PCE EW-1 Pumping 5 years - Shallow (Layer 1)	PCE EW-1 Pumping 10 years - Shallow (Layer 1)	TCE EW-1 Pumping 1 year - Shallow (Layer 1)	TCE EW-1 Pumping 5 years - Shallow (Layer 1)	TCE EW-1 Pumping 10 years - Shallow (Layer 1)
5 years	Above 5 ug/L at and adjacent to SMC and NuStar source areas.	Above 5 ug/L at and adjacent to SMC and NuStar source areas.	Above 5 ug/L at and adjacent to SMC and NuStar source areas.	Above 4 ug/L at, adjacent to, and north of both SMC and NuStar source areas.	4 ug/L isocon extending north of SMC source area. 4 and 10 ug/L iscons present north of NuStar.	4 ug/L isocon extending north of SMC source area. 4 and 10 ug/L iscons present north of NuStar.
10 years	Above 5 ug/L at and adjacent to SMC and NuStar source areas.	Above 5 ug/L at and adjacent to SMC and NuStar source areas.	Above 5 ug/L at and adjacent to SMC and NuStar source areas.	Above 4 ug/L at, adjacent to, and north of both SMC and NuStar source areas.	Two 4 ug/L isocons north of the SMC source area. Smallwer 4 ug/L isocon north of NuStar source area.	Two 4 ug/L isocons north of the SMC source area. Smallwer 4 ug/L isocon north of NuStar source area.
15 years	Above 5 ug/L at and adjacent to SMC and NuStar source areas.	Above 5 ug/L at and adjacent to SMC and NuStar source areas.	Above 5 ug/L at and adjacent to SMC and NuStar source areas.	Above 4 ug/L at, adjacent to, and north of both SMC and NuStar source areas.	Small 4 ug/L isocons present north of NuStar and extending from SMC source area.	No 4 ug/L isocon north or extending from SMC site. Small 4 ug/L isocon north of NuStar.

Intermediate Zone	PCE - Cleanup Level 5 ug/L			TCE - Cleanup Level 4 ug/L		
Time Period Represented	PCE EW-1 Pumping 1 year - Intermediate (Layer 4)	PCE EW-1 Pumping 5 years - Intermediate (Layer 4)	PCE EW-1 Pumping 10 years - Intermediate (Layer 4)	TCE EW-1 Pumping 1 year - Intermediate (Layer 4)	TCE EW-1 Pumping 5 years - Intermediate (Layer 4)	TCE EW-1 Pumping 10 years - Intermediate (Layer 4)
5 years	Small 5 ug/L isocon present NE of SMC site. No 5 ug/L isocon at SMC site. No 5 ug/L icson beyond NuStar site.	5 ug/L isocon not extending beyond NuStar site.	5 ug/L isocon not extending beyond NuStar site.	A 4 ug/L isocon with a small 10 ug/L isocon in the middle of it NE of SMC source area. Small 4 ug/L isocon present at western side of NuStar site.	A 4 ug/L isocon extending NE of SMC source area. A small 4 ug/L isocon present at western side of NuStar site.	A 4 ug/L isocon extending NE of SMC source area. A small 4 ug/L isocon present at western side of NuStar site.
10 years	Small 5 ug/L isocon extending from western side of NuStar site.	Small 5 ug/L isocon extending from western side of NuStar site.	5 ug/L isocon not extending beyond NuStar site.	Fairly large 4 ug/L isocon NE of SMC source area. 4 isocon present at western side of NuStar. No 10 ug/L isocon in SMC source area or extending beyond NuStar source area.	A 4 isocon NE of and away from SMC source area. 1 iscocon also away from SMC source area. 4 isocon present at western side of NuStar. No 10 isocon extending beyond NuStar source area.	A 4 isocon NE of and away from SMC source area. 1 iscocons pointed toward SMC source area. 4 isocon present at western side of NuStar. No 10 isocon extending beyond NuStar source area.
15 years	5 ug/L isocon not extending beyond NuStar site.	5 ug/L isocon not extending beyond NuStar site.	5 ug/L isocon not extending beyond NuStar site.	4 ug/L isocon NE of SMC source area. 4 ug/L isocon present at western side of NuStar. No 4 ug/L isocon in SMC source area. No 10 ug/L isocon extending beyond NuStar source area.	Small 4 ug/L isocon present at western side of NuStar. No 10 ug/L isocon extending beyond NuStar source area.	Small 4 ug/L isocon present at western side of NuStar. No 10 ug/L isocon extending beyond NuStar source area.

Deep Zone	PCE - Cleanup Level 5 ug/L			TCE - Cleanup Level 4 ug/L		
Time Period Represented	PCE EW-1 Pumping 1 year - Intermediate (Layer 9)	PCE EW-1 Pumping 5 years - Intermediate (Layer 9)	PCE EW-1 Pumping 10 years - Intermediate (Layer 9)	TCE EW-1 Pumping 1 year - Intermediate (Layer 9)	TCE EW-1 Pumping 5 years - Intermediate (Layer 9)	TCE EW-1 Pumping 10 years - Intermediate (Layer 9)
5 years	No 5 ug/L isocon extending beyond NuStar site.	No 5 ug/L isocon extending beyond NuStar site.	No 5 ug/L isocon extending beyond NuStar site.	A 4 ug/L isocon with a small 10 ug/L isocon in the middle of it NE of SMC source area.	A 4 ug/L isocon extending NE of SMC source area. A small 4 ug/L isocon north of western side of NuStar site.	A 4 ug/L isocon extending NE of SMC source area. A small 1 ug/L isocon migrating from north western side of NuStar site.
10 years	No 5 ug/L isocon extending beyond NuStar site.	No 5 ug/L isocon extending beyond NuStar site.	No 5 ug/L isocon extending beyond NuStar site.	Fairly large 4 ug/L isocon NE of SMC source area. No 10 ug/L isocon.	A small 4 ug/L isocon NE of and away from SMC source area. No 10 ug/L isocon.	A very small 4 ug/L isocon NE of and away from SMC source area. No 10 ug/L isocon. SMC site not included in iscons.
15 years	No 5 ug/L isocon extending beyond NuStar site.	No 5 ug/L isocon extending beyond NuStar site.	No 5 ug/L isocon extending beyond NuStar site.	A 4 ug/L isocon NE of SMC source area. No isocon near SMC source area. No 10 ug/L isocon.	No 4 ug/L isocon.	No 4 ug/L isocon.

Notes:
Yellow highlight indicates concentrations above cleanup level are migrating away from known source areas.

Table: B-5 COV Water Station 3 Model Projected Maximum PCE and TCE Concentrations and Arrival Times

Scenario	Well	PCE			TCE		
		Maximum Concentration			Maximum Concentration		
		Time	Year	ug/L	Time	Year	ug/L
EW-1 Pumping 1 year	COV3a	14.8	2028	0.477	16.8	2030	1.586
	COV3b	17.8	2031	0.242	19.7	2033	0.441
	COV3c	13.8	2027	0.492	16.0	2029	1.989
EW-1 Pumping 5 years	COV3a	14.0	2027	0.312	17.0	2030	0.899
	COV3b	17.8	2031	0.181	19.7	2033	0.237
	COV3c	14.0	2027	0.292	16.0	2029	1.142
EW-1 Pumping 10 years	COV3a	14.8	2028	0.277	17.0	2030	0.757
	COV3b	17.8	2031	0.176	19.7	2033	0.220
	COV3c	13.8	2027	0.246	16.8	2030	0.926

Notes:
Time is in units of years.
Year indicates year maximum concentration projected to arrive based on model start date of January 2013.
Year indicated uses time shown rounded up.
Model indicates the arrival time for PCE at COV3 is three years. The same time for each scenario.
Model indicates the arrival time for TCE at COV3 is seven years for the EW-1 Pumping 1 year scenario.
Model indicates the arrival time for TCE at COV3 is 7.9 years for the EW-1 pumping 5 and 10 years scenarios.

Figure GM-1

PCE after 5 years
EW- Pumping: 1 yr
Shallow

Figure GM-2

PCE after 10 years
EW- Pumping: 1 yr
Shallow

Figure GM-3

PCE after 15 years
EW- Pumping: 1 yr
Shallow

Figure GM-4

TCE after 5 years
EW- Pumping: 1 yr
Shallow

Figure GM-5

TCE after 10 years
EW- Pumping: 1 yr
Shallow

Figure GM-6

TCE after 15 years
EW- Pumping: 1 yr
Shallow

Figure GM-7

PCE after 5 years
EW- Pumping: 1 yr
USA

Figure GM-8

PCE after 10 years
EW- Pumping: 1 yr
USA

Figure GM-9

PCE after 15 years
EW- Pumping: 1 yr
USA

Figure GM-10

TCE after 5 years
EW- Pumping: 1 yr
USA

Figure GM-11

TCE after 10 years
EW- Pumping: 1 yr
USA

Figure GM-12

TCE after 15 years
EW- Pumping: 1 yr
USA

Figure GM-13

PCE after 5 years
EW- Pumping: 1 yr
Deep

Figure GM-14

PCE after 10 years
EW- Pumping: 1 yr
Deep

Figure GM-15

PCE after 15 years
EW- Pumping: 1 yr
Deep

Figure GM-16

TCE after 5 years
EW- Pumping: 1 yr
Deep

Figure GM-17

TCE after 10 years
EW- Pumping: 1 yr
Deep

Figure GM-18

TCE after 15 years
EW- Pumping: 1 yr
Deep

Figure GM-19

PCE after 5 years
EW- Pumping: 5 yrs
Shallow

Note: The minimum contour shown is the PCE or TCE cleanup level. If no contours are shown, all modelled data are below the PCE or TCE cleanup levels.

Figure GM-20

PCE after 10 years
EW- Pumping: 5 yrs
Shallow

Figure GM-21

PCE after 15 years
EW- Pumping: 5 yrs
Shallow

Figure GM-22

TCE after 5 years
EW- Pumping: 5 yrs
Shallow

Figure GM-23

TCE after 10 years
EW- Pumping: 5 yrs
Shallow

Figure GM-24

TCE after 15 years
EW- Pumping: 5 yrs
Shallow

Figure GM-25

PCE after 5 years
EW- Pumping: 5 yrs
USA

Figure GM-26

PCE after 10 years
EW- Pumping: 5 yrs
USA

Figure GM-27

PCE after 15 years
EW- Pumping: 5 yrs
USA

Figure GM-28

TCE after 5 years
EW- Pumping: 5 yrs
USA

Figure GM-29

TCE after 10 years
EW- Pumping: 5 yrs
USA

Figure GM-30

TCE after 15 years
EW- Pumping: 5 yrs
USA

Figure GM-31

PCE after 5 years
EW- Pumping: 5 yrs
Deep

Figure GM-32

PCE after 10 years
EW- Pumping: 5 yrs
Deep

Figure GM-33

PCE after 15 years
EW- Pumping: 5 yrs
Deep

Figure GM-34

TCE after 5 years
EW- Pumping: 5 yrs
Deep

Figure GM-35

TCE after 10 years
EW- Pumping: 5 yrs
Deep

Figure GM-36

TCE after 15 years
EW- Pumping: 5 yrs
Deep

Figure GM-37

PCE after 5 years
EW- Pumping: 10 yrs
Shallow

Figure GM-38

PCE after 10 years
EW- Pumping: 10 yrs
Shallow

Figure GM-39

PCE after 15 years
EW- Pumping: 10 yrs
Shallow

Figure GM-40

TCE after 5 years
EW- Pumping: 10 yrs
Shallow

Note: The minimum contour shown is the PCE or TCE cleanup level. If no contours are shown, all modelled data are below the PCE or TCE cleanup levels.

Figure GM-41

TCE after 10 years
EW- Pumping: 10 yrs
Shallow

Figure GM-42

TCE after 15 years
EW- Pumping: 10 yrs
Shallow

Figure GM-43

PCE after 5 years
EW- Pumping: 10 yrs
USA

Figure GM-44

PCE after 10 years
EW- Pumping: 10 yrs
USA

Figure GM-45

PCE after 15 years
EW- Pumping: 10 yrs
USA

Figure GM-46

TCE after 5 years
EW- Pumping: 10 yrs
USA

Figure GM-47

TCE after 10 years
EW- Pumping: 10 yrs
USA

Figure GM-48

TCE after 15 years
EW- Pumping: 10 yrs
USA

Figure GM-49

PCE after 5 years
EW- Pumping: 10 yrs
Deep

Figure GM-50

PCE after 10 years
EW- Pumping: 10 yrs
Deep

Figure GM-51

PCE after 15 years
EW- Pumping: 10 yrs
Deep

Figure GM-52

TCE after 5 years
EW- Pumping: 10 yrs
Deep

Figure GM-53

TCE after 10 years
EW- Pumping: 10 yrs
Deep

Figure GM-54

TCE after 15 years
EW- Pumping: 10 yrs
Deep

Note: The minimum contour shown is the PCE or TCE cleanup level. If no contours are shown, all modelled data are below the PCE or TCE cleanup levels.

APPENDIX C

Applicable or Relevant and Appropriate Requirements

C.1 Federal Requirements

The Clean Water Act. The Clean Water Act (CWA) was established to protect the quality of surface water in the United States (33 United States Code (U.S.C.) Section 1251 et seq). The statute utilizes a variety of regulatory and non-regulatory tools to reduce direct pollutant discharges into waterways, finance municipal wastewater treatment facilities, and manage polluted runoff. Section 304 of the CWA requires the U.S. Environmental Protection Agency (EPA) to publish water quality criteria, which are developed for the protection of human health and aquatic species. Federal water quality standards are published in *Quality Criteria for Water, EPA 440/5-86-001*, dated May 1, 1986. Updates to water quality standards are included in the Federal Register (51 FR 43665) as they are developed. The State of Washington uses federal water quality standards to set water quality standards for the protection of state surface water.

The discharge of pollutants into navigable waters is regulated under Sections 401 and 404 of the CWA. These requirements include regulations for the excavation of shoreline materials and the placement of fill material below the ordinary high water elevation of U.S. waters. These regulations are implemented by the U.S. Army Corps of Engineers (USACE) and EPA. The guidelines also provide that no discharge will be authorized which contributes to significant degradation of U.S waters. Sections 401—404 of the CWA may be applicable to environmental remediation projects that address potential groundwater discharges to surface water, or shoreline cleanup projects if sediment removal or capping technologies are implemented.

Safe Drinking Water Act (42 USC Section 300f). The Safe Drinking Water Act (SDWA) sets a framework for the Underground Injection Control (UIC) Program to control the injection of wastes into groundwater. EPA and individual states implement the UIC program, which sets standards for safe waste injection practices and bans certain types of injection altogether.

Resource Conservation and Recovery Act. The Resource Conservation and Recovery Act (RCRA) is the principal federal law in the United States governing the disposal of solid waste and hazardous waste. RCRA handles many regulatory functions of hazardous and non-hazardous waste. The Subtitle C program tracks the progress of hazardous wastes from their point of generation through their transport, and their treatment and/or disposal. The overall process has become known as the "cradle to grave" system. In the State of Washington, RCRA is implemented by the Department of Ecology (Ecology) under the Dangerous Waste Regulations (Washington Administrative Code [WAC] 173-303).

Federal Clean Air Act. The Federal Clean Air Act (FCAA) regulates the emissions of hazardous pollutants into air. Specific controls for this program are regulated under federal, state, and local programs. In the State of Washington, the FCAA is implemented through the Washington Clean Air Act (Revised Code of Washington [RCW] 70.94). Remedial actions that result in the release of hazardous substances to air are regulated under the Washington Clean Air Act.

Endangered Species Act. The Endangered Species Act of 1973 (16 U.S.C. 1531-1544, 87 Statute 884) was established to protect ecosystems upon which threatened and endangered species of fish, wildlife, and plants depend.

United States Fish and Wildlife Service Mitigation Policy (46 FR 7644). The policy provides guidance for United States Fish and Wildlife Service personnel responsible for making recommendations to protect or conserve fish and wildlife resources.

The Fish and Wildlife Coordination Act (16 U.S.C. 661-667e). The act of March 10, 1934 authorizes the Secretaries of Agriculture and Commerce to provide assistance to and cooperate with federal and state agencies to protect, rear, stock, and increase the supply of game and fur-bearing animals, as well as to study the effects of domestic sewage, trade wastes, and other polluting substances on wildlife.

C.2 Washington State and Local Requirements

Cleanup standards are adopted under the Model Toxics Control Act (MTCA) for remedial actions at sites where hazardous substances are present. The specific processes for identifying, investigating, and remediating those sites are defined and cleanup standards are developed for soil, groundwater, surface water, and air (WAC 173-340). The development of cleanup levels for sediments is described in MTCA (WAC 173-340-760) through reference to WAC 173-294. In addition to MTCA, other state requirements may apply to this remedial action, and are summarized below.

State Environmental Policy Act (43.21C RCW; WAC 197-11). The State Environmental Policy Act (SEPA) was created to ensure that state and local government officials consider potential environmental impacts when making decisions. These decisions may be related to issuing permits for private projects, constructing public facilities, or adopting regulations, policies, or plans. The SEPA process begins when an application for a permit is submitted to a state or local government agency, or when an agency proposes to take an action such as the implementation of a remedial action. One agency is identified as the "lead agency" under the SEPA Rules (WAC 197-11-924—938), and is responsible for conducting the environmental review for a proposal and documenting that review in the appropriate SEPA documents.

Washington Water Pollution Control Act (Chapter 90.48 of RCW; WAC 173-201A). This act provides for the protection of surface water and groundwater quality. Under this act, groundwater quality standards are established for surface waters of the state (WAC 173-201A). In accordance with RCW Chapter 90.48, Ecology will issue a water quality certification, including cleanup actions under MTCA, which may result in discharging to state waters. According to RCW 90.48.039, the procedural requirements of the aforementioned chapter do not apply to any person conducting a remedial action at a facility pursuant to a consent decree, order, or agreed order issued pursuant to chapter 70.105D RCW.

Washington Hydraulic Code (Chapter 77.55 of RCW; WAC 220 110). Under this code, any organization or agency wishing to conduct any construction activity that will use, divert, obstruct, or change the natural flow or bed of state waters must do so under the terms of a permit (called the Hydraulic Project Approval [HPA]) issued by the Washington Department of Fish and Wildlife.

Washington State Clean Air Act (RCW 70.94). As discussed in above, the FCAA is implemented in Washington through the Washington Clean Air Act (RCW 70.94). Ecology, the Energy Facility Site Evaluation Council (EFSEC), and any of seven local air quality agencies have received EPA approval to administer Washington's air operating permit program.

Washington Solid Waste Management – Reduction and Recycling Act (Chapter 70.95 RCW; Chapter 173-350 WAC). This act establishes a state-wide program for solid waste handling, recovery, and/or recycling to prevent land, air, and water pollution and conserve the natural and economic resources of the state.

Washington Hazardous Waste Management Act (Chapter 70.105 RCW; Chapter 173-303 WAC). Under this act, hazardous waste materials must be monitored until they are properly disposed of or are converted to non-hazardous waste. Any hazardous materials transported from the Site must be sampled, tracked, and monitored under the appropriate regulations. This act also establishes regulations for hazardous waste treatment, storage, transfer, and disposal facilities.

Underground Injection Control Program (Chapter 173-218 WAC). The program was designed to protect groundwater quality by preventing groundwater contamination by regulating the discharge of fluids into UIC wells. The program satisfies the intent and requirements of Washington State Water Pollution Control Act (Chapter 90.48 RCW) as well as Part C of the SDWA.

Compensatory Mitigation Policy for Aquatic Resources and Aquatic Resources Mitigation Act. (Chapters 75.46 and 90.74 RCW). RCW 75.46 states that the guidance shall develop procedures that provide for alternative mitigation that have a low risk to the environment and have a high net environmental, social, and economic benefit when compared to "status quo" operations. In 1996, the Washington State Legislature passed the Aquatic Resources Mitigation Act (RCW 90.74), stipulating that it is the policy of the state to authorize mitigation measures by requiring state regulatory agencies to consider mitigation proposals for infrastructure projects that are "timed, designed, and located in a manner to provide equal (or better) biological values and function, compared to traditional on-site mitigation proposals." When making regulatory decisions regarding mitigation plans, the agencies must consider factors identified in the Hydraulic Code, the State Water Pollution Control Act, and the Aquatic Resources Mitigation Act.

Water Resources Act (Chapter 90.54 RCW). This act establishes fundamental policies for the utilization and management of the waters of the State of Washington.

State Aquatic Lands Management Laws (Chapters 79.90—79.96 RCW; WAC 332-30, particularly WAC 332-30-11). Section 332-30-11 of WAC authorizes a port district to manage some or all of those aquatic lands within the port district, provided that the port district adheres to the aquatic land management laws and policies of the state.

Growth Management Act (Chapters 36.70A, 36.70.A.150, and 36.70.A.200 RCW). The Growth Management Act (GMA) was adopted because the Washington State Legislature found that uncoordinated and unplanned growth posed a threat to the environment, sustainable economic development, and the quality of life in Washington. This act requires counties and cites to classify and designate natural resource lands and critical areas (including "waters of the state"). Additionally, select cities and counties (typically those experiencing the fastest growth) must adopt comprehensive and development regulations regarding land use within their jurisdiction. The state sets goals and manages deadlines for compliance, while comprehensive plans and regulations are often developed and implemented at the local level.

APPENDIX D

NuStar Source Area Feasibility Study Evaluation Supporting Documentation

Table D-1
Soil Analytical Summary Tables - VOCs in Soil (≤ 25 feet bgs)
NuStar Vancouver Facility

Sample ID	Collection Date	Sample Depth (feet)	Method	Chemicals of Potential Concern (COPCs) cis-1,2-Dichloroethene	Tetrachloro-ethene	Trichloro-ethene
			Soil Cleanup Levels	0.35	0.03	0.05
MW-1	11/3/1993	8	8010	<0.0005	0.0047	0.0015
		17	8010	0.0041	0.025	0.0064
MW-2	11/3/1993	20.5	8010	<0.0005	0.0056	0.0014
MW-3	11/3/1993	12.5	8010	<0.0005	0.0042	<0.0005
		20	8010	<0.0005	0.011	0.00059
MW-4	11/4/1994	9.5	8010	<0.0005	0.0059	<0.0005
		18.5	8010	<0.0005	0.016	<0.0005
MW-5	11/4/1994	12.5	8010	<0.0025	0.21	<0.0025
		21.5	8010	<0.0025	0.16	<0.0025
MW-6	11/4/1994	15.5	8010	<0.0005	<0.0005	<0.0005
MW-7	11/4/1996	5	8010	<0.01	0.22	<0.01
		15	8010	<0.01	0.52	<0.01
MW-8	11/5/1996	5	8010	<0.01	0.014	<0.01
		10	8010	<0.01	<0.01	<0.01
MW-9	11/5/1996	15	8010	<0.01	0.042	<0.01
		20	8010	<0.01	0.050	<0.01
		24.5	8010	<0.01	0.043	<0.01
MW-11	11/6/1996	24.5	8010	<0.01	<0.01	<0.01
MW-12	11/6/1996	15	8010	<0.01	<0.01	<0.01
MW-13	11/7/1996	20	8010	0.012	<0.01	<0.01
		24.5	8010	<0.01	1.6	0.1
GP1	10/23/1997	20	8010	<0.05	0.055	<0.05
GP2	10/23/1997	5	8010	<0.05	<0.05	<0.05
		10	8010	<0.05	<0.05	<0.05
		15	8010	<0.05	0.078	<0.05
		20	8010	<0.05	0.915	0.0775
GP3	10/23/1997	5	8010	<0.05	1.07	<0.05
		10	8010	<0.500	11.5	1.28
		15	8010	<0.100	1.24	0.248
		20	8010	<0.05	0.191	<0.05
		25	8010	<0.05	0.07	<0.05
GP4	10/23/1997	20	8010	<0.05	<0.05	<0.05
GP5	10/23/1997	15	8010	<0.05	0.0582	<0.05
GP6	10/24/1997	15	8010	<0.05	0.0869	<0.05
GP7	10/24/1997	10	8010	<0.05	0.151	<0.05
GP8	10/24/1997	5	8010	<0.05	0.0734	<0.05
		10	8010	<0.05	<0.05	<0.05
		20	8010	<0.05	2.1	0.123
		25	8010	<0.05	<0.05	<0.05

Please refer to notes at end of table.

Table D-1
Soil Analytical Summary Tables - VOCs in Soil (≤ 25 feet bgs)
NuStar Vancouver Facility

				Chemicals of Potential Concern (COPCs)		
Sample ID	Collection Date	Sample Depth (feet)	Method	cis-1,2-Dichloroethene	Tetrachloro-ethene	Trichloro-ethene
			Soil Cleanup Levels	0.35	0.03	0.05
GP9	10/24/1997	11.5	8010	<0.05	0.261	0.0895
		20	8010	<0.25	10.9	1.32
		25	8010	<0.05	0.057	<0.05
GP10	10/24/1997	15	8010	<0.05	0.387	<0.05
MW-14	10/30/1997	10	8010	--	--	--
		25	8010	<0.05	<0.05	<0.05
MW-15	10/30/1997	10	8010	--	--	--
		25	8010	<0.05	<0.05	<0.05
MW-16	10/30/1997	10	8010	--	--	--
		25	8010	<0.05	0.121	<0.05
MW-17	10/30/1997	25	8010	<0.05	<0.05	<0.05
IW	7/22/1999	17-18.5	8010	<0.05	0.483	<0.05
		23-24.5	8010	<0.05	9.76	0.731
MP1	7/21/1999	20	8010	<0.05	1.24	0.0781
MP2	7/21/1999	20	8010	<0.05	2.12	0.172
MP3	7/23/1999	25	8010	<0.05	5.74	1.07
MP4	7/23/1999	25	8010	<0.05	29.5	0.985
S1	7/19/1999	25	8010	<0.05	<0.05	<0.05
TMP3	7/20/1999	5	8010	<0.05	<0.05	<0.05
V1	7/20/1999	25	8010	<0.05	<0.05	<0.05
MW-18	9/11/2000	25	8010	<0.05	<0.05	<0.05
EX	7/22/1999	17-18.5	8010	<0.05	1.95	0.171
		23-24.5	8010	<0.05	2.19	0.108
EX-3	5/18/2000	20	8010	<0.05	<0.05	<0.05
EX-4	5/18/2000	20	8010	<0.05	0.384	<0.05
EX-5	5/19/2000	25	8010	<0.05	0.191	0.073
IN-1	9/29/2000	25	8010	<0.05	<0.05	<0.05
IN-2	5/17/2000	20	8010	0.133	0.267	<0.05
IN-3	5/17/2000	20	8010	<0.05	61	4.65
IN-4	5/17/2000	25	8010	<0.05	1.06	<0.05
IN-5	5/18/2000	25	8010	<0.05	0.255	<0.05
IN-6	9/28/2000	25	8010	<0.05	<0.05	<0.05
IN-7	9/28/2000	25	8010	<0.05	<0.05	<0.05
IN-8	9/28/2000	25	8010	0.083	8.18	0.13
IN-9	9/28/2000	20	8010	<0.05	0.126	<0.05
AGP-03-13	5/10/2006	13	8260B	<0.0956	<0.0956	<0.0956
AGP-10-6.5	4/25/2006	6.5	8260B	<0.359	3.14	<359
AGP-12-13	4/25/2006	13	8260B	<0.0783	2.99	0.568
AGP-20-17.5	4/28/2005	17.5	8260B	<0.107	0.544	<0.107
AGP-21-13	5/1/2006	13	8260B	<0.0939	0.0995	<0.0939
AGP-22-18	5/2/2006	18	8260B	<0.184	41.7	2.18

Please refer to notes at end of table.

Table D-1
Soil Analytical Summary Tables - VOCs in Soil (≤ 25 feet bgs)
NuStar Vancouver Facility

				Chemicals of Potential Concern (COPCs)		
Sample ID	Collection Date	Sample Depth (feet)	Method	cis-1,2-Dichloroethene	Tetrachloro-ethene	Trichloro-ethene
			Soil Cleanup Levels	0.35	0.03	0.05
AGP-23-12.5	5/8/2006	12.5	8260B	<0.103	0.483	<0.103
AGP-24-12	5/8/2006	12	8260B	<0.0961	1.93	0.144
AGP-26-18	5/3/2006	18	8260B	<0.115	4.03	0.182
AGP-27-8.75	5/2/2006	8.75	8260B	<0.0896	1.51	<0.0896
AGP-28-9	5/3/2006	9	8260B	<0.218	59.3	0.536
AGP-28-17.5	5/3/2006	17.5	8260B	<0.403	65.2	1.87
AGP-29-9.5	5/4/2006	9.5	8260B	<4.78	1,320	<4.78
AGP-29-18	5/4/2006	18	8260B	<0.093	14.9	<0.093
AGP-32-14	5/9/2006	14	8260B	<0.0984	<0.0984	<0.0984
AGP-33-14	5/12/2006	14	8260B	<0.0952	<0.0952	<0.0952
AGP-35-18.5	5/15/2006	18.5	8260B	<0.0953	<0.0953	<0.0953
AGP-36-18	5/16/2006	18	8260B	<0.0933	<0.0933	<0.0933
AGP-38-24	5/11/2006	24	8260B	<0.109	0.204	<0.109
AGP-39-17.5	5/16/2006	17.5	8260B	<0.0964	<0.0964	<0.0964
AGP-42-17	6/19/2006	17	8260B	<0.0988	<0.0988	<0.0988
AGP-43-16.5	6/15/2006	16.5	8260B	<0.106	<0.106	<0.106
AGP-45-7	6/23/2006	7	8260B	<0.0994	<0.0994	<0.0994
AGP-52-4	6/13/2007	15.5-16	8260B	<0.228	<0.228	<0.228
AGP-54-5	6/15/2007	20.5-21	8260B	<0.228	<0.228	<0.228
AGP-55-6	6/19/2007	20.5-21	8260B	<0.223	<0.223	<0.223
AGP-56-6	6/19/2007	17.5-18	8260B	<0.209	<0.209	<0.209
AGP-57-4	6/19/2007	16-16.5	8260B	<0.216	<0.216	<0.216
CB-1(17.5)	9/20/2010	17.5	8260B	<30	10,000	93
CB-1(9)	9/20/2010	9	8260B	<40	6,700,000	<4,000
CB-2 (18)	9/20/2010	18	8260B	<5	19	<5
CB-2 (9.5)	9/20/2010	9	8260B	<40	130,000	<40
CB-3 (9)	9/21/2010	9	8260B	<5	1,800	6.9
CB-3(18)	9/21/2010	18	8260B	<40	24,000	180
CB-4 (18)	9/21/2010	18	8260B	<5	2,000	<5

Notes:

1. Concentrations in milligrams per kilogram (mg/kg) parts per million (ppm).
2. < = Not detected at corresponding numerical limit.
3. **Bolded** values indicate analyte detected above laboratory method detection limits (MDL).
4. -- = Compound not reported or sample not analyzed.
5. feet bgs = Feet below ground surface.
6. Shading indicates concentration exceeds cleanup level.
7. Cleanup level from Table 5-1.

CAP18™ Reagent Estimation Software - Cascade Design

For technical assistance or to place an order: (317) 576-1998

Use of this Software constitutes acceptance of the License and Disclaimer included with this spreadsheet.

SITE NAME: Nustar Vancouver
PREPARED BY: Ash Creek Associates
DATE PREPARED: 18-Dec-13

1. Site Model / Treatment Area Volume

1.1. Treatment Area Volume

Length (parallel to predominant groundwater flow direction)	80	Ft
Width (perpendicular to predominant groundwater flow direction)	540	Ft
Thickness of Treatment Zone	25	Ft

1.2. Treatment Area Characteristics

Soil Characteristics		
Nominal Soil Type (enter clay, silt, silty sand, sand, or gravel)	sand	
Bulk Density (accept default or enter ρ_b)	1.60	g/cc
Bulk Density Units Conversion =	99.9	lbs/cu. Ft
Fraction Organic Carbon (accept default or enter f_{oc})	0.0005	(decimal)
Hydraulic Characteristics		
Total Porosity (accept default or enter n)	0.38	(decimal)
Effective Porosity (accept default or n_e)	0.29	(decimal)
Hydraulic Conductivity (accept default or enter K)	173	Ft/day
Hydraulic Conductivity Units Conversion =	6.1E-02	cm/sec
Hydraulic Gradient (accept default or enter i)	0.0005	Ft/Ft
CAP18™ Lifespan (accept default or enter T_R)	3	yr

1.3. Calculations

Treatment Area	43,200	sq. Ft			
Treatment Volume	1,080,000	cu. Ft	=	40,000	cu. Yards
Seepage Velocity (V_X)	2.98E-01	Ft/day	=	1.09E+02	Ft/yr
Total Pore Volume (V_P)	410,400	cu. Ft	=	3,070,005	gallons

2. Hydrogen Demand

2.1. Dissolved Contaminant Demand

	Concentration (mg/L)	Mass (lbs)	Stoichiometric Demand (wt/wt H_2)	Hydrogen Demand (lbs)
Tetrachloroethene (PCE)	1.72	44.1	20.6	2.1
Trichloroethene (TCE)	0.89	22.8	21.7	1.1
cis-1,2-Dichloroethene (DCE)	1.42	36.4	24.0	1.5
Vinyl Chloride	0.25	6.4	31.0	0.2
Carbon Tetrachloride	0	0.0	25.4	0.0
1,1,1-Trichloroethane (TCA)	0	0.0	33.1	0.0
1,1-Dichloroethane (DCA)	0	0.0	49.1	0.0
Perchlorate	0	0.0	6.2	0.0
User-Supplied Electron Acceptor	0	0.0	0	0
User-Supplied Electron Acceptor	0	0.0	0	0

2.2. Sorbed Contaminant Demand

	K_{oc} (L/kg)	Concentration (mg/kg)	Mass (lbs)	Stoichiometric Demand (wt/wt H_2)	Hydrogen Demand (lbs)
Tetrachloroethene (PCE)	230	0.2	21	20.6	1.0
Trichloroethene (TCE)	87	0.0	4	21.7	0.2
cis-1,2-Dichloroethene (DCE)	49	0.0	4	24.0	0.2
Vinyl Chloride	30	0.0	0	31.0	0.0
Carbon Tetrachloride	71	0.0	0	25.4	0.0
1,1,1-Trichloroethane (TCA)	90	0.0	0	33.1	0.0
1,1-Dichloroethane (DCA)	37	0.0	0	49.1	0.0
User-Supplied Electron Acceptor		0	0	0	0
User-Supplied Electron Acceptor		0	0	0	0

2.3. Background Demand

	Concentration (mg/L)	Mass (lbs)	Stoichiometric Demand (wt/wt H_2)	Pore Flush Factor (Dimensionless)	Hydrogen Demand (lbs)
Oxygen	2	51.2	7.9	4.08	26.4
Nitrate	80	2,049.5	10.3	4.08	816.3
Manganese	2	51.2	27.3	4.08	7.7
Iron	20	512.4	55.4	4.08	37.8
Sulfate	10	256.2	11.9	4.08	88
Water Hardness (as $CaCO_3$)	50	1,281.0	69.6	4.08	75.2

3. TOTAL CAP18™ DEMAND

Dissolved Contaminant Stoichiometric Hydrogen Demand	=	5 lbs H_2
Sorbed Contaminant Stoichiometric Hydrogen Demand	=	1 lbs H_2
Background Stoichiometric Hydrogen Demand	=	1051 lbs H_2
Total Stoichiometric Hydrogen Demand	=	1057 lbs H_2
Microbial Degradation Factor (recommend 5x)	=	5 (multiplier)
Design Contingency Factor (recommend 5x)	=	2 (multiplier)
Total Hydrogen Demand	=	8,459 lbs H_2
CAP18™ Requirement	**=**	**81,802 lbs CAP18™**

Software Version 1d (beta)

CAP18™ Reagent Estimation Software - Cascade Design

For technical assistance or to place an order: (317) 576-1998

Use of this Software constitutes acceptance of the License and Disclaimer included with this spreadsheet.

SITE NAME: Nustar Vancouver
PREPARED BY: Ash Creek Associates **DATE PREPARED:** 18-Dec-13

1. Site Model / Treatment Area Volume

1.1. Treatment Area Volume

Length (parallel to predominant groundwater flow direction)	80	Ft
Width (perpendicular to predominant groundwater flow direction)	200	Ft
Thickness of Treatment Zone	25	Ft

1.2. Treatment Area Characteristics

Soil Characteristics		
Nominal Soil Type (enter clay, silt, silty sand, sand, or gravel)	sand	
Bulk Density (accept default or enter ρ_b)	1.60	g/cc
Bulk Density Units Conversion =	99.9	lbs/cu. Ft
Fraction Organic Carbon (accept default or enter f_{oc})	0.0005	(decimal)
Hydraulic Characteristics		
Total Porosity (accept default or enter n)	0.38	(decimal)
Effective Porosity (accept default or n_e)	0.29	(decimal)
Hydraulic Conductivity (accept default or enter K)	173	Ft/day
Hydraulic Conductivity Units Conversion =	6.1E-02	cm/sec
Hydraulic Gradient (accept default or enter i)	0.0005	Ft/Ft
CAP18™ Lifespan (accept default or enter T_R)	3	yr

1.3. Calculations

Treatment Area	16,000	sq. Ft			
Treatment Volume	400,000	cu. Ft	=	14,815	cu. Yards
Seepage Velocity (V_X)	2.98E-01	Ft/day	=	1.09E+02	Ft/yr
Total Pore Volume (V_P)	152,000	cu. Ft	=	1,137,039	gallons

2. Hydrogen Demand

2.1. Dissolved Contaminant Demand

	Concentration (mg/L)	Mass (lbs)	Stoichiometric Demand (wt/wt H_2)	Hydrogen Demand (lbs)
Tetrachloroethene (PCE)	1.72	16.3	20.6	0.8
Trichloroethene (TCE)	0.89	8.4	21.7	0.4
cis-1,2-Dichloroethene (DCE)	1.42	13.5	24.0	0.6
Vinyl Chloride	0.25	2.4	31.0	0.1
Carbon Tetrachloride	0	0.0	25.4	0.0
1,1,1-Trichloroethane (TCA)	0	0.0	33.1	0.0
1,1-Dichloroethane (DCA)	0	0.0	49.1	0.0
Perchlorate	0	0.0	6.2	0.0
User-Supplied Electron Acceptor	0	0.0	0	0
User-Supplied Electron Acceptor	0	0.0	0	0

2.2. Sorbed Contaminant Demand

	K_{oc} (L/kg)	Concentration (mg/kg)	Mass (lbs)	Stoichiometric Demand (wt/wt H_2)	Hydrogen Demand (lbs)
Tetrachloroethene (PCE)	230	0.2	8	20.6	0.4
Trichloroethene (TCE)	87	0.0	2	21.7	0.1
cis-1,2-Dichloroethene (DCE)	49	0.0	1	24.0	0.1
Vinyl Chloride	30	0.0	0	31.0	0.0
Carbon Tetrachloride	71	0.0	0	25.4	0.0
1,1,1-Trichloroethane (TCA)	90	0.0	0	33.1	0.0
1,1-Dichloroethane (DCA)	37	0.0	0	49.1	0.0
User-Supplied Electron Acceptor		0	0	0	0
User-Supplied Electron Acceptor		0	0	0	0

2.3. Background Demand

	Concentration (mg/L)	Mass (lbs)	Stoichiometric Demand (wt/wt H_2)	Pore Flush Factor (Dimensionless)	Hydrogen Demand (lbs)
Oxygen	2	19.0	7.9	4.08	9.8
Nitrate	80	759.1	10.3	4.08	302.4
Manganese	2	19.0	27.3	4.08	2.8
Iron	20	189.8	55.4	4.08	14.0
Sulfate	10	94.9	11.9	4.08	33
Water Hardness (as $CaCO_3$)	50	474.4	69.6	4.08	27.8

3. TOTAL CAP18™ DEMAND

Dissolved Contaminant Stoichiometric Hydrogen Demand	=	2	lbs H_2
Sorbed Contaminant Stoichiometric Hydrogen Demand	=	1	lbs H_2
Background Stoichiometric Hydrogen Demand	=	389	lbs H_2
Total Stoichiometric Hydrogen Demand	=	392	lbs H_2
Microbial Degradation Factor (recommend 5x)	=	5	(multiplier)
Design Contingency Factor (recommend 5x)	=	2	(multiplier)
Total Hydrogen Demand	=	3,133	lbs H_2
CAP18™ Requirement	**=**	**30,297**	**lbs CAP18™**

CAP18™ Reagent Estimation Software - Curtain Design

For technical assistance or to order: (317) 576-1998

Use of this Software constitutes acceptance of the License and Disclaimer included with this spreadsheet.

SITE NAME: NuStar Vancouver
PREPARED BY: MWS **DATE PREPARED:** 10/20/2009

1. Site Model / Treatment Area Volume

1.1. Treatment Area Volume

Curtain Length (perpendicular to predominant groundwater flow direction)	500	Ft
Thickness of Treatment Zone	25	Ft

1.2. Treatment Area Characteristics

Soil Characteristics		
Nominal Soil Type (enter clay, silt, silty sand, sand, or gravel)	sand	
Hydraulic Characteristics		
Total Porosity (accept default or enter *n*)	0.38	(decimal)
Effective Porosity (accept default or n_e)	0.29	(decimal)
Hydraulic Conductivity (accept default or enter *K*)	50	Ft/day
Hydraulic Conductivity Units Conversion =	1.8E-02	cm/sec
Hydraulic Gradient (accept default or enter *i*)	0.001	Ft/Ft
CAP18™ Lifespan (accept default or enter T_R)	3	yr

1.3. Calculations

Seepage Velocity (V_x)	0.17	Ft/day	=	63	Ft/yr
Water Volume Passing in Time T_R (V_W)	684,375	cu. Ft	=	5,119,481	gallons

2. Hydrogen Demand

2.1. Dissolved Contaminant Demand

	Concentration (mg/L)	Mass (lbs)	Stoichiometric Demand (wt/wt H_2)	Hydrogen Demand (lbs)
Tetrachloroethene (PCE)	1.5	64.1	20.6	3.1
Trichloroethene (TCE)	0.6	25.6	21.7	1.2
cis-1,2-Dichloroethene (DCE)	1.3	55.5	24.0	2.3
Vinyl Chloride	0.065	2.8	31.0	0.1
Carbon Tetrachloride	0	0.0	25.4	0.0
1,1,1-Trichloroethane (TCA)	0	0.0	33.1	0.0
1,1-Dichloroethane (DCA)	0	0.0	49.1	0.0
Perchlorate	0	0.0	12.3	0.0
User-Supplied Electron Acceptor	0	0.0	0	0
User-Supplied Electron Acceptor	0	0.0	0	0

2.2. Background Demand

	Concentration (mg/L)	Mass (lbs)	Stoichiometric Demand (wt/wt H_2)	Hydrogen Demand (lbs)
Oxygen	2	85.4	7.9	10.8
Nitrate	80	3,417.8	12.3	277.9
Manganese	2	85.4	27.3	3.1
Iron	20	854.4	55.4	15.4
Sulfate	10	427.2	11.9	35.9
Water Hardness (as $CaCO_3$)	50	2,136.1	69.6	30.7

3. TOTAL CAP18™ DEMAND

Dissolved Contaminant Stoichiometric Hydrogen Demand	=	7	lbs H_2
Background Stoichiometric Hydrogen Demand	=	374	lbs H_2
Total Stoichiometric Hydrogen Demand	=	380	lbs H_2
Microbial Degradation Factor (recommend 5x)	=	5	(multiplier)
Design Contingency Factor (recommend 5x)	=	5	(multiplier)
Total Hydrogen Demand	=	4,185	lbs H_2
CAP18™ Requirement	**=**	**40,469**	**lbs CAP18™**

Software Version 1d (beta)

CAP18™ Reagent Estimation Software - Curtain Design

For technical assistance or to order: (317) 576-1998

Use of this Software constitutes acceptance of the License and Disclaimer included with this spreadsheet.

SITE NAME: NuStar Vancouver
PREPARED BY: MWS **DATE PREPARED:** 10/20/2009

1. Site Model / Treatment Area Volume

1.1. Treatment Area Volume

Curtain Length (perpendicular to predominant groundwater flow direction)	500	Ft
Thickness of Treatment Zone	25	Ft

1.2. Treatment Area Characteristics

Soil Characteristics		
Nominal Soil Type (enter clay, silt, silty sand, sand, or gravel)	sand	
Hydraulic Characteristics		
Total Porosity (accept default or enter *n*)	0.38	(decimal)
Effective Porosity (accept default or n_e)	0.29	(decimal)
Hydraulic Conductivity (accept default or enter *K*)	50	Ft/day
Hydraulic Conductivity Units Conversion =	1.8E-02	cm/sec
Hydraulic Gradient (accept default or enter *i*)	0.001	Ft/Ft
CAP18™ Lifespan (accept default or enter T_R)	3	yr

1.3. Calculations

Seepage Velocity (V_x)	0.17	Ft/day	=	63	Ft/yr
Water Volume Passing in Time T_R (V_W)	684,375	cu. Ft	=	5,119,481	gallons

2. Hydrogen Demand

2.1. Dissolved Contaminant Demand

	Concentration (mg/L)	Mass (lbs)	Stoichiometric Demand (wt/wt H_2)	Hydrogen Demand (lbs)
Tetrachloroethene (PCE)	1.5	64.1	20.6	3.1
Trichloroethene (TCE)	0.6	25.6	21.7	1.2
cis-1,2-Dichloroethene (DCE)	1.3	55.5	24.0	2.3
Vinyl Chloride	0.065	2.8	31.0	0.1
Carbon Tetrachloride	0	0.0	25.4	0.0
1,1,1-Trichloroethane (TCA)	0	0.0	33.1	0.0
1,1-Dichloroethane (DCA)	0	0.0	49.1	0.0
Perchlorate	0	0.0	12.3	0.0
User-Supplied Electron Acceptor	0	0.0	0	0
User-Supplied Electron Acceptor	0	0.0	0	0

2.2. Background Demand

	Concentration (mg/L)	Mass (lbs)	Stoichiometric Demand (wt/wt H_2)	Hydrogen Demand (lbs)
Oxygen	2	85.4	7.9	10.8
Nitrate	80	3,417.8	12.3	277.9
Manganese	2	85.4	27.3	3.1
Iron	20	854.4	55.4	15.4
Sulfate	10	427.2	11.9	35.9
Water Hardness (as $CaCO_3$)	50	2,136.1	69.6	30.7

3. TOTAL CAP18™ DEMAND

Dissolved Contaminant Stoichiometric Hydrogen Demand	=	7	lbs H_2
Background Stoichiometric Hydrogen Demand	=	374	lbs H_2
Total Stoichiometric Hydrogen Demand	=	380	lbs H_2
Microbial Degradation Factor (recommend 5x)	=	5	(multiplier)
Design Contingency Factor (recommend 5x)	=	5	(multiplier)
Total Hydrogen Demand	=	4,185	lbs H_2
CAP18™ Requirement	**=**	**40,469**	**lbs CAP18™**

Subject: NUSTAR VANCOUVER FS – PUMPING ALT			Page: 1 of
Project No: 1126	Date: 1/2/2014	By: MWS	

GIVEN RADIUS OF INFLUENCE OF 90 FT (WELL SPACING WITH OVERLAP) [27.4 m]
AQUIFER TRANSMISSIVITY OF 3.6 ft^2/min = [$0.0056\ m^2/sec$]

or $\frac{3.6\ ft^2/min}{30\ ft} = 0.12\ ft/min$ HYDRAULIC CONDUCTIVITY [$0.00061\ m/sec$]

ESTIMATED DRAWDOWN FROM ROI EQUATION ESTIMATE:

$$R = 3000(s)\sqrt{K} \quad (m)$$

$$s = \frac{R}{3000\sqrt{K}} = \frac{27.4\ m}{3000\sqrt{0.00061\ m/sec}} = 0.37\ m$$

or 1.2 feet

DUPUIT EQUATION FOR FLOW IN UNCONFINED AQUIFER

$$Q = \frac{\pi K (H^2 - h^2)}{\ln(R/r)}$$

$H = 30$ FT
$h = 30 - 1.2 = 28.8$ FT
$R = 90$ FT
$r = 0.5$ FT

$$Q = \frac{\pi (0.12\ ft/min)(30^2\ ft^2 - 28.8^2\ ft^2)}{\ln(90\ ft / 0.5\ ft)} = 5.1\ ft^3/min$$

or

38 gal/min

if 6" well ⇒ 34 gpm (OK)

or $R \approx 3(H-h)\sqrt{K}$ K in 10^{-4} cm/sec; rest in ft

$$H - h = \frac{R}{3\sqrt{K}} = \frac{90}{3\sqrt{610}} = 1.2\ ft$$

1/6/14

MEMORANDUM

Project No.: 130171-02

September 11, 2014

To: Amanda Spencer, Apex Companies, LLC

From: **Peter S. Bannister, PE**
Senior Engineer

Timothy J. Flynn, LHG, CGWP
Principal Hydrogeologist

Re: **Predicted Groundwater Concentrations and Cleanup Timeframes using Port of Vancouver Groundwater Flow Model - Revised**
NuStar Terminal Services, Inc. – Vancouver Facility

1 Introduction

This memorandum presents results of groundwater modeling performed by Aspect Consulting, LLC (Aspect) in coordination with Apex Companies, LLC (Apex) for NuStar Terminal Services Port of Vancouver facility, located in Vancouver, Washington. This work was conducted under a contract order with Apex. This revised memorandum expands upon an earlier version (dated February 19, 2014), and describes additional model scenarios and results requested by Apex.

The Port of Vancouver (POV) numerical groundwater flow model (Parametrix et al., 2008; Parametrix, 2011) was used to compare model-predicted restoration timeframes under different pumping scenarios for the Intermediate Zone of the aquifer under monitored natural attenuation of tetrachloroethene (PCE) and trichloroethene (TCE) concentrations in the vicinity of the NuStar facility. Restoration timeframes were defined as the time required for groundwater concentrations to achieve PCE and TCE proposed Cleanup Levels (CULs) of 5 micrograms per liter (µg/L) and 4 µg/L, respectively. Aspect assigned initial concentrations in the POV model to 2012 observed TCE and PCE concentrations provided by Apex. A total of four pumping scenarios were simulated. The POV extraction well, EW-1, was simulated for two pumping scenarios: with and without pumping. The Great Western Malting (GWM) wells were simulated for two pumping scenarios: with and without pumping. Under all pumping scenarios, model results showed limited pumping influence from GWM wells and/or EW-1. The POV model has not been calibrated for contaminant transport, and this may affect the accuracy of predicted restoration timeframes. The restoration timeframes under all pumping scenarios were similar, within the range of model uncertainty.

This memorandum is organized by first outlining the model objective (Section 2), summarizing changes to the POV model (Section 3), and providing model results of groundwater concentrations over time (Section 4). Lastly, we provide recommendations for verifying the model-predicted restoration timeframes, acknowledging that the POV model has not been calibrated for contaminant transport (Section 5).

2 Model Objectives

The objectives of this groundwater transport modeling effort were to simulate groundwater concentrations in the vicinity of the NuStar facility, and to predict restoration timeframes using 2012 observations as initial concentrations. The results of the modeling effort may be used to assess the efficacy of monitored natural attenuation for the NuStar source area. The POV model was designed to simulate groundwater flow and transport using industry-standard modeling codes: MODFLOW and MT3D. Aspect utilized the POV model without modification for scenario evaluation, except for input assumptions described in this memorandum.

3 Input to POV Model

As input to the POV model, Aspect specified a longer simulation period, updated initial concentrations, and evaluated pumping scenarios. The simulation period was conducted over a period of 532 weeks (10.2 years) to allow contaminant transport over a longer time period than provided by the POV model (82 weeks or 1.6 years). Aspect also specified initial concentrations and pumping rates at selected wells, and further details are provided below.

3.1 Initial Concentrations

As input to the POV model, Aspect specified the initial concentrations for PCE and TCE to reflect aquifer conditions in 2012. Apex provided maps showing 2012 isocontours of PCE and TCE groundwater concentrations in the vicinity of the NuStar facility (Apex, 2013), which are provided as Attachment 1. Figures 16 and 17 in Attachment 1 show the 2012 PCE and TCE concentrations in the Shallow Zone groundwater. Figures 19 and 20 in Attachment 1 show the 2012 PCE and TCE concentrations in the Intermediate Zone groundwater. Residual shallow zone concentrations for the POV Swan and Cadet Manufacturing sources were not included.

Aspect imported the mapped concentrations as initial concentrations in the POV model. The initial groundwater concentrations were assigned to zones of uniform value using the geometric mean of the isocontours defining the area. The table below shows the initial concentrations for the different areas:

Table 1 – Mapped Concentrations and Initial Concentrations in Model

Aquifer Zone	Area Between Concentration Isocontours (µg/L)	Model Zone	Assigned Initial PCE or TCE Concentration in Model (µg/L)
Shallow	<1	1	0.3
	1-20	2	4.5
	20-200	3	63.2
	200-1,000	4	447
Intermediate	<1	1	0.3
	1-10	5	3.2
	>10	6	31.6

Figures 1 and 2 show the initial PCE and TCE concentrations assigned in the Shallow Zone groundwater (Layers 1 and 2). Figures 3 and 4 show the initial PCE and TCE concentrations assigned in the Intermediate Zone groundwater (Layers 3 through 9).

3.2 POV EW-1 Pumping

Changes in groundwater concentrations were evaluated for two different flow conditions based on EW-1 pumping scenario: with EW-1 pumping, and without EW-1 pumping. The pumping rate of 2,500 gallons per minute (gpm) from EW-1 was previously assigned in the POV model, and was not modified for evaluation of conditions with EW-1 pumping. To simulate the scenario without EW-1 pumping, Aspect assigned a pumping rate of 0 gpm.

3.3 GWM Pumping

Changes in groundwater concentrations were evaluated for two different flow conditions based on GWM pumping scenarios: with GWM pumping, and without GWM pumping. GMW well pumping rates were previously assigned in the POV model, and were not modified for evaluation of conditions with GWM pumping. To simulate the scenario without GWM pumping, Aspect assigned a pumping rate of 0 gpm to all GMW wells.

4 Model Results

Model results were evaluated for selected monitoring well locations completed in the Intermediate Zone, including: MW-20i, MW-21i-40, MW-21i-105, MW-22i, MW-23i, MW-24i, MW-31i, and MW-32i. These wells were selected because the model predicted maximum PCE or TCE concentrations at these locations typically exceeded 1 µg/L. Locations for the selected monitoring wells are shown on Figures 19 and 20 in Attachment 1.

Figure 5 shows modeled concentrations over time *without* EW-1 pumping. Results for PCE concentrations are shown in the top two graphs, and results for TCE concentrations are shown in the bottom two graphs. Results with GWM wells pumping are shown in the left two graphs, and results without GWM pumping are shown in the right two graphs. A logarithmic scale is used to show concentrations.

Figure 6 is similar to Figure 5, but shows results *with* EW-1 pumping. Figures 5 and 6 also show the proposed CULs for PCE and TCE. Similar patterns in modeled groundwater concentrations over time were observed while comparing Figures 5 and 6, indicating minimal pumping influence from EW-1 and the GWM wellfield for most monitoring well locations.

Table 2 shows the restoration timeframe as the number of years for groundwater concentrations to reach proposed CULs. The top table shows model results *without* EW-1 pumping, for PCE and TCE, and with and without GWM pumping. The bottom table is similar to the top table, but shows model results *with* EW-1 pumping. The restoration timeframe was calculated for each well using linear trendline analysis. If the modeled concentrations did not exceed the proposed CUL, the table shows "NA" for not applicable. The results shown in Table 2 indicate limited pumping influences on restoration timeframes for most wells.

Based on model results, PCE concentrations remained less than the proposed CUL of 5 µg/L at wells MW-22i and MW-23i, with and without pumping from EW-1 and GWM wells. Within approximately 3 years, PCE concentrations decreased to less than the proposed CUL at MW-21i-40, MW-21i-105, MW-31i, and MW-32i. The influence of pumping from EW-1 resulted in PCE concentrations at MW-20i exceeding the CUL and a restoration timeframe of approximately 5 years. Pumping at EW-1 had little effect on PCE restoration timeframes at the other monitoring wells evaluated (MW-21i-40, MW-21i-105, MW-22i, MW-23i, MW-24i, MW-31i, and MW-32i). The restoration timeframe for PCE at MW-24i was projected to be less than approximately 15 years. The POV model has not been calibrated for contaminant transport, and this may affect the accuracy of predicted PCE restoration timeframes.

Based on model results, TCE concentrations remained less than the proposed CUL of 4 µg/L at well MW-20i. Within approximately 3 years, TCE concentrations decreased to less than the proposed CUL at MW-21i-40, MW-21i-105, MW-22i, MW-31i, and MW-32i. The influence of pumping from EW-1 resulted in a shorter restoration timeframe at MW-23i. Pumping at EW-1 had little effect on TCE restoration timeframes at the other monitoring wells evaluated (MW-20i, MW-21i-40, MW-21i-105, MW-22i, MW-24i, MW-31i, and MW-32i).The restoration timeframe for TCE at MW-24i was projected to be less than approximately 12 years. As indicated above, the POV model has not been calibrated for contaminant transport, and this may affect the accuracy of predicted TCE restoration timeframes.

5 Recommendations

The POV model was used “as-is”, without calibration to observed (empirical) groundwater concentration data. Model results provide comparisons of the relative influence of different pumping scenarios on restoration timeframe. Use of these model results without contaminant transport calibration or verification may yield over-predicted or under-predicted restoration timeframes. Model calibration would require re-running the POV model, and possibly changing the model parameters. Model verification would not require re-running the POV model. To verify the model, we recommend comparing model results to post-2012 observed groundwater concentrations. Finally, the implications of long-term model predictions should be assessed, and alternative methods to improve the accuracy of restoration timeframes should be evaluated.

References

Apex Companies, LLC (Apex), 2013, Draft 2013 Remedial Investigation Report, NuStar Terminal Services, Inc. Vancouver Facility, Vancouver, Washington.

Parametrix, 2011, DRAFT – Interim action summary report groundwater pump and treatment system SMC and Cadet Sites, Vancouver, Washington. June 17, 2011.

Parametrix, S.S. Papadopulos & Associates, Pacific Groundwater Group, and Keta Waters, 2008, Vancouver Lake Lowlands, Groundwater model summary report. February 2008.

Limitations

Work for this project was performed for Apex Companies, LLC (Client), and this memorandum was prepared in accordance with generally accepted professional practices for the nature and conditions of work completed in the same or similar localities, at the time the work was performed. This memorandum does not represent a legal opinion. No other warranty, expressed or implied, is made.

All reports prepared by Aspect Consulting for the Client apply only to the services described in the Agreement(s) with the Client. Any use or reuse by any party other than the Client is at the sole risk of that party, and without liability to Aspect Consulting. Aspect Consulting's original files/reports shall govern in the event of any dispute regarding the content of electronic documents furnished to others.

Attachments

Table 1 – Mapped Concentrations and Initial Concentrations in Model (in Text)
Table 2 – Estimated Restoration Timeframes
Figure 1 – Initial PCE Concentrations assigned to Shallow Zone
Figure 2 – Initial TCE Concentrations assigned to Shallow Zone
Figure 3 – Initial PCE Concentrations assigned to Intermediate Zone
Figure 4 – Initial TCE Concentrations assigned to Intermediate Zone
Figure 5 – Predicted GW Concentrations over Time without EW-1 Pumping
Figure 6 – Predicted GW Concentrations over Time with EW-1 Pumping
Attachment 1 – Maps Showing 2012 Isocontours of PCE and TCE Groundwater Concentrations (from Apex)

W:\130171 NuStar Modeling Support\Deliverables\Cleanup Timeframe Memo\Revised Final\GW Cleanup Timeframe Rev NuStar Memo 9-11-2014.docx

Table 2: Estimated Restoration Timeframes

NuStar Terminal Services, Inc. – Vancouver Facility

Number of Years for Concentrations to Reach Proposed CULs *without* EW-1 Pumping

		Intermediate Zone Monitoring Wells							
	GWM Pumping	**MW-20i**	**MW-21i-40**	**MW-21i-105**	**MW-22i**	**MW-23i**	**MW-24i**	**MW-31i**	**MW-32i**
PCE	with	NA	2.9	0.2	NA	NA	12.9	0.7	3.2
	without	NA	3.0	0.3	NA	NA	14.7	NA	3.1
TCE	with	NA	3.8	0.2	4.2	4.2	12.1	0.6	1.1
	without	NA	3.9	0.3	4.6	6.2	13.2	NA	1.2

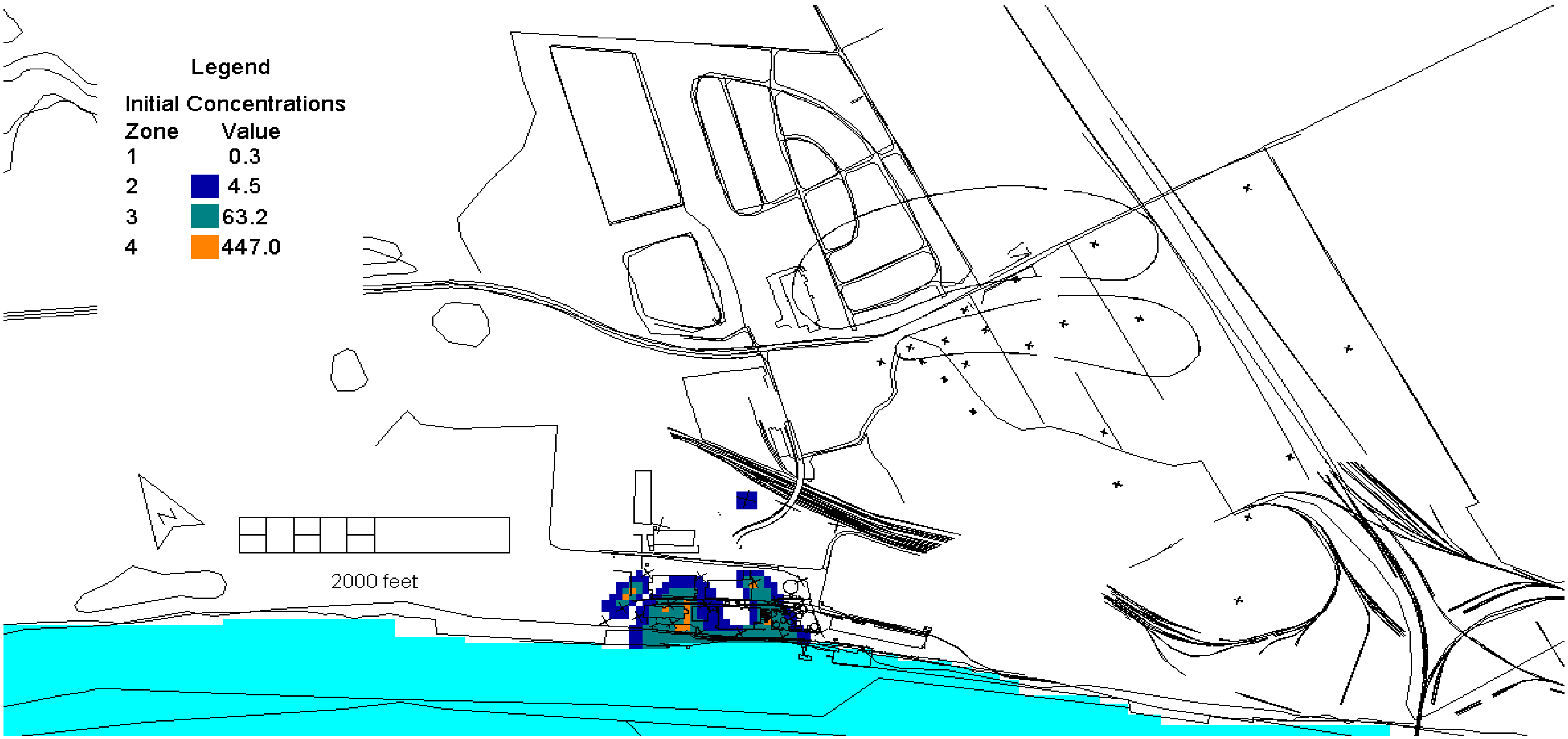
Number of Years for Concentrations to Reach Proposed CULs *with* EW-1 Pumping

		Intermediate Zone Monitoring Wells							
	GWM Pumping	**MW-20i**	**MW-21i-40**	**MW-21i-105**	**MW-22i**	**MW-23i**	**MW-24i**	**MW-31i**	**MW-32i**
PCE	with	5.6	2.8	0.2	NA	NA	11.1	0.3	3.1
	without	4.6	2.9	0.2	NA	NA	12.3	0.5	3.1
TCE	with	NA	3.7	0.1	3.9	2.8	10.7	0.4	1.1
	without	NA	3.7	0.2	4.1	3.4	11.5	0.5	1.1

Notes:

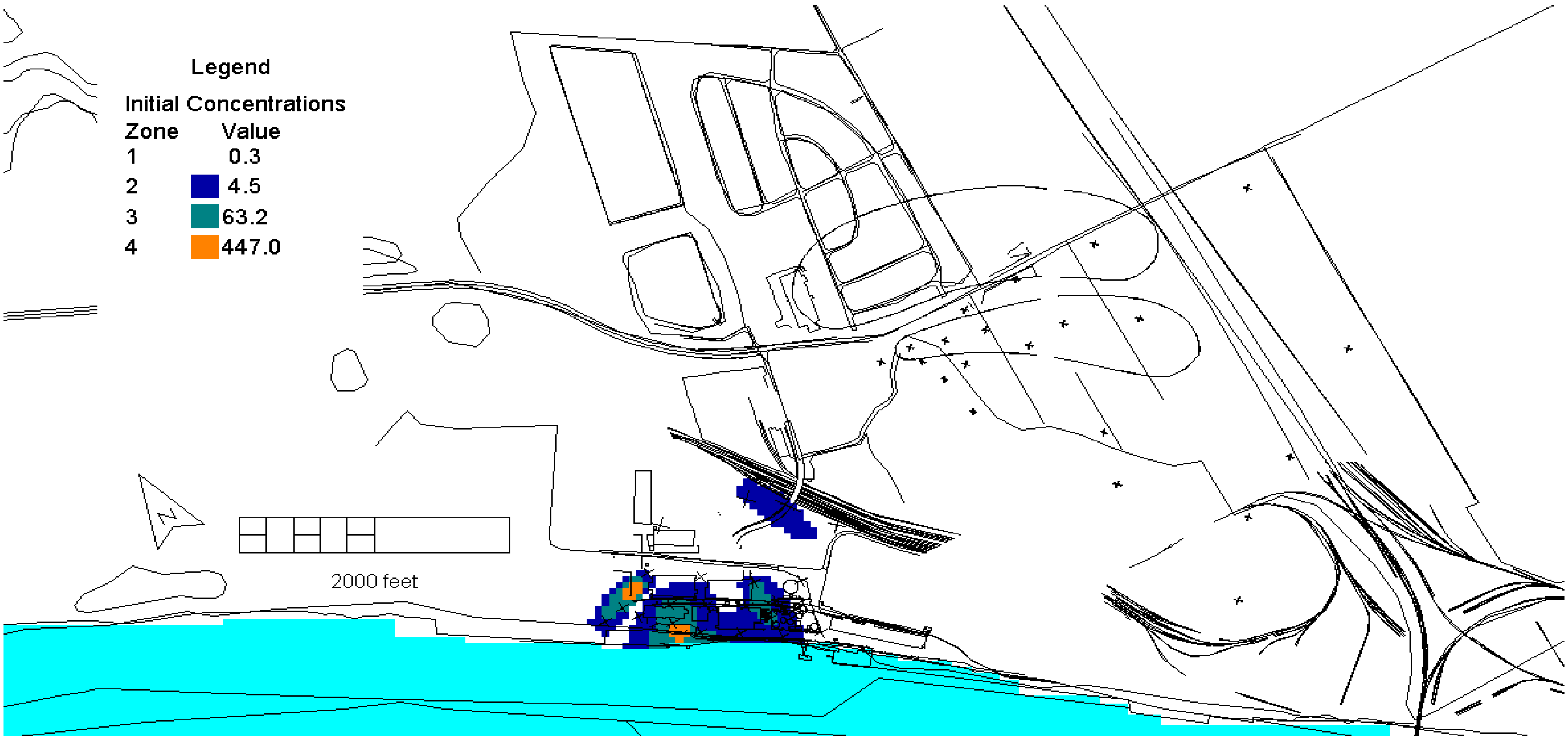
Results based on log-linear trendline analysis of model results shown on Figures 5 and 6.

Shaded "NA" indicates not applicable; model-calculated concentration does not exceed the proposed CULs.



Aspect Consulting, LLC
9/11/2014
P:\NuStar\Data\Analyses\[NuStarAnalysis_2014.xlsx]ModelMaps

Figure 1
Initial PCE Concentrations assigned to Shallow Zone
NuStar Terminal Services, Inc. – Vancouver Facility



Aspect Consulting, LLC

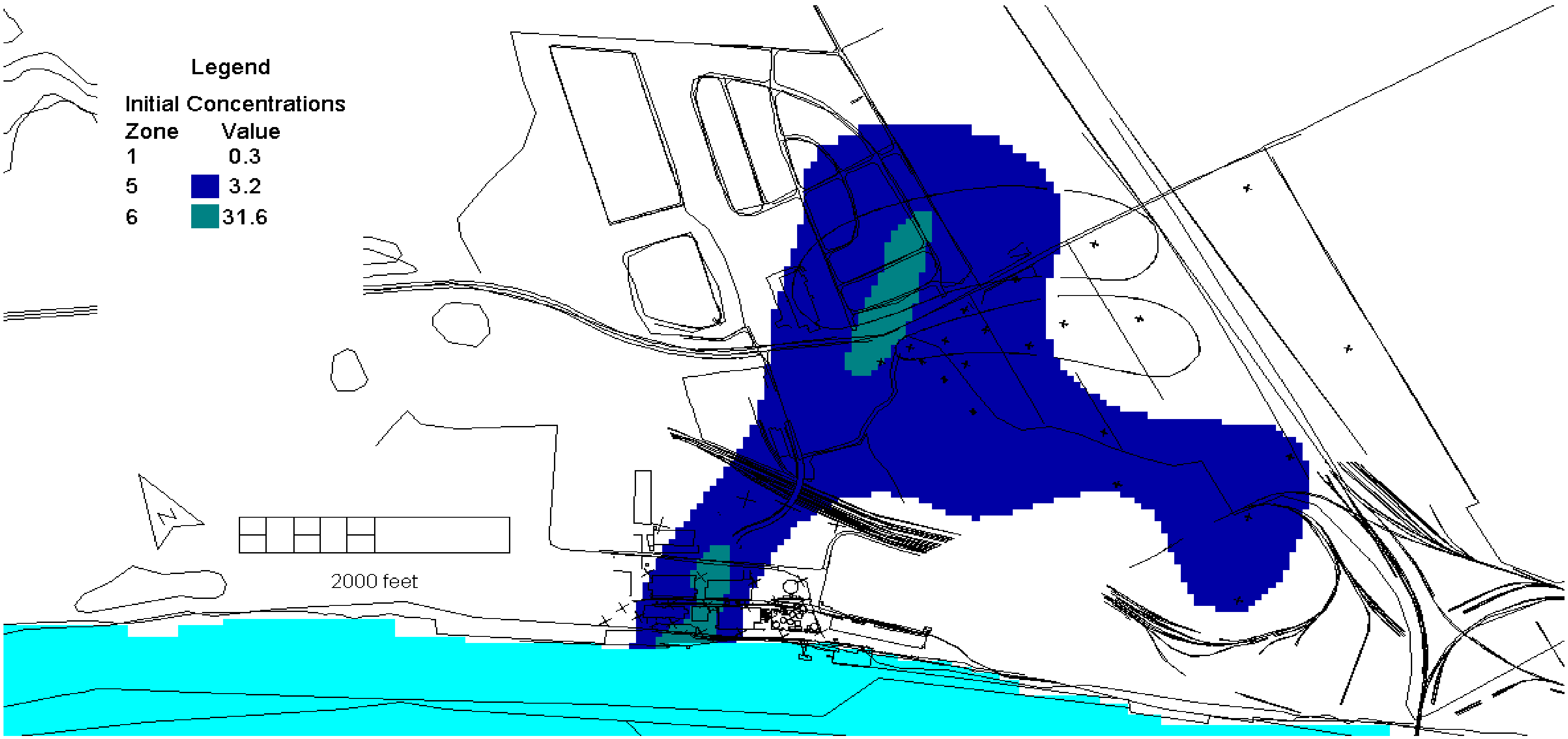
9/11/2014

P:\NuStar\Data\Analyses\[NuStarAnalysis_2014.xlsx]ModelMaps

Figure 2

Initial TCE Concentrations assigned to Shallow Zone

NuStar Terminal Services, Inc. – Vancouver Facility



Aspect Consulting, LLC

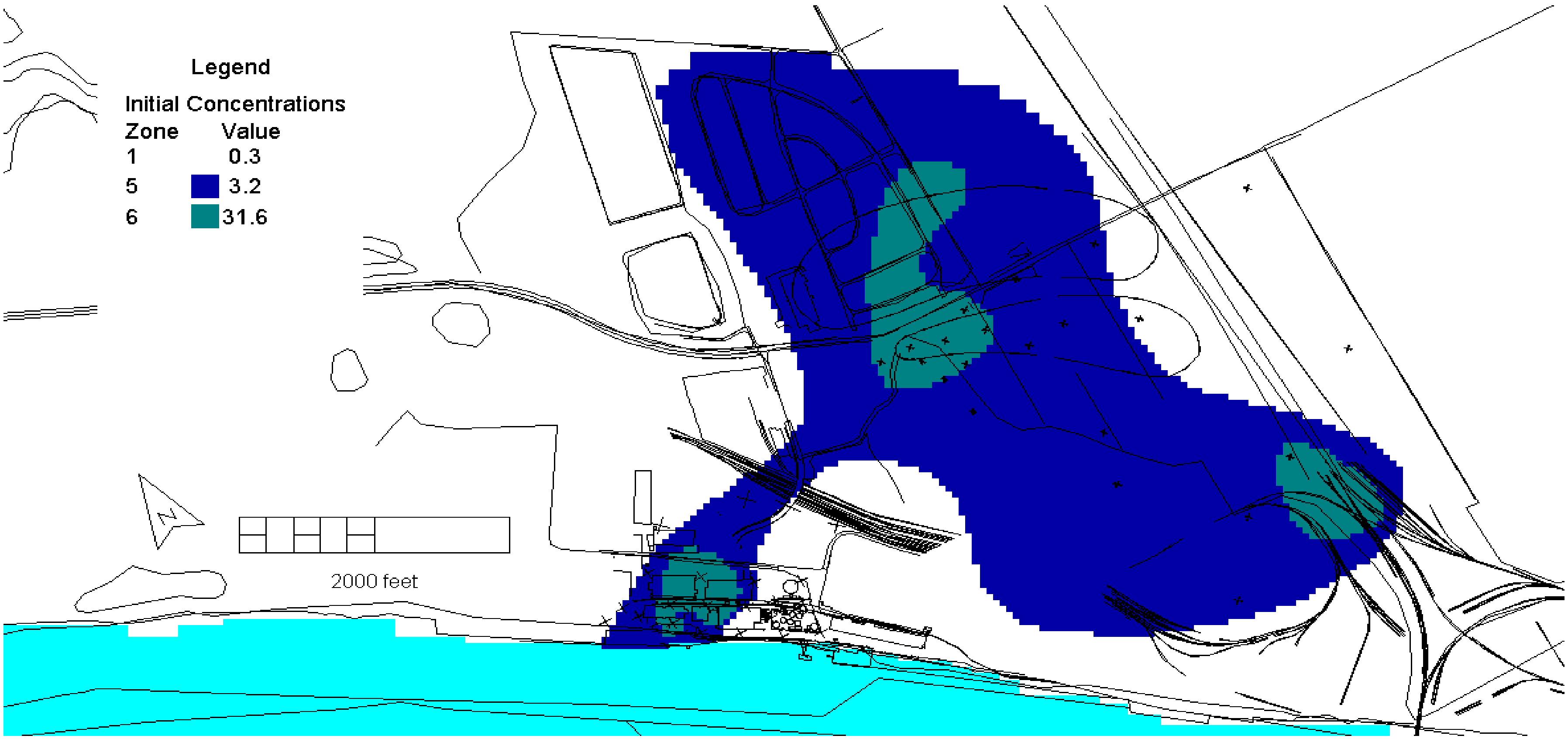
9/11/2014

P:\NuStar\Data\Analyses\[NuStarAnalysis_2014.xlsx]ModelMaps

Figure 3

Initial PCE Concentrations assigned to Intermediate Zone

NuStar Terminal Services, Inc. – Vancouver Facility



Aspect Consulting, LLC

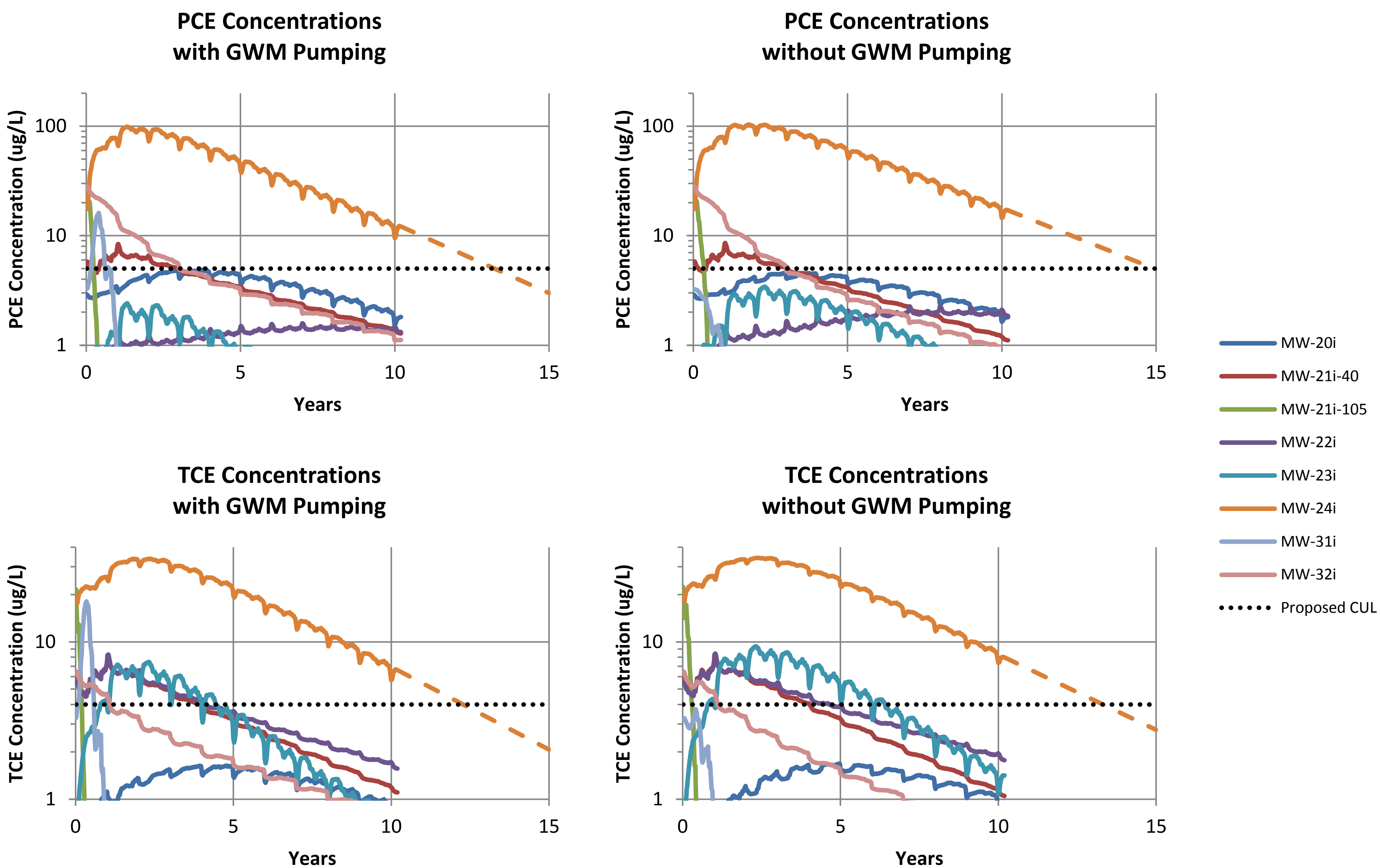
9/11/2014

P:\NuStar\Data\Analyses\[NuStarAnalysis_2014.xlsx]ModelMaps

Figure 4

Initial TCE Concentrations assigned to Intermediate Zone

NuStar Terminal Services, Inc. – Vancouver Facility



Note: Line is dashed where extrapolated using trendline analysis.

Aspect Consulting, LLC
9/11/2014
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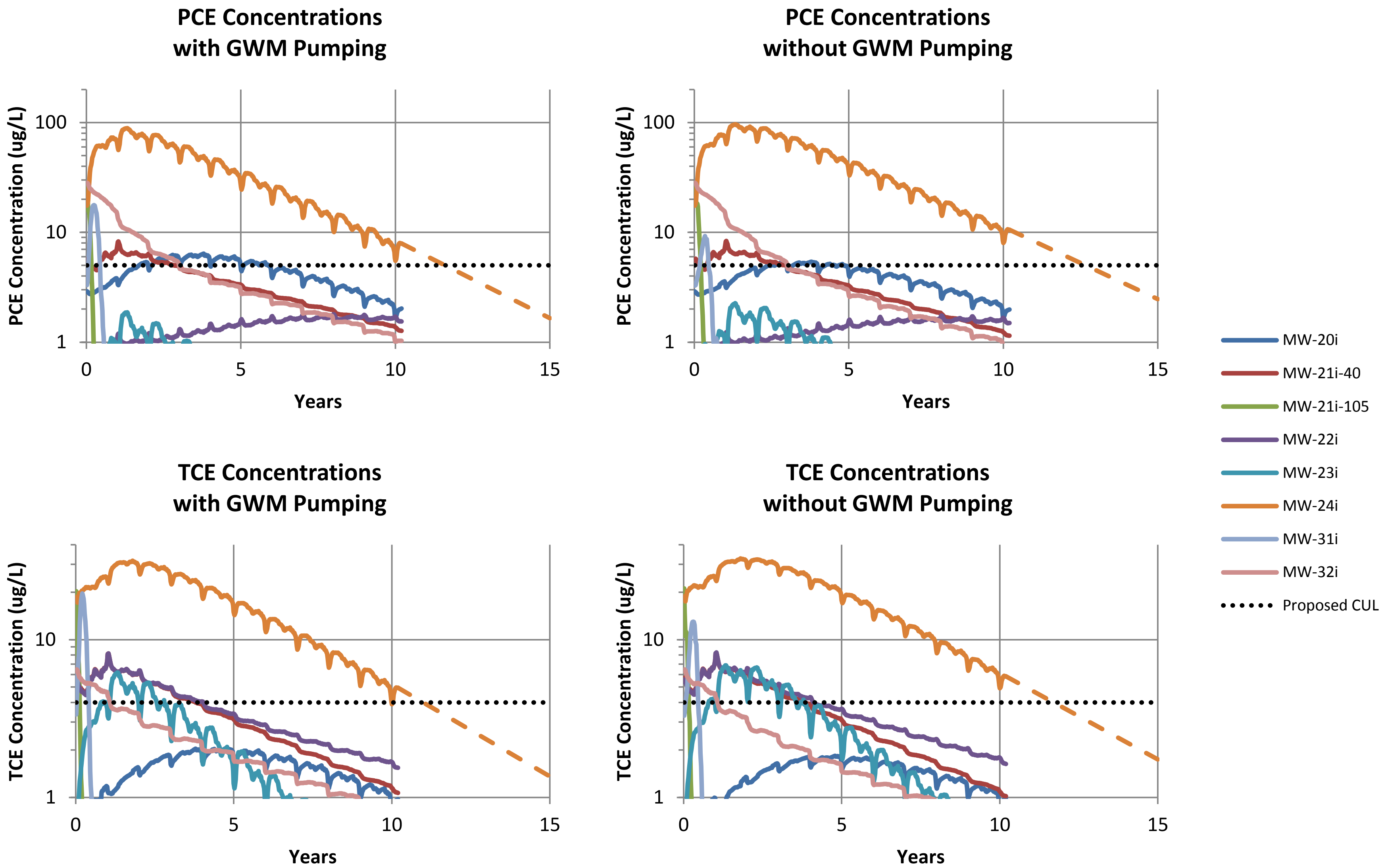
Figure 5
Predicted GW Concentrations over Time without EW-1 Pumping
NuStar Terminal Services, Inc. – Vancouver Facility



Note: Line is dashed where extrapolated using trendline analysis.

Aspect Consulting, LLC
9/11/2014
P:\NuStar\Data\Analyses\NuStarAnalysis_2014.xlsx

Figure 6
Predicted GW Concentrations over Time with EW-1 Pumping
NuStar Terminal Services, Inc. – Vancouver Facility

ATTACHMENT 1

Maps Showing 2012 Isocontours of PCE and TCE Groundwater Concentrations (from Apex)

PCE in Shallow Zone 1Q 2008

PCE in Shallow Zone 4Q 2012*

N

LEGEND:

- ◎ Swan Manufacturing (POV) Monitoring Well
- ⊙ ST Services (NuStar) Monitoring Well
- ⊕ Cadet Manufacturing (POV) Monitoring Well
- ⌖ Great Western Malting Extraction Well
- 1.16 Concentration in Groundwater (µg/L)
- 1µg/L Isoconcentration Contour
- 20µg/L Isoconcentration Contour
- 200µg/L Isoconcentration Contour
- 1,000µg/L Isoconcentration Contour
- 10,000µg/L Isoconcentration Contour

0 600 1,200

Approximate Scale in Feet

NOTE:

Base Map, Legend and Scale from S.S. Papadopulos & Associates, Inc. Expert Report of Dimitrios Vlassopoulos Port of Vancouver v. Cadet Manufacturing Company, May 2005

2008 and 2012 Isocontours of Tetrachloroethene (PCE) Concentrations in Shallow Zone Groundwater

Draft 2013 Remedial Investigation Report

NuStar Terminals Services, Inc. Vancouver Facility

Vancouver, Washington

Ash Creek Associates A Division of Apex Companies, LLC APEX

Project Number	1126-14	Figure
	March 2013	16

TCE in Shallow Zone 1Q 2008

TCE in Shallow Zone 4Q 2012*

N

LEGEND:

- ◎ Swan Manufacturing (POV) Monitoring Well
- ⊙ ST Services (NuStar) Monitoring Well
- ⊕ Cadet Manufacturing (POV) Monitoring Well
- ⌖ Great Western Malting Extraction Well
- 19.9 Concentration in Groundwater (µg/L)
- 1µg/L Isoconcentration Contour
- 20µg/L Isoconcentration Contour
- 200µg/L Isoconcentration Contour
- 1,000µg/L Isoconcentration Contour

NOTE:

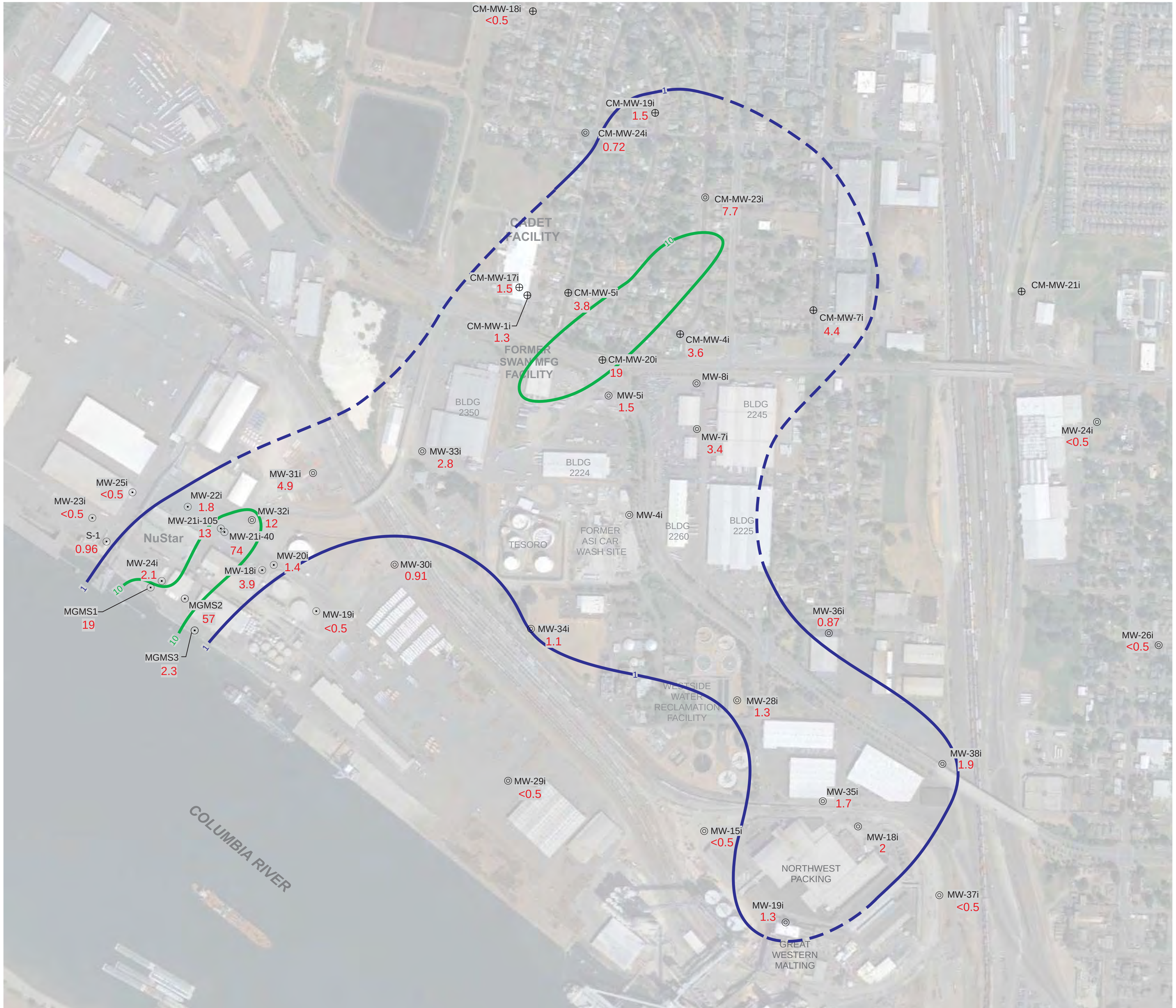
Base Map, Legend and Scale from S.S. Papadopulos & Associates, Inc. Expert Report of Dimitrios Vlassopoulos Port of Vancouver v. Cadet Manufacturing Company, May 2005

2008 and 2012 Isocontours of Trichloroethene (TCE) Concentrations in Shallow Zone Groundwater

Draft 2013 Remedial Investigation Report
NuStar Terminals Services, Inc. Vancouver Facility
Vancouver, Washington

Ash Creek Associates
A Division of Apex Companies, LLC
APEX

Project Number	1126-14	Figure
March 2013		17



LEGEND:

- Swan Manufacturing (POV) Monitoring Well
- ST Services (NuStar) Monitoring Well
- Cadet Manufacturing (POV) Monitoring Well
- Great Western Malting Extraction Well
- 4.4 PCE Concentration in Groundwater (µg/L)
- Isoconcentration Contours (µg/L)

NOTES:

1) Data from most recent monitoring event.
For NuStar wells, data are from 4Q 2012.
For POV wells, data are from 3Q 2012.

2) MW-29i is sampled annually; therefore, data are present for 1Q 2012.

Base Map, Legend and Scale from S.S. Papadopulos & Associates, Inc. Expert Report of Dimitrios Vlassopoulos Port of Vancouver v. Cadet Manufacturing Company, May 2005

N

0 600 1,200
Approximate Scale in Feet

Tetrachloroethene (PCE) in Intermediate Zone - Final Monitoring Event 2012

Draft 2013 Remedial Investigation Report
NuStar Terminals Services, Inc. Vancouver Facility
Vancouver, Washington

Ash Creek Associates A Division of Apex Companies, LLC APEX	Project Number	1126-14	Figure
	March 2013		19

LEGEND:

- Swan Manufacturing (POV) Monitoring Well
- ST Services (NuStar) Monitoring Well
- Cadet Manufacturing (POV) Monitoring Well
- Great Western Malting Extraction Well
- 0.71 TCE Concentration in Groundwater (µg/L)
- Isoconcentration Contours (µg/L)

NOTES:

1) Data from most recent monitoring event.
For NuStar wells, data are from 4Q 2012.
For POV wells, data are from 3Q 2012.

2) MW-29i is sampled annually; therefore, data are present for 1Q 2012.

Base Map, Legend and Scale from S.S. Papadopulos & Associates, Inc. Expert Report of Dimitrios Vlassopoulos Port of Vancouver v. Cadet Manufacturing Company, May 2005

N

0 600 1,200
Approximate Scale in Feet

Trichloroethene (TCE) in Intermediate Zone - Final Monitoring Event 2012

Draft 2013 Remedial Investigation Report
NuStar Terminals Services, Inc. Vancouver Facility
Vancouver, Washington

Ash Creek Associates, A Division of Apex Companies, LLC — APEX	Project Number	1126-14	Figure
	March 2013		20

Aspect
CONSULTING

APPENDIX E

SMC Source Area Feasibility Study Evaluation Supporting Documentation

Feasibility Study Conceptual Design/Costs
SMC Source Area

Alternative A
Monitored Natural Attenuation

The Monitored Natural Attenuation alternative involves utilizing natural processes to reduce contaminants of concern (COC) levels to acceptable concentrations. These processes include natural biodegradation, dispersion, dilution, sorption, volatilization, and chemical and biological stabilization, transformation, or destruction of hazardous substances. Monitoring is used to verify that these processes are actively reducing hazardous substances concentrations. An extensive monitoring well network is in place throughout the source area and the project area.

For the purposes of the SMC source area remedy evaluation, this alternative assumes that the existing pump & treat system would be turned off and no further remedial efforts would be completed. In general, this alternative is being used as a baseline alternative (essentially a No Action alternative) in which others can be compared. This alternative does not meet the RAOs for the SMC source area.

No costs are assumed to be incurred with implementation of this alternative.

Alternative A Cost Estimate: Source Area Monitored Natural Attenuation
Port of Vancouver
Vancouver, Washington

Activity	Unit Costs	Unit	Extended Cost
Groundwater Monitoring			
2014	$5,000	per year	$5,000
2015	$5,150	per year	$5,150
2016	$5,305	per year	$5,305
2017	$5,464	per year	$5,464
2018	$5,628	per year	$5,628
2019	$5,796	per year	$5,796
2020	$5,970	per year	$5,970
2021	$6,149	per year	$6,149
2022	$6,334	per year	$6,334
2023	$6,524	per year	$6,524
2024	$6,720	per year	$6,720
2025	$6,921	per year	$6,921
2026	$7,129	per year	$7,129
2027	$7,343	per year	$7,343
2028	$7,563	per year	$7,563
2029	$7,790	per year	$7,790
2030	$8,024	per year	$8,024
2031	$8,264	per year	$8,264
2032	$8,512	per year	$8,512
2033	$8,768	per year	$8,768
2034	$9,031	per year	$9,031
2035	$9,301	per year	$9,301
2036	$9,581	per year	$9,581
2037	$9,868	per year	$9,868
2038	$10,164	per year	$10,164
2039	$10,469	per year	$10,469
2040	$10,783	per year	$10,783
2041	$11,106	per year	$11,106
2042	$11,440	per year	$11,440
2043	$11,783	per year	$8,768
Estimated Total Cost			**$234,862**

Notes:

This alternative includes monitoring of source area wells only.
This alternative assumes 20 years of monitoring required for MNA.
Monitoring costs include labor and lab costs and a 3% yearly increase.
Site-wide costs to achieve closure is included in the Project Area alternatives.

Feasibility Study Conceptual Design/Costs
SMC Source Area

Alternative B
Excavation of Source Area Material

This alternative primarily includes excavation and off-site disposal of impacted source area material. As discussed in the RI Report, it appears that the presence of a fine-grained sand layer within the source area has confined some contaminants to that layer and continues to slowly migrate to shallow groundwater. The majority of the fine-grained sand layer is saturated most of the year. It is expected that much of the contaminants reside in the pore space of the soil particles and are slowly leaching to shallow groundwater.

While excavation is primarily a vadose zone soil remedial action, the relatively shallow depth and the unique complexity of this site lends itself to consider a removal action for saturated material. Based on an evaluation of site data, the removal action area is approximately 70 feet by 100 feet and would extend to a depth of 27 feet below ground surface (bgs). This yields an approximate excavation volume of 7,000 cubic yards.

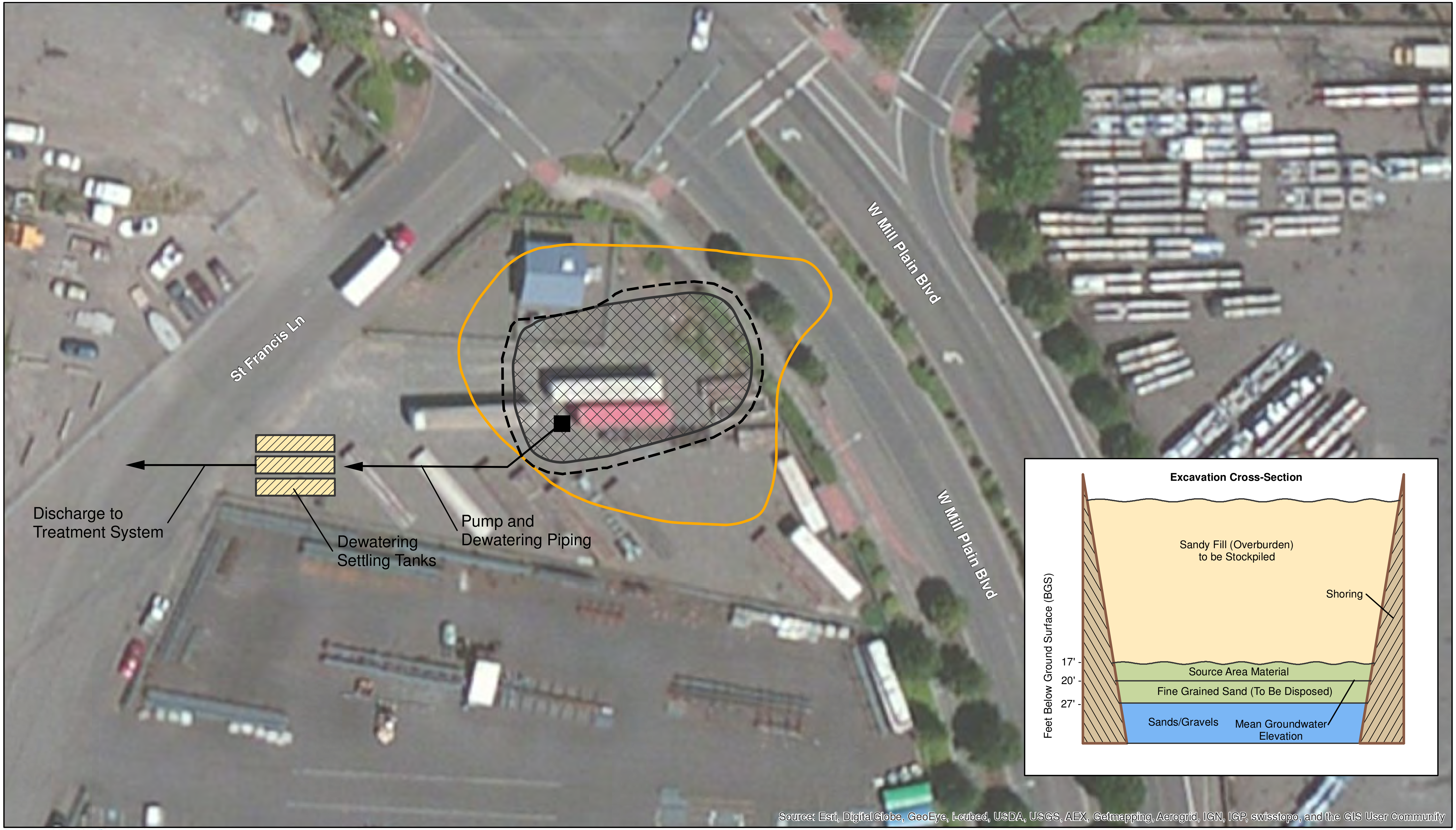
The top 17 feet is considered overburden material and is expected to be free of any contamination. Much of the overburden is clean fill (about 4,500 cubic yards) that was placed during the remedial excavation in 1998. The former excavation was stopped at approximately 17 feet bgs due to the presence of groundwater. This proposed alternative would primarily target the underlying 10 feet of material from the previous excavation depth, which includes the fine-grained sand layer. Due to the expected presence of groundwater at less than 20 feet bgs, this alternative will require significant shoring and dewatering. Extracted groundwater from the dewatering will be required to be treated prior to discharge to a sanitary sewer or other method of disposal.

Based on the conceptual design, approximately 2,500 cubic yards of excavated contaminated soil (saturated) would be placed into lined trucks and transported to a permitted municipal landfill (Subtitle D) for disposal under an approved permit. Confirmation sampling would be conducted in accordance with an Ecology-approved sampling and analysis plan (SAP) and quality assurance project plan (QAPP).The excavation would be backfilled with a combination of imported clean fill and the stockpiled clean overburden material.

Attachments

Figure E-1 : Conceptual Design of Remedial Excavation

Estimated Costs for Implementation of Alternative B



Parametrix Date: 1/17/2014 Path: P:\GIS\POV\MXD_PDF\PumpStation\POV_FigE_1_ExcavationArea.mxd

N

0 50 100
Feet

Potential Extent of Residual Source Area
Focused Treatment Area
Conceptual Excavation Area

Figure E-1
Conceptual Excavation Area

Feasibility Study
Port of Vancouver
Vancouver, Washington

Alternative B Cost Estimate: Source Area Remedial Excavation
Port of Vancouver
Vancouver, Washington

Activity	Quantity	Unit	Unit Costs	Extended Cost	Notes
Preparatory Activities					
Environmental Engineering Assistance (Design and Specs)	1	lump sum	$10,000	$10,000	Parametrix estimate. Professional judgement.
Contaminated Media Management Plan	1	lump sum	$4,000	$4,000	Parametrix estimate. Professional judgement.
Contractor Solicitation and Procurement	1	lump sum	$3,000	$3,000	Parametrix estimate. Professional judgement.
Project Management and Meetings	1	lump sum	$3,000	$3,000	Parametrix estimate. Professional judgement.
Construction Activities (Excavation)					
Contractor Health and Safety and Worker Protection	1	lump sum	$1,000	$1,000	Parametrix estimate. Professional judgement.
Excavation Oversight, including Supplies and Equipment	20	days	$1,000	$20,000	Parametrix estimate. Professional judgement.
Equipment Mobilization	1	lump sum	$4,000	$4,000	Contractor estimate.
Contractor Equipment Rate	20	days	$3,000	$60,000	Estimate for contractor daily rate for personnel, trackhoe, support trucks, and misc. equipment and supplies
Source Area Clean Overburden Excavation	4,500	yards	$6	$26,550	70'x100' = 7000 sqft x 17' = 119,000 cuft = 4400 cuyds. Use 4,500 yards. Based on similar project.
Overburden Stockpiling onsite - visqueen and cover	1	lump sum	$1,000	$1,000	Parametrix estimate. Professional judgement.
Backfill Overburden, Additional Fill Material, Compaction	7,000	cubic yards	$6	$42,000	Place back 4,500 yards stockpiled overburden + 2500 yards fill material. Only need fill for removed material, overburden placed back in excavation.
Source Area Contaminated Soil Excavation	2,500	yards	$6	$15,000	70'x100' = 7000 sqft x 10' = 70,000 cuft = 2592 cuyds. Assuming depth of fine-grain sand layer varies from 5-10'. Use 2,500 yards.
Haul and Landfill Disposal of Contaminated Soil	3750	tons	$70	$262,500	Transportation and landfill disposal of $70/ton. Based on recent projects. Assume Subtitle D (Hillsboro) disposal.
Soil Sampling and Analysis	1	lump sum	$5,000	$5,000	Sample analyses primarily for VOCs; includes profiling and confirmation samples.
Shoring (Sheet Pile) and Dewatering/Disposal	1	lump sum	$400,000	$400,000	Groundwater 20-25 feet bgs. Would pump water out, and flocculate, then have the bulk settle into a weir tank. Dispose of solids and pump water through GPTIA. Based on recetn project and professional judgement.
Closure Activities					
Closure Report	1	lump sum	$15,000	$15,000	Parametrix estimate. Professional judgement.
Project Management and Meetings	1	lump sum	$3,000	$3,000	Parametrix estimate. Professional judgement.
Estimated Total Cost				**$875,050**	

NOTES:

Estimate does not include operation of the existing pump and treatment system. Costs above considered supplemental to the P&T.

Costs above do not include the site-wide monitoring that will be required to achieve site closure.

Monitoring costs above is only for source area; remaining costs for monitoring is included in the Project Area alternatives.

Feasibility Study Conceptual Design/Costs
SMC Source Area

Alternative C
AS/SVE in the Source Area

This alternative includes the construction of an air sparging and soil vapor extraction (AS/SVE) system in the source area and primarily targets the fine-grained sand layer. The AS/SVE system works on the injection of air into the groundwater to volatilize contaminants. The volatile contaminants in the air phase rise into the vadose zone, where they are captured by the SVE wells under a vacuum influence. The volatilized contaminants are then adsorbed via a granulated activated carbon (GAC) canister prior to ventilation to the atmosphere. A typical timeframe for remediation of groundwater contaminants to beneath levels of concern is 2 to 4 years.

Based on the extent and depth of source area contamination (target area), the preliminary conceptual design suggests that a total of approximately 8 air sparging wells would be adequate to treat the SMC source area. The AS wells would be installed to the bottom of the fine-grained sand layer (approximately 25 feet below gorund surface [bgs]), with a 0.5 foot well screen at the bottom (groundwater is approximately 20 feet bgs). Seven to ten soil vapor extraction wells would be installed around the AS wells to capture soil vapors in the vadose zone. The SVE wells would be drilled to approximately 15 to 20 feet bgs, with a 10 foot well screen.

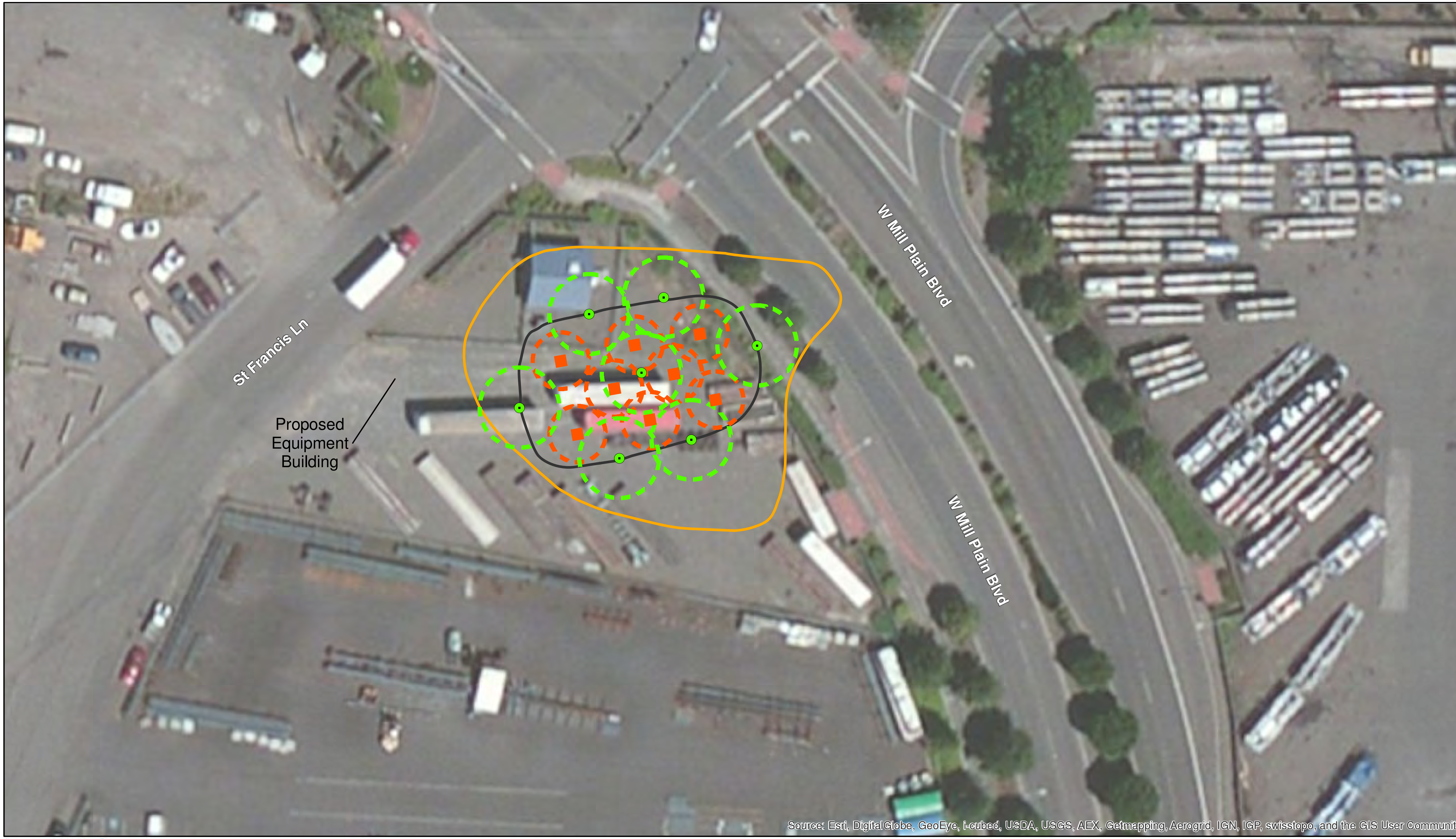
The AS wells would be connected via a hose or piping to an air blower and the SVE wells connected via 2-inch PVC piping to a vacuum unit. A small equipment shed would likely be required to house the blower, vacuum, electrical unit, sound insulation, and other equipment. The air collected by the vacuum would be discharged through a GAC canister for treatment, prior to ventilation to the atmosphere.

Due to the complexity of the source area, installation of an AS/SVE system would be difficult and potentially problematic. A design study would be required to evaluate the precise geology of the fine-grained sand layer and placement of AS wells. The relatively thin depth of the fine-grained sand layer may be difficult in terms of placement of the AS wells. In addition, based on past evaluation, the fine-grained sand layer is not always fully saturated, thus limiting the effectiveness of air sparging in that layer. Completion of AS wells below the fine-grained sand layer would not be effective due to the tight formation of the sand which would promote lateral movement of air at the fine-grained sand layer interface, rather than vertical movement through the contaminated zone.

Attachments

Figure E-2: Conceptual Design of AS/SVE

Estimated Costs for Implementation of Alternative C



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N

0 50 100
Feet

- Horizontal AS Well
- SVE Well
- Potential Extent of Residual Source Area
- Focused Treatment Area
- Estimated Air Sparging Radius of Influence
- Estimated Soil Vapor Extraction Radius of Influence
- AS Piping
- SVE Piping

Figure E-2
Conceptual AS/SVE System Layout (Horizontal AS Wells)

Feasibility Study
Port of Vancouver
Vancouver, Washington

Alternative C Cost Estimate: Source Area Air Sparge/Soil Vapor Extraction System
Port of Vancouver
Vancouver, Washington

Activity	Quantity	Unit	Unit Costs	Extended Cost	Notes
Preparatory Activities					
Environmental Engineering Assistance (Design and Specs)	1	lump sum	$10,000	$10,000	Parametrix estimate. Professional judgement.
Contractor Solicitation and Procurement	1	lump sum	$3,000	$3,000	Parametrix estimate. Professional judgement.
Project Management and Meetings	1	lump sum	$2,000	$2,000	Parametrix estimate. Professional judgement.
Air Sparge/Soil Vapor Extraction System					
Air Sparging Wells/ Soil Vapor Wells	1	lump sum	$25,000	$25,000	Assume 8 sparge wells (25') and 7 SVE wells (20'). Includes drilling and completion of wells. Cascade Drilling bid Aug 2013.
Construction of System; Contractor Labor	1	lump sum	$20,000	$20,000	Environmental contractor costs; 7 days of construction after wells installed.
Equipment					
8x10' TuffShed	1	shed	$3,000	$3,000	8 x 10 foot shed.
Regenerative Blower (SVE) - Rotron, Model 808	1	blower	$7,000	$7,000	Typcial costs. Professional judgement.
Rotary scroll Compressor (AS) - Powerex, Model SED 1007	1	compressor	$10,000	$10,000	Typcial costs. Professional judgement.
Vent-Scrub Carbon Adsorber (Siemens GAC Air treatment unit (55 gal))	1	lump sum	$1,000	$1,000	Typcial costs. Professional judgement.
Muffler (Sound Reduction)	1	lump sum	$500	$500	Typcial costs. Professional judgement.
SVE moisture separator tank	1	lump sum	$200	$200	Typcial costs. Professional judgement.
Misc. Piping, Valves, etc.	1	lump sum	$2,600	$2,600	Typcial costs. Professional judgement.
Pressure regulator/gauges	1	lump sum	$300	$300	Typcial costs. Professional judgement.
Flow meter	1	lump sum	$300	$300	Typcial costs. Professional judgement.
System control panel	1	lump sum	$5,000	$5,000	Typcial costs. Professional judgement.
Visqueen	4	20' x 100'	$100	$400	
3" gravel cap	50	cubic yards	$30	$1,500	75 x 100 x 0.25 = 1175 cubic feet = 43 cubic yards
Operation and Maintenance, Monitoring	16	per year for 4 years	$2,500	$40,000	4 monitoring events per year; assume 4 years
Laboratory	16	per year for 4 years	$250	$4,000	Quarterly effluent monitoring (air)
Other Maintenance	4	lump sum	$5,000	$20,000	Parametrix estimate. Professional judgement.
Closure Activities					
Closure Report	1	lump sum	$15,000	$15,000	Parametrix estimate. Professional judgement.
Project Management and Meetings	1	lump sum	$3,000	$3,000	
Estimated Total Cost				**$173,800**	

NOTES:

Estimate does not include operation of the existing pump and treatment system. Costs above considered supplemental to the P&T.

Costs above do not include the site-wide monitoring that will be required to achieve site closure.

Monitoring costs above is only for source area; remaining costs for monitoring is included in the Project Area alternatives.

Feasibility Study Conceptual Design/Costs
SMC Source Area

Alternative D
Injection of Chemical Oxidant in the Source Area

This alternative consists of injecting a chemical oxidant (likely Fenton's Reagent) below the water table using a combination of injection wells and temporary direct-push injection points.

As is typical of in-situ oxidizing treatments, the injection of Fenton's Reagent disrupts aquifer equilibrium conditions in two ways: 1) physical agitation of the aquifer, and 2) liberation of bound TCE from the soil matrix. Both of these actions can result in dissolved TCE concentrations that are initially higher after treatment than those observed prior to treatment. After mobilizing the bound TCE, subsequent treatments are aimed at destroying the resulting dissolved TCE. After the final treatment, equilibrium conditions would be re-established naturally and TCE concentrations decreased. It is estimated that two to three treatment events would occur, followed by monthly monitoring of the wells for 1 to 3 years.

Chemical oxidation was the chosen method for the interim action during source remediation (see FS Section 2.4), and proved to be an effective method of destroying residual TCE. This alternative includes additional injection points and direct delivery to the fine-grain sand layer, approximately 20 to 25 feet below ground surface (bgs).

Approximately 50 to 60 injection borings would be completed up to 30 feet bgs throughout the 70' x 100' source area. The size and distribution of source area would make implementing an effective delivery system manageable. Because of the rapid decomposition of oxidizing agents, injection points would have to be located throughout the source area in order to achieve the cleanup goals.

Due to the complexity of the source area, effectiveness of chemical oxidation via injection could be difficult and potentially problematic, similar to those described for the AS/SVE option. A design study would be required to evaluate the precise geology of the fine-grained sand layer and placement of injection points. The relatively thin depth of the fine-grained sand layer may be difficult in terms of placement of the chemical oxidant. Distribution of chemical oxidants may also be difficult in the tight formation of the fine-grained sand layer. Past experience during the source area interim action indicated that the radius of influence from injection points may be limited; thus, requiring a high concentration of injection points within the target area.

Attachments

Figure E-3: Conceptual Design of Chemical Injection

Estimated Costs for Implementation of Alternative D

Parametrix Date: 1/17/2014 Path: P:\GIS\POV\MXD_PDF\PumpStation\POV_Fig_E_3_InjectionPoints.mxd

N

0 50 100
Feet

Potential Extent of Residual Source Area
Focused Treatment Area
Temporary Injection Point

Figure E-3
Conceptual Substrate Injection Points

Feasibility Study
Port of Vancouver
Vancouver, Washington

Alternative D Cost Estimate: Source Area Injection of Substrate (Fenton's Reagent or Other Oxidant)
Port of Vancouver
Vancouver, Washington

Activity	Quantity	Unit	Unit Costs	Extended Cost	Notes
Preparatory Activities					
Environmental Engineering Assistance (Design and Specs)	1	lump sum	$8,000	$8,000	Parametrix estimate. Professional judgement.
Contractor Solicitation and Procurement	1	lump sum	$2,000	$2,000	Parametrix estimate. Professional judgement.
Project Management and Meetings	1	lump sum	$2,000	$2,000	Parametrix estimate. Professional judgement.
Injection Events					
Equipment Mobilization	1	lump sum	$3,000	$3,000	Parametrix estimate. Professional judgement.
Temporary probe boring wells (average 50 holes) (contractor and equipment)	1	lump sum	$30,000	$30,000	Assume average of 50 temporary probe borings. Includes drilling and completion of wells. Cascade Drilling bid based on conceptual design.
Second event (assume same scenario as first event)	1	lump sum	$30,000	$30,000	Assume average of 50 temporary probe borings. Includes drilling and completion of wells. Cascade Drilling bid based on conceptual design.
Third Event (assume half of first event)	1	lump sum	$15,000	$15,000	Assume average of 25 temporary probe borings. Includes drilling and completion of wells. Cascade Drilling bid based on conceptual design.
Equipment/Miscellaneous					
Fenton's Reagent or emulsified oil (average 250 gallons/hole)	1	lump sum	$40,000	$40,000	Cascade Drilling estimate. Professional judgement.
Operation and Maintenance, Monitoring	1	lump sum	$1,000	$1,000	Environmental contractor; equipment maintenance, monitoring.
Laboratory	4	events	$4,000	$16,000	Sample analyses primarily for VOCs; includes profiling and confirmation samples in VMW wells, MW-5, etc.
Other Maintenance	1	lump sum	$3,000	$3,000	Parametrix estimate. Professional judgement.
Closure Activities					
Closure Report	1	lump sum	$10,000	$10,000	Parametrix estimate. Professional judgement.
Project Management and Meetings	1	lump sum	$3,000	$3,000	Parametrix estiamte. Professional judgement.
Estimated Total Cost				**$163,000**	

NOTES:

Estimate does not include operation of the existing pump and treatment system. Costs above considered supplemental to the P&T.

Costs above do not include the site-wide monitoring that will be required to achieve site closure.

Monitoring costs above is only for source area; remaining costs for monitoring is included in the Project Area alternatives.

Feasibility Study Conceptual Design/Costs
SMC Source Area

Alternative E
Pump and Treat in the Source Area

This alternative includes pump and treat to reduce the source area concentrations. As discussed throughout the FS, a groundwater pump and treat system was installed at the SMC site as an interim action. The groundwater pump and treatment interim action (GPTIA) has been operational since June 2009 and was primarily designed to capture the overall project area plume in the intermediate zone and treat dissolved phase concentrations. However, as the GPTIA was installed in the SMC source area it was also designed to provide concurrent treatment of the source area groundwater concentrations.

The extraction well EW-1 has operated at a rate of approximately 2,500 gpm. The system involves pumping groundwater from below the SMC source area and treating the groundwater through an air stripping process. The air strippers remove the TCE and other VOCs from the water and transfer them to an air stream for discharge to the atmosphere. The treated water is then dechlorinated and discharged to the Columbia River via a pre-existing stormwater outfall.

The conceptual design of this alternative is the continued pumping of the GPTIA for source area control and treatment. Consequently, the groundwater model was used to evaluate minimum pump rate required, source area and shallow groundwater reduction over time, derivation of a "protective" level, and estimate plume configuration given specific pumping sceanrios.

<u>Minimum Pump Rate to Control Source Area</u>

The model was used to evaluate a minimum pump rate which could be used to contain just the source area. It was determined that a minimum pump rate of 200 gallons per minute (38,500 cubic feet per day) was sufficient to contain the source area. Results are further discussed in Appendix B.

Due to the current infrastructure at the site, a minimum pump rate with the current system is approximately 1,250 gpm. This pump rate was used to evaluate costs associated with source area treatment.

<u>Level Protective of Intermediate</u>

The model was used to develop a concentration in the source area that would be considered protective of the intermediate zone. "Protective" is interpreted as the concentration in which the intermediate zone will not be impacted above the MTCA Method B cleanup level for TCE.

A constant source area was assumed in the model starting with the 1st Quarter 2013 source area concentrations. A simulation run of 20 years was conducted until a maximum concentration in layer 3 (top of USA) leveled off to within 0.1 micrograms per liter (µg/L). With this analysis, it was determined that the findings were linear with respect to the source area concentration. It was found that the top of the USA concentration was always 1.64% of the source concentration. Therefore, to determine the protective level of the source area which will not impact the intermediate USA zone above the MTCA Method B cleanup level of 4 µg/L: 243 µg/L in source area X 1.64% = 4 µg/L.

Therefore, it was determined that a concentration in the source area of approximately 250 µg/L is protective and could theoretically be left in-place without impacting a remedy for the intermediate zone (i.e. Monitored Natural Attenuation [MNA]) This level used to evaluate the applicability of MNA alternatives, as well as providing a target level for source area reduction.

Cleanup of the Source Area

An evaluation of the timeframe for cleanup of the source area was conducted. Two TCE levels were evaluated; the 250 µg/L protective level derived above and the 4 µg/l MTCA Method B cleanup level. The time in which these levels could be met using the GPTIA was evaluated as descried below.

The GPTIA has been very successful at treating the project area plume and the SMC source area, and provides capture of the dissolved phase groundwater plume. Monitoring well MW-5 has had the highest concentration of TCE and saw a significant increase in TCE concentration immediately after the GPTIA was initiated. MW-5 gives the best representation of groundwater cleanup in the source area. In June 2009, prior to operation of the GPTIA, monitoring well MW-5 had a TCE concentration of 2,700 µg/L. Once the GPTIA was operational, the TCE concentration in monitoring well MW-5 jumped to 5,000 µg/l (later in June 2009) and then to a high of 21,000 µg/L in December 2009. This drastic concentration increase is a result of contaminants being mobilized from the source area to extraction well EW-1. Monitoring well MW-5 is located within approximately 50 feet of EW-1, between the main source area and the extraction well. Since the high of 21,000 µg/L in December 2009, the TCE concentration in monitoring well MW-5 has decreased steadily to 2,700 in November 2013.

Log-linear analysis of the trend line shown on Figure E-1 found that the best estimate for MW-5 to reach a concentration of 250 µg/L is 6 years with an upper end estimate of 10 years. Consequently, this suggests that operation of EW-1 needs to continue for at least 5 years and possibly up to 10 years to reach concentrations in the SMC source area that are protective of the intermediate USA. A similar methodology was used on the remaining source area wells; however, it should be noted that the data is sporadic in nature and emphasis was placed on MW-5, since it has the highest concentration and appears to be more representative of source area conditions. Graphs of all wells are attached and the results of the timeframe to reach the various levels provided below.

Source Area Monitoring Well	3rd Quarter 2013 TCE Concentration (µg/L)	Estimated Years to Reach TCE Criteria		
		Protective Level 250 µg/L	Target Level 40 µg/L	Cleanup Level 4 µg/L
MW-05	**2700**	**6**	**11**	**30+**
IMW-05	37	0	0	2
VMW-08	370	N/A	N/A	N/A
VMW-09	320	30+	30+	30+
VMW-10	140	0	1	2
VMW-11	63	0	0	1

As shown above, it is expected that MW-5 could reach the protective level within 6 years provided continued GPTIA operation. It is not expected to reach the cleanup level for more than 30 years.

The remaining wells show that levels are currently met or will be met shortly. However, data for wells VMW-8 and VMW-9 do not follow a linear line analysis; thus, no conclusions can be drawn. However, both wells are close to the protective level currently and would be expected to decrease over time as the remainder of the source area cleans up.

Modeled Groundwater Results for Pumping Scenarios

Using the pump stress and source area assumptions described above, future TCE and PCE concentration distributions were analyzed for the following scenarios:

1. Pumping of EW-1 stops in 1 year (2014). This represents a baseline scenario or a no action scenario.
2. Pumping of EW-1 stops in 5 years (2018).
3. Pumping of EW-1 stops in 10 years (2028).

The resulting distribution of TCE and PCE for the above three scenarios were then generated for the following time periods:

- Year 5 (2018)
- Year 10 (2023)
- Year 15 (2028)

Results are presented as iscoconcentration maps for the model layer representing the shallow zone (model layer 1). The results suggest that the shallow zone will be pulled back to within the SMC property within 5 years of continued GPTIA pumping. See attached figure.

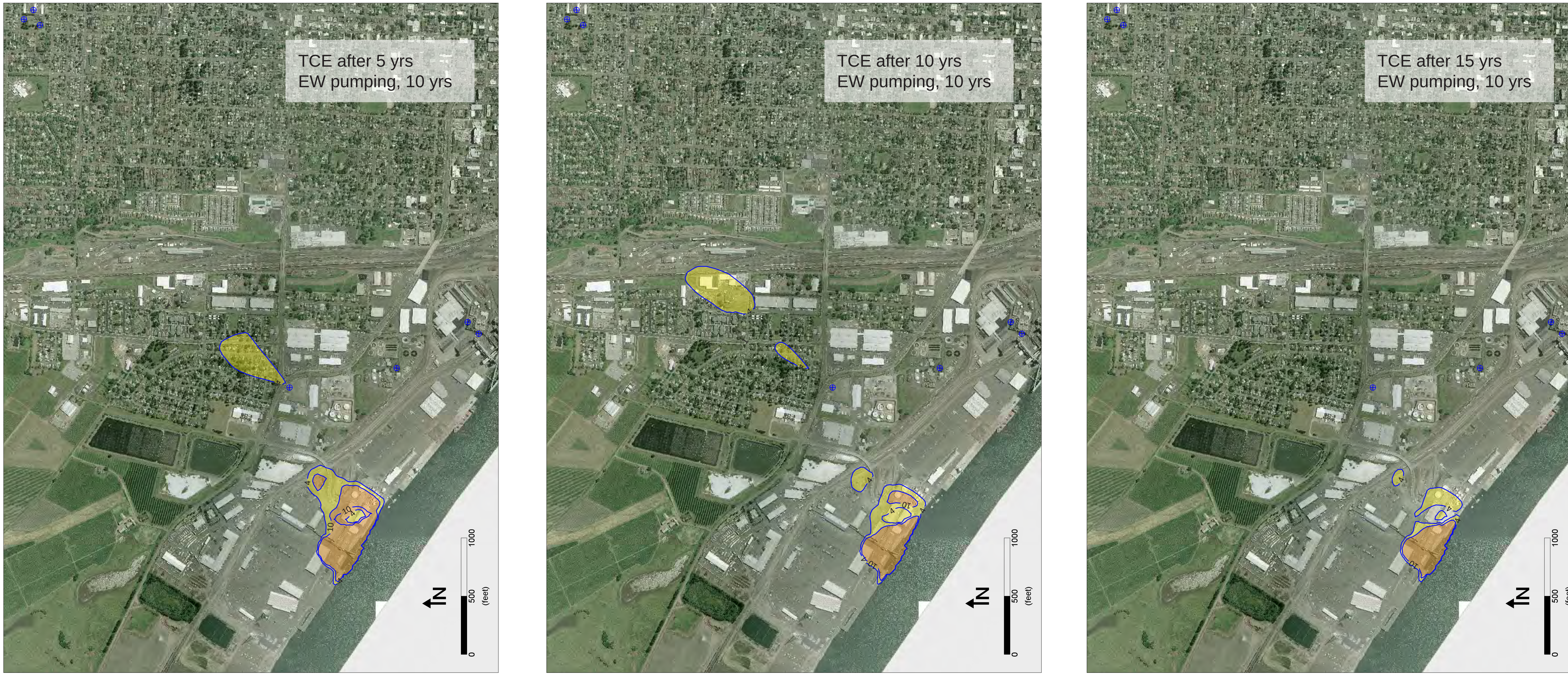
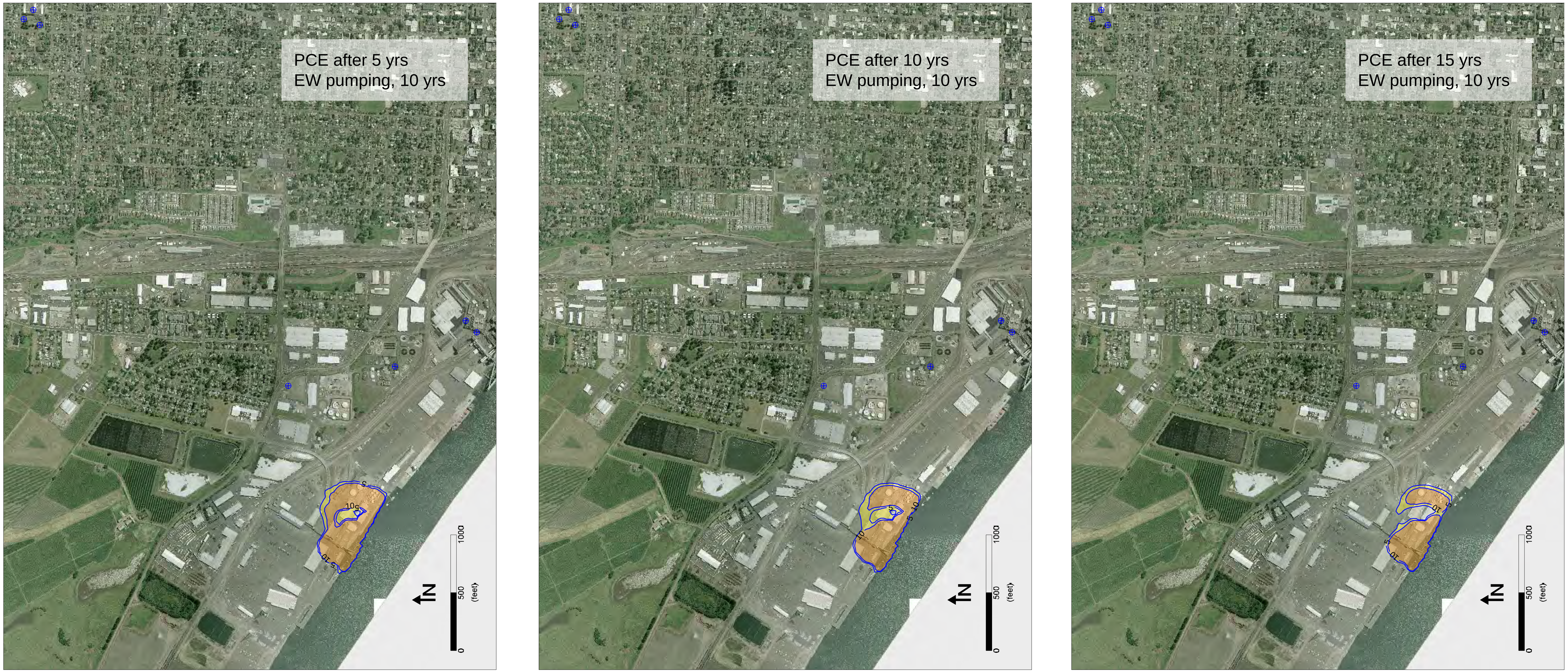


Figure 8-5
Modeled TCE Groundwater Concentrations Above Cleanup Level
Shallow Zone
Year 5, Year 10, Year 15
EW-1 Pumping for 10 Years



Parametrix 275-1940-006-0113-4995

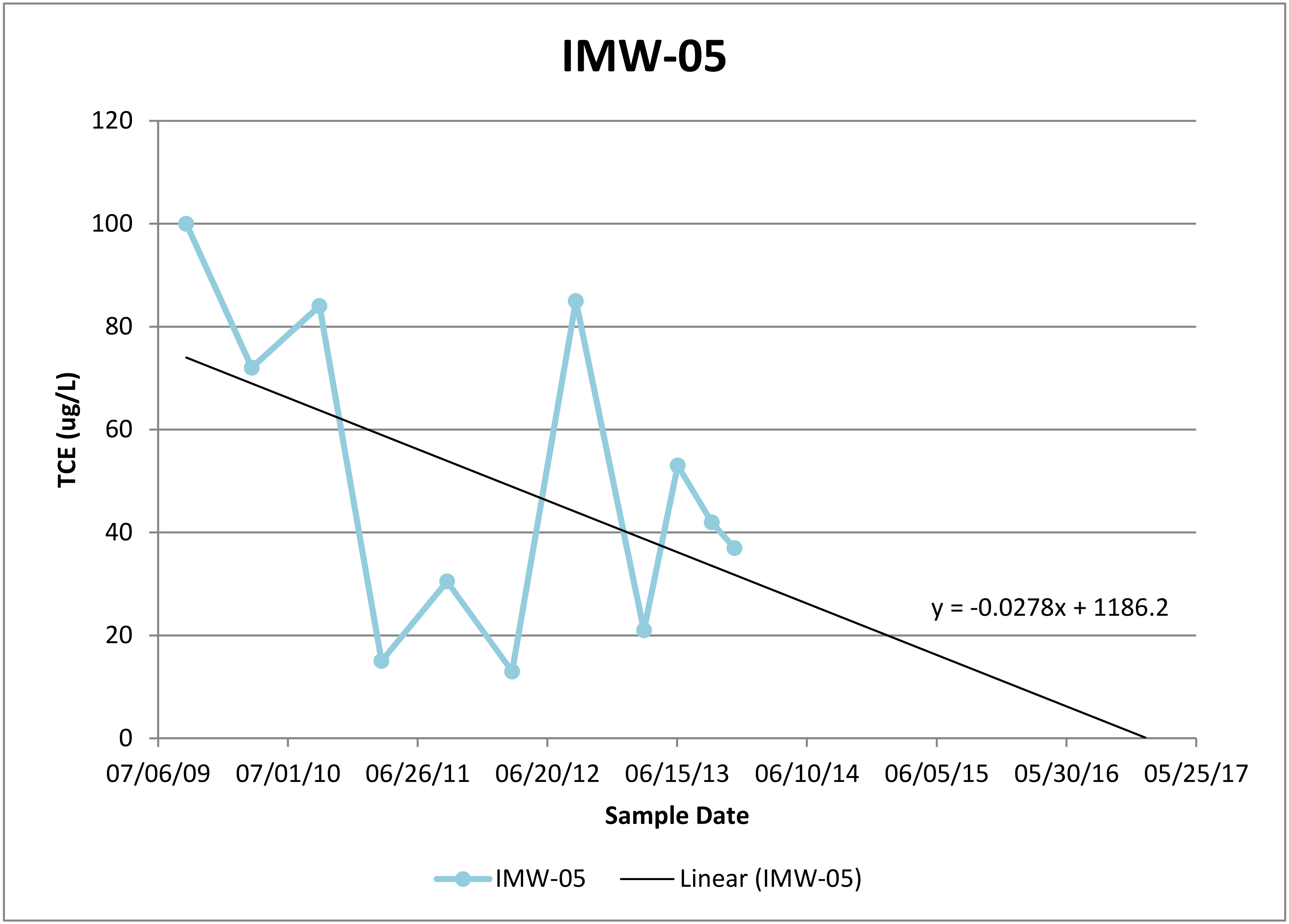
Figure 8-6

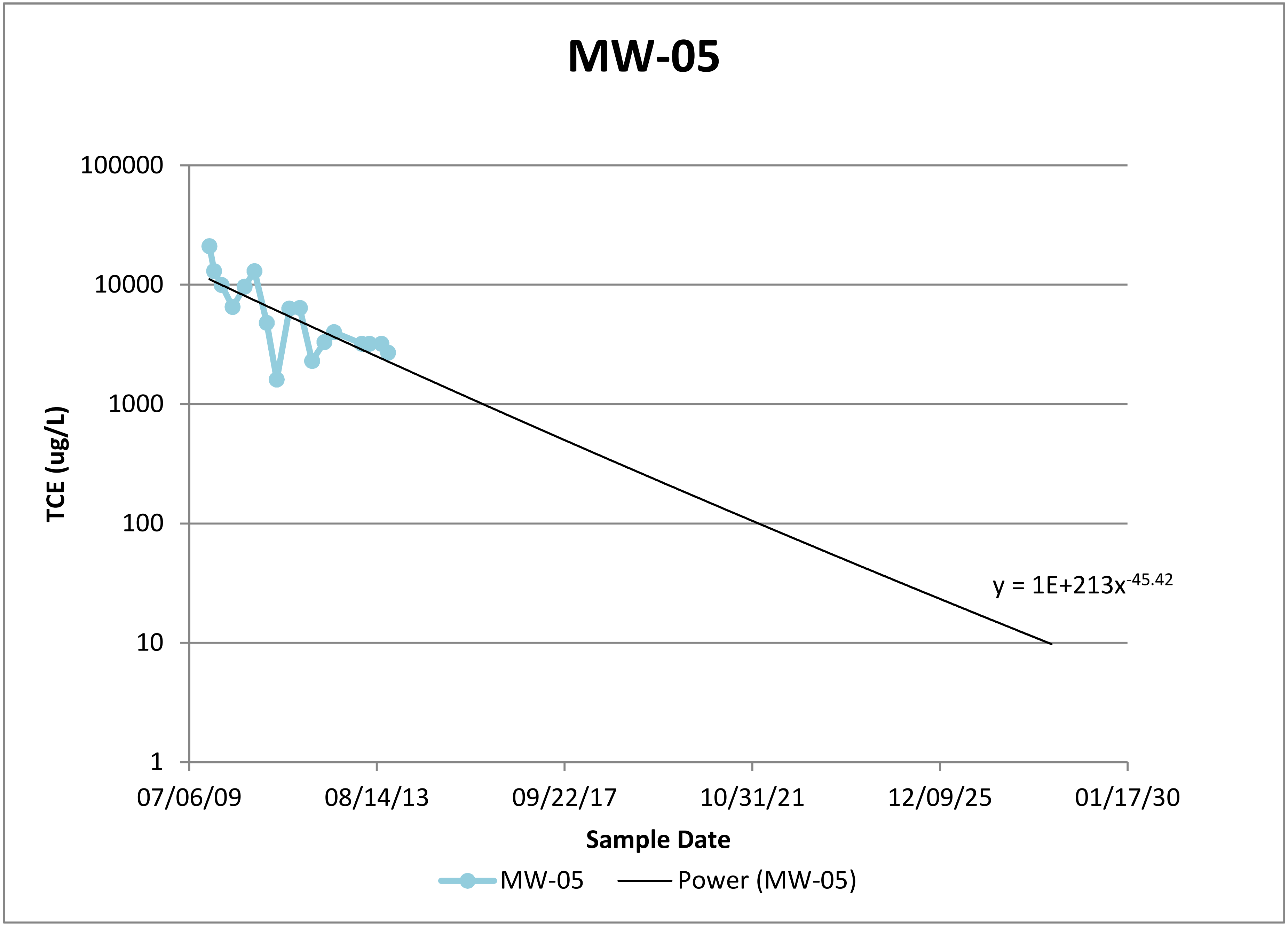
Modeled PCE Groundwater Concentrations Above Cleanup Level

Shallow Zone

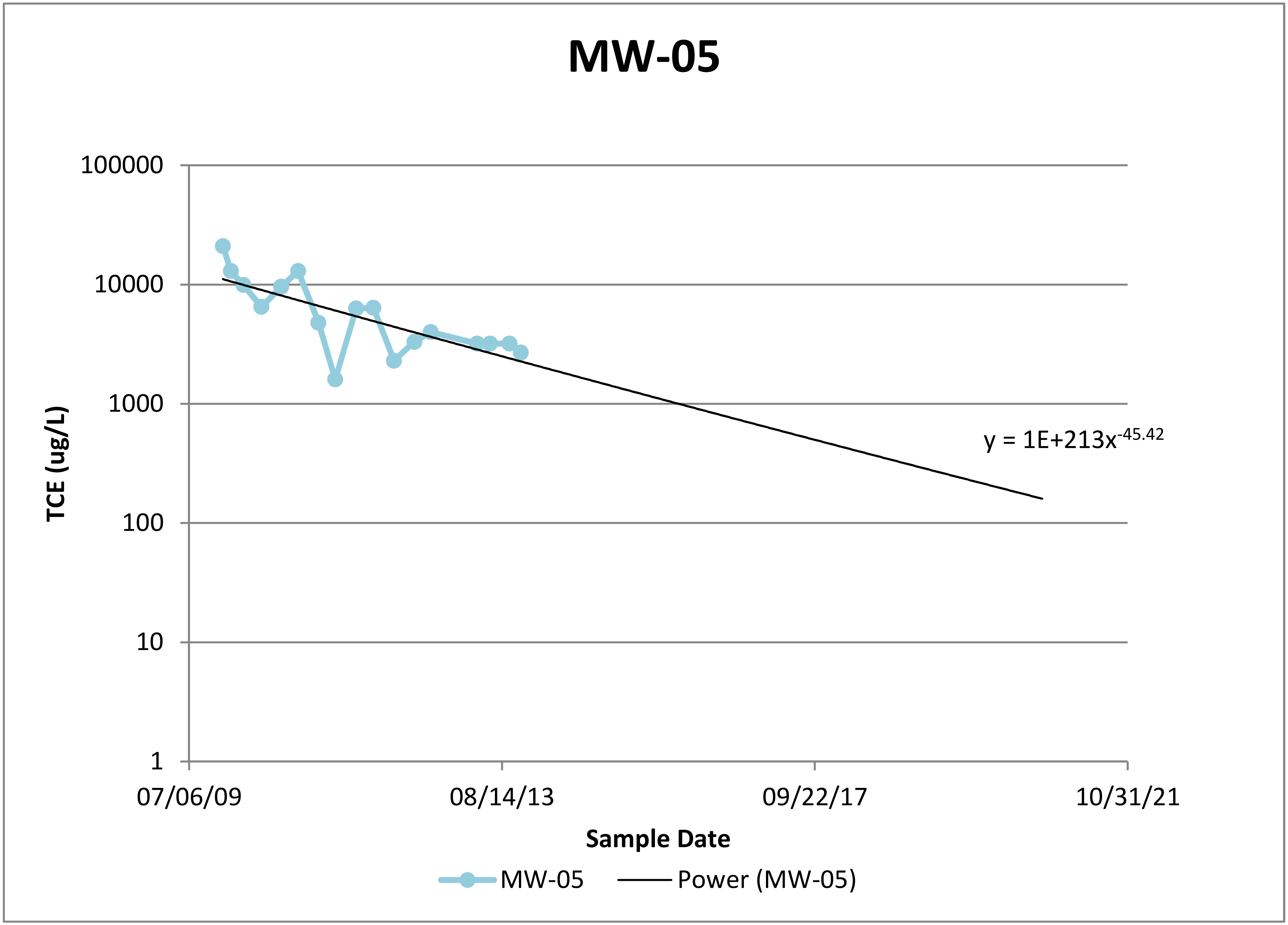
Year 5, Year 10, Year 15

EW-1 Pumping for 10 Years

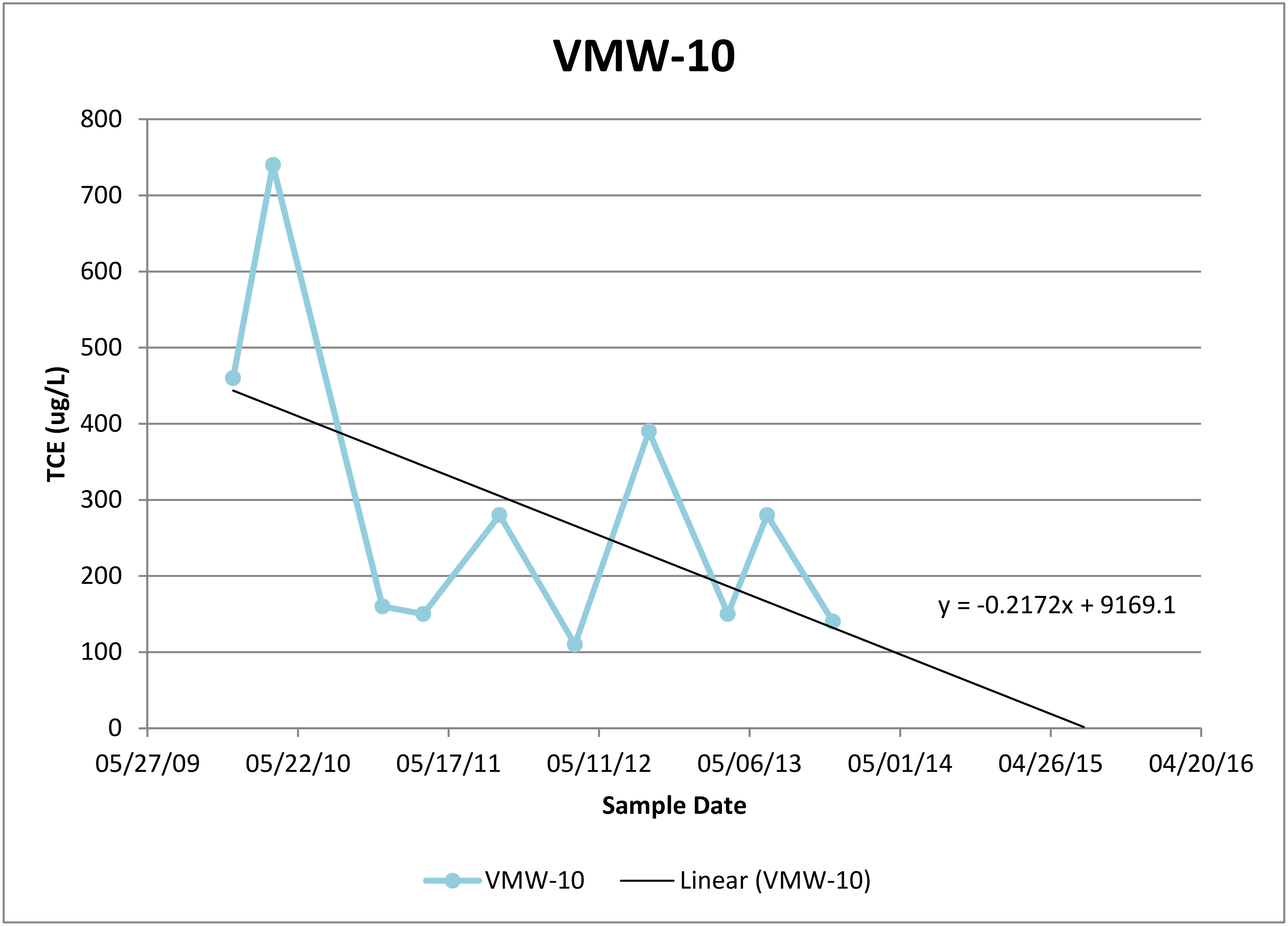

IMW-05
120
100
80
60
40
20
0
TCE (ug/L)
y = -0.0278x + 1186.2
07/06/09
07/01/10
06/26/11
06/20/12
06/15/13
06/10/14
06/05/15
05/30/16
05/25/17
Sample Date
IMW-05
Linear (IMW-05)

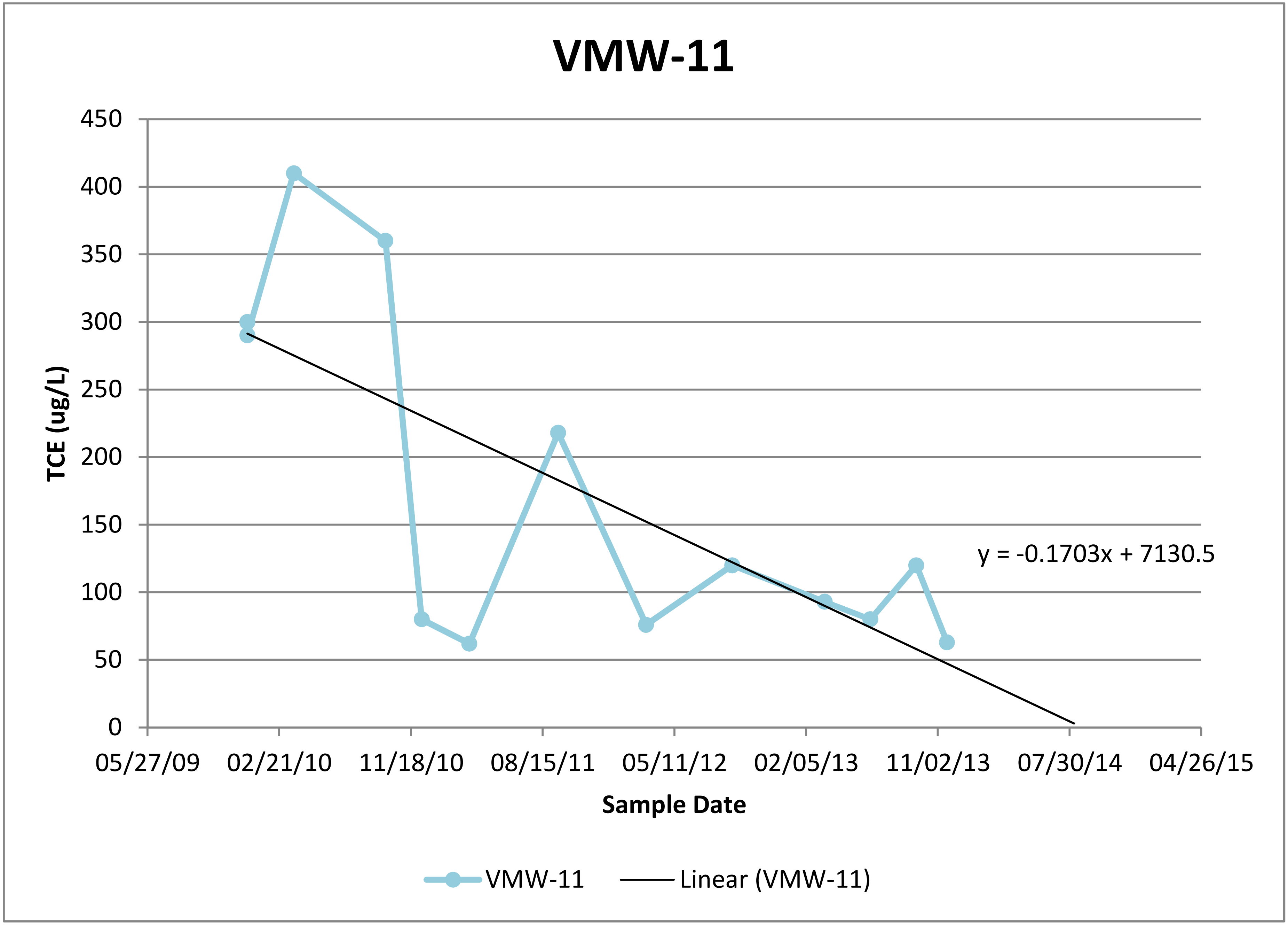


MW-05
100000
10000
1000
100
10
1
TCE (ug/L)
07/06/09
08/14/13
09/22/17
10/31/21
12/09/25
01/17/30
Sample Date
y = 1E+213x-45.42
MW-05
Power (MW-05)

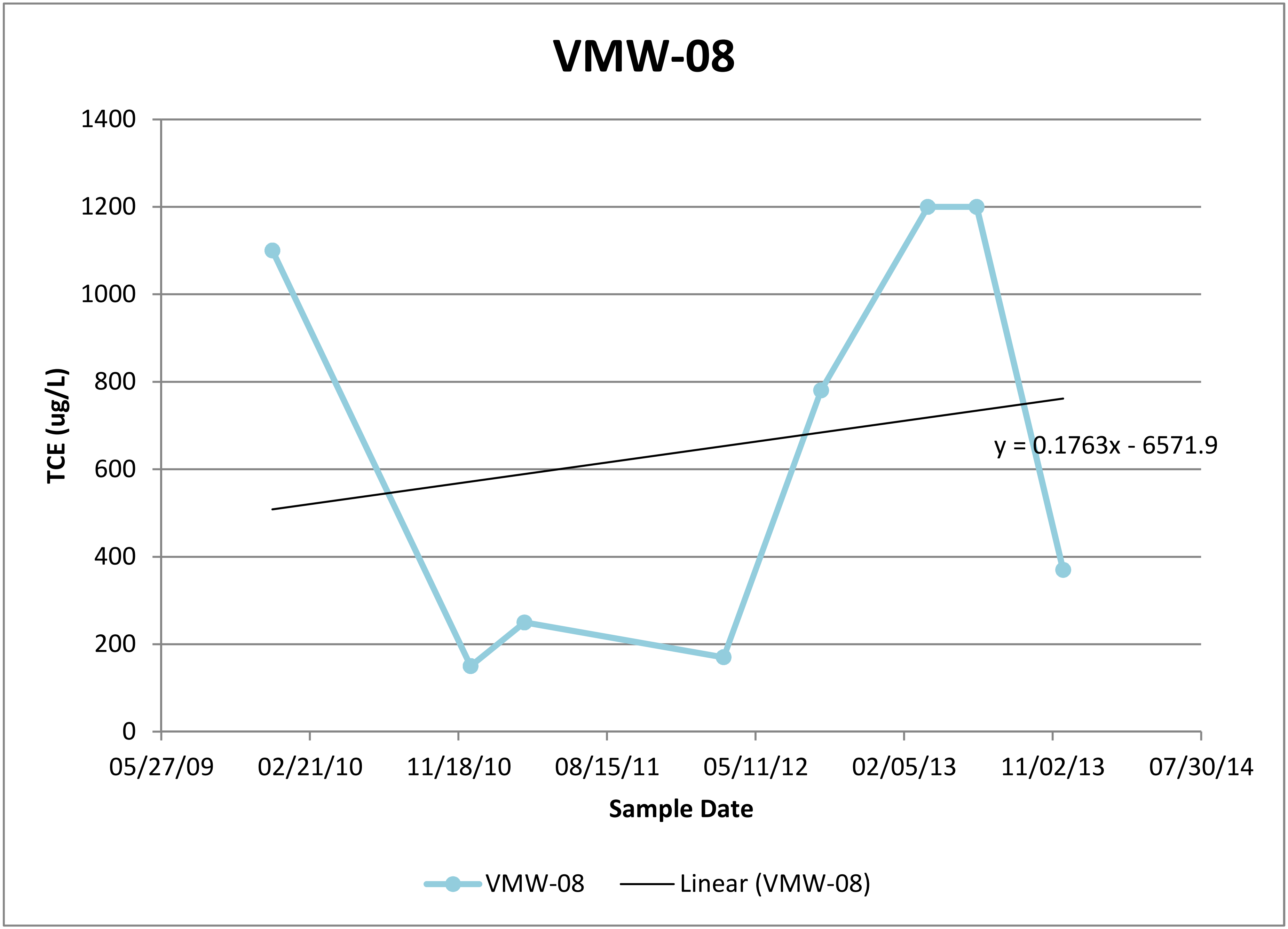


MW-05
100000
10000
1000
100
10
1
TCE (ug/L)
y = 1E+213x-45.42
07/06/09
08/14/13
09/22/17
10/31/21
Sample Date
MW-05
Power (MW-05)

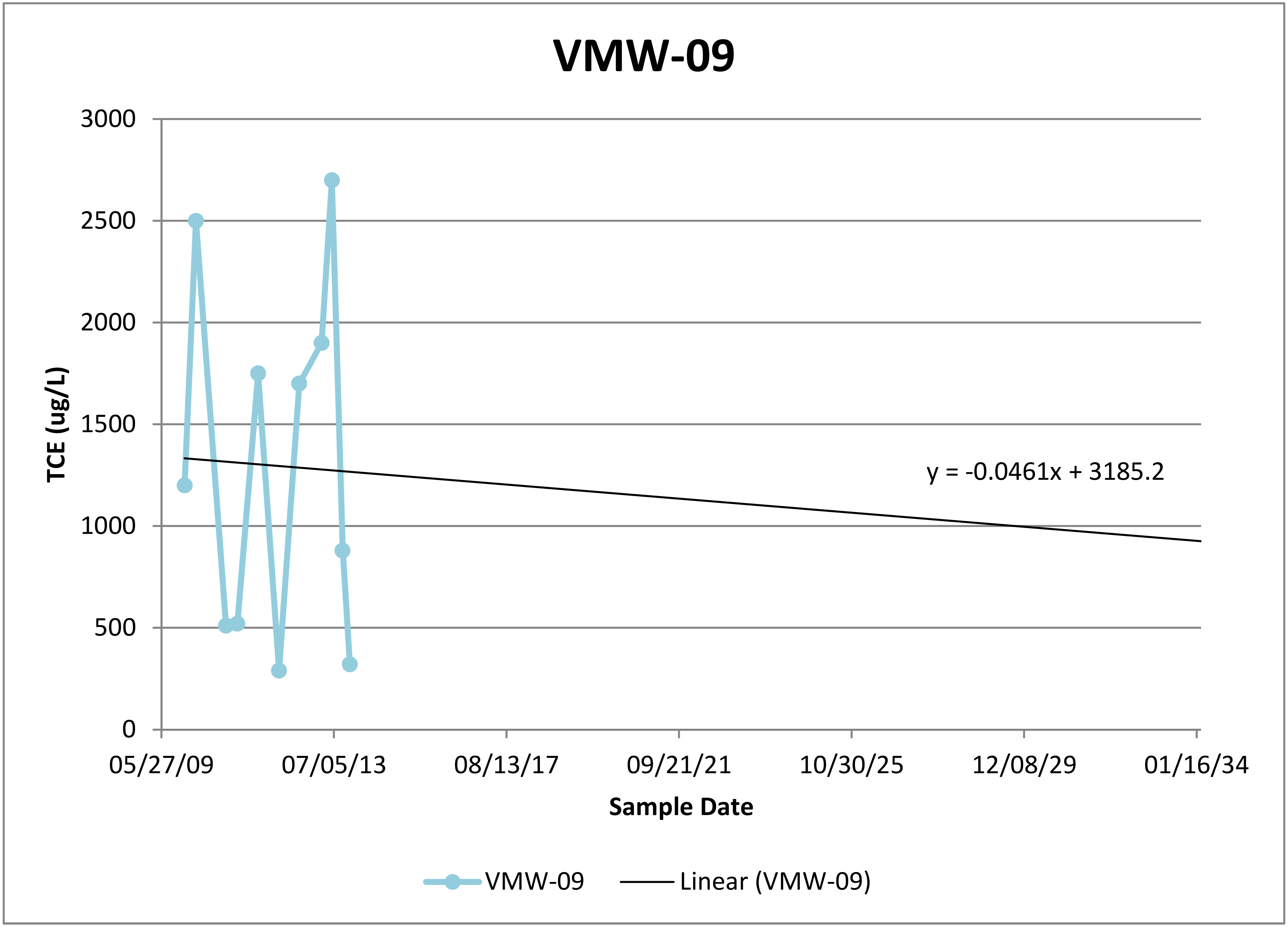

VMW-10
800
700
600
500
400
300
200
100
0
TCE (ug/L)
y = -0.2172x + 9169.1
05/27/09
05/22/10
05/17/11
05/11/12
05/06/13
05/01/14
04/26/15
04/20/16
Sample Date
VMW-10
Linear (VMW-10)



VMW-11
450
400
350
300
250
200
150
100
50
0
TCE (ug/L)
y = -0.1703x + 7130.5
05/27/09
02/21/10
11/18/10
08/15/11
05/11/12
02/05/13
11/02/13
07/30/14
04/26/15
Sample Date
VMW-11
Linear (VMW-11)



VMW-08
1400
1200
1000
800
600
400
200
0
TCE (ug/L)
y = 0.1763x - 6571.9
05/27/09
02/21/10
11/18/10
08/15/11
05/11/12
02/05/13
11/02/13
07/30/14
Sample Date
VMW-08
Linear (VMW-08)



VMW-09
3000
2500
2000
1500
1000
500
0
TCE (ug/L)
y = -0.0461x + 3185.2
05/27/09
07/05/13
08/13/17
09/21/21
10/30/25
12/08/29
01/16/34
Sample Date
VMW-09
Linear (VMW-09)

Alternative E Cost Estimate: Source Area Pump and Treat and MNA
Port of Vancouver
Vancouver, Washington

Activity	Unit Costs	Unit	Extended Cost	Extended Cost
Operation and Maintenance				
2014	$125,000	per year	$125,000	$125,000
2015	$128,750	per year	$128,750	$128,750
2016	$132,613	per year	$132,613	$132,613
2017	$136,591	per year	$136,591	$136,591
2018	$140,689	per year	$140,689	$140,689
2019	$144,909	per year	$144,909	$144,909
2020	$149,257	per year	$149,257	$149,257
2021	$153,734	per year	$153,734	$153,734
2022	$158,346	per year	$158,346	$158,346
2023	$163,097	per year	$163,097	$163,097
Estimated O&M Total			$1,432,985	$1,432,985
Allocation to Source Area		**25%**	**$358,246.23**	
		60%		**$859,790.95**
Groundwater Monitoring				
2014	$10,000	per year	$10,000	$10,000
2015	$10,300	per year	$10,300	$10,300
2016	$10,609	per year	$10,609	$10,609
2017	$10,927	per year	$10,927	$10,927
2018	$11,255	per year	$11,255	$11,255
2019	$11,593	per year	$11,593	$11,593
2020	$11,941	per year	$11,941	$11,941
2021	$12,299	per year	$12,299	$12,299
2022	$12,668	per year	$12,668	$12,668
2023	$13,048	per year	$13,048	$13,048
Insitutional Controls	$10,000	lump sum	$10,000	$10,000
Estimated Total Cost			**$482,885**	**$984,430**

Notes:
This alternative assumes 10 years of pumping required to treat source area, along with 10 years of source area monitoring.
O&M costs only include O&M going forward. Capital costs have already been paid, and are not reflected in the cost estimate for this alternative.
O&M costs are estimated for a pump rate of 1,250 gpm (half of current gpm, due to only source containment required.
Monitoring and O&M costs include labor and lab costs and a 3% yearly increase.
Allocation to Source Area is determined by assuming 30% of Project Area O&M costs due to requirement to treat shallow plume until confiend to SMC.
Costs above do not include the site-wide monitoring that will be required to achieve site closure.
Monitoring costs above is only for source area; remaining costs for monitoring is included in the Project Area alternatives.

APPENDIX F

Project Area Study Evaluation Supporting Documentation

APPENDIX G

NuStar Vancouver Sediment Conceptual Model – Supporting Information

Appendix G

NuStar Vancouver Sediment Conceptual Model – Supporting Information

This appendix details the information used to develop a conceptual model for sediment impacts near the NuStar facility.

Introduction

An initial sediment investigation was conducted from November 7 to 8, 2011, as required by the Washington State Department of Ecology (Ecology), for completion of the NuStar remedial investigation (RI). The analytical results from the November 2011 sediment investigation, and subsequent July 2012 and November 2012 investigations, indicated that some samples of river sediments contained chlorinated volatile organic compounds (VOCs). The sediment analytical results indicated a need for a conceptual model in order to understand the likely source to sediments to develop the appropriate remedial approach for sediments at the site.

The first step in developing a sediment conceptual model was to evaluate the historical information regarding solvent handling at the NuStar Facility. Chlorinated solvents were historically loaded onto railcars in the area near Warehouse No. 13 denoted as the Historical Direct Loading Area ("source area") on Figure G-1. Direct loading (direct transfer from rail tank cars to tank trucks) was the method used for transfer of chlorinated solvents in the source area. Direct loading in this area ended in 1982; solvent handling at the terminal ended as early as 1990 but definitely by the mid-1990s. During the time at which solvents were handled at the terminal, there is no documentation of any direct releases to the Columbia River or river sediments, nor is there any record of solvents being transported by vessel. Therefore, it is not possible that any direct solvent release occurred during materials transfer to or from vessels at the dock.

The second step in developing a sediment conceptual model was to evaluate the river dynamics of the Columbia River channel at the NuStar Facility (Port of Vancouver Berth #7; Figure G-1). The river channel at the NuStar facility is not quiescent; rather it is subject to scour and deposition due to tidal and other river stage fluctuations, boatwash, and dredging (Port of Vancouver, 2011). The river channel near the Facility (at Berth 7; Figure G-1) is dredged on a periodic basis to maintain a depth (-43 feet Columbia River Datum) suitable for vessel navigation, with the most recent dredging events occurring in December 2009 and December 2012. Typically, the channel is dredged up to the Berth #7 dolphins as depicted on Figure G-1. Because the shoreline at the NuStar facility is in a zone of erosion and deposition, it is not likely that VOCs in river sediments could exist for a long time, unless there was a constant source to sediment (i.e., groundwater containing VOCs).

Many lines of evidence were taken into consideration when developing the sediment conceptual model, including the nature and extent of sediment impacts, the nature and extent of upland groundwater impacts, sediment thickness and lithology, the feasibility of groundwater to sediment equilibrium partitioning of VOCs, the location of historical storm drain lines, catch basins, and outfalls, and the local river dynamics including river stage fluctuations, boatwash, scour, and deposition. Based on the review of historical solvent handling processes at the Facility and our understanding of historical and recent groundwater conditions at the NuStar facility, two scenarios were further evaluated as potential sources to river sediments. These were:

1) Discharge of solvents through historical storm water outfalls in the seawall.
2) Migration of site groundwater containing VOCs through river sediments.

An evaluation of both scenarios is provided in the sections below.

Storm Drains as Potential Pathway for Surface Release

Historical storm drains were evaluated as a potential pathway for solvent released in the source area to migrate to the seawall outfall, and ultimately to river sediments. Historical site maps indicate that the storm drains had outfalls at the seawall at the locations shown on Figure G-1; however, historical outfalls are no longer present and their former presence is not certain. In order to evaluate all possible scenarios for impacts to sediment, historical storm drain systems were considered as a preferential pathway for dense non-aqueous-phase liquid (DNAPL) to discharge at the seawall. It should be noted that the evaluation is not intended to confirm that a storm drain system actually existed at the referenced location.

Based on historical site maps, two historical storm drains lines have been identified at the NuStar facility, as shown on Figure G-2. Storm drain line #1 transects through the former solvent handling area while storm drain line #2 transects slightly to the east of the former solvent handling area. A catch basin for storm drain line #1 was located at the northwest corner of Warehouse No. 13 and in the center of the former solvent handling area. The catch basin for storm drain line #2 is located to the east of Warehouse No. 13 and outside of the former solvent handling area. Because the catch basin for storm drain line #1 is located within the former solvent handling area, and the catch basin for storm drain line #2 is not, we would expect the most impacted sediments to be located near the outfall for storm drain line #1, and lesser sediment impacts, if any, near the outfall for storm drain line #2. The opposite is true, as shown on Figure G-3. Surface sediment VOC concentrations in samples collected from the vicinity of the storm drain line #1 outfall (samples “B” and “2”) are lower than concentrations in samples collected near the storm drain line #2 outfall (samples “C” and “3”).

Additionally, the storm drain outfalls at the NuStar facility are located approximately nine feet above river level as shown on the cross-section in Figure G-2. The extent of sediment impacts is not consistent with DNAPL leaking from an outfall onto river sediments. In that scenario, widespread impacts both parallel and perpendicular to the shoreline would be expected, as DNAPL spreading is influenced by gravity flow and river stage fluctuations. Instead, an abrupt drop-off in VOC concentrations at the sediment depth that coincides with the Shallow Zone/Intermediate Zone groundwater transition is observed.

As previously discussed, solvent has not been handled at the NuStar terminal in over 20 years and therefore any release to a drain pipe would have occurred at least 20 years ago. Boat wash, scour, deposition, and routine dredging all occur in the Columbia River channel adjacent to the NuStar facility. If DNAPL had discharged to river sediments over 20 years ago, the impacted sediments would have then been subject to at least 20 years of river activity. Furthermore, lithological information from sediment cores indicate that the silty sediments (where VOCs would preferentially adsorb) are typically less than one foot thick in most areas. It would be unlikely that DNAPL or elevated sediment concentrations would persist in a thin sediment layer in this dynamic environment for over 20 years.

Groundwater as Potential Source to Sediment

Equilibrium Evaluation. The first step in evaluating groundwater as a potential VOC source to sediments was to determine if the concentrations of chlorinated VOCs in groundwater were sufficient to adsorb to sediments at the concentrations measured in the 2011 and 2012 investigations. MTCA Equation 747-1 (Ecology, 2007) was used to determine if the maximum concentrations measured in sediments in 2011/2012 could be explained by partitioning from groundwater at 2008 VOC concentrations. Concentrations of VOCs in groundwater in 2008 were selected for this evaluation as they were considered consistent with the timeframe for migration and adsorption to river sediments. Furthermore, the concentration and extent of VOCs in groundwater have decreased rapidly since 2008 in response to ongoing groundwater interim actions; therefore, the 2008 concentrations represent the most recent stable concentrations for use in evaluating equilibrium partitioning between groundwater and sediments.

Equation 747-1 is a three-phase partitioning equation that takes into account site-specific information such as sediment concentration and fraction organic carbon (derived from organic carbon measured directly in the sediment samples), as well as chemical-specific information, to back-calculate the minimum concentration in groundwater that could result in the measured sediment concentration. For example, in order to achieve a PCE concentration of 9.2 mg/kg in sediments (Location 3), a minimum PCE concentration in groundwater of 3,332 micrograms per liter (µg/L) would be necessary.

A cross-section through the NuStar shoreline, seawall, and upland portion of the terminal (near Warehouse 13) is presented on Figure G-2. Equilibrium partitioning calculations for PCE, TCE, cis-1-,2 DCE, and 1,1-DCA in sediment samples “H”, “7” and “3” were performed and the calculations and results are included as Tables G-1, G-2, and G-3, respectively. These sample locations were selected as they extend perpendicular to the shoreline immediately downgradient from the former solvent handling area. Figure G-2 includes equilibrium data as well as historical soil boring and monitoring well data, from 2006/2007 and 2008 respectively, as well as sediment data from the 2011/2012 investigations. Three sediment cores are represented on the cross-section; sample location “3” is in contact with Shallow Zone groundwater, location “7” is in contact with Intermediate Zone groundwater, and location “H” is in contact with deeper Intermediate Zone groundwater. The concentrations in groundwater necessary to partition to sediments at the concentrations measured are presented in the data boxes adjacent to the sample location name. In the Shallow Zone, there is a good correlation between upland groundwater concentrations and the required partitioning concentration. For example, in boring AGP-10, the PCE concentration in groundwater is 3,280 µg/L and the concentration needed to achieve the sediment concentrations observed is 3,332 µg/L. In the Intermediate Zone, there are no available groundwater data available between boring AGP-12 and the seawall.

However, the groundwater data are within an order of magnitude of the groundwater to sediment partitioning concentration, so are considered reasonable. Collectively, these data support that 2008 groundwater concentrations could partition to sediments at the concentrations measured during the 2011/2012 sediment investigations.

Extent of Sediment Impacts Relative to Extent of Upland Groundwater Impacts. Sediment data from the 2011 and 2012 investigations are summarized on Figure G-3. Groundwater data from first quarter 2008, collected prior to the 2008 enhanced bioremediation groundwater interim action, are shown, and groundwater isocontours are included to highlight the upland areas with the highest groundwater concentrations prior to the more recent (2008 and 2011) interim actions. The data indicate that the most elevated sediment samples (Locations “C”, “3” and “D”) are immediately downgradient from the most impacted groundwater at well MW-7. As upland concentrations decrease away from the source area, the VOC concentrations in downgradient sediments also decrease. The strong correlation between the extent of impacted sediment and impacted groundwater at the NuStar facility support groundwater as a likely source of VOCs in sediments.

Sediment in Contact with Shallow vs. Intermediate Zone Groundwater. River stage prediction data, bathymetry maps, and depth to sediment measurements were used to collect sediment samples at target depths. The sediment samples could then be correlated with upland elevations representative of Shallow and Intermediate Zone groundwater. Sediment samples depicted on Figure G-3 are labelled as Shallow Zone or Intermediate Zone samples, accordingly. As depicted on Figure G-2 and described in Section 2.2.8.1 of the FS, groundwater flow at the NuStar Facility is generally toward the river in the Shallow Zone and is bi-directional in the Intermediate zone. Concentrations of VOCs in site groundwater are generally one to two orders of magnitude higher in Shallow Zone groundwater relative to Intermediate Zone groundwater at the same location. Similarly, sediments are generally more impacted at depths that are in contact with Shallow Zone groundwater rather than at depths in contact with Intermediate Zone groundwater. These relative concentrations support the hypothesis that sediment impacts at the Facility are sourced from upland groundwater.

Sediment Concentration and Lithology. A schematic of sediment sample cores for locations “C”, “3”, and “D” are shown on Figure G-2 and sediment concentration data and lithology information are summarized on Figure G-4. Sample cores were collected perpendicular to the river bottom, and are representative of changes in riverbed lithology rather than a concentration profile in the direction of the groundwater flowpath (perpendicular to the seawall). This is important to note, because in order to be consistent with a groundwater source scenario, it would be anticipated that VOC concentrations would increase in sediments as you sample deeper in the core, if the core had been collected perpendicular to the seawall and sediment type was consistent throughout the core.

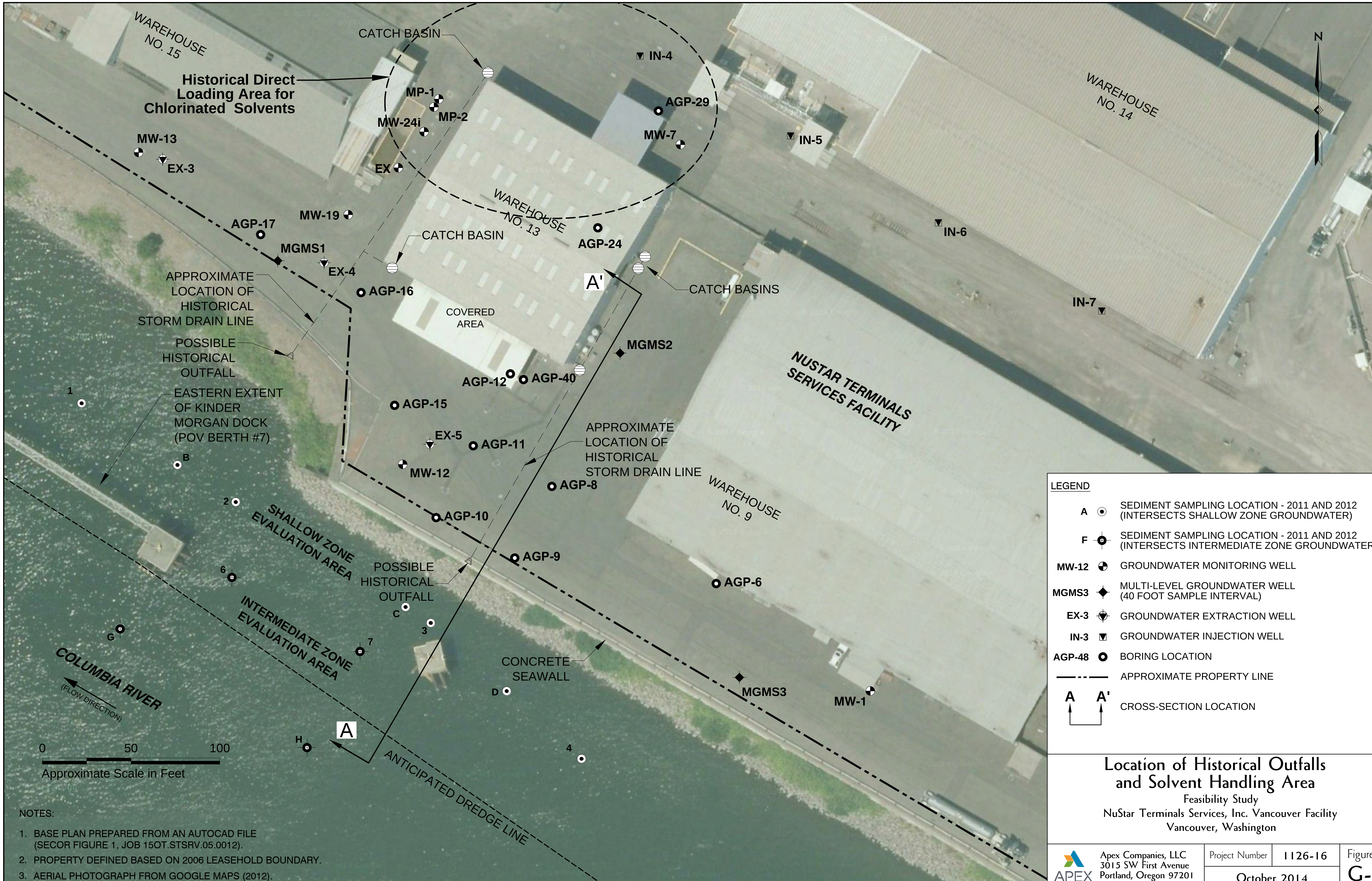
Instead, VOC concentrations are generally higher in samples where the soil type has a higher silty content relative to sand. This is due to the presence of a higher organic content in silts versus sands, which then increases the adsorption capacity of the sediment. For example, at sample location “3”, the lithology consists of silty sediment underlain by sands to the maximum depth explored. PCE, TCE, and cis-DCE concentrations are higher in the silty sediments than the underlying sands. This correlation is observed at 16 of the 18 sediment sample locations. Given the inherent heterogeneity in soil types, this level of correlation is strong. Where VOC concentration is not directly correlated with soil type, it is likely due to challenges associated with sampling and lithologically describing the heterogeneous river bottom. Samples collected for VOC using Environmental Protection Agency (EPA) Method 5035A are small (thumb-sized) compared to the one- to two-foot core logging intervals. It is possible that the soil type associated with samples collected for analysis is not consistent with the majority or the remaining soil core, or the soil core is highly heterogeneous in nature and a "representative" sample does not exist.

Conclusions

Three sediment investigations were conducted to define the extent of VOCs in Columbia River sediment. In order to support the cleanup remedy selection in the feasibility study (FS), it was essential to understand the most likely source of impacts to river sediment. Historical site process information, as well as site groundwater and sediment data suggest that elevated VOC concentrations in site groundwater is likely the predominant method by which river sediments have been impacted. While it is possible that some contribution may have come from DNAPL in historical seawall outfalls, the data are less compelling that this would be the predominant source to sediments.

Reference

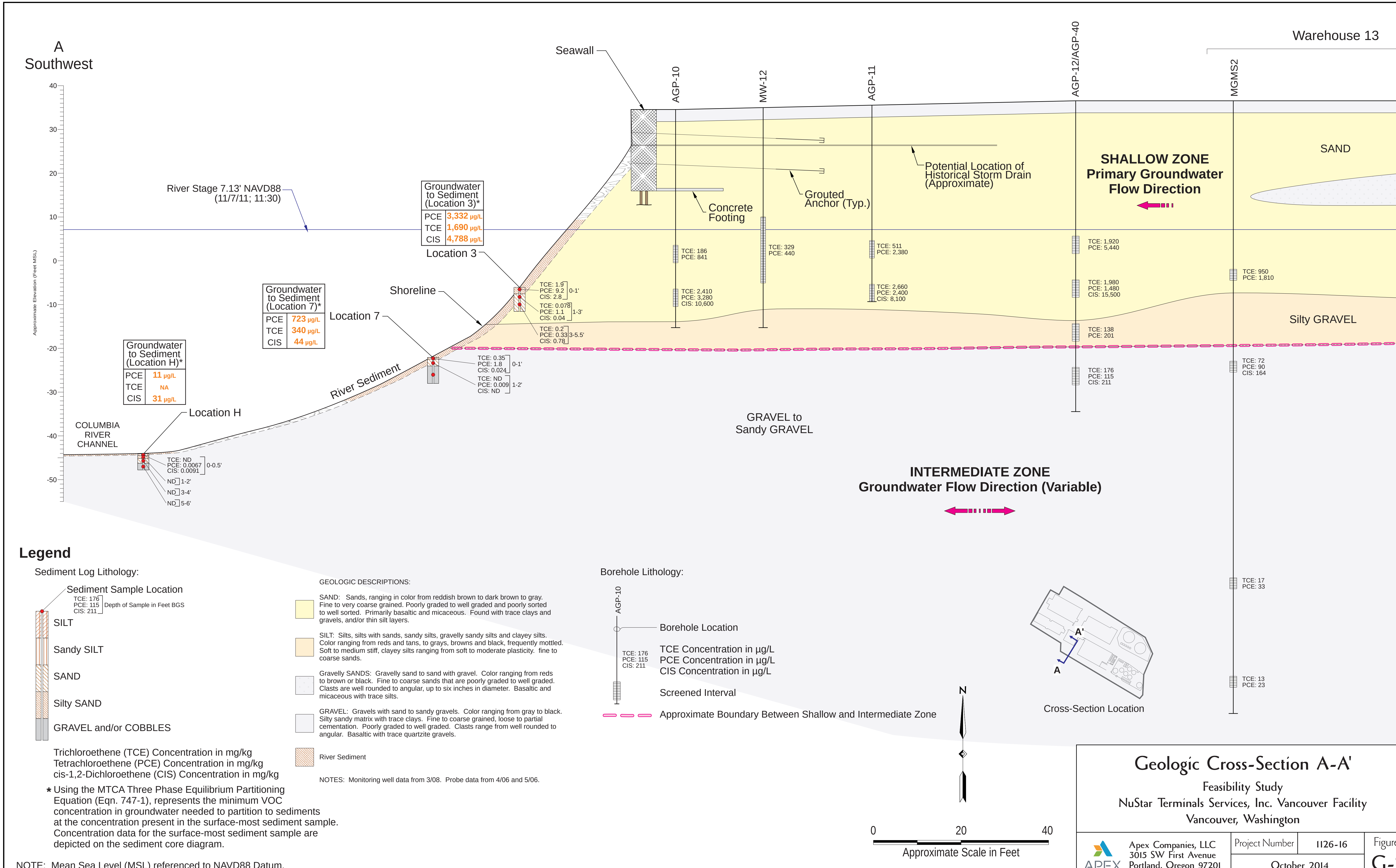
Port of Vancouver, 2011. *Port of Vancouver Berth Sedimentation Analysis Engineering.* Presentation prepared by Coast and Harbor Engineering. June 24, 2011 (updated July 11, 2011).

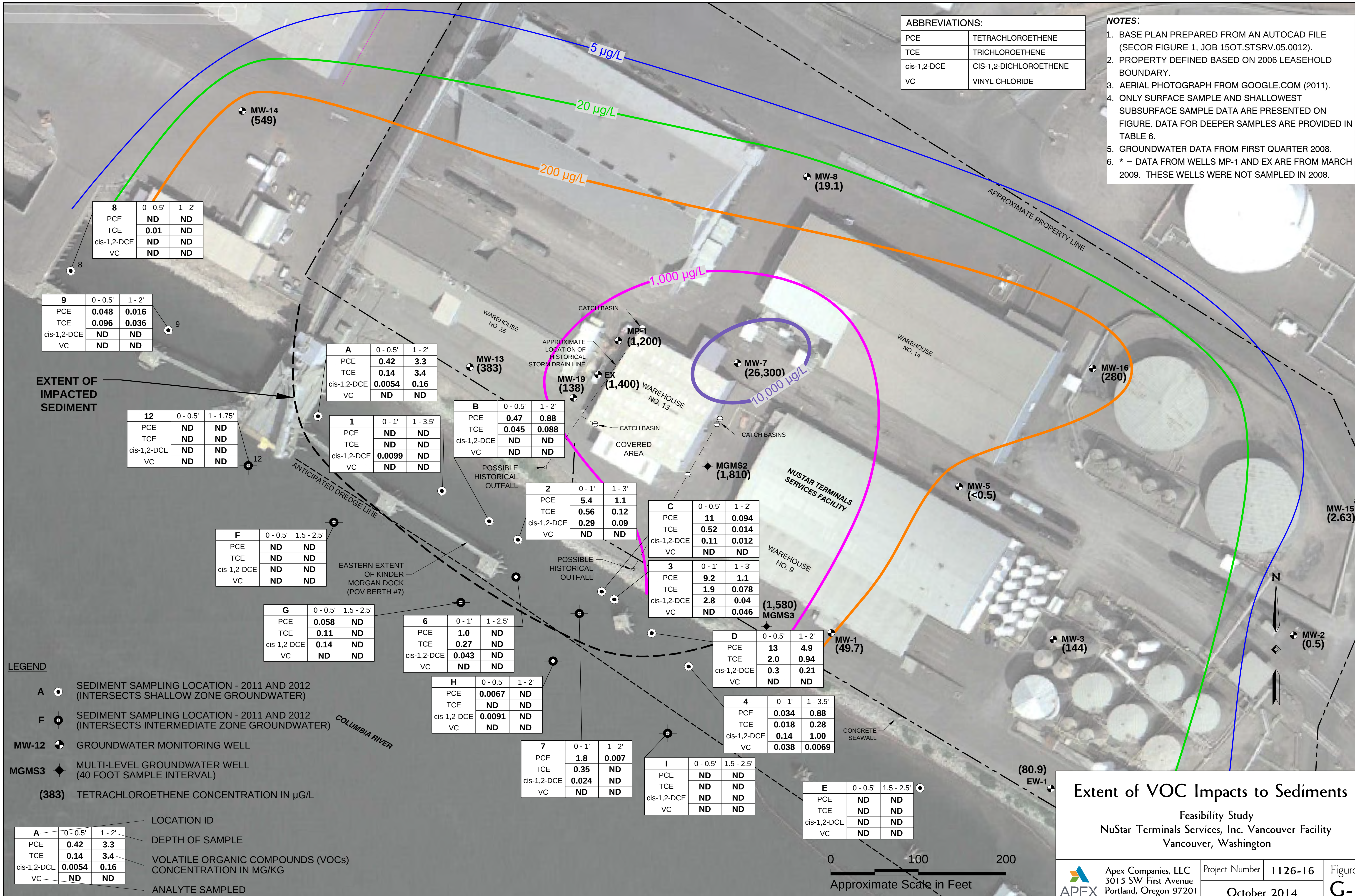


Location of Historical Outfalls and Solvent Handling Area

Feasibility Study
NuStar Terminals Services, Inc. Vancouver Facility
Vancouver, Washington

APEX — Apex Companies, LLC, 3015 SW First Avenue, Portland, Oregon 97201	Project Number	1126-16	Figure G-1
	October 2014		


A
Southwest
Seawall
Warehouse 13
AGP-10
MW-12
AGP-11
AGP-12/AGP-40
MGMS2
Approximate Elevation (Feet MSL)
River Stage 7.13' NAVD88
(11/7/11; 11:30)
Potential Location of Historical Storm Drain (Approximate)
Grouted Anchor (Typ.)
Concrete Footing
SHALLOW ZONE
Primary Groundwater Flow Direction
SAND
Silty GRAVEL
Groundwater to Sediment (Location 3)*
PCE 3,332 µg/L
TCE 1,690 µg/L
CIS 4,788 µg/L
Location 3
Groundwater to Sediment (Location 7)*
PCE 723 µg/L
TCE 340 µg/L
CIS 44 µg/L
Location 7
Shoreline
Groundwater to Sediment (Location H)*
PCE 11 µg/L
TCE NA
CIS 31 µg/L
Location H
River Sediment
COLUMBIA RIVER CHANNEL
TCE: 1.9 PCE: 9.2 CIS: 2.8 0-1'
TCE: 0.078 PCE: 1.1 CIS: 0.04 1-3'
TCE: 0.2 PCE: 0.33 CIS: 0.78 3-5.5'
TCE: 0.35 PCE: 1.8 CIS: 0.024 0-1'
TCE: ND PCE: 0.009 CIS: ND 1-2'
TCE: ND PCE: 0.0067 CIS: 0.0091 0-0.5'
ND 1-2'
ND 3-4'
ND 5-6'
TCE: 186 PCE: 841
TCE: 2,410 PCE: 3,280 CIS: 10,600
TCE: 329 PCE: 440
TCE: 511 PCE: 2,380
TCE: 2,660 PCE: 2,400 CIS: 8,100
TCE: 1,920 PCE: 5,440
TCE: 1,980 PCE: 1,480 CIS: 15,500
TCE: 138 PCE: 201
TCE: 176 PCE: 115 CIS: 211
TCE: 950 PCE: 1,810
TCE: 72 PCE: 90 CIS: 164
TCE: 17 PCE: 33
TCE: 13 PCE: 23
GRAVEL to Sandy GRAVEL
INTERMEDIATE ZONE
Groundwater Flow Direction (Variable)
Legend
Sediment Log Lithology:
Sediment Sample Location
TCE: 176 PCE: 115 CIS: 211 Depth of Sample in Feet BGS
SILT
Sandy SILT
SAND
Silty SAND
GRAVEL and/or COBBLES
Trichloroethene (TCE) Concentration in mg/kg
Tetrachloroethene (PCE) Concentration in mg/kg
cis-1,2-Dichloroethene (CIS) Concentration in mg/kg
* Using the MTCA Three Phase Equilibrium Partitioning Equation (Eqn. 747-1), represents the minimum VOC concentration in groundwater needed to partition to sediments at the concentration present in the surface-most sediment sample. Concentration data for the surface-most sediment sample are depicted on the sediment core diagram.
NOTE: Mean Sea Level (MSL) referenced to NAVD88 Datum.
GEOLOGIC DESCRIPTIONS:
SAND: Sands, ranging in color from reddish brown to dark brown to gray. Fine to very coarse grained. Poorly graded to well graded and poorly sorted to well sorted. Primarily basaltic and micaceous. Found with trace clays and gravels, and/or thin silt layers.
SILT: Silts, silts with sands, sandy silts, gravelly sandy silts and clayey silts. Color ranging from reds and tans, to grays, browns and black, frequently mottled. Soft to medium stiff, clayey silts ranging from soft to moderate plasticity. fine to coarse sands.
Gravelly SANDS: Gravelly sand to sand with gravel. Color ranging from reds to brown or black. Fine to coarse sands that are poorly graded to well graded. Clasts are well rounded to angular, up to six inches in diameter. Basaltic and micaceous with trace silts.
GRAVEL: Gravels with sand to sandy gravels. Color ranging from gray to black. Silty sandy matrix with trace clays. Fine to coarse grained, loose to partial cementation. Poorly graded to well graded. Clasts range from well rounded to angular. Basaltic with trace quartzite gravels.
River Sediment
NOTES: Monitoring well data from 3/08. Probe data from 4/06 and 5/06.
Borehole Lithology:
AGP-10
Borehole Location
TCE: 176 PCE: 115 CIS: 211
TCE Concentration in µg/L
PCE Concentration in µg/L
CIS Concentration in µg/L
Screened Interval
Approximate Boundary Between Shallow and Intermediate Zone
N
A'
A
Cross-Section Location
0 20 40
Approximate Scale in Feet
Geologic Cross-Section A-A'
Feasibility Study
NuStar Terminals Services, Inc. Vancouver Facility
Vancouver, Washington
APEX
Apex Companies, LLC
3015 SW First Avenue
Portland, Oregon 97201
Project Number 1126-16
October 2014
Figure G-2



ABBREVIATIONS:

PCE	TETRACHLOROETHENE
TCE	TRICHLOROETHENE
cis-1,2-DCE	CIS-1,2-DICHLOROETHENE
VC	VINYL CHLORIDE

NOTES:

1. BASE PLAN PREPARED FROM AN AUTOCAD FILE (SECOR FIGURE 1, JOB 15OT.STSRV.05.0012).
2. PROPERTY DEFINED BASED ON 2006 LEASEHOLD BOUNDARY.
3. AERIAL PHOTOGRAPH FROM GOOGLE.COM (2011).
4. ONLY SURFACE SAMPLE AND SHALLOWEST SUBSURFACE SAMPLE DATA ARE PRESENTED ON FIGURE. DATA FOR DEEPER SAMPLES ARE PROVIDED IN TABLE 6.
5. GROUNDWATER DATA FROM FIRST QUARTER 2008.
6. * = DATA FROM WELLS MP-1 AND EX ARE FROM MARCH 2009. THESE WELLS WERE NOT SAMPLED IN 2008.

8	0 - 0.5'	1 - 2'
PCE	ND	ND
TCE	0.01	ND
cis-1,2-DCE	ND	ND
VC	ND	ND

9	0 - 0.5'	1 - 2'
PCE	0.048	0.016
TCE	0.096	0.036
cis-1,2-DCE	ND	ND
VC	ND	ND

A	0 - 0.5'	1 - 2'
PCE	0.42	3.3
TCE	0.14	3.4
cis-1,2-DCE	0.0054	0.16
VC	ND	ND

12	0 - 0.5'	1 - 1.75'
PCE	ND	ND
TCE	ND	ND
cis-1,2-DCE	ND	ND
VC	ND	ND

1	0 - 1'	1 - 3.5'
PCE	ND	ND
TCE	ND	ND
cis-1,2-DCE	0.0099	ND
VC	ND	ND

B	0 - 0.5'	1 - 2'
PCE	0.47	0.88
TCE	0.045	0.088
cis-1,2-DCE	ND	ND
VC	ND	ND

2	0 - 1'	1 - 3'
PCE	5.4	1.1
TCE	0.56	0.12
cis-1,2-DCE	0.29	0.09
VC	ND	ND

C	0 - 0.5'	1 - 2'
PCE	11	0.094
TCE	0.52	0.014
cis-1,2-DCE	0.11	0.012
VC	ND	ND

3	0 - 1'	1 - 3'
PCE	9.2	1.1
TCE	1.9	0.078
cis-1,2-DCE	2.8	0.04
VC	ND	0.046

F	0 - 0.5'	1.5 - 2.5'
PCE	ND	ND
TCE	ND	ND
cis-1,2-DCE	ND	ND
VC	ND	ND

G	0 - 0.5'	1.5 - 2.5'
PCE	0.058	ND
TCE	0.11	ND
cis-1,2-DCE	0.14	ND
VC	ND	ND

6	0 - 1'	1 - 2.5'
PCE	1.0	ND
TCE	0.27	ND
cis-1,2-DCE	0.043	ND
VC	ND	ND

D	0 - 0.5'	1 - 2'
PCE	13	4.9
TCE	2.0	0.94
cis-1,2-DCE	0.3	0.21
VC	ND	ND

H	0 - 0.5'	1 - 2'
PCE	0.0067	ND
TCE	ND	ND
cis-1,2-DCE	0.0091	ND
VC	ND	ND

4	0 - 1'	1 - 3.5'
PCE	0.034	0.88
TCE	0.018	0.28
cis-1,2-DCE	0.14	1.00
VC	0.038	0.0069

7	0 - 1'	1 - 2'
PCE	1.8	0.007
TCE	0.35	ND
cis-1,2-DCE	0.024	ND
VC	ND	ND

I	0 - 0.5'	1.5 - 2.5'
PCE	ND	ND
TCE	ND	ND
cis-1,2-DCE	ND	ND
VC	ND	ND

E	0 - 0.5'	1.5 - 2.5'
PCE	ND	ND
TCE	ND	ND
cis-1,2-DCE	ND	ND
VC	ND	ND

LEGEND

A — SEDIMENT SAMPLING LOCATION - 2011 AND 2012 (INTERSECTS SHALLOW ZONE GROUNDWATER)

F — SEDIMENT SAMPLING LOCATION - 2011 AND 2012 (INTERSECTS INTERMEDIATE ZONE GROUNDWATER)

MW-12 — GROUNDWATER MONITORING WELL

MGMS3 — MULTI-LEVEL GROUNDWATER WELL (40 FOOT SAMPLE INTERVAL)

(383) — TETRACHLOROETHENE CONCENTRATION IN µG/L

A	0 - 0.5'	1 - 2'
PCE	0.42	3.3
TCE	0.14	3.4
cis-1,2-DCE	0.0054	0.16
VC	ND	ND

LOCATION ID

DEPTH OF SAMPLE

VOLATILE ORGANIC COMPOUNDS (VOCs) CONCENTRATION IN MG/KG

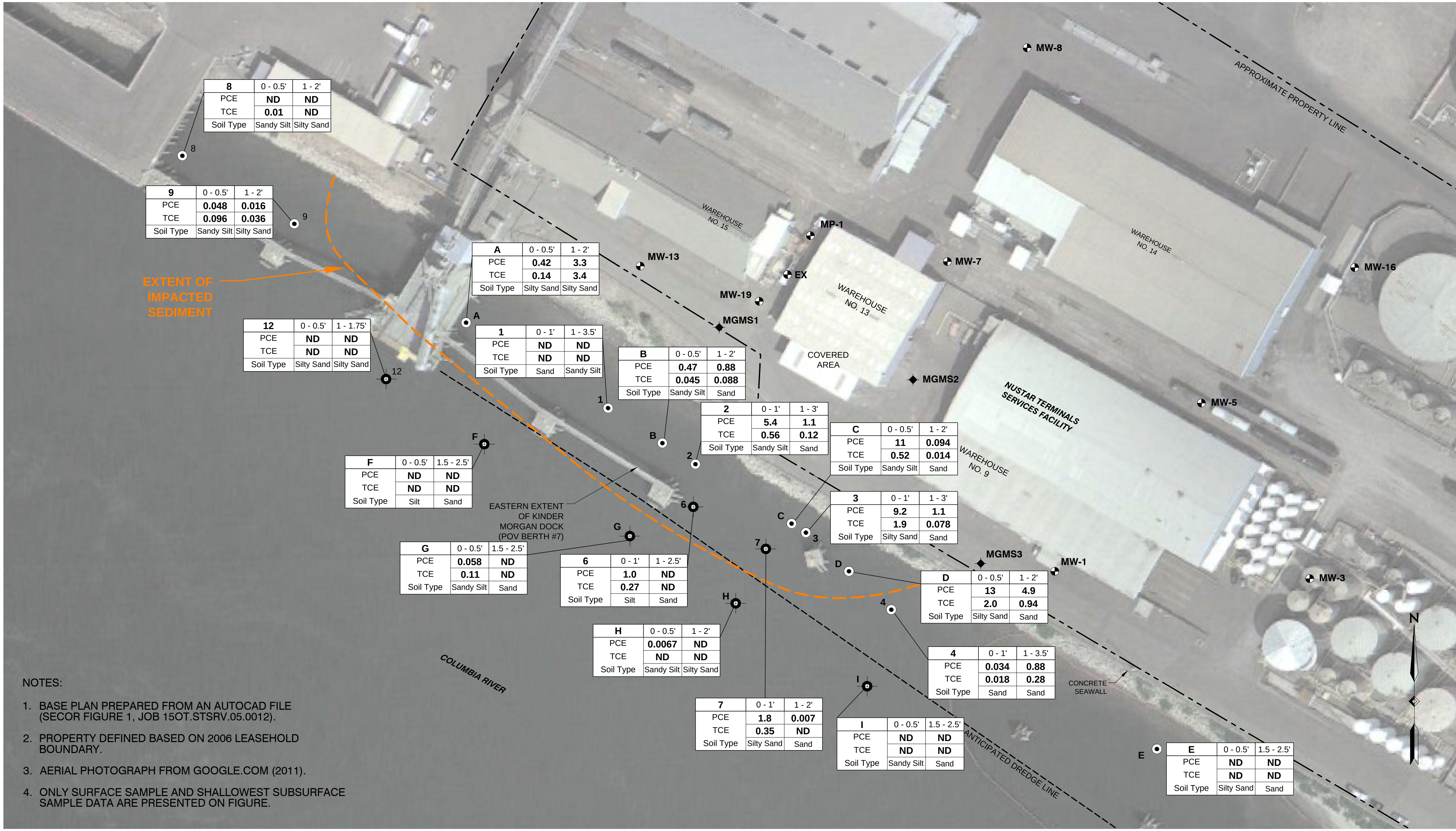
ANALYTE SAMPLED

Extent of VOC Impacts to Sediments

Feasibility Study
NuStar Terminals Services, Inc. Vancouver Facility
Vancouver, Washington

Apex Companies, LLC
3015 SW First Avenue
Portland, Oregon 97201

Project Number	1126-16	Figure
October 2014		G-3



NOTES:

1. BASE PLAN PREPARED FROM AN AUTOCAD FILE (SECOR FIGURE 1, JOB 15OT.STSRV.05.0012).
2. PROPERTY DEFINED BASED ON 2006 LEASEHOLD BOUNDARY.
3. AERIAL PHOTOGRAPH FROM GOOGLE.COM (2011).
4. ONLY SURFACE SAMPLE AND SHALLOWEST SUBSURFACE SAMPLE DATA ARE PRESENTED ON FIGURE.

LEGEND

- A — SEDIMENT SAMPLING LOCATION - 2011 AND 2012 (INTERSECTS SHALLOW ZONE GROUNDWATER)
- F — SEDIMENT SAMPLING LOCATION - 2011 AND 2012 (INTERSECTS INTERMEDIATE ZONE GROUNDWATER)
- MW-12 — GROUNDWATER MONITORING WELL
- MGMS3 — MULTI-LEVEL GROUNDWATER WELL (40 FOOT SAMPLE INTERVAL)

A	0 - 0.5'	1 - 2'
PCE	0.42	3.3
TCE	0.14	3.4
Soil Type	Silty Sand	Silty Sand

LOCATION ID

DEPTH OF SAMPLE

VOLATILE ORGANIC COMPOUNDS (VOCs) CONCENTRATION IN MG/KG
(PCE: TETRACHLOROETHENE)
(TCE: TRICHLOROETHENE)

SOIL TYPE

NOTE: SAMPLES 1 THROUGH 7 BASED ON WET WEIGHT. THE OTHER SAMPLE RESULTS ARE BASED ON DRY WEIGHT.

0 100 200
Approximate Scale in Feet

Sediment Analytical Results and Soil Type

Feasibility Study
NuStar Terminals Services, Inc. Vancouver Facility
Vancouver, Washington

APEX
Apex Companies, LLC
3015 SW First Avenue
Portland, Oregon 97201

Project Number	1126-16	Figure
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Table G-1

Chemical of Concern	C_{sed} (mg/kg)	K_d (L/kg)	H_{cc} (unitless)	K_{oc} (L/kg)	C_w (mg/L)
1,1-DCA		0.069	0.23	53	0.000
1,2-DCA		0.049	0.040	38	0.000
cis-1,2-DCE	0.0091	0.047	0.17	36	0.031
PCE	0.0067	0.351	0.75	270	0.011
TCE		0.122	0.42	94	0.000
Vinyl Chloride		0.02	1.1	19	0.000

Location H

Notes:

1. 1,1-DCA = 1,1-dichloroethane; 1,2-DCA = 1,2-dichloroethane;
   cis-1,2-DCE = cis-1,2-dichloroethene; PCE = tetrachloroethene; TCE - trichloroethene.
2. L = Liter.
3. kg = Kilogram.
4. mg = Milligram.
5. g = Gram.
6. mL = Milliliter.

MTCA Equation 747-1: Three-Phase Partitioning Equilibrium Equation

Parameter	Definition	Default Value	Units
C_{sed}	Sediment Screening Level from RI ("No Effects" Level - minimum of available be	--	mg/kg
C_w	Pore Water Concentration	Chermical-specific	µg/L
DF	Dilution Factor	1	unitless
K_d	Distribution Coefficient	Chemical-specific	L/kg
Foc	Soil Fraction of Organic Carbon*	0.0013	unitless, g/g
Koc	Soil Organic Carbon-Water Partitioning Coefficient (mL/g)	Chemical-specific	mL/g
θ_w	Water-filled Soil Porosity	0.4	unitless, mL/mL
θ_a	Air-filled Soil Porosity	0	unitless, mL/mL
H_{cc}	Henry's Law Constant	Chemical-specific	unitless
ρ_b	Dry Soil Bulk Density	1.6	kg/L

$C_w = C_{sed} / (DF \times [K_d + (\theta_w + \theta_a \times H_{cc}) / \rho_b])$

Kd = Foc x Koc

TOC = 1,300 mg/kg for Sample H (mudline)

Table G-2

Chemical of Concern	C_{sed} (mg/kg)	K_d (L/kg)	H_{cc} (unitless)	K_{oc} (L/kg)	C_w (mg/L)
1,1-DCA	0.00130	0.440	0.23	53	0.002
1,2-DCA		0.315	0.040	38	0.000
cis-1,2-DCE	0.0	0.299	0.17	36	0.044
PCE	1.80	2.241	0.75	270	0.723
TCE	0.35	0.780	0.42	94	0.340
Vinyl Chloride		0.16	1.1	19	0.000

Location 7 - mudline

Notes:

1. 1,1-DCA = 1,1-dichloroethane; 1,2-DCA = 1,2-dichloroethane;
   cis-1,2-DCE = cis-1,2-dichloroethene; PCE = tetrachloroethene; TCE - trichloroethene.
2. L = Liter.
3. kg = Kilogram.
4. mg = Milligram.
5. g = Gram.
6. mL = Milliliter.

MTCA Equation 747-1: Three-Phase Partitioning Equilibrium Equation

Parameter	Definition	Default Value	Units
C_{sed}	Sediment Screening Level from RI ("No Effects" Level - minimum of available ben	--	mg/kg
C_w	Pore Water Concentration	Chemical-specific	µg/L
DF	Dilution Factor	1	unitless
K_d	Distribution Coefficient	Chemical-specific	L/kg
Foc	Soil Fraction of Organic Carbon*	0.0083	unitless, g/g
Koc	Soil Organic Carbon-Water Partitioning Coefficient (mL/g)	Chemical-specific	mL/g
θ_w	Water-filled Soil Porosity	0.4	unitless, mL/mL
θ_a	Air-filled Soil Porosity	0	unitless, mL/mL
H_{cc}	Henry's Law Constant	Chemical-specific	unitless
ρ_b	Dry Soil Bulk Density	1.6	kg/L

$C_w = C_{sed} /(DF \times [K_d + (\theta_w + \theta_a \times H_{cc})/\rho_b])$

Kd = Foc x Koc
TOC = 8,300 mg/kg

Table G-3

Chemical of Concern	C_{sed} (mg/kg)	K_d (L/kg)	H_{cc} (unitless)	K_{oc} (L/kg)	C_w (mg/L)
1,1-DCA	0.08400	0.493	0.23	53	0.113
1,2-DCA		0.353	0.040	38	0.000
cis-1,2-DCE	2.8	0.335	0.17	36	4.788
PCE	9.20	2.511	0.75	270	3.332
TCE	1.90	0.874	0.42	94	1.690
Vinyl Chloride		0.18	1.1	19	0.000

Location 3 - mudline

Notes:

1. 1,1-DCA = 1,1-dichloroethane; 1,2-DCA = 1,2-dichloroethane; cis-1,2-DCE = cis-1,2-dichloroethene; PCE = tetrachloroethene; TCE - trichloroethene.
2. L = Liter.
3. kg = Kilogram.
4. mg = Milligram.
5. g = Gram.
6. mL = Milliliter.

MTCA Equation 747-1: Three-Phase Partitioning Equilibrium Equation

Parameter	Definition	Default Value	Units
C_{sed}	Sediment Screening Level from RI ("No Effects" Level - minimum of available be	--	mg/kg
C_w	Pore Water Concentration	Chermical-specific	µg/L
DF	Dilution Factor	1	unitless
K_d	Distribution Coefficient	Chemical-specific	L/kg
Foc	Soil Fraction of Organic Carbon*	0.0093	unitless, g/g
Koc	Soil Organic Carbon-Water Partitioning Coefficient (mL/g)	Chemical-specific	mL/g
θ_w	Water-filled Soil Porosity	0.4	unitless, mL/mL
θ_a	Air-filled Soil Porosity	0	unitless, mL/mL
H_{cc}	Henry's Law Constant	Chemical-specific	unitless
ρ_b	Dry Soil Bulk Density	1.6	kg/L

$C_w = C_{sed} / (DF \times [K_d + (\theta_w + \theta_a \times H_{cc}) / \rho_b])$

Kd = Foc x Koc

TOC = 9,300 mg/kg