

FEASIBILITY STUDY

Quendall Terminals Site

Prepared for: U.S. Environmental Protection Agency, Region 10

Project No. 020027 • October 14, 2013 Draft Final

On behalf of

Altino Properties, Inc. and

J.H. Baxter & Co.

Prepared by

Aspect Consulting, LLC and

Arcadis U.S., Inc.

EXECUTIVE SUMMARY

Contents

Introduction **ES-1**

Site Description and Source Areas **ES-1**

Geology and Hydrogeology **ES-2**

Conceptual Site Model **ES-4**

Remedial Action Objectives **ES-5**

Site Areas and Media Targeted for Remedial Action **ES-6**

Technology Identification and Screening **ES-7**

Development of Remedial Alternatives **ES-7**

Detailed and Comparative Analysis of Alternatives **ES-9**

Overall Protection of Human Health and the Environment ES-9
Compliance with ARARs ES-10
Long-Term Effectiveness and Permanence ES-11
Reduction of Toxicity, Mobility, or Volume through Treatment ES-12
Short-Term Effectiveness ES-13
Implementability ES-14
Cost ES-15
Comparative Analysis Summary ES-16

List of Tables

ES-1 Assembly of Technologies and Process Options into Remedial Alternatives

ES-2 Remedial Alternative Summary

ES-3 Remedial Alternative Institutional Control and Long-Term Monitoring Summary

ES-4 Summary Evaluation of Remedial Alternatives

ES-5 Comparative Rating of Remedial Alternatives

List of Figures

ES-1 Site Plan Showing Historical Features

ES-2 Geologic Cross Section A-A'

ES-3 Areas Targeted for Remedial Action

ES-4 Estimated Extent of DNAPL along Cross Section B-B'

ES-5 Alternative 2 – Remedy Components

ES-6 Alternative 3 – Remedy Components

ES-7 Alternative 4 – Remedy Components

ES-8 Alternative 5 – Remedy Components

ES-9 Alternative 6 – Remedy Components

ES-10 Alternative 7 – Remedy Components

ES-11 Alternative 8 – Remedy Components

ES-12 Alternative 9 – Remedy Components

ES-13 Alternative 10 – Remedy Components

ES-14 Projected Groundwater Restoration 100 Years After Implementation of Alternative Remedial Actions

ES-15 Estimated DNAPL Volumes Removed or Treated Under Alternative Remedial Actions

ES-16 Projected Reduction in Contaminant Mass Flux to Sediments100 Years After Implementation of Alternative Remedial Actions

Introduction

Under the direction of the U.S. Environmental Protection Agency (EPA), the Quendall Terminals owners (Altino Properties, Inc. and J.H. Baxter & Company; the Respondents) are conducting a Remedial Investigation (RI) and Feasibility Study (FS) at the Quendall Terminals Site (Site). The RI/FS is being conducted in accordance with the Site Administrative Settlement Agreement and Order on Consent (AOC; EPA 2003a), pursuant to the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). The RI Report (Anchor QEA and Aspect 2012) was provided to EPA on March 19, 2012.

The purpose of this FS is to develop and evaluate a range of remedial alternatives that protect human health and the environment, and maintain that protection over time. EPA, in consultation with other agencies and with public input, will use the information in the RI and FS Reports to select a remedial action, which will be documented in a Record of Decision (ROD), in accordance to the National Oil and Hazardous Substnaces Pollution Contingency Plan (NCP; 40 Code of Federal Regulations (CFR) 300).

Site Description and Source Areas

The Site is located on the southeast shore of Lake Washington, in Renton, Washington (Figure ES-1), within a former industrial area that now includes residential and commercial uses. The Site encompasses approximately 51 acres and includes the Quendall Terminals Property located at 4503 Lake Washington Boulevard North, a portion of Lake Washington immediately adjacent to the Quendall Terminals Property, and a portion of the Burlington Northern Railroad right-of-way to the east (referred to as the Railroad Property). The upland portion of the Site encompasses approximately 22 acres and is relatively flat, with approximately 1,500 feet of Lake Washington shoreline. Aquatic lands that are part of the Site are either owned privately or owned by the State of Washington. The lake area within and adjacent to the Site is considered prime habitat for the rearing of juvenile salmonid stocks, including Chinook salmon, which are listed as threatened under the Endangered Species Act (ESA).

Shortly after Lake Washington was lowered in 1916, Reilly Tar & Chemical Company developed the Quendall Terminals Property as a creosote manufacturing facility. In 1971, the property was sold to Quendall Terminals and the upland property was used intermittently to store diesel fuel and crude/waste oils. Fuel and oil storage operations ceased in 1983 when the last storage tanks were demolished. From approximately 1977 to 2009, the Site was primarily used for log sorting and storage.

Figure ES-1 shows the locations of historical Site features. Coal and oil-gas tar residue (collectively referred to as coal tars) were distilled into three fractions that were shipped off the Site. Releases of coal tars and distillate products to the environment occurred

where product transport, production, storage, and/or disposal were performed. Five general release areas have been identified, as follows:

- Offshore, along the former T-Dock, coal tar feed stock was offloaded and transferred to Site uplands through a pipeline located on the dock deck. A large spill occurred sometime between 1930 and 1940 at the western end of the T-Dock during vessel offloading. Elevated concentrations of polycyclic aromatic hydrocarbons (PAHs) in surface sediments along the main stem of the T-Dock indicate that there also may have been spills from leaks in the piping.
- Around the former Still House, coal tar was distilled, and creosote and light distillates were transferred to surrounding tanks via piping. Reported releases include product releases directly onto the earthen floor of the former Still House.
- The former Railroad Tank Car Loading Area at the railroad tracks east of the former Still House was situated on a trestle built over May Creek and is a location of apparent historical spills.
- The former May Creek Channel, located south of the manufacturing plant and storage tanks, received wastes from historical operations. Wastes from nearby tanks were reportedly placed in the eastern portion of the former channel, and the western portion of the former channel reportedly received creosote wastes discharged from the former Still House sewer outfall.
- The north and south sumps received effluent from the former Still House cooling lines, and this effluent sometimes contained creosote and tars. Tank bottoms from nearby storage tanks were also reportedly placed west of the north sump, where Quendall Pond is now located.

Some solid wastes produced in the manufacturing process were also disposed of at the Site. Heavy tar produced by the distillation process was cooled and solidified in pitch bays located north of the former Still House. The waste pitch was chiseled out and reportedly placed near the shoreline. Solid tar products have also been observed in shallow soils around the northern railroad loading area, where solid products were loaded onto railcars.

Geology and Hydrogeology

The Site is located within the Puget Sound Lowland, a physiographic feature dominated by repeated advances and recessions of glacial ice. Much of what is now the upland portion of the Site was formed by the lowering of Lake Washington in 1916, which exposed the alluvial delta of May Creek. Site topography has been modified over the past 90 years by filling and grading activities. Site geologic units are illustrated in the cross section on Figure ES-2. Geologic units include the following:

- **Fill.** Present at the ground surface and ranges from 1 foot to more than 10 feet thick. The Fill Unit is a mixture of silt, sand, and gravel as well as wood debris,

glass, brick, and pitch-like materials. Wood chips and bark from former log sorting operations are common in the upper few feet.

- **Shallow Alluvium.** Extends from the base of the Fill Unit to depths of between 30 and 50 feet below ground surface (bgs). The Shallow Alluvium was deposited as a series of gently dipping foreset beds consisting of very soft peat and organic silts interbedded with very loose, silty, fine to medium sand. As a result of their depositional history, including repeated slumping, the discontinuous layers generally slope downward toward the west and northwest.
- **Deeper Alluvium.** Extends from the base of the Shallow Alluvium to depths of between 90 and 140 feet bgs. The Deeper Alluvium generally consists of more homogeneous, coarser materials including medium dense to dense sand and gravel. Near the top of the Deeper Alluvium, lower-permeability interbedded silt to silty sand layers are also present, and are most likely a transitional zone representing the continuation of the May Creek delta. Silty sand layers have been observed as deep as 83 feet bgs.
- **Lacustrine Clay.** Beneath the Deeper Alluvium, a layer of lacustrine clay at least 10 feet thick has been encountered at depths below 90 feet bgs.

The lake bottom substrate is typically a fine silt/mud, although there are several areas with a sandier bottom, including a sandspit north of the former T-Dock and sediment near the outer harbor line south of the former T-Dock. With the exception of a wood-debris area along the southern shoreline, aquatic vegetation is dominated by dense areas of Eurasian water milfoil.

The majority of the Site hydrocarbon contamination, including dense non-aqueous phase liquids (DNAPL), is present within the Shallow Alluvium. Evidence from field observations suggests that interbedded, low-permeability layers in the Shallow Alluvium create stratigraphic “traps” that can stop, slow, or alter migration of DNAPL. The presence of heterogeneous, interbedded, and discontinuous layers of lower-permeability materials in the Shallow Alluvium (and, to a lesser extent, at the top of the Deeper Alluvium) impedes the movement of DNAPL.

Hydrogeologic units affected by Site contamination include the following:

- **Shallow Aquifer.** Occurs in the Fill Unit and in the Shallow Alluvium to depths of approximately 30 to 50 feet bgs, with the water table typically encountered at depths of 6 to 8 feet bgs. Hydraulic conductivity estimates in the Shallow Aquifer indicate at least a two-order-of-magnitude range from 1×10^{-2} to 1×10^{-4} centimeters per second (cm/sec), with interbedded lower-permeability silt and peat layers and high heterogeneity.
- **Deep Aquifer.** Occurs in the Deeper Alluvium to a depth of approximately 140 feet bgs. Hydraulic conductivity estimates for the Deep Aquifer average approximately 2×10^{-2} cm/sec.

The groundwater flow system includes recharge in the upland areas east of the Site and the May Creek drainage south/southeast of the Site, with flow toward the west and discharge to Lake Washington. Site groundwater originates from precipitation on and east of the Site and recharge from alluvial deposits in the May Creek drainage immediately

south of the Site. The elevation of Lake Washington is controlled by the U.S. Army Corps of Engineers (USACE) and typically fluctuates up to 2 feet during the year. The lake level is typically lowest in the late fall and early winter, and highest during the late spring and summer.

Site groundwater generally flows horizontally across the Site in an east to west direction, ultimately discharging to Lake Washington. Based on the observed hydraulic gradient, the estimated time for groundwater to travel through the Deep Aquifer from the eastern property boundary to Lake Washington is approximately 5 years.

Vertical hydraulic interaction between the Shallow and Deep Aquifers is limited by the horizontal stratification of the Shallow Alluvium and varies depending on location. Shallow groundwater in the eastern portion of the Site near the Railroad Property typically flows downward through the Shallow Aquifer into the upper portion of the Deep Aquifer. Within the central areas of the Site, groundwater flow is primarily horizontal, and vertical exchange between the Shallow Aquifer and Deep Aquifer is limited. Near the shoreline of Lake Washington, groundwater in the Deep Aquifer has an upward flow component and travels through the Shallow Aquifer before discharging to surface water.

Conceptual Site Model

The primary source of Site contamination is DNAPL that originated as creosote and other coal-tar products. DNAPL is present in the shallow subsurface in much of the upland area, extending nearshore beneath Lake Washington adjacent to Quendall Pond, and in surface sediment offshore along the location of the former T-Dock. The DNAPL tends to occur within discrete layers or thin lenses in the Shallow Alluvium rather than in continuous “pools.” The subsurface movement of DNAPL is influenced by the prevailing east-to-west groundwater flow direction, but the deltaic nature of the Shallow Alluvium (i.e., sloping and interbedded silt, sand, and peat layers) also plays a significant role in how DNAPL migrates in the subsurface. Boring and test pit logs indicate that DNAPL impacts approximately 9.7 acres of the Site and is present as deep as 34 feet bgs, but is most typically observed in the upper 20 feet bgs. Approximately 445,000 gallons of DNAPL are estimated to be present at the Site.

Contaminants in DNAPL migrate via a variety of transport mechanisms into other Site media, including soil, groundwater, sediment, and air. Where DNAPL is present, benzene, naphthalene, and carcinogenic polycyclic aromatic hydrocarbon (cPAH) concentrations are above preliminary remediation goals (PRGs) in groundwater, with impacted groundwater generally extending downgradient (both horizontally and vertically) from DNAPL-impacted areas. The migration of dissolved chemicals in groundwater is primarily controlled by the east-to-west groundwater flow direction and contaminant-specific mobility. Benzene and naphthalene are relatively mobile and, based on both empirical data and groundwater modeling, have likely migrated deeper and further downgradient from DNAPL source areas compared to the less mobile cPAHs. Groundwater transport of soluble coal-tar product constituents from the Site uplands has

also contributed contaminants to nearshore area sediment. Contaminated groundwater migration from DNAPL source areas represents a secondary contaminant source to soil and sediment.

Arsenic concentrations in groundwater also exceed the PRG in both the Shallow Alluvium and the Deeper Alluvium. These exceedances may be caused, at least in part, by mobilization of naturally occurring arsenic under reducing conditions, which occur in areas of soils containing DNAPL, dissolved-phase hydrocarbon contamination, and naturally high levels of organic carbon (e.g., peat).

A baseline human health risk assessment (HHRA) and an ecological risk assessment (ERA) were conducted in accordance with EPA guidance to identify Site chemicals of concern (COCs) and evaluate potential risks associated with their presence in Site media. The HHRA concluded that risks posed to human receptors exceed a cancer risk of one in ten thousand and/or a hazard quotient (HQ) of 1 for non-cancer risk. The human health risk drivers are benzene, naphthalene, cPAHs, and arsenic. The ERA concluded that risks to terrestrial invertebrates, plants, and wildlife (birds and mammals), as well as to benthic invertebrates, aquatic plants, and aquatic-dependent wildlife, exceed an HQ of 1. The ecological risk drivers are PAHs.

Remedial Action Objectives

Applicable or relevant and appropriate requirements (ARARs) were identified, and remedial action objectives (RAOs) and PRGs were developed for the Site in accordance with CERCLA guidance. RAOs and PRGs help define the extent of contaminated media requiring remedial action, and inform the development of remedial alternatives that will protect human health and the environment and comply with ARARs.

The following RAOs were developed by EPA to mitigate potential Site risks:

Source Control RAOs:

- **SC1: Source Material as Principal Threat.** Treat or remove DNAPL in subsurface soils and groundwater to prevent contamination of groundwater above COC maximum contaminant levels (MCLs) to the extent practicable.
- **SC2: Source Material.** Contain DNAPL in subsurface soils and groundwater where treatment or removal is not practicable.
- **SC3: Source Material: Soil.** Reduce migration of COCs to groundwater from soils that exceed remediation goals for the protection of groundwater.
- **SC4: Source Material: Sediment.** Reduce migration of COCs to surface water from sediments that exceed remediation goals for the protection of surface water.

Human Health Protection RAOs:

- **HH1: Groundwater.** Restore groundwater to its highest beneficial use (drinking water) by meeting COC MCLs in the Site Shallow Alluvium and Deeper Alluvium aquifers within a reasonable period of time.

- **HH2: Sediment.** Reduce to acceptable levels the risk to adults and children who ingest resident fish and shellfish taken from the Site for subsistence.
- **HH3: Sediment.** Reduce to acceptable levels the human health risk from playing, wading, or swimming resulting in incidental ingestion or/and dermal exposure to contaminated sediments that exceed remediation goals.
- **HH4: Surface Water.** Reduce to acceptable levels the human health risk from direct contact or incidental ingestion of surface water contaminated with COCs exceeding remediation goals (water quality standards or MCLs).
- **HH5: Vapor.** Reduce to acceptable levels the human health risk from inhalation of vapors from groundwater and/or soils contaminated with COCs exceeding soil or groundwater remediation goals.
- **HH6: Soils (Surface and Subsurface).** Reduce to acceptable levels the human health risk from direct contact or incidental ingestion of COCs in soil exceeding soil remediation goals.

Environmental Protection RAOs:

- **EP1: Surface Water.** Reduce to acceptable levels the risk to aquatic-dependent organisms when direct contact with surface water or incidental ingestion of COCs in surface water exceeds remediation goals (water quality standards).
- **EP2: Upland Soil.** Reduce to acceptable levels the risk to terrestrial wildlife when direct contact and incidental ingestion or consumption of soil invertebrates results in exposures to COCs that exceed remediation goals.
- **EP3: Sediment.** Reduce to acceptable levels the risk to aquatic-dependent wildlife (sediment probing birds and piscivorous mammals) where surface sediments containing COCs exceed remediation goals.
- **EP4: Sediment.** Reduce to acceptable levels the risk to benthos where surface sediments containing COCs exceed remediation goals.

Site Areas and Media Targeted for Remedial Action

Site areas targeted for remedial action, including areas with contaminant concentrations above PRGs and areas containing DNAPL, are shown on Figure ES-3. These areas were delineated for the purposes of developing remedial alternatives. PRG-exceedance areas were designated as follows based on type of media impacted and depth of contamination:

- The Surface Soil Area;
- The Subsurface Soil and Groundwater Area; and
- The Surface and Subsurface Sediment Area.

In addition, DNAPL areas—differentiated based on location-specific DNAPL mobility, depth, and effect on groundwater quality—were designated as follows:

- DNAPL-impacted soil in the former Railroad Tank Car Loading Area (RR DNAPL Area);
- DNAPL-impacted soil in the former May Creek Channel (MC DNAPL Area);
- DNAPL-impacted soil around Quendall Pond (QP-U DNAPL Area);
- DNAPL-impacted sediments offshore of Quendall Pond (QP-S DNAPL Area); and
- DNAPL-impacted sediments along the former T-Dock (TD DNAPL Area).

DNAPL occurrences that are not part of a specific area are collectively described as Other Upland DNAPL Areas or Other Aquatic DNAPL Areas.

Figure ES-4 provides a cross section, oriented as shown on Figure ES-3, with delineated DNAPL areas highlighted. Site areas were also differentiated with respect to DNAPL cumulative thickness.

Technology Identification and Screening

Remedial technologies and process options were identified and screened for their potential effectiveness in satisfying the Site RAOs. For each contaminated medium (DNAPL, soil, groundwater, and sediment), remedial technologies were first evaluated with respect to their potential applicability to Site conditions and COCs. Remedial technologies retained from this initial screening were then evaluated relative to one another based on their potential effectiveness, implementability, and cost. In most cases, for remedial technologies that were retained, one representative process option within a given technology group was identified for the purposes of developing remedial alternatives for evaluation in this FS. After EPA selects a Site remedy, other process options may be re-evaluated during remedial design to optimize the final remedy.

Development of Remedial Alternatives

Retained remedial technologies and process options were assembled into the following alternatives. To assist the reader, descriptive titles for the numbered alternatives are provided below with the areas that are the primary focus of the remedy listed in parentheses.

- **Alternative 1 – No Action** (included to establish a baseline for comparison);
- **Alternative 2 – Containment:** soil and sediment capping;

- **Alternative 3 – Containment with Targeted Solidification of Principal Threat Material (PTM)[1] (RR and MC DNAPL Areas):** treatment of deep upland PTMs via *in situ* solidification, passive groundwater treatment, and soil and sediment capping;
- **Alternative 4 – Containment with Targeted PTM Removal (TD, QP-S, and QP-U DNAPL Areas):** targeted treatment of PTMs via removal/off-site disposal, passive groundwater treatment, and soil and sediment capping;
- **Alternative 5 – Containment with Targeted PTM Solidification (RR, MC, and QP-U DNAPL Areas and ≥ 4-Foot-Thickness) and Removal (TD and QP-S DNAPL Areas):** targeted treatment of PTMs via *in situ* solidification and removal/off-site disposal, passive groundwater treatment, and soil and sediment capping;
- **Alternative 6 – Containment with Targeted PTM Solidification (RR and MC DNAPL Areas and ≥ 2-Foot-Thickness) and Removal (TD, QP-S, and QP-U DNAPL Areas):** targeted treatment of PTMs via *in situ* solidification and removal/off-site disposal, passive groundwater treatment, and soil and sediment capping;
- **Alternative 7 – Containment with PTM Solidification (Upland) and Removal (Sediment):** treatment of upland PTMs via *in situ* solidification; treatment of sediment PTMs via removal/off-site disposal, and soil and sediment capping;
- **Alternative 8 – Containment of PTM Removal (Upland and Sediment):** treatment of upland and sediment PTMs via removal/on-site thermal desorption, and soil and sediment capping;
- **Alternative 9 – Containment with Solidification and Removal of Contaminated Soil and Removal of Contaminated Sediment:** treatment of deep upland PTMs and contaminated soil via *in situ* solidification; treatment of shallow upland PTMs, sediment PTMs, and contaminated soil and sediment via removal/on-site thermal desorption; and soil and sediment capping; and
- **Alternative 10 – Containment with Removal of Contaminated Soil and Sediment:** treatment of PTMs and contaminated soil and sediment via removal/on-site thermal desorption, and soil and sediment capping.

Table ES-1 summarizes how retained technologies and process options were assembled into these alternatives. Groundwater and sediment cap modeling was used to help develop alternatives in two ways: 1) to evaluate how Site-wide alternatives could be structured to meet RAOs and 2) to provide conceptual design criteria for the purpose of developing alternatives and estimating costs. Table ES-2 provides summary descriptions of Alternatives 2 through 10, the components of which are depicted on Figures ES-5 through ES-13, respectively. Consistent with EPA key principles and guidance, the range

[1] PTMs for the Site include DNAPL, DNAPL-impacted soil, and DNAPL-impacted sediment. Upland PTMs include DNAPL and DNAPL-impacted soil located east of the shoreline. Sediment PTMs include DNAPL and DNAPL-impacted sediment west of the shoreline.

of remedial alternatives illustrates the tradeoffs associated with different cleanup strategies.

Detailed and Comparative Analysis of Alternatives

The NCP remedy selection criteria include the following:

Threshold Criteria

1. Overall protection of human health and the environment;
2. Compliance with applicable or relevant and appropriate requirements (ARARs);

Balancing Criteria

3. Long-term effectiveness and permanence;
4. Reduction of toxicity, mobility, or volume through treatment;
5. Short-term effectiveness;
6. Implementability;
7. Cost;

Modifying Criteria

8. State acceptance; and
9. Community acceptance.

The threshold and balancing criteria are used to evaluate and compare the remedial alternatives in the FS. (The two modifying criteria are evaluated by EPA at a later stage in the CERCLA process.) CERCLA requires that remedies selected for implementation achieve the threshold criteria, except when compliance with one or more ARARs is not technically practicable, in which case EPA may grant a waiver. The five balancing criteria are used to highlight tradeoffs between the alternatives, to facilitate remedy selection.

Table ES-4 provides a comparative analysis of the alternatives with respect to the threshold and balancing criteria, along with the estimated present worth cost of each alternative. For each of the balancing criteria except cost, a rating of “high,” “moderate,” or “low” is assigned based on the degree to which an alternative meets the requirements of that criterion. A summary of the comparative rating of alternatives is provided in Table ES-5. Results of the comparative analysis are discussed below.

Overall Protection of Human Health and the Environment

This criterion addresses the overall ability of each alternative to eliminate, reduce, or control potential exposures to hazardous substances in both the short and long term, and evaluates whether the alternative achieves the RAOs for protection of human health and the environment. EPA developed PRGs to address unacceptable Site risks, COCs, and

potential exposure pathways; those PRGs are used in this FS to determine whether each alternative provides adequate overall protection of human health and the environment. If an alternative is projected to achieve PRGs or otherwise effectively control exposure to Site media exceeding PRGs, then that alternative meets this NCP criterion.

With the exception of the baseline No Action alternative (Alternative 1), all of the remedial alternatives are protective of human health and the environment. For the purposes of retaining alternatives, this threshold criterion was evaluated only on the basis of whether the criterion was met. All alternatives include containment technologies (including capping), enhanced natural recovery (ENR), institutional controls, and monitoring to achieve the required protectiveness. In addition, Alternatives 3 through 10 include progressively increased treatment and/or removal of contaminated materials and rely less on maintenance of containment measures to ensure protectiveness.

In general, differences in overall protectiveness between the alternatives are a function of the degree of PTM treatment/removal and location on the Site relative to the potential for future exposure. Alternatives that include treatment/removal of contaminated materials—particularly in sensitive areas of the Site (e.g., along the shoreline)—would reduce the reliance on institutional controls to manage the long-term risk by providing more permanent reductions in toxicity, mobility, and/or volumes of contaminants. However, those more aggressive alternatives would have a higher cost and lower short-term effectiveness, would be more difficult to implement and, due to the complexity of the Site, in all likelihood would leave residual contamination which would still necessitate reliance on institutional controls.

Compliance with ARARs

This criterion assesses whether the alternative complies with the chemical-specific, action-specific, and location-specific ARARs and other "To Be Considered" (TBC) criteria, advisories, and guidance. With the exception of the No Action alternative (Alternative 1), all alternatives are expected to comply with all ARARs except the Safe Drinking Water Act (SDWA), which requires achievement of groundwater MCLs throughout the Site. To assess compliance with the SDWA, groundwater modeling was used to predict the volumes of contaminated groundwater exceeding the MCLs for benzene, benzo(a)pyrene, and arsenic 100 years after implementation of each alternative. Results are provided on Figure ES-14 and are summarized below:

- Benzo(a)pyrene was predicted to exceed its MCL in groundwater after 100 years for all alternatives. In Alternative 10, the groundwater model predicted that the benzo(a)pyrene MCL would be achieved when construction is complete; however, as a simplifying assumption for modeling purposes, it was assumed that 100 percent of the PMTs were removed with no residuals remaining because the quantity of residuals is difficult to estimate. However, some amount of residual soil contamination associated with incomplete removal is likely due to the complexity of subsurface conditions. A sensitivity analysis was performed in which it was assumed that a 2-inch-thick layer of soil containing 10 milligrams per kilogram benzo(a)pyrene remained in the excavation as residual. Under this scenario, the model results indicated that benzo(a)pyrene would exceed its MCL for more than 100 years. The presence of residuals following removal is considered the more likely scenario.

- Benzene was predicted to exceed its MCL after 100 years for Alternatives 1 through 7 and 9. Assuming no residual soil contamination, benzene was predicted to achieve its MCL after 28 years for Alternative 8 and after 14 years for Alternative 10. The model sensitivity analysis results indicate that the presence of residuals following construction for Alternatives 8 and 10 does not significantly increase the timeframe to achieve the MCL for benzene in groundwater.
- Arsenic was predicted to exceed its MCL after 100 years for all alternatives.

In summary, none of the alternatives would achieve compliance with all ARARs because none of the alternatives would achieve compliance with the SDWA (based on modeling of groundwater concentrations 100 years following implementation). Because all ARARs must be met or waived per CERCLA upon completion of remedial actions, all alternatives may require a waiver.

Long-Term Effectiveness and Permanence

This NCP balancing criterion evaluates each alternative's long-term effectiveness and permanence by assessing the magnitude of residual risk remaining following remedy implementation, and the adequacy and reliability of engineering and institutional control measures to manage those potential residual risks. The magnitude of residual risk was evaluated in the context of achieving RAOs, and considered the total volume of DNAPL removed or treated in each alternative (Figure ES-15). The adequacy and reliability of controls were evaluated based on the likelihood for re-exposure of contained materials based on their location and the specific controls used. A summary of institutional controls and monitoring activities under each alternative is provided in Table ES-3. Even though most alternatives include similar institutional controls, the institutional controls would be more effective for alternatives where the remedy would reduce the quantity of contamination remaining, particularly in areas of the Site most susceptible for future disturbance and potential release in the event of remedy failure. For instance, there is less short-term risk in the event of technology failure (e.g., cap disturbance during a seismic event or violation of restrictive covenants) if there is less residual contamination and a lower potential level of exposure. In the event that a control measure fails, all alternatives would have monitoring to identify the failure and to repair the measures. The reduced effectiveness of controls would be due to the potential for short-term exposures until the failure could be corrected.

Long-term effectiveness and permanence could also vary based on the location and characteristics of residual contamination; for instance, shallow contaminants are generally more accessible than deep contaminants; therefore, controls for deep contaminants are considered more effective than for shallow contaminants. Areas of the Site representing the greatest future exposure risk include the QP-U, QP-S, and TD DNAPL Areas.

The differences in long-term effectiveness and permanence among the alternatives are summarized as follows:

- Alternative 1 would not provide any removal, treatment, or control measures; therefore, this alternative is rated low for this criterion.

- Alternative 2 would not significantly reduce the volume of contaminated materials. In particular, this alternative would rely on passive controls with a risk of failure to address highly toxic and potentially mobile PTMs along the shoreline area (i.e., in the QP-U DNAPL Area.). Therefore, this alternative is rated low for this criterion.
- Alternative 3 would achieve modest reductions in the volume of contamination, primarily through treatment of PTMs. This alternative would improve reliability of control for potentially mobile DNAPL near the lake through the use of DNAPL collection trenches; however, due to the potential future shoreline habitat area, these trenches are assumed to be located 100 feet away from the shoreline and therefore do not address potentially mobile DNAPL closest to the lake in the QP-U DNAPL Area. Therefore, this alternative is rated low for this criterion.
- Alternative 4 would achieve a significantly larger reduction in the volume of contamination compared to Alternative 3, and would also improve effectiveness by removing contamination with the greatest future exposure risk (i.e., PTMs in the QP-U, QP-S, and TD DNAPL Areas.). Therefore, this alternative is rated moderate for this criterion.
- Alternatives 5 and 6 would provide more substantial reductions in the volume of contamination compared to Alternative 4, and similarly address contamination with the greatest future exposure risk. However, a significant volume of PTMs and contaminated groundwater would remain on site. These alternatives are rated moderate for this criterion.
- Alternatives 7 through 10 would greatly reduce the magnitude of residual risk through removal or treatment of all PTMs and substantial reductions in the volume of contaminated groundwater. These alternatives are rated high for this criterion.

Reduction of Toxicity, Mobility, or Volume through Treatment

This criterion evaluates the degree to which each remedial alternative reduces toxicity, mobility, or volume through treatment. (Contaminant reduction via off-site disposal is not considered because the criterion is based on the statutory preference for treatment.) The comparative rating of alternatives was based primarily on the expected toxicity, mobility, or volume reduction through treatment of PTMs, using the estimated total volume of DNAPL treated as a metric. For the purposes of this FS evaluation, treatment by thermal destruction technologies (incineration and thermal desorption) was rated higher than *in situ* solidification, because preference was given to technologies that permanently destroy the COCs (thus reducing toxicity, mobility, and volume) over technologies that permanently isolate COCs, and because *in situ* solidification would slightly increase the total volume of contaminated materials.

As a secondary factor for evaluating this criterion, reduction in volume and mobility of contaminated groundwater due to treatment was considered. Figure ES-16 shows, for Alternatives 2 through 10, projected reduction in contaminant mass flux to sediments 100 years after remedy implementation. Groundwater treatment metrics were considered

secondary to the PTM treatment metric because the majority of contaminant mass at the Site, and the highest toxicity materials, are contained in the PTMs.

The remedial alternatives are rated with respect to this criterion as follows:

- Alternatives 1, 2, and 4 include no treatment of PTMs and are rated low for this criterion.
- Alternative 3 would treat an estimated 9 percent of PTMs via *in situ* solidification, and is rated low for this criterion.
- Alternatives 5 and 6 would treat approximately 46 and 68 percent of PTMs, respectively. These alternatives would achieve similarly modest reductions in groundwater volume and flux as Alternative 3 by treating deep PTMs and installing a PRB. These alternatives are rated moderate.
- Alternatives 7 and 8 would treat all PTMs and greatly reduce the volume and mobility of contaminated groundwater. Alternative 7 would achieve treatment through *in situ* solidification, while Alternative 8 would achieve treatment through on-site thermal desorption. Both alternatives are rated high for this criterion.
- Alternatives 9 and 10 would treat all PTMs and also would treat a substantial volume of contaminated soil and sediment. Alternative 9 would use a combination of *in situ* solidification and on-site desorption, while Alternative 10 would use on-site desorption. These alternatives are rated high for this criterion.

Short-Term Effectiveness

This criterion is used to evaluate the effects and potential risks associated with remedial alternative implementation, considering the protection of workers, protection of the community, and potential impacts to the environment. In general, short-term impacts increase with construction duration and the quantities of contaminated materials removed or handled. Many impacts can be adequately managed through standard construction practices such as health and safety programs and best management practices (BMPs). Some impacts would be difficult to control, however, including vapor emissions from disturbance of contaminated materials, impacts to the community from construction noise and traffic, and water quality impacts from dredging.

Remedial alternatives are rated with respect to this criterion as follows:

- Alternative 1 has no construction activities and, therefore, no construction impacts. However, it does not attain RAOs in the foreseeable future. Therefore, it was rated moderate for this criterion.
- Among the active alternatives, Alternative 2 would have the shortest construction period, would disturb a minimum of contaminated material, and would present the least amount of risk to workers, the community, and the environment. This alternative is rated high for this criterion.
- Alternative 3 would present a greater short-term risk than Alternative 2 due to additional construction activities. However, the total volume of soil disturbed in

this alternative would be relatively modest and the construction duration would be relatively short. This alternative is also rated high for this criterion.

- Alternative 4 would have a longer construction duration and increased short-term impacts from excavation of PTMs in soil and dredging of PTMs in sediment, which would result in air and water quality impacts. This alternative is rated moderate for this criterion.
- Alternative 5 would be similar to Alternative 4 with respect to construction duration and potential for water quality impacts. It would treat a greater volume of upland material but would employ *in situ* solidification, resulting in fewer short-term impacts than removal. This alternative is rated moderate for this criterion.
- Alternative 6 would have a longer construction duration than Alternatives 4 and 5. It would have a similar potential for water quality impacts through dredging but greater impacts due to more extensive upland construction. This alternative is also rated moderate for this criterion.
- Alternatives 7 and 8 would have relatively long construction durations and involve disturbance of very large quantities of PTMs, which would result in significant extended air and water quality impacts. These alternatives are rated low for this criterion.
- Alternatives 9 and 10 would have very long construction durations and the greatest short-term impacts to workers, the community, and the environment. These alternatives are rated low for this criterion.

Implementability

This criterion is used to evaluate the relative implementability of the alternatives, focusing on their technical feasibility, administrative feasibility; and the availability of services and materials. In general, implementability decreases with increased complexity of the alternatives. Alternatives involving *in situ* solidification (Alternatives 3, 5, 6, 7, and 9) would require bench and/or pilot testing of potential amendment mixtures to determine proper mixes. Alternatives involving deep excavations (Alternatives 8 and 10) would have substantially increased complexity due to robust shoring and dewatering system requirements. Alternatives involving dredging (Alternatives 4 through 10) would have implementability issues associated with the complexity of dredging, materials handling, residuals management, and water monitoring. Alternatives involving on-site thermal treatment (Alternatives 8, 9, and 10) would require treatability testing, and would be technically and administratively challenging due to air emissions controls and monitoring.

With the exception of the reactive caps, the technologies used by all alternatives are proven technologies that have been implemented at other, similar sites and could be implemented at the Site. While reactive caps are innovative, their use is increasing, and there are no market or technical limitations preventing their implementation.

Remedial alternatives are rated with respect to this criterion as follows:

- Among the active alternatives, Alternative 2 would be the easiest to construct. This alternative is rated high for this criterion.
- Alternative 3 would have greater technical complexity due to additional treatment and containment measures and the need to bench and pilot test *in situ* solidification. However, all components are proven technologies and the construction quantities are modest. This alternative is also rated high for this criterion.
- Alternative 4 would have greater technical complexity for aquatic remedial components (i.e., dredging of DNAPL-containing sediments). This alternative is rated moderate for this criterion, primarily because of the complexities of dredging DNAPL.
- Alternatives 5 and 6 are similar to Alternative 4 but would have slightly more complicated upland remedial components due to more extensive solidification. These alternatives are also rated moderate for this criterion.
- Alternative 7 would involve more extensive dredging and solidification than Alternative 6, but would not include a PRB due to the increased solidification area. The technical feasibility of treating or removing all PTMs at the Site is lower than the feasibility of targeting hot spots under Alternatives 3 through 6. This alternative is rated moderate for this criterion.
- Alternative 8 would involve significantly greater implementability challenges than Alternative 7 due to the complexities of shoring and dewatering extensive excavations and providing on-site thermal treatment of a large volume of material. This alternative is rated low for this criterion.
- Alternatives 9 and 10 would involve the largest soil and sediment removal volumes and very extensive in-water and upland construction activities. The scope of these activities would encounter severe technical and administrative challenges. These alternatives are rated low for this criterion.

Cost

Cost estimates were developed for each alternative per EPA guidance. The estimated present worth cost for each alternative, in 2013 dollars and using a discount factor of 1.6 percent, is listed in Table ES-4. Costs are broken out as either capital or long-term operation, maintenance, and monitoring (OM&M) costs, which are also listed in the table. In general, alternatives involving more extensive treatment of PTMs would have higher capital and lower long-term costs. Among the treatment technologies, *in situ* solidification is significantly cheaper on a unit cost basis than removal and off-site disposal or on-site thermal treatment.

Alternatives 9 and 10 have the highest estimated present worth costs (approximately $262 and $409 million, respectively). The estimated present worth costs for the other active alternatives range from roughly $26 million (Alternative 2) to $140 million (Alternative 8).

Comparative Analysis Summary

The comparative analysis illustrates the tradeoffs for different methods and levels of containment, removal, and/or treatment for Alternatives 2 through 10. Alternatives focused on containment with limited removal and/or treatment rate high for short-term effectiveness and implementability, but would rely more on monitoring and maintenance of containment measures to ensure long-term effectiveness. Containment-focused alternatives also would retain greater residual risk of future exposure, except where augmented by removal and/or treatment of PTMs posing the highest risk of future exposure (QP and TD DNAPL Areas). In contrast, alternatives involving more extensive removal and/or treatment would rely less on monitoring and maintenance of containment measures to achieve long-term effectiveness and permanence but because of the greater scale, complexity, and duration of construction, rate lower for short-term effectiveness and implementability. Further, alternatives with extensive removal and/or treatment would have much higher costs associated with the greater volumes involved and the added complexity of addressing PTM at greater depths.

Certain statutory requirements for CERCLA remedial actions (such as cost effectiveness or using permanent solutions to the maximum extent practicable) are not evaluated in the FS, but are important considerations during selection of a final remedy. EPA will select a preferred remedy and prepare a proposed plan based on the analysis presented in this FS, risk management considerations, and statutory requirements for remedial actions. The preferred alternative may be one of the alternatives described in the FS or a combination of elements from different alternatives, as appropriate. State and community acceptance of the preferred remedy will be evaluated in the ROD once comments on the FS and proposed plan are received.

Table ES-1 - Assembly of Technologies and Process Options into Remedial Alternatives

DRAFT FINAL

Quendall Terminals
Renton, Washington

Technology General Response Actions		Remedial Technologies/ Process Options	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5	Alternative 6	Alternative 7	Alternative 8	Alternative 9	Alternative 10
			No Action	Containment	Containment with Targeted PTM Solidification (RR and MC DNAPL Areas)	Containment with Targeted PTM Removal (TD, QP-S, and QP-U DNAPL Areas)	Containment with Targeted PTM Solidification (RR, MC, and QP-U DNAPL Areas and ≥ 4-Foot-Thickness) and Removal (TD and QP-S DNAPL Areas)	Containment with Targeted PTM Solidification (RR and MC DNAPL Areas and ≥ 2-Foot-Thickness) and Removal (TD, QP-S, and QP-U DNAPL Areas)	Containment with PTM Solidification (Upland) and Removal (Sediment)	Containment with PTM Removal (Upland and Sediment)	Containment with Solidification and Removal of Contaminated Soil and Removal of Contaminated Sediment	Containment with Removal of Contaminated Soil and Sediment
Upland DNAPL/Soil	Institutional Controls	Deed and Access Restrictions	--	X	X	X	X	X	X	X	X	X
	In Situ Containment	Cover or Cap	--	X	X	X	X	X	X	X	X	X
	In Situ Treatment	Solidification	--	--	Deep PTMs[2]	--	QP-U DNAPL Area plus shallow PTMs >4-foot cumulative thickness[1] and deep PTMs[2]	ShallowPTMs >2-foot cumulative thickness[1] and deep PTMs[2]	All PTMs	--	All deep contaminated soil (below approx. 15 feet bgs)	--
	Removal	DNAPL Collection Trenches	--	--	At former May Creek and Quendall Pond shoreline	At former May Creek and Quendall Pond shoreline	--	--	--	--	--	--
		Excavation	--	--	--	QP-U DNAPL Area	--	QP-U DNAPL Area	--	All PTMs	All shallow contaminated soil (above approx. 15 feet bgs)	All contaminated soil
	Ex Situ Treatment	On-site Thermal Desorption	--	--	--	--	--	--	--			
	Disposal	Off-site Landfill	--	--	--	QP-U DNAPL Area	--	QP-U DNAPL Area	--	--	--	--
Aquatic DNAPL/Sediment	Institutional Controls	Deed Restrictions	--	X	X	X	X	X	X	X	X	X
	Monitoring	Biological/Physical Recovery	--	X	X	X	X	X	X	X	X	X
	Enhanced Natural Recovery (ENR)	Thin-layer Placement	--	Offshore sediments outside PTM areas exceeding BTV	Offshore sediments outside PTM areas exceeding BTV	Offshore sediments outside PTM areas exceeding BTV	Offshore sediments outside PTM areas exceeding BTV	Offshore sediments outside PTM areas exceeding BTV	Offshore sediments outside PTM areas exceeding BTV	Offshore sediments outside PTM areas exceeding BTV	Offshore sediments outside PTM areas exceeding BTV	Offshore sediments outside PTM areas exceeding BTV
	In Situ Containment	Engineered Sand Cap	--	Nearshore sediments outside PTM areas	Nearshore sediments outside PTM areas	Nearshore sediments outside PTM areas	Nearshore sediments outside PTM areas	Nearshore sediments outside PTM areas	Nearshore sediments outside PTM areas	Nearshore sediments outside PTM areas	Nearshore sediments outside areas of PTMs or MCL exceedances	Nearshore sediments outside areas of PTMs or MCL exceedances
	In Situ Treatment	Reactive Sediment Cap	--	All aquatic DNAPL areas[4]	All aquatic DNAPL areas	Aquatic DNAPL areas DA-3, DA-4, DA-5, DA-7, and DA-8	Aquatic DNAPL areas DA-3, DA-4, DA-5, DA-7, and DA-8	Aquatic DNAPL areas DA-3, DA-4, DA-5, DA-7, and DA-8	--	--	--	--
		Reactive Residuals Cover	--	--	--	Removal areas to address residuals	Removal areas to address residuals	Removal areas to address residuals	Removal areas to address residuals	Removal areas to address residuals	Removal areas to address residuals	Removal areas to address residuals
	Removal[3]	Mechanical Dredging with Sheet Pile Containment	--	--	--	QP-S DNAPL Area (DA-6)	QP-S DNAPL Area (DA-6)	QP-S DNAPL Area (DA-6)	Aquatic DNAPL areas DA-5, DA-6, DA-7, and DA-8	Aquatic DNAPL areas DA-5, DA-6, DA-7, and DA-8	Nearshore sediments in areas of PTMs or MCL exceedances	Nearshore sediments in areas of PTMs or MCL exceedances
		Hydraulic Dredging with Water Quality Controls	--	--	--	TD DNAPL Area (DA-1 and DA-2)	TD DNAPL Area (DA-1 and DA-2)	TD DNAPL Area (DA-1 and DA-2)	Aquatic DNAPL areas DA-1, DA-2, DA-3, and DA-4	Aquatic DNAPL areas DA-1, DA-2, DA-3, and DA-4	Aquatic DNAPL areas DA-1, DA-2, DA-3, and DA-4	Aquatic DNAPL areas DA-1, DA-2, DA-3, and DA-4
	Ex Situ Treatment	On-site Thermal Desorption	--	--	--	--	--	--	--	All removed sediment	All removed sediment	All removed sediment
	Disposal	Off-site Landfill	--	--	--	All removed sediment	All removed sediment	All removed sediment	All removed sediment	--	--	--
Groundwater	Institutional Controls	Deed Restrictions	--	X	X	X	X	X	X	X	X	X
	Monitoring	Groundwater Monitoring	--	X	X	X	X	X	X	X	X	X
	In Situ Containment	Slurry Wall Barriers	--	--	Funnel and gate system along most of Site shoreline	Funnel and gate system along most of Site shoreline	Funnel and gate system along most of Site shoreline	Funnel and gate system along most of Site shoreline	--	--	--	--
	In Situ Treatment	Permeable Reactive Barrier	--	--					--	--	--	--
	Removal	Pumping from Vertical Wells	--	--	--	--	--	--	--	--	--	Pump and treat groundwater from below excavated areas
	Ex Situ Treatment	On-site Treatment	--	--	--	--	--	--	--	--	--	
	Disposal	Undetermined	--	--	--	--	--	--	--	--	--	

Notes:

-- Dashes indicate action not included for that alternative.

[1] Cumulative thickness of DNAPL-impacted soil in the top 20 feet of soil column.

[2] Deep PTMs refers to the RR DNAPL Area and polygon MC-1 (Former May Creek; refer to Figure 4-6 of main report).

[3] Process options for dredging are evaluated on a preliminary basis in this FS and will be more fully evaluated during remedial design.

[4] In Alternative 2, the reactive sediment cap configuration in the QP-S DNAPL Area (DA-6) differs from that in the other sediment cap areas. Refer to Section 6.3.2.3 of main report.

BTV = background threshold value
DNAPL = dense non-aqueous phase liquid
PTM = principal threat material
QP-U= Quendall Pond-Upland
RR = Railroad

Table ES-2 - Remedial Alternative Summary

Quendall Terminals
Renton, Washington

		Upland		Sediment		
	Remedial Alternative	Upland PTMs	Contaminated Soil Outside PTM Areas	Sediment PTMs	Contaminated Sediment Outside PTM Areas	Groundwater
2	**Containment**	Upland DNAPL and contaminated soil would be capped with clean soil to prevent direct contact exposure. Institutional controls would be established to place restrictions on future land use and control future construction and redevelopment activities, including requirements for vapor intrusion assessment or mitigation for future buildings.		Two configurations of a reactive sediment cap (RCM and amended sand cap) would be installed in aquatic DNAPL areas (DA-1 through DA-8). The amended sand cap would be installed in the QP-S DNAPL Area (DA-6), and the RCM cap in all other areas. The objective of the RCM cap is to sequester DNAPL using a relatively thin reactive cap. From the shoreline to approximately 75 feet offshore, sediment would be removed prior to capping to maintain the existing profile of the nearshore area. The objective of the thick amended sand cap is to sequester DNAPL using a relatively thick reactive cap in areas where the amount of DNAPL is greater and could overwhelm a thinner RCM cap during the design life, and where the effect on aquatic habitat due to capping could be mitigated (e.g., along the shoreline). Existing sediment would not be removed prior to installation of amended sand cap.	An engineered sand cap (1.5 feet sand) and ENR (6-inches sand) would be installed outside of the aquatic DNAPL areas. The engineered sand cap would be placed in the nearshore area and where existing surface sediment concentrations are relatively high along the property line. From the shoreline to approximately 75 feet offshore, sediment would be removed prior to capping to maintain the existing profile. ENR would be applied in remaining areas of sediment contamination. It would immediately reduce surface sediment concentrations, providing a clean bioturbation layer and reducing surface sediment porewater concentrations.	Institutional controls would be established to place restrictions on groundwater use.
3	**Containment with Targeted PTM Solidification (RR and MC DNAPL Areas)**	Upland cap as described above. In addition, DNAPL collection trenches would be installed in the former May Creek and Quendall Pond Areas, to prevent DNAPL migration from upland soils to sediments. The gravel-filled trenches would be installed landward of the PRB (see Groundwater column) and habitat area. The trench bottoms would contain perforated piping and would slope to collection sumps. Deep PTMs in the RR and MC DNAPL Areas and overlying contaminated soil would be solidified *in situ* . Roughly 13,000 CY of soil would be mixed with amendments using 4- to 8-foot-diameter augers. Amendments may include cement, bentonite, and/or powdered activated carbon.	Same as above	Same as above except that the QP-S DNAPL Area (DA-6) would receive a RCM cap (similar to the other sediment DNAPL areas) instead of an amended sand cap.	Same as above	A PRB would be installed near the shoreline to reduce contaminant migration. It would extend to the base of the Shallow Alluvium, and would have a funnel and gate configuration. The impermeable funnel sections would consist of bentonite slurry. Granular activated carbon would be used in the gate sections to adsorb contaminants. Institutional controls would be established to place restrictions on groundwater use.
4	**Containment with Targeted PTM Removal (TD, QP-S, and QP-U DNAPL Areas)**	Upland cap and DNAPL collection trenches as described above. In addition, PTM soil in the QP-U DNAPL Area and overlying contaminated soil (roughly 13,000 CY) would be excavated. Sheet piling would be used to shore the excavation, and wells and sumps would be used for construction dewatering. The excavation would be backfilled with clean imported fill. Excavated materials would be segregated to the extent practical, for disposal at hazardous and non-hazardous waste landfills as appropriate.	Same as above	A RCM reactive sediment cap would be installed in aquatic DNAPL areas DA-3, DA-4, DA-5, DA-7, and DA-8 as described in Alternative 2. Areas DA-1, DA-2, and DA-6 would be dredged, a reactive residuals cover would be placed, and then backfilled to existing grade. The nearshore QP-S DNAPL Area (DA-6) would be removed by mechanical dredging inside a temporary sheet pile enclosure. The offshore TD DNAPL Area (DA-1 and DA-2) would be hydraulically dredged. Best management practices such as oil booms and/or silt curtains may be used to reduce resuspension and release of contaminants. Dredged material would be dewatered and transported off site for landfill disposal.	Same as above	Same as above
5	**Containment with Targeted PTM Solidification (RR, MC, and QP-U DNAPL Areas and ≥ 4-Foot-Thickness) and Removal (TD and QP-S DNAPL Areas)**	Upland cap and solidification of deep PTMs as described above for Alternative 3. In addition, the QP-U DNAPL Area and areas of the Site where a minimum 4-foot thickness of PTM soil has been observed in the upper 20 feet of soil column would be solidified *in situ* to 20-foot depth. Roughly 23,000 CY of soil would be solidified using methods and amendments as noted above.	Same as above	Same as above	Same as above	Same as above
6	**Containment with Targeted PTM Solidification (RR and MC DNAPL Areas and ≥ 2-Foot-Thickness) and Removal (TD, QP-S, and QP-U DNAPL Areas)**	Upland cap, solidification of deep PTMs, and excavation in the QP-U DNAPL Area as described above for Alternative 2, 3, and 4, respectively. In addition, areas of the Site where a minimum 2-foot thickness of PTM soil has been observed in the upper 20 feet of soil column would be solidified *in situ* to 20-foot depth. Roughly 23,000 CY of soil would be solidified using methods and amendments as noted above.	Same as above	Same as above	Same as above	Same as above
7	**Containment with PTM Solidification (Upland) and Removal (Sediment)**	PTM soil and overlying contaminated soil and soil to 2 feet below DNAPL (roughly 240,000 CY) would be solidified *in situ* . Solidification methods and amendments would be similar to those described above for Alternative 4.	Same as above	Offshore aquatic DNAPL areas (DA-1 through DA-4) would be hydraulically dredged. Nearshore areas (DA-5 through DA-8) would be removed by mechanical dredging within a sheet pile enclosure. A reactive residuals cover would be placed, and then backfilled to existing grade as described for Alternative 4. Dredged material would be dewatered and transported off site for landfill disposal.	Same as above	Institutional controls would be established to place restrictions on groundwater use.
8	**Containment with PTM Removal (Upland and Sediment)**	PTM soil and overlying contaminated soil (roughly 210,000 CY) would be excavated, treated on site, and backfilled. Sheet piling would be used to construct excavation cells, with cell dewatering via internal wells and sumps. Excavated soils would be treated using thermal desorption. It is assumed that residual concentrations may exceed PRGs; therefore, capping of backfilled areas would be required.	Same as above	Same as above	Same as above	Same as above
9	**Containment with Solidification and Removal of Contaminated Soil and Removal of Contaminated Sediment**	Contaminated soil (roughly 710,000 CY) that could act as a source of groundwater contamination above MCLs beyond a reasonable restoration timeframe would be treated on site. Contaminated soil above approximately 15 feet in depth would be excavated, treated on site using thermal desorption, and backfilled. Sheet piling would be used to construct excavation cells, with cell dewatering via internal wells and sumps. Contaminated soil below 15 feet in depth would be solidified *in situ* using the same methods described above. It is assumed that residual concentrations may exceed PRGs; therefore, capping of backfilled areas would be required. Institutional controls addressing soil vapors would likely not be required because volatile contaminants should be effectively treated.		Offshore PTM areas (DA-1 through DA-4) would be hydraulically dredged to approximately 2 feet below PTMs. Nearshore PTM areas (DA-5 through DA-8) and an additional volume of nearshore sediments (based on estimated MCL exceedances) would be removed by mechanical dredging within a sheet pile enclosure. A reactive residuals cover would be placed, and then the area would be backfilled to existing grade. Dredged material would be dewatered and treated by thermal desorption on site.	An engineered sand cap and ENR would be installed outside of the dredging areas (PTMs and MCL exceedances) as described for Alternative 2 .	Same as above
10	**Containment with Removal of Contaminated Soil and Sediment**	Same as above, except that both shallow and deep contaminated soils would be removed, treated on Site by thermal desorption and backfilled.		Same as above	Same as above	Pump and treat technology would be used to address contamination remaining below the excavated areas. An estimated pumping rate of roughly 90 gpm is needed to achieve containment. Extracted groundwater would be treated on site and potentially discharged to the sanitary sewer, to groundwater on the Site, or to Lake Washington. Institutional controls would be established to place restrictions on groundwater use.

Notes:

[1] Refer to Section 6 of main report for complete descriptions of the remedial alternatives.

CY = cubic yard

DNAPL = dense non-aqueous-phase liquid

ENR = enhanced natural recovery

MCL = maximum contaminant level

PRB = permeable reactive barrier

PRG = preliminary remedial goal

QP-U = Quendall Pond-Upland

RCM = reactive core mat

Table ES-3 - Remedial Alternative Institutional Control and Long-Term Monitoring Summary

Quendall Terminals
Renton, Washington

	Remedial Alternative									
	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6	Alt 7	Alt 8	Alt 9	Alt 10
Institutional Controls[1]										
Upland Institutional Controls										
Protection of engineering controls such as soil caps by limiting activities which may damage the control features or increase the potential for exposure.		X	X	X	X	X	X	X	X	X
Evaluation of vapor intrusion potential and/or construction of vapor controls beneath future buildings located above areas containing volatile COCs.		X	X	X	X	X	X	X	X	X
Implementation of a construction management plan specifying monitoring and material management requirements for subsurface activities that would contact potentially contaminated media.		X	X	X	X	X	X	X	X	X
Use of construction techniques that minimize the potential vertical mobilization of DNAPL for future deep-foundation elements potentially penetrating areas of DNAPL.[2]		X	X	X	X	X				
Prohibition on future use of groundwater for drinking purposes and on construction of wells (other than for remediation or monitoring purposes).		X	X	X	X	X	X	X	X	X
Offshore Institutional Controls										
Protection of sediment caps by limiting activities which may damage the caps.		X	X	X	X	X	X	X	X	X
Enforcement and permit tools (i.e., administrative orders, consent decrees)		X	X	X	X	X	X	X	X	X
Informational devices (i.e., seafood consumption advisories, education and public outreach, and site registry for capped areas)		X	X	X	X	X	X	X	X	X
Monitoring and notification of waterway users to restrict specific activities to protect the engineered sand cap and reactive cap.[3]		X	X	X	X	X	X	X	X	X
Long-Term Monitoring Activities[1]										
Upland Monitoring										
Periodic inspection of upland cap integrity.		X	X	X	X	X	X	X	X	X
Periodic groundwater monitoring.		X	X	X	X	X	X	X	X	X
Offshore Monitoring										
Periodic surveys to inspect sediment cap integrity.[4]		X	X	X	X	X	X	X	X	X
Periodic sediment sampling and analysis in sediment cap and ENR areas.		X	X	X	X	X	X	X	X	X

Notes:
[1] In some cases, the areal extent to which institutional controls would apply and the amount of long-term monitoring required would depend on the areal coverage of the various caps and other factors. Refer to Table 6-4 of main report for estimated cap coverage areas.
[2] Such techniques may include use of displacement piles. Specific foundation elements and construction techniques would depend on geotechnical requirements for future structures.
[3] May include restrictions on anchorage within the areas that are capped; restrictions on grounding of small vessels on the shoreline and on vessel draft, horsepower, speed, and time in area; and restrictions on piling placement or removal through cap, or other potential in-water construction/structures.
[4] Cap inspections would also be conducted after a significant natural event, such as a large-magnitude earthquake.

Abbreviations:
COC = chemical of concern
DNAPL = dense non-aqueous phase liquid
ENR = enhanced natural recovery

Table ES-4 - Summary Evaluation of Remedial Alternatives

Quendall Terminals
Renton, Washington

	Remedial Alternative	NCP Threshold Criteria		NCP Balancing Criteria				Present Worth Cost ($ Millions)		
		Protective of Human Health and the Environment?	Complies with all ARARs?	Long-Term Effectiveness and Permanence	Reduction of Toxicity, Mobility, or Volume through Treatment	Short-Term Effectiveness	Implementability	Capital	OM&M	Total
1	No Action (Baseline for Comparison)	**No.** No measures to reduce risk or prevent inadvertent exposure/mobilization of contaminants.	Does not comply with ARARs.	**Low.** No measures to reduce risk or prevent inadvertent exposure/mobilization of contaminants.	**Low.** No treatment provided.	**Moderate.** No action implemented. RAOs not achieved in foreseeable future.	**High.** Requires no action.	0	0	0
2	Containment	**Yes.** Reliance on engineering controls, institutional controls, and monitoring to achieve protectiveness.	Complies with all ARARs except groundwater MCLs under the SDWA. Minimal reduction in volume of groundwater exceeding MCLs for benzene, benzo(a)pyrene, and arsenic.	**Low.** Achieves human health and environmental RAOs but relies on containment measures, which have a risk of failure. Requires long-term monitoring to assess remedy performance and maintain controls as needed.	**Low.** No treatment provided.	**High.** Construction actions are of relatively short duration and would result in limited impacts to workers, community, and the environment. Time to achieve RAOs (design and construction duration) estimated to be approximately 2 years.	**High.** No anticipated challenges in coordinating with appropriate agencies, obtaining materials or constructing components.	18	7.6	26
3	Containment with Targeted PTM Solidification (RR and MC DNAPL Areas)	**Yes.** Achieves protectiveness through combination of containment and treatment. Reduces potential migration and improves reliability compared to Alternative 2 through treatment of PTMs and installation of DNAPL collection trenches and groundwater treatment PRB near shoreline.	Complies with all ARARs except groundwater MCLs under the SDWA. Modest reduction in volume of groundwater exceeding MCLs for benzene, benzo(a)pyrene, and arsenic.	**Low.** Similar to Alternative 2, but provides targeted treatment to reduce the extent of groundwater contamination and reduce the potential for DNAPL and contaminated groundwater to migrate from uplands to lake.	**Low.** An estimated 9 percent of DNAPL is treated. Modest reductions in groundwater volume and contaminant flux are achieved through PTM and groundwater treatment.	**High.** Similar to Alternative 2, with slightly greater impacts (including construction traffic, noise, and air emissions) due to *in situ* solidification of deep upland PTMs and DNAPL collection trench/PRB construction. Time to achieve RAOs estimated to be approximately 3 years.	**High.** Similar to Alternative 2, except that *in situ* solidification will require bench and/or pilot testing.	22	9.2	31
4	Containment with Targeted PTM Removal (TD, QP-S, and QP-U DNAPL Areas)	**Yes.** Achieves protectiveness through combination of containment and treatment. Further reduces potential future exposures compared to Alternative 3 through removal of PTMs in shallow sediments and potentially mobile DNAPL near the shoreline.	Complies with all ARARs except groundwater MCLs under the SDWA. Modest reduction in volume of groundwater exceeding MCLs for benzene, benzo(a)pyrene, and arsenic.	**Moderate.** Removes PTMs presenting the most significant risk for re-exposure (shallow sediments and potentially mobile DNAPL near the shoreline).	**Low.** No reduction in PTMs is achieved through treatment (PTMs removed under this alternative are disposed of at an off-site facility). Modest reductions in groundwater volume and contaminant flux are achieved similar to Alternative 3.	**Moderate.** Increased short-term impacts compared to Alternatives 2 and 3 due to air and water quality impacts from dredging DNAPL-impacted sediments and overall longer construction duration. Time to achieve RAOs is estimated to be approximately 4 years.	**Moderate.** Dredging of DNAPL-impacted sediments provides technical and administrative challenges to minimizing contaminant releases.	40	4.8	44
5	Containment with Targeted PTM Solidification (RR, MC, and QP-U DNAPL Areas and ≥ 4-Foot-Thickness) and Removal (TD and QP-S DNAPL Areas)	**Yes.** Achieves protectiveness through combination of containment and treatment similar to Alternative 4 but provides additional treatment of upland PTMs.	Complies with all ARARs except groundwater MCLs under the SDWA. Modest reduction in volume of groundwater exceeding MCLs for benzene, benzo(a)pyrene, and arsenic.	**Moderate.** Similar to Alternative 4, but provides additional treatment of upland PTMs by targeting areas of greater than 4-feet- cumulative DNAPL thickness.	**Moderate.** An estimated 46 percent of PTMs is treated. Modest reductions in groundwater volume and contaminant flux are achieved similar to Alternatives 3 and 4.	**Moderate.** Similar to Alternative 4, but with slightly greater short-term impacts (traffic, noise, and air impacts) due to greater volume of upland soil treated. Time to achieve RAOs is estimated to be approximately 4 years.	**Moderate.** Similar to Alternative 4.	42	4.1	47
6	Containment with Targeted PTM Solidification (RR and MC DNAPL Areas and ≥ 2-Foot-Thickness) and Removal (TD, QP-S, and QP-U DNAPL Areas)	**Yes.** Achieves protectiveness through combination of containment and treatment. Achieves protectiveness similar to Alternatives 4 and 5 but provides additional treatment of upland PTMs.	Complies with all ARARs except groundwater MCLs under the SDWA. Modest reduction in volume of groundwater exceeding MCLs for benzene, benzo(a)pyrene, and arsenic.	**Moderate.** Similar to Alternatives 4 and 5, but provides additional treatment of upland PTMs by also targeting areas of greater than 2-feet-cumulative DNAPL thickness.	**Moderate.** An estimated 68 percent of PTMs are treated. Modest reductions in groundwater volume and contaminant flux are achieved similar to Alternatives 3, 4, and 5.	**Moderate.** Similar to Alternatives 4 and 5, but with greater short-term impacts (traffic, noise, and air impacts) due to greater volume of upland soil treated. Time to achieve RAOs is estimated to be approximately 5 years.	**Moderate.** Similar to Alternatives 4 and 5, but with a slightly longer construction duration.	57	4.1	61
7	Containment with PTM Solidification (Upland) and Removal (Sediment)	**Yes.** Achieves protectiveness through combination of containment and treatment. Greatly reduces potential future exposures through removal of all sediment PTMs and treatment of all upland PTMs.	Complies with all ARARs except groundwater MCLs under the SDWA. Substantial reduction in volume of groundwater exceeding MCLs for benzene, benzo(a)pyrene, and arsenic.	**High.** Permanently treats all PTMs at the Site via *in situ* solidification of upland PTMs and removal of sediment PTMs.	**High.** An estimated 85 percent of PTMs are treated and significant reductions in groundwater volume and contaminant flux are achieved.	**Low.** Greater short-term impacts (traffic, noise, and air impacts) than Alternative 6 due to longer construction duration, greater volume of soil treated, and greater volume of DNAPL-impacted sediment treated. Time to achieve RAOs is estimated to be approximately 6 years.	**Moderate.** Similar implementation challenges as Alternatives 4 through 6, but with a significantly longer construction duration.	78	2.7	80
8	Containment with PTM Removal (Upland and Sediment)	**Yes.** Achieves protectiveness through combination of containment and treatment. Greatly reduces potential future exposures through removal of all PTMs.	Complies with all ARARs except groundwater MCLs under the SDWA. Potentially eliminates groundwater exceeding MCLs for benzene. Substantial reduction in volume of groundwater exceeding MCLs for benzo(a)pyrene and arsenic.	**High.** Permanently treats all PTMs at the Site via removal/on-site thermal desorption.	**High.** All PTMs are treated and significant reductions in groundwater volume and contaminant flux are achieved.	**Low.** Similar to Alternative 7 but greater short-term impacts due to longer construction duration and greater potential for air emissions from excavation, soil handling, and on-site treatment compared to *in situ* solidification. Time to achieve RAOs is estimated to be approximately 7 years.	**Low.** Increased technical challenges compared to Alternative 7 due to complexity of shoring and dewatering for deep excavations and to provide on-site thermal treatment, which is locally uncommon.	137	2.7	140
9	Containment with Solidification and Removal of Contaminated Soil and Removal of Contaminated Sediment	**Yes.** Achieves protectiveness primarily through treatment, although containment of low-level contaminated materials is still required.	Complies with all ARARs except groundwater MCLs under the SDWA. Potentially eliminates groundwater exceeding MCLs for benzene. Substantial reduction in volume of groundwater exceeding MCLs for benzo(a)pyrene and arsenic.	**High.** Permanently treats all PTMs at the Site via *in situ* solidification of shallow upland PTMs and removal/on-site treatment of deep upland PTMs of sediment PTMs. Also treats significant volumes of low-level contaminated soil and sediment.	**High.** All PTMs are treated. Treatment of lower level contaminated soil and sediment provide additional reductions in contaminated groundwater volume and contaminant flux compared to Alternatives 7 and 8.	**Low.** Increased short-term impacts compared to Alternatives 7 and 8 due to very longer construction duration and very large volumes of soil and sediment treated. Time to achieve RAOs is estimated to be approximately 14 years.	**Low.** Technical and administrative challenges for treatment of soils and sediments on this scale are expected to be significant.	259	2.7	262
10	Containment with Removal of Contaminated Soil and Sediment	**Yes.** Achieves protectiveness primarily through treatment, although containment of low-level contaminated materials is still required.	Complies with all ARARs except groundwater MCLs under the SDWA. Potentially eliminates groundwater exceeding MCLs for benzene. Substantial reduction in volume of groundwater exceeding MCLs for benzo(a)pyrene and arsenic.	**High.** Similar to Alternative 9, except all materials treated using removal/on-site thermal desorption, and additional treatment of groundwater provided by long-term pump-and-treat.	**High.** All PTMs are treated. Treatment of materials via on-site thermal desorption rather than a combination of *in situ* solidification and thermal desorption provides additional groundwater restoration, including potential removal of benzene exceeding MCLs, compared to Alternative 9.	**Low.** Similar to Alternative 9 but with even greater short-term impacts due to greater extent of removal/on-site thermal treatment instead of *in situ* solidification. Time to achieve RAOs is estimated to be approximately 15 years.	**Low.** Technical challenges are even greater than for Alternative 9 due to the complexities of shoring and dewatering for very deep excavations.	380	29	409

Notes:

Estimated present worth costs are in 2013 dollars, and were calculated using a discount factor of 1.6 percent. The itemized estimates are provided in Appendix D.

ARAR = applicable or relevant and appropriate requirement
DNAPL = dense non-aqueous phase liquid
MC = May Creek
MCL = maximum contaminant level
OM&M = operation, maintenance, and monitoring
PRB = permeable reactive barrier
PTM = principal threat materials
QP-S = Quendall Pond-Sediment
QP-U = Quendall Pond-Upland
RAO = remedial action objective
RR = Railroad
SDWA = Safe Drinking Water Act
TD = T-Dock

Table ES-5 - Comparative Rating of Remedial Alternatives

Quendall Terminals
Renton, Washington

		Threshold Criteria		NCP Balancing Criteria				
	Remedial Alternative	Protective of Human Health and the Environment?	Complies with ARARs	Long-Term Effectiveness and Permanence	Reduction of Toxicity, Mobility, or Volume through Treatment	Short-Term Effectiveness	Implementability	Estimated Present Worth Cost[2] ($M)
1	No Action (Baseline for Comparison)	No	No	○	○	◑	●	0
2	Containment	Yes	(Note 1)	○	○	●	●	$26
3	Containment with Targeted PTM Solidification (RR and MC DNAPL Areas)	Yes	(Note 1)	○	○	●	●	$31
4	Containment with Targeted PTM Removal (TD, QP-S, and QP-U DNAPL Areas)	Yes	(Note 1)	◑	○	◑	◑	$44
5	Containment with Targeted PTM Solidification (RR, MC, and QP-U DNAPL Areas and ≥ 4-Foot-Thickness) and Removal (TD and QP-S DNAPL Areas)	Yes	(Note 1)	◑	◑	◑	◑	$47
6	Containment with Targeted PTM Solidification (RR and MC DNAPL Areas and ≥ 2-Foot-Thickness) and Removal (TD, QP-S, and QP-U DNAPL Areas)	Yes	(Note 1)	◑	◑	◑	◑	$61
7	Containment with PTM Solidification (Upland) and Removal (Sediment)	Yes	(Note 1)	●	●	○	◑	$80
8	Containment with PTM Removal (Upland and Sediment)	Yes	(Note 1)	●	●	○	○	$140
9	Containment with Solidification and Removal of Contaminated Soil and Removal of Contaminated Sediment	Yes	(Note 1)	●	●	○	○	$262
10	Containment with Removal of Contaminated Soil and Sediment	Yes	(Note 1)	●	●	○	○	$409

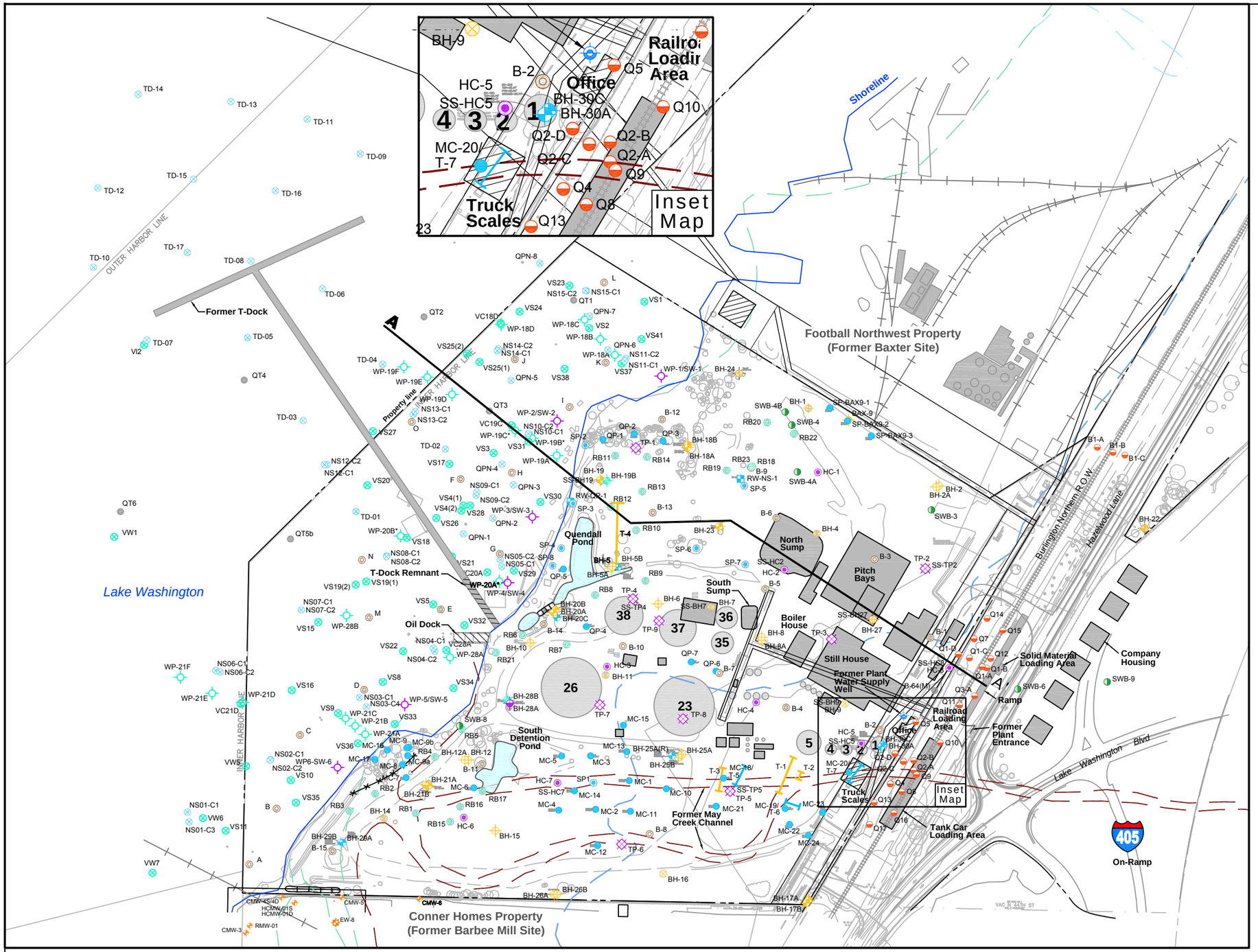
Notes:

[1] Complies with all ARARs except the Safe Drinking Water Act, which requires achievement of groundwater MCLs throughout the Site.

[2] Estimated mid-range present worth costs are in 2013 dollars, and were calculated using a discount factor of 1.6 percent. The itemized estimates are provided in Appendix D.

Legend:

○	The alternative rates low for the criterion.
◑	The alternative rates moderate for the criterion.
●	The alternative rates high for the criterion.



Summary of Explorations by Consultant

Consultant	Year	Exploration Type	Exploration ID	Map Symbol
Anchor QEA	2009	Subsurface Sediment Core	TD-01 through TD-17	
Aspect Consulting	2007	Monitoring Wells	CMW-1 through CMW-6	
	2007	Extraction Wells	EW-1 through EW-8	
	2009	Monitoring Wells	BH-5B, BH-25A(R), BH-29A, BH-29B, BH-30A, BH-30C	
		Soil Borings	QP-1 through QP-7, MC-1 through MC-24 SP-BAX9-1 through SP-BAX9-3	
		Trenches	T-5 through T-7	
	2003	Monitoring Wells	RW-NS-1, RW-QP-1	
		Soil Borings	SP1 through SP8	
		Surface Soil Samples	SS-BH7, SS-BH9, SS-BH19, SS-BH27, SS-TP2, SS-HC2, SS-HC5, SS-HC7, SS-HC8	(a)
Pinnacle Geosciences	2008	Soil Borings	Q1 through Q17, B1-A through B1-C	
Retec	2001	Soil Borings	RB1 through RB23	
	2001	Subsurface Sediment Core	WP-18 through WP-28	
	2000	Monitoring Wells	BH-19B, BH-28B	
	1997	Subsurface Sediment Core	VS-1 through VS-41, VC18 through VC28 VW-1 through VW-7	
Shannon & Wilson	1997	Soil Borings	SWB-3, SWB-4, SWB-4A, SWB-4B, SWB-8	
Hart Crowser	1997	Surface Sediment Samples	WP-1/SW-1 through WP-6/SW-6	
	1996, 1995	Soil Borings	HC-1 through HC-8	
		Monitoring Wells	BH-28A	
		Test Pits	TP-1 through TP-9	
Woodward Clyde	1990	Monitoring Wells	BH-24, BH-25A, BH-25B, BH-26A, BH-26B, BH-27	
Woodward Clyde	1988	Monitoring Wells	BH-17A, BH-17B, BH-18A, BH-18B, BH-19, BH-20A, BH-20B, BH-21A, BH-21B, BH-22, BH-23, BAX-9	
Woodward Clyde	1983	Monitoring Wells	BH-1, BH-2, BH-2A, BH-5, BH-5A, BH-6, BH-8, BH-8A, BH-10, BH-12, BH-12A, BH-15	
		Soil Borings	BH-4, BH-7, BH-9, BH-11, BH-14, BH-16	
		Trenches	T-1 through T-4	
Twelker	1971	Soil Borings	B-1 through B-15, A through M	
Metro	1963	Soil Borings	B-64(M)	

Notes
(a) Surface soil samples co-located with previous explorations.
Exploration ID of the surface soil sample includes the ID of the previous exploration.

Legend

- Detention Pond
- Existing Structure
- 23 — Historical Tank with Tank Number
- Other Historical Feature
- Shoreline (2009)
- Shoreline (1936)
- Shoreline (1916)
- May Creek (1920)
- A — A' Cross Section Location and Designation

N
0 200 400
Feet
Exploration Map

N
0 100 200
Feet
Inset Map

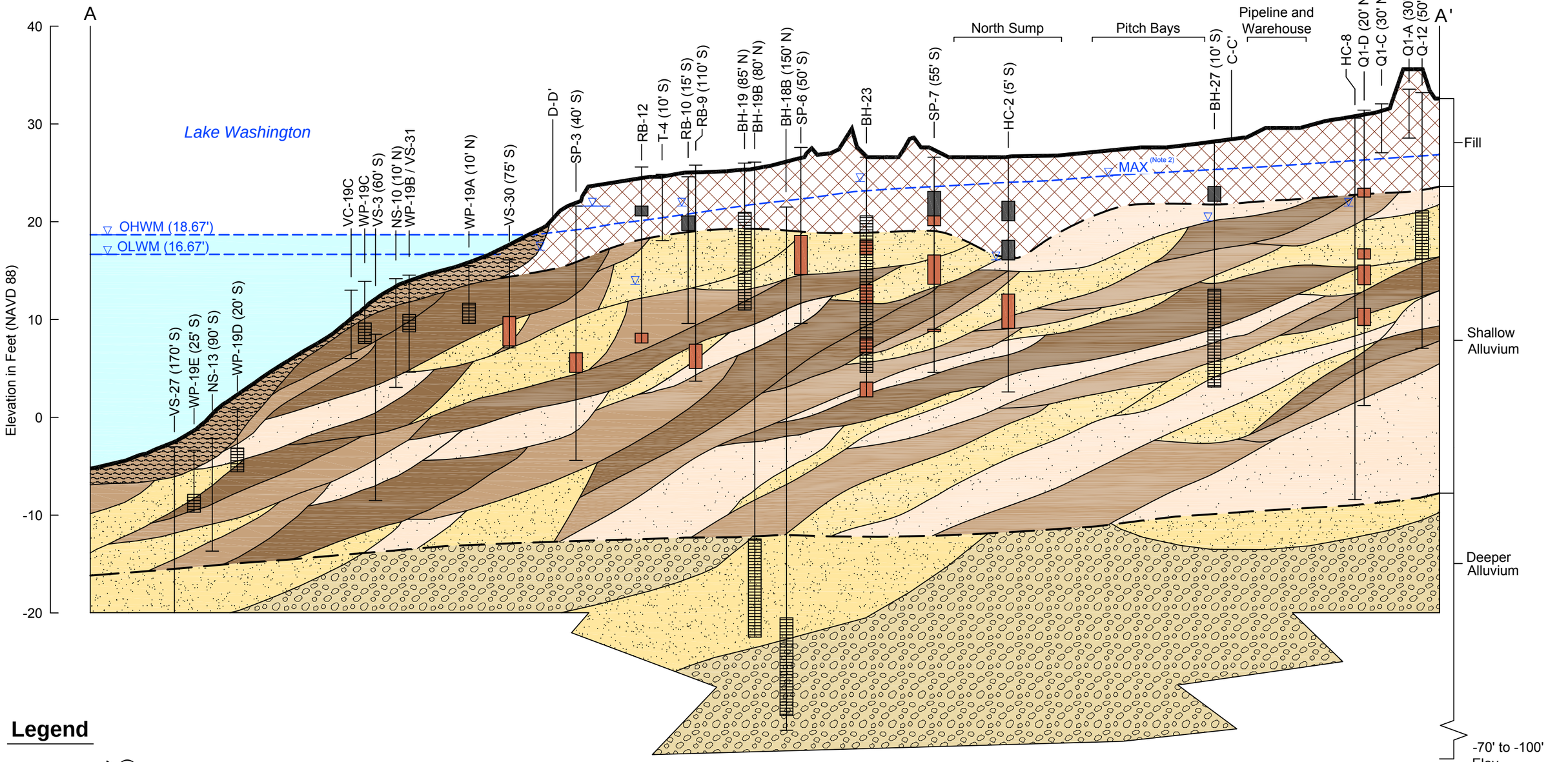
DRAFT FINAL
October 14, 2013

Site Plan Showing Historical Features

Quendall Terminals Feasibility Study Report
Renton, Washington

FIRM:	FIGURE NO.
ASPECT	ES-1
DRAWN BY: JJP/DAH/SCC	

CAD Path: Q:\Quendall\020027 Quendall Terminals\2013-06 FS Draft Final Executive Summary\ES2\020027-31.dwg Figure 3-1 (11 x 17) || Coordinate System: NAD 1983 State Plane Washington North FIPS 4601 Feet || Date Saved: Oct 11, 2013 3:08pm || User: scudd



Legend

BH-27 (10' S) — Exploration ID and Offset from Cross Section

Water Level Observed at Time of Drilling

- Solidified Tar Products
- Non-Aqueous Phase Liquids
- Well Screen

- Fill
- Organic Sandy Silt (Mud)
- Peat/Organic Silt
- Silt/Clayey Silt
- Sandy Silt/Silty Sand
- Sand
- Gravelly Sand/ Sandy Gravel

Horizontal Scale
0 — 100 — 200
Feet

Vertical Scale
0 — 10 — 20
Feet

Vertical Exaggeration X10

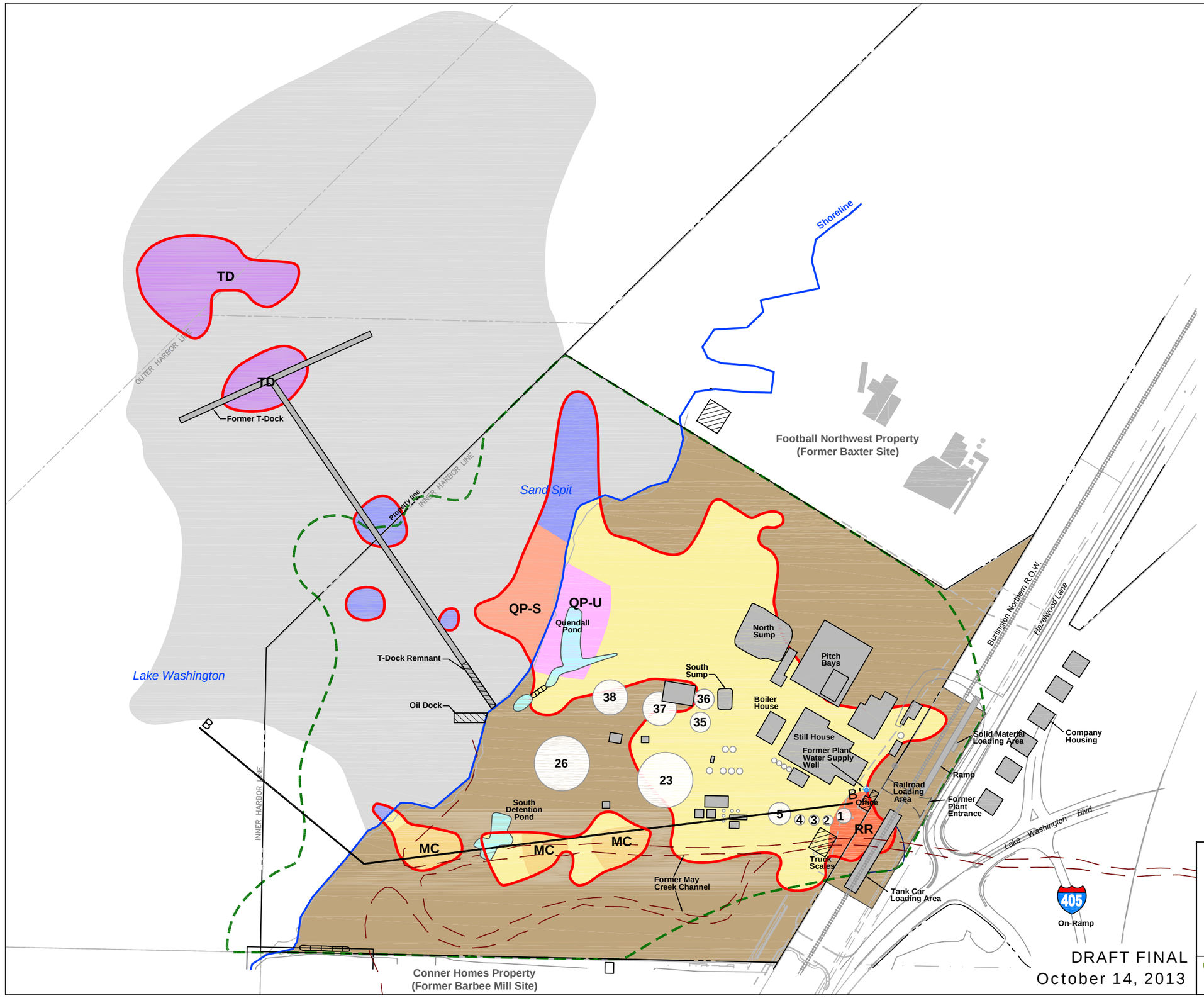
Notes:
1. Refer to Figure ES-1 for exploration locations.
2. Maximum observed groundwater elevation based on periodic monitoring of shallow aquifer monitoring wells.

DRAFT FINAL
October 14, 2013

Geologic Cross Section A-A'
Quendall Terminals Feasibility Study Report
Renton, Washington

Aspect Consulting | ARCADIS | FIRM: ASPECT | DRAWN BY: JJP/PMB/SCC | FIGURE NO. ES-2

CAD Path: Q:\Quendall\020027 Quendall Terminals\2013-06 FS Draft Final Executive Summary\ES2\020027-34.dwg Figure 3-4 (11 x 17) || Coordinate System: NAD 1983 State Plane Washington North FIPS 4601 Feet || Date Saved: Oct 11, 2013 3:10pm || User: scudd



Legend

- Current Shoreline (Ordinary High Water)
- Property Line
- B B' — Cross Section Location and Designation
- Detention Pond
- Existing Structure
- 23 — Historical Tank with Tank Number
- Other Historical Feature
- Estimated Extent of DNAPL
- Estimated Extent of PRG Exceedances in Groundwater (Subsurface Soil and Groundwater Area)
- Former May Creek Channel DNAPL Area
- Quendall Pond Upland DNAPL Area
- Quendall Pond Sediment DNAPL Area
- Former Railroad DNAPL Area
- T-Dock DNAPL Area
- Other Upland DNAPL Areas
- Other Aquatic DNAPL Areas
- Surface Soil Area*
- Surface and Subsurface Sediment Area*

* PRG Exceedance Areas

Notes

1. Refer to Section 4.4 of main report for descriptions of the areas identified in the Legend.
2. Refer to Figure 3-5 of main report for notes regarding delineation of DNAPL.

N

0 200 400

Feet

Areas Targeted for Remedial Action

Quendall Terminals Feasibility Study Report

Renton, Washington

DRAFT FINAL

October 14, 2013

Aspect CONSULTING | ARCADIS | FIRM: ASPECT | DRAWN BY: JJP/DAH/SCC | FIGURE NO. ES-3

CAD Path: Q:\Quendall\020027 Quendall Terminals\2013-06 FS Draft Final Executive Summary\ES2\020027-41.dwg Figure 4-1 (11 x 17) || Date Saved: Oct 11, 2013 3:13pm || User: scudd

B

B'

Elevation in Feet (NAVD 88)

40
30
20
10
0
-10
-20
-30
-40

Lake Washington

OHWM (18.67')
OLWM (16.67')

WP-21F (38' S)
NS06-C1/C2 (15' N)
WP-21E (25' S)
WP-21D/VC21D
VS-16 (80' N)
VW-5 (90' S)
NS02-C1/C2 (50' S)
C (25' N)
VS-9 (100' N)
WP-21C (100' N)
WP-21B (100' N)/VS-35 (85' S)
WP-21A (100' N)/VS-36 (80' N)
RB-2
MC-17 (70' N)
BH-14 (50' S)
MC-8 (50' N)
MC-7 (25' N)
RB-1 (44' S)
BH-21B (15' N)
BH-21A (4' N)
BH-12 (60' N)
RB-16 (40' S)
SWB-8 (110' N)
RB-17 (15' S)
C-C'
HC-7 (5' N)
SP-1 (25' S)
MC-1 (30' S)
MC-10 (60' S)
BH-25A(R)
BH-25B
BH-25A
MC-18 (50' S)
TP-5 (60' S)
D-D'
MC-20 (70' S)
BH-9 (70' N)
HC-5 (15' S)
BH-30A/C (20' S)

MC

(Note 3)
MAX

RR

Other Upland DNAPL Areas

Other Upland DNAPL Areas

Shallow Alluvium

Deeper Alluvium

-122.1' Bottom Elevation

Note: BH-30C well screen located from elevation -54' to -64'

Legend

MC-17 (70' N) — Exploration ID and Offset from Cross Section

Water Level Observed at Time of Drilling

Solidified Tar Products

Non-Aqueous Phase Liquids

Well Screen

Fill or Surface Sediment: Silt, Sand, Gravel, Wood and Mixed Debris

Shallow Alluvium: Stratified Organic Silt, Peat, Sand

Deeper Alluvium: Sand and Gravels

Estimated Extent of DNAPL

Notes:
1. Refer to Figure ES-1 for exploration locations.
2. Figure ES-3 Notes and Legend also apply to this figure.
3. Maximum observed groundwater elevation based on periodic monitoring of shallow aquifer monitoring wells.

Horizontal Scale
0 100 200
Feet

Vertical Scale
0 10 20
Feet

Vertical Exaggeration x10

DRAFT FINAL
October 14, 2013

Estimated Extent of DNAPL along Cross Section B-B'

Quendall Terminals Feasibility Study Report
Renton, Washington

Aspect CONSULTING | ARCADIS | FIRM: ASPECT | DRAWN BY: JJP/DAH/SCC | FIGURE NO. ES-4

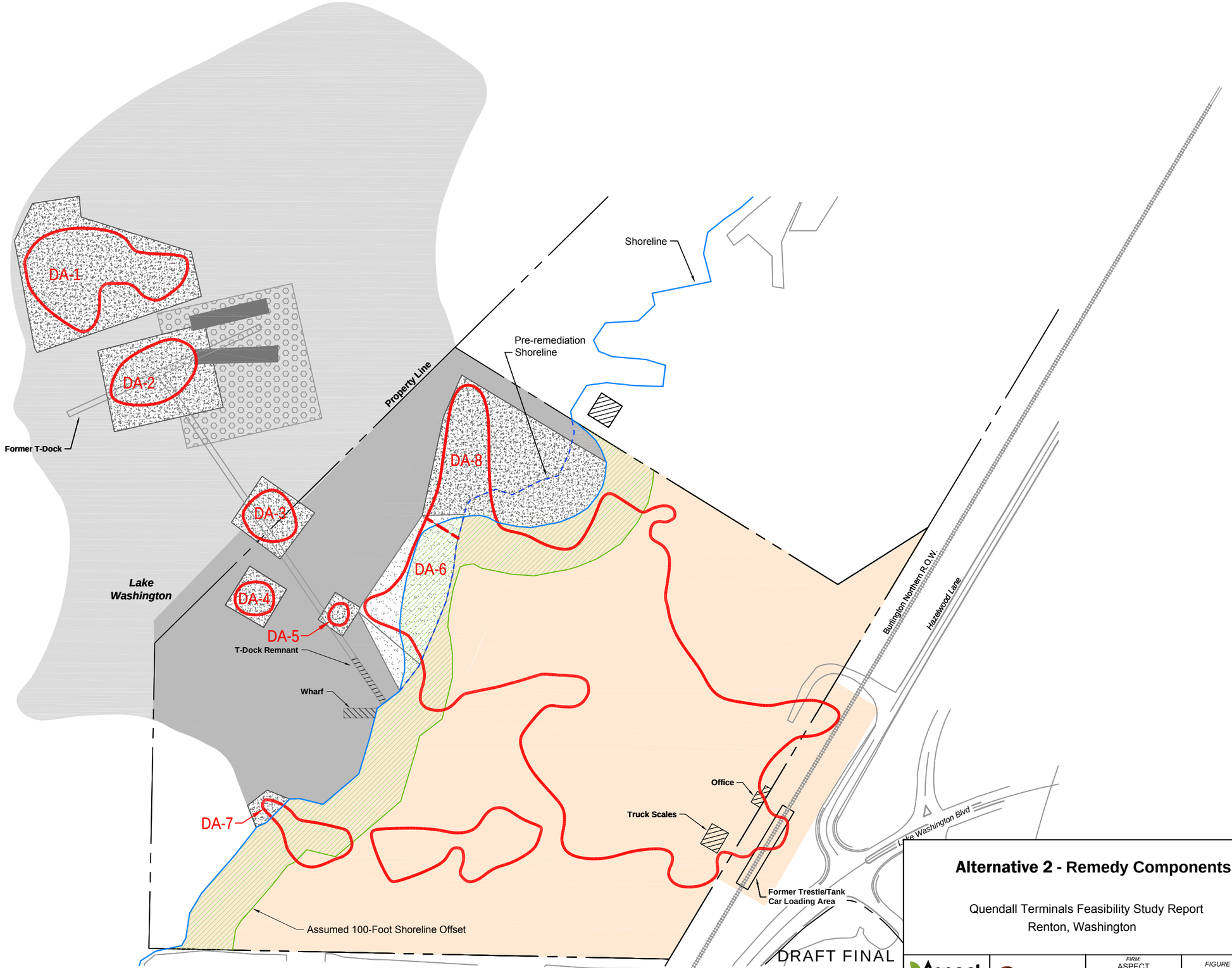
CAD Path: Q:\Quendall\020027 Quendall Terminals\2013-06 FS Draft Final Executive Summary\ES2 (020027-43.dwg Figure 4-3 (11 x 17) || Coordinate System: NAD 1983 State Plane Washington North FIPS 4601 Feet || Date Saved: Oct 11, 2013 3:18pm || User: scudd

Legend

- Existing Structure
- DNR Dry Dock Cap
- DNR Dry Dock Concrete Hulls
- Estimated Extent of DNAPL
- Habitat Area
- Permeable Cap
- Enhanced Natural Recovery
- Engineered Sand Cap (Note 2)
- RCM Reactive Cap (Note 2)
- Amended Sand Reactive Cap
- DA-1 Aquatic DNAPL Area

Notes:

1. Altered shoreline to result in no net loss of waters of the United States.
2. This alternative includes sediment removal (not shown on this figure) from the shoreline to approximately 75 feet offshore in areas where engineered sand cap and RCM reactive cap are to be placed, to maintain the existing nearshore area profile. Refer to Section 6.3 of main report.



N

0 200 400

Feet

Alternative 2 - Remedy Components

Quendall Terminals Feasibility Study Report
Renton, Washington

DRAFT FINAL
October 14, 2013

Aspect CONSULTING | ARCADIS

FIRM: ASPECT
DRAWN BY: JJP/PMB/ELG/SCC

FIGURE NO.
ES-5

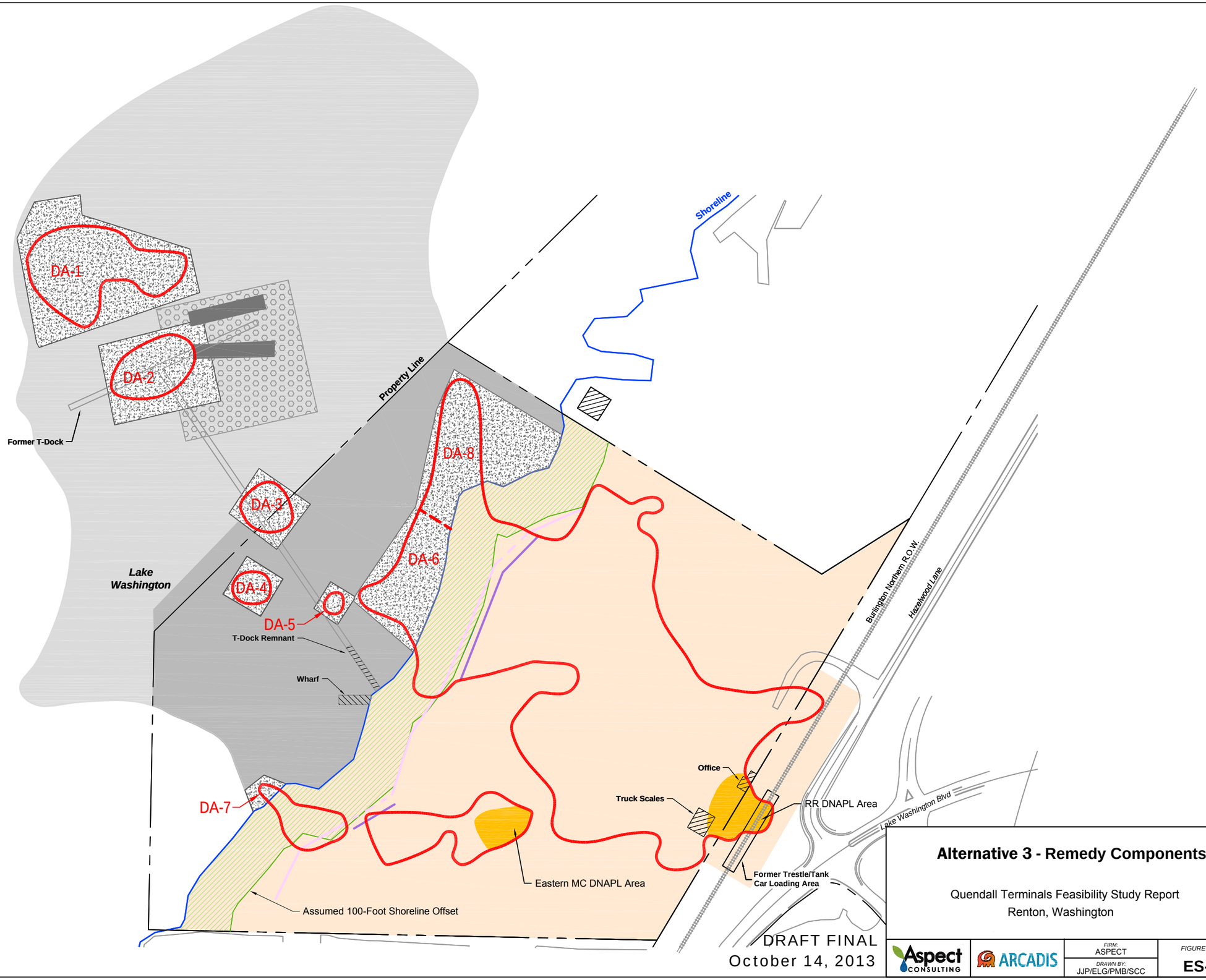
CAD Path: Q:\Quendall\020027 Quendall Terminals\2013-06 FS Draft Final Executive Summary\ES2\020027_Plan-Alternatives 2-8 (Shoreline Change).dwg ALT 2 NEW || Date Saved: Oct 11, 2013 3:23pm || User: scudd

Legend

- Existing Structure
- DNR Dry Dock Cap
- DNR Dry Dock Concrete Hulls
- Estimated Extent of DNAPL
- Permeable Treatment Gate
- Impermeable Funnel
- DNAPL Collection Trench
- Habitat Area
- Permeable Cap
- Solidified Soil
- Enhanced Natural Recovery
- Engineered Sand Cap (Note 1)
- RCM Reactive Cap (Note 1)
- DA-1 Aquatic DNAPL Area

Note:

1. This alternative includes sediment removal (not shown on this figure) from the shoreline to approximately 75 feet offshore in areas where engineered sand cap and RCM reactive cap are to be placed, to maintain the existing nearshore area profile. Refer to Section 6.3 of main report.



Alternative 3 - Remedy Components

Quendall Terminals Feasibility Study Report
Renton, Washington

DRAFT FINAL
October 14, 2013

FIRM:	FIGURE NO.
ASPECT	ES-6
DRAWN BY: JJP/ELG/PMB/SCC	

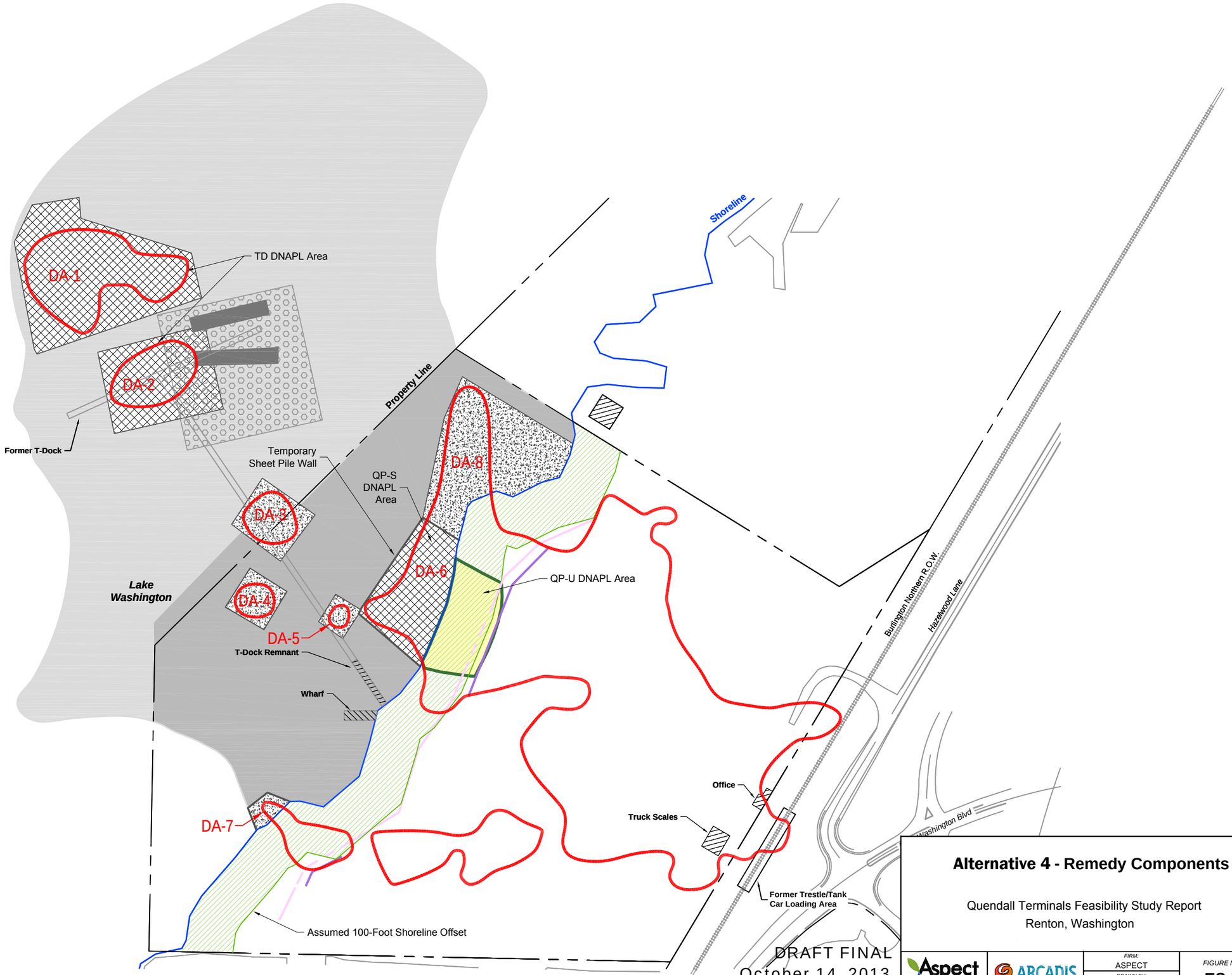
CAD Path: Q:\Quendall\020027 Quendall Terminals\2013-06 FS Draft Final Executive Summary\ES2\020027_Plan-Alternatives 2-8.dwg ALT 3 NEW || Date Saved: Oct 11, 2013 3:33pm || User: scudd

Legend

- Existing Structure
- DNR Dry Dock Cap
- DNR Dry Dock Concrete Hulls
- Estimated Extent of DNAPL
- Permeable Treatment Gate
- Impermeable Funnel
- DNAPL Collection Trench
- Habitat Area
- Soil Excavation Cell
- Enhanced Natural Recovery
- Engineered Sand Cap (Note 2)
- Dredge Area
- RCM Reactive Cap (Note 2)
- Excavated Soil and Backfill
- DA-1 Aquatic DNAPL Area

Notes:

1. This alternative also includes permeable upland cap similar to Alternative 3. Refer to Figure ES-6 for cap extent.
2. This alternative includes sediment removal (not shown on this figure) from the shoreline to approximately 75 feet offshore in areas where engineered sand cap and RCM reactive cap are to be placed, to maintain the existing nearshore area profile. Refer to Section 6.3 of main report.



Alternative 4 - Remedy Components

Quendall Terminals Feasibility Study Report
Renton, Washington

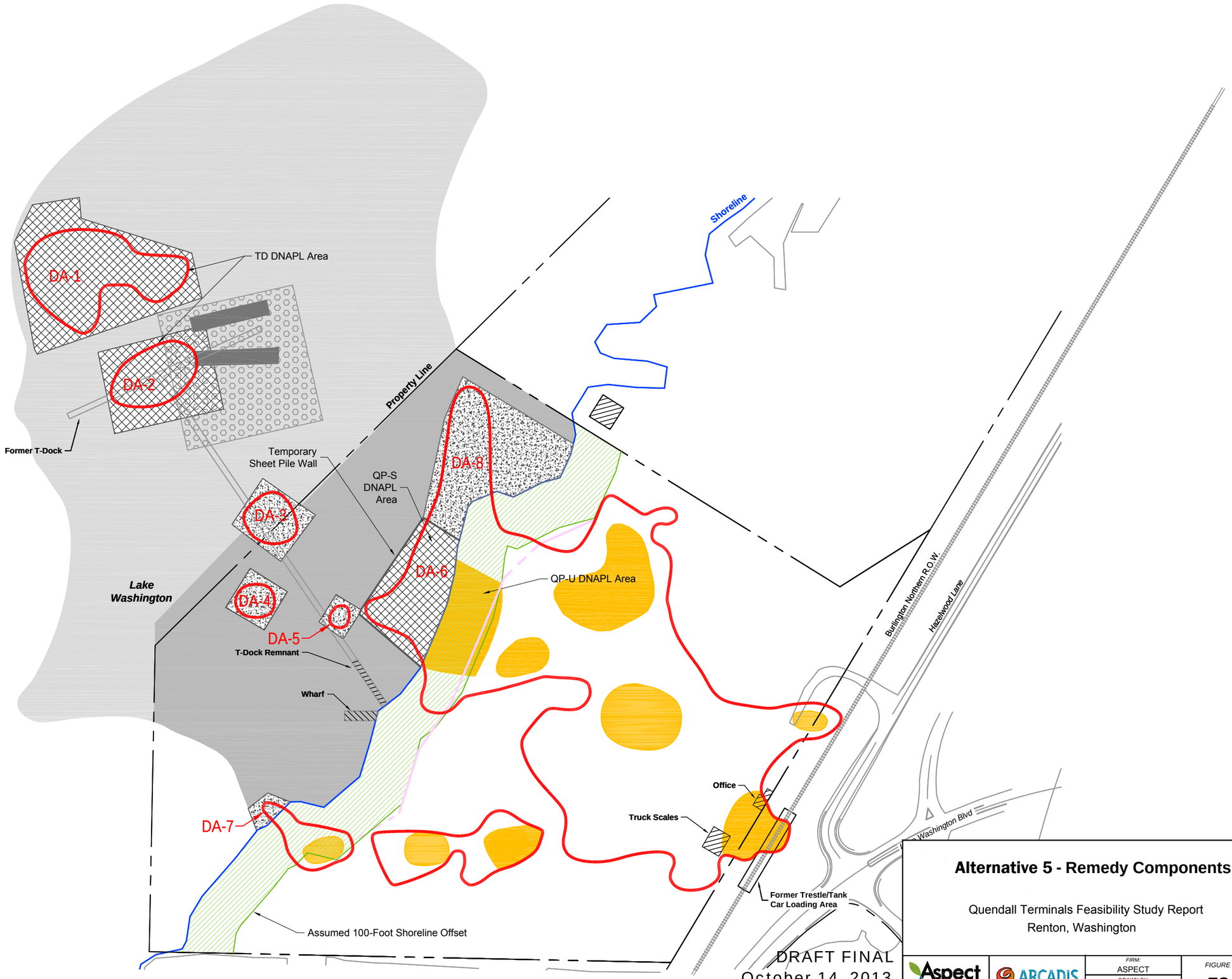
DRAFT FINAL
October 14, 2013

Aspect CONSULTING | ARCADIS | FIRM: ASPECT | DRAWN BY: JJP/ELG/PMB/SCC | FIGURE NO. ES-7

CAD Path: Q:\Quendall\020027 Quendall Terminals\2013-06 FS Draft Final Executive Summary\ES2\020027_Plan-Alternatives 2-8.dwg ALT 4 NEW || Date Saved: Oct 11, 2013 3:48pm || User: scudd

Legend

- Existing Structure
- DNR Dry Dock Cap
- DNR Dry Dock Concrete Hulls
- Estimated Extent of DNAPL
- Permeable Treatment Gate
- Impermeable Funnel
- Habitat Area
- Solidified Soil
- Enhanced Natural Recovery
- Engineered Sand Cap (Note 2)
- Dredge Area
- RCM Reactive Cap (Note 2)
- DA-1 Aquatic DNAPL Area



Notes:

1. This alternative also includes permeable upland cap similar to Alternative 3. Refer to Figure ES-6 for cap extent.
2. This alternative includes sediment removal (not shown on this figure) from the shoreline to approximately 75 feet offshore in areas where engineered sand cap and RCM reactive cap are to be placed, to maintain the existing nearshore area profile. Refer to Section 6.3 of main report.

N

0 200 400

Feet

DRAFT FINAL
October 14, 2013

Alternative 5 - Remedy Components

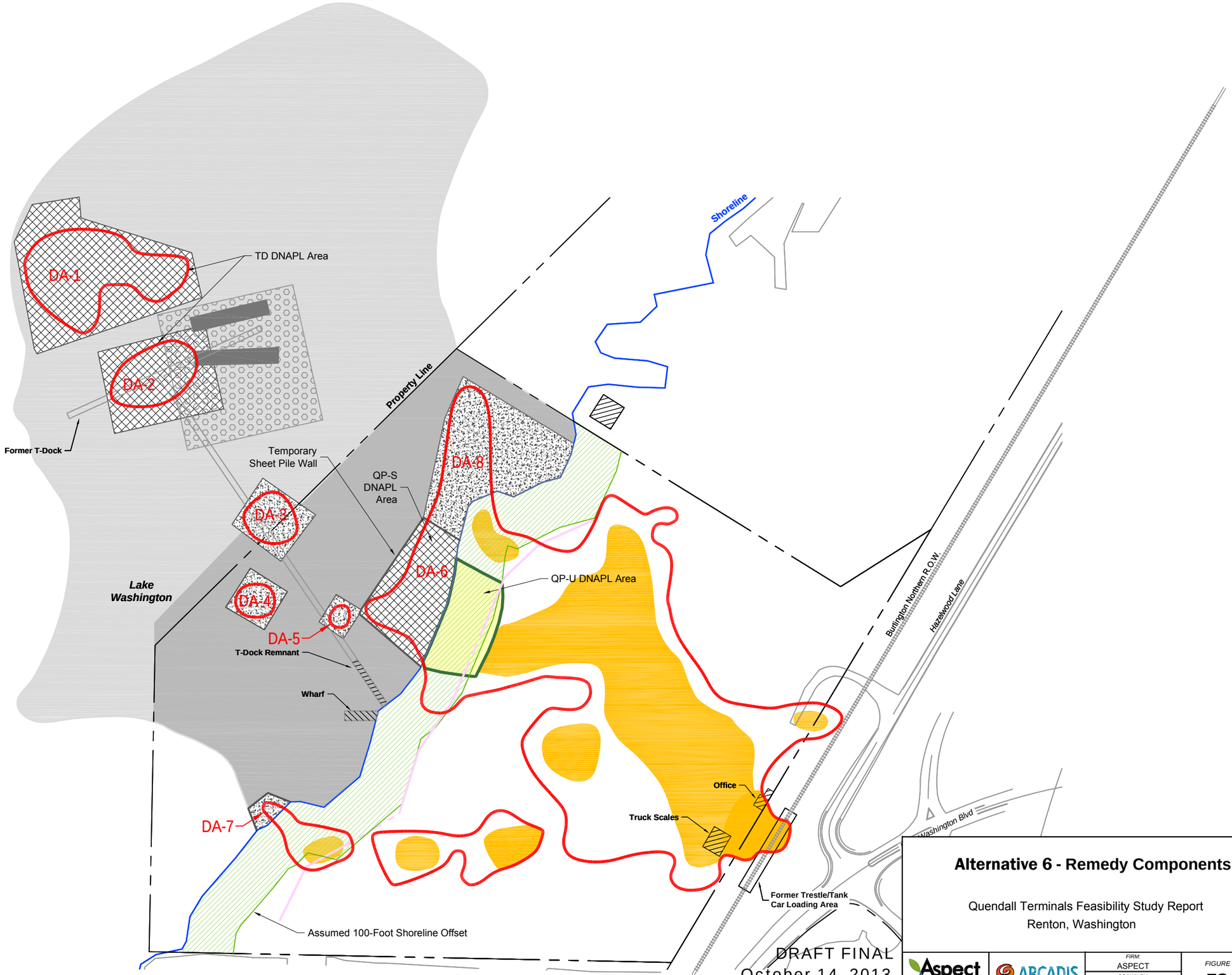
Quendall Terminals Feasibility Study Report
Renton, Washington

Aspect CONSULTING | ARCADIS | FIRM: ASPECT | DRAWN BY: JJP/ELG/PMB/SCC | FIGURE NO. ES-8

CAD Path: Q:\Quendall\020027 Quendall Terminals\2013-06 FS Draft Final Executive Summary\ES2\020027_Plan-Alternatives 2-8.dwg ALT 5 NEW || Date Saved: Oct 11, 2013 3:50pm || User:scudd

Legend

- Existing Structure
- DNR Dry Dock Cap
- DNR Dry Dock Concrete Hulls
- Estimated Extent of DNAPL
- Permeable Treatment Gate
- Impermeable Funnel
- Habitat Area
- Solidified Soil (to 20 foot depth)
- Soil Excavation Cell
- Enhanced Natural Recovery
- Engineered Sand Cap (Note 2)
- Dredge Area
- RCM Reactive Cap (Note 2)
- Excavated Soil and Backfill
- DA-1 Aquatic DNAPL Area



Notes:

1. This alternative also includes permeable upland cap similar to Alternative 3. Refer to Figure ES-6 for cap extent.
2. This alternative includes sediment removal (not shown on this figure) from the shoreline to approximately 75 feet offshore in areas where engineered sand cap and RCM reactive cap are to be placed, to maintain the existing nearshore area profile. Refer to Section 6.3 of main report.

N

0 200 400

Feet

Alternative 6 - Remedy Components

Quendall Terminals Feasibility Study Report
Renton, Washington

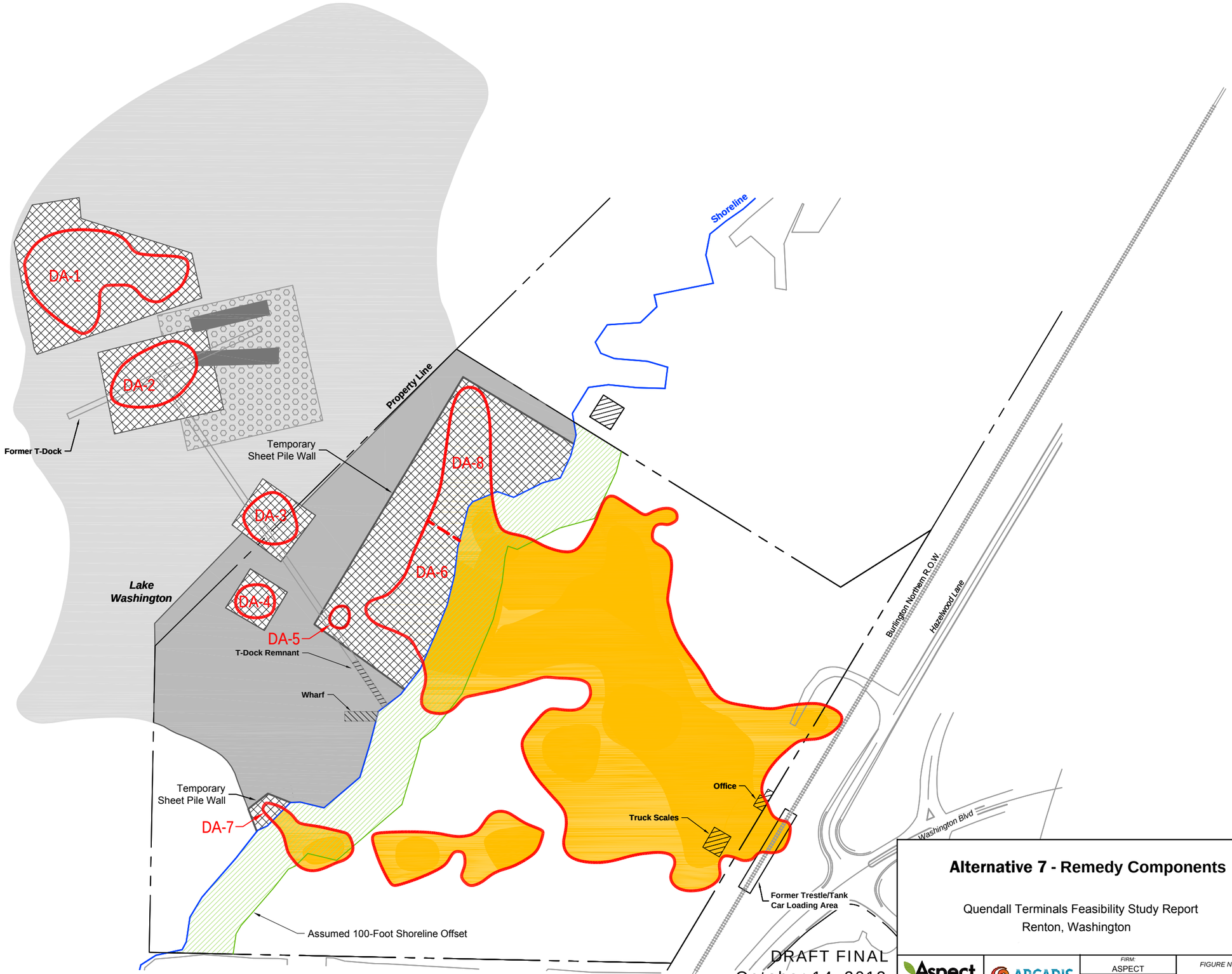
DRAFT FINAL
October 14, 2013

Aspect CONSULTING | ARCADIS | FIRM: ASPECT | DRAWN BY: JJP/ELG/PMB/SCC | FIGURE NO. ES-9

CAD Path: Q:\Quendall\020027 Quendall Terminals\2013-06 FS Draft Final Executive Summary\ES2\020027_Plan-Alternatives 2-8.dwg ALT 6 NEW || Date Saved: Oct 11, 2013 3:50pm || User: scudd

Legend

- Existing Structure
- DNR Dry Dock Cap
- DNR Dry Dock Concrete Hulls
- Estimated Extent of DNAPL
- Habitat Area
- Solidified Soil
- Enhanced Natural Recovery
- Engineered Sand Cap (Note 2)
- Dredge Area
- DA-1 Aquatic DNAPL Area



Notes:

1. This alternative also includes permeable upland cap similar to Alternative 3. Refer to Figure ES-6 for cap extent.
2. This alternative includes sediment removal (not shown on this figure) from the shoreline to approximately 75 feet offshore in areas where engineered sand cap is to be placed, to maintain the existing nearshore area profile. Refer to Section 6.3 of main report.

N

0 200 400

Feet

Alternative 7 - Remedy Components

Quendall Terminals Feasibility Study Report
Renton, Washington

DRAFT FINAL
October 14, 2013

Aspect CONSULTING | ARCADIS | FIRM: ASPECT | DRAWN BY: JJP/ELG/PMB/SCC | FIGURE NO. ES-10

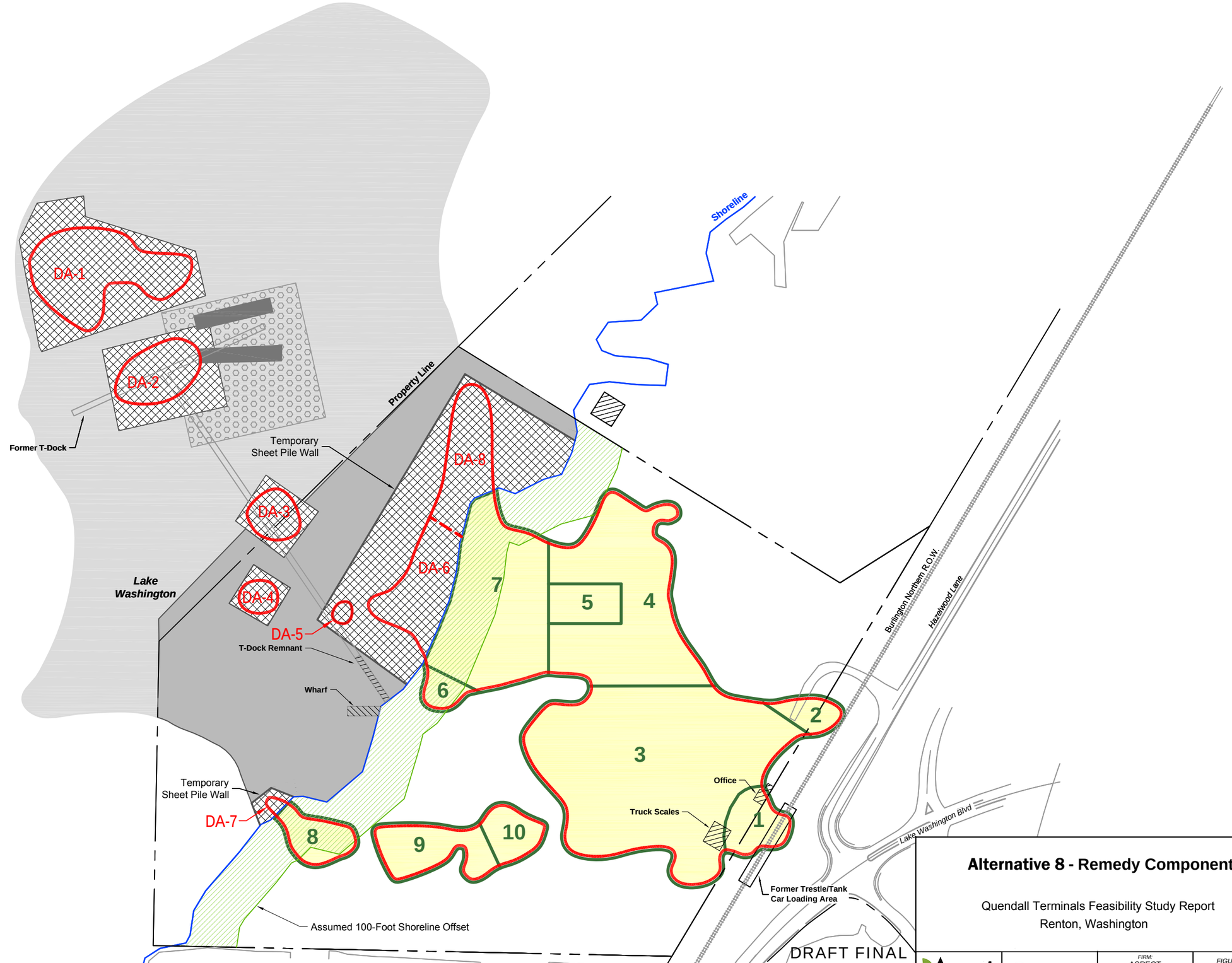
C:\GIS Path: Q:\Quendall\0220027 Quendall Terminals\2013-06 FS Draft Final Executive Summary\ES2\0220027_Plan-Alternatives 2-8.mxd ALT 7 NEW || Date Saved: Oct 11, 2013 3:51pm || User: scudd

Legend

- Existing Structure
- DNR Dry Dock Cap
- DNR Dry Dock Concrete Hulls
- Estimated Extent of DNAPL
- 5 — Soil Excavation Cell
- Habitat Area
- Excavated Soil and Backfill
- Enhanced Natural Recovery
- Engineered Sand Cap (Note 2)
- Dredge Area
- DA-1 — Aquatic DNAPL Area

Notes:

1. This alternative also includes permeable upland cap similar to Alternative 3. Refer to Figure ES-6 for cap extent.
2. This alternative includes sediment removal (not shown on this figure) from the shoreline to approximately 75 feet offshore in areas where engineered sand cap is to be placed, to maintain the existing nearshore area profile. Refer to Section 6.3 of main report.



N

0 200 400

Feet

Alternative 8 - Remedy Components

Quendall Terminals Feasibility Study Report
Renton, Washington

DRAFT FINAL
October 14, 2013

Aspect CONSULTING | ARCADIS

FIRM: ASPECT
DRAWN BY: JJP/ELG/PMB/SCC

FIGURE NO.
ES-11

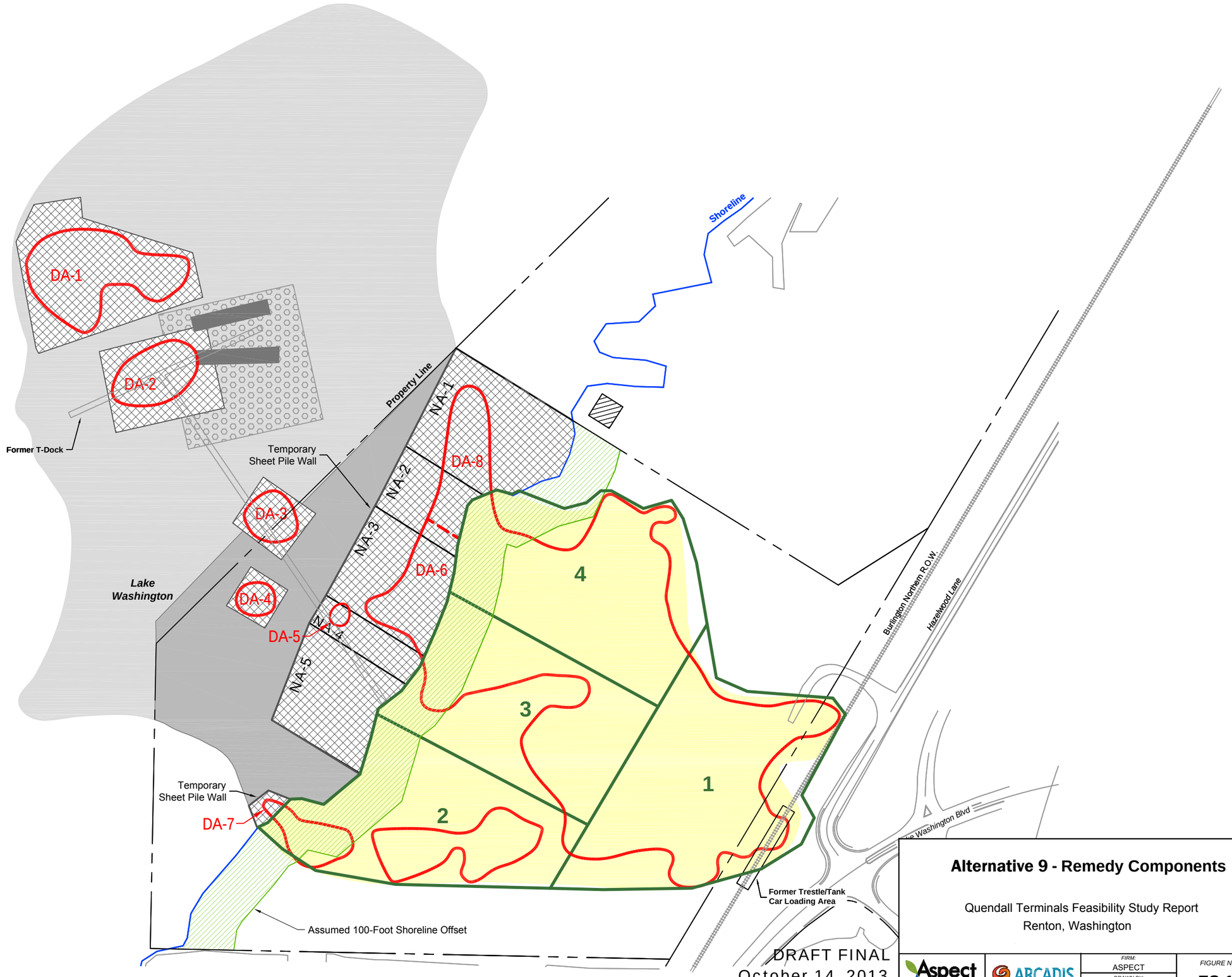
CAD Path: Q:\Quendall\020027 Quendall Terminals\2013-06 FS Draft Final Executive Summary\ES2\020027_Plan-Alternatives 2-8.dwg,ALT 8 NEW || Date Saved: Oct 11, 2013 3:51pm || User: scudd

Legend

- Existing Structure
- DNR Dry Dock Cap
- DNR Dry Dock Concrete Hulls
- Estimated Extent of DNAPL
- 4 — Soil Excavation Cell
- Habitat Area
- Enhanced Natural Recovery
- Engineered Sand Cap (Note 3)
- Dredge Area
- Excavated and Backfilled or Solidified Soil
- NA-1 — Sediment Excavation Cell
- DA-1 — Aquatic DNAPL Area

Notes:

1. Soil removal and sediment dredging areas based on maximum extent of DNAPL and of cPAHs and arsenic exceeding PRGs in groundwater and porewater.
2. This alternative also includes permeable upland cap similar to Alternative 3. Refer to Figure ES-6 for cap extent.
3. This alternative includes sediment removal (not shown on this figure) from the shoreline to approximately 75 feet offshore in area where engineered sand cap is to be placed, to maintain the existing nearshore area profile. Refer to Section 6.3 of main report.



DRAFT FINAL
October 14, 2013

Alternative 9 - Remedy Components

Quendall Terminals Feasibility Study Report
Renton, Washington

FIRM:	FIGURE NO.
ASPECT	ES-12
DRAWN BY: JJP/PMB/SCC	

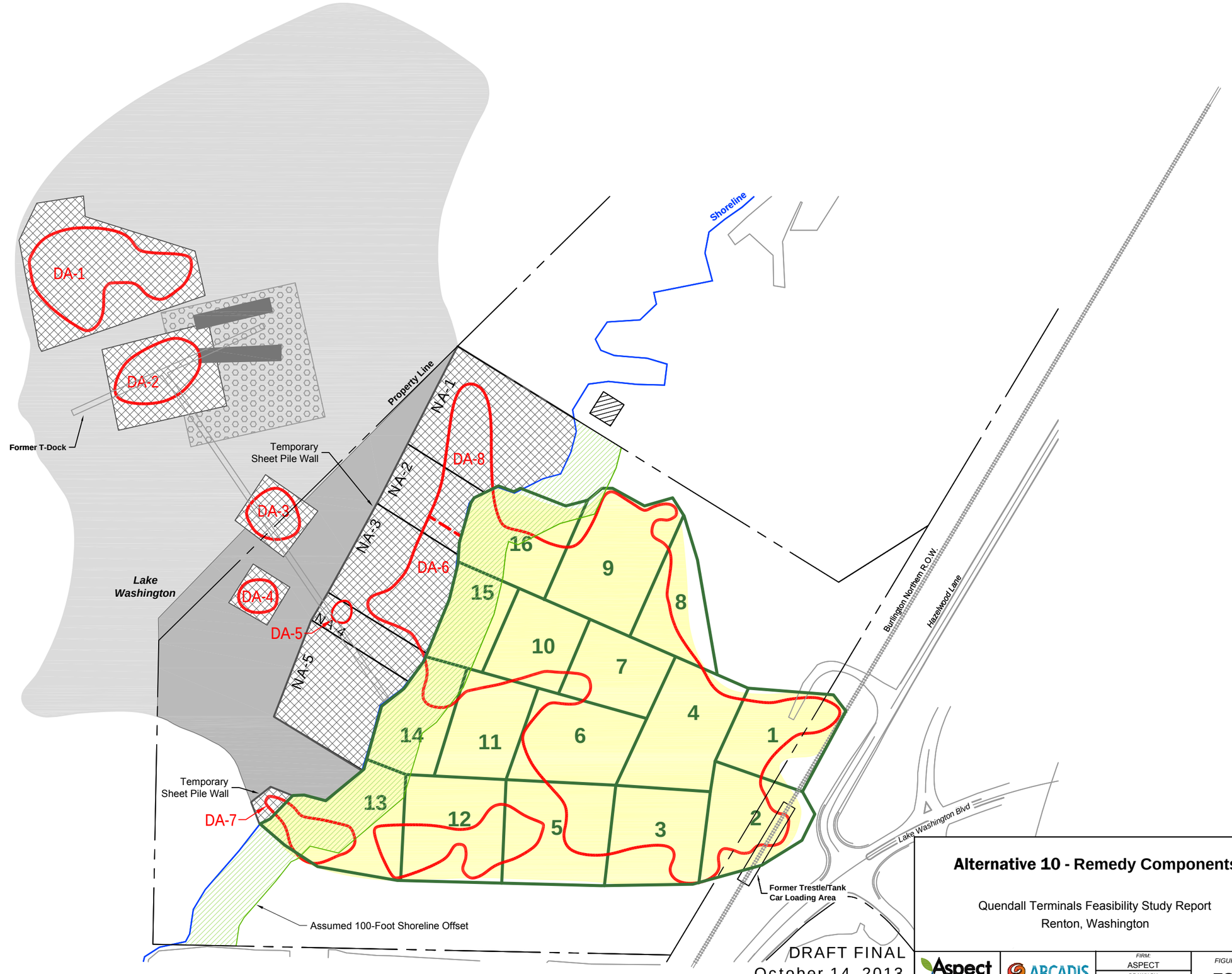
Path: Q:\Quendall\020027 Quendall Terminals\2013-06 FS Draft Final Executive Summary\ES2\020027_Plan-Alternatives 9-10.dwg ALT 9 NEW || Coordinate System: NAD 1983 State Plane Washington North FIPS 4601 Feet || Date Saved: Oct 11, 2013 3:53pm || User: scudd

Legend

- Existing Structure
- DNR Dry Dock Cap
- DNR Dry Dock Concrete Hulls
- Estimated Extent of DNAPL
- 4 — Soil Excavation Cell
- Habitat Area
- Enhanced Natural Recovery
- Engineered Sand Cap (Note 3)
- Dredge Area
- Excavated Soil and Backfill
- NA-1 — Sediment Excavation Cell
- DA-1 — Aquatic DNAPL Area

Notes:

1. Soil removal and sediment dredging areas based on maximum extent of DNAPL and of cPAHs and arsenic exceeding PRGs in groundwater and porewater.
2. This alternative also includes permeable upland cap similar to Alternative 3. Refer to Figure ES-6 for cap extent.
3. This alternative includes sediment removal (not shown on this figure) from the shoreline to approximately 75 feet offshore in area where engineered sand cap is to be placed, to maintain the existing nearshore area profile. Refer to Section 6.3 of main report.



Alternative 10 - Remedy Components

Quendall Terminals Feasibility Study Report
Renton, Washington

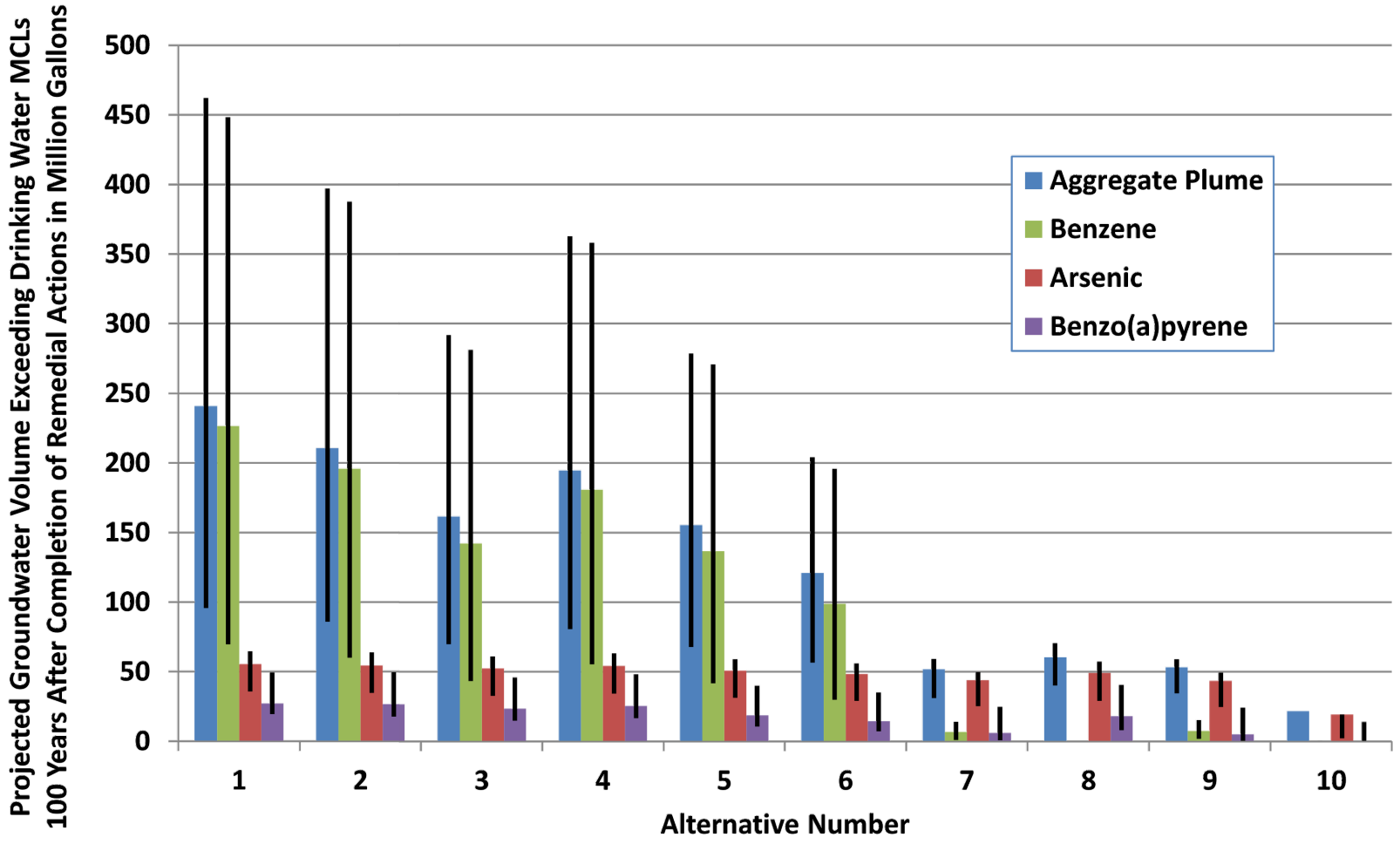
DRAFT FINAL
October 14, 2013

Aspect CONSULTING | ARCADIS

FIRM: ASPECT
DRAWN BY: JJP/PMB/SCC

FIGURE NO.
ES-13

Path: Q:\Quendall\020027 Quendall Terminals\2013-06 FS Draft Final Executive Summary\ES2\020027_Plan-Alternatives 9-10.dwg ALT 10 NEW || Coordinate System: NAD 1983 State Plane Washington North FIPS 4601 Feet || Date Saved: Oct 11, 2013 3:54pm || User: scudd



Note:
Black bars for Alternatives 1, 7, and 8 represent results of a sensivity analysis. Black bars for other alternatives are estimates derived from sensitivity analysis results. See Appendix A for details.

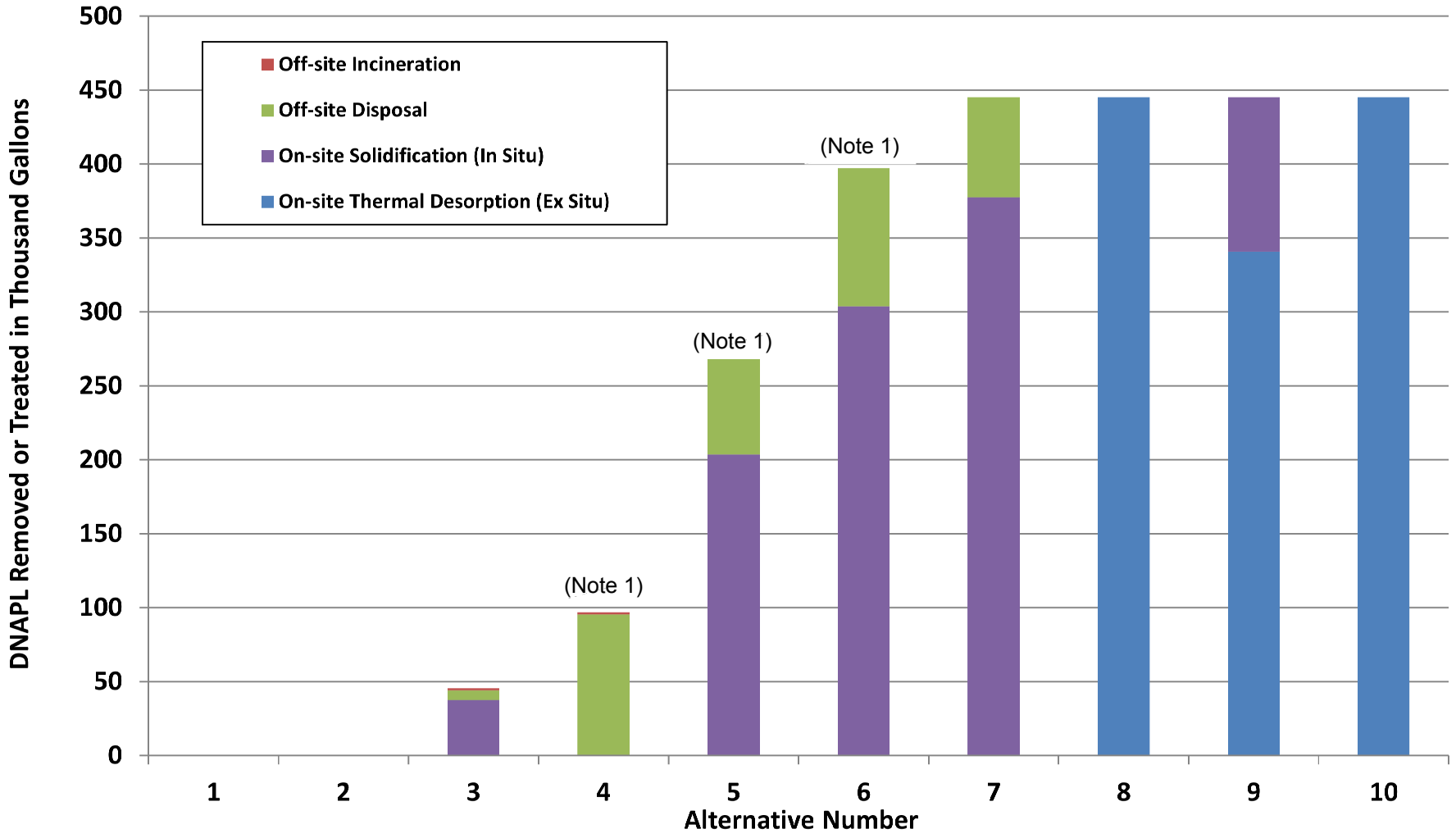
DRAFT FINAL
October 14, 2013

Projected Groundwater Restoration
100 Years After Implementation
of Alternative Remedial Actions

Quendall Terminals Feasibility Study Report
Renton, Washington

Aspect CONSULTING / ARCADIS		FIRM: ASPECT DRAWN BY: JJP/SCC	FIGURE NO. ES-14

CAD Path: Q:\Quendall\020027 Quendall Terminals\2013-06 FS Draft Final Executive Summary\ES2\020027-71.dwg 7-1 || Date Saved: Oct 11, 2013 2:45pm || User: scudd



Note:

1. Partial treatment/removal in this alternative includes treatment/removal of DNAPL with the greatest future exposure risk (i.e., the QP-U, QP-S, and TD DNAPL Areas).

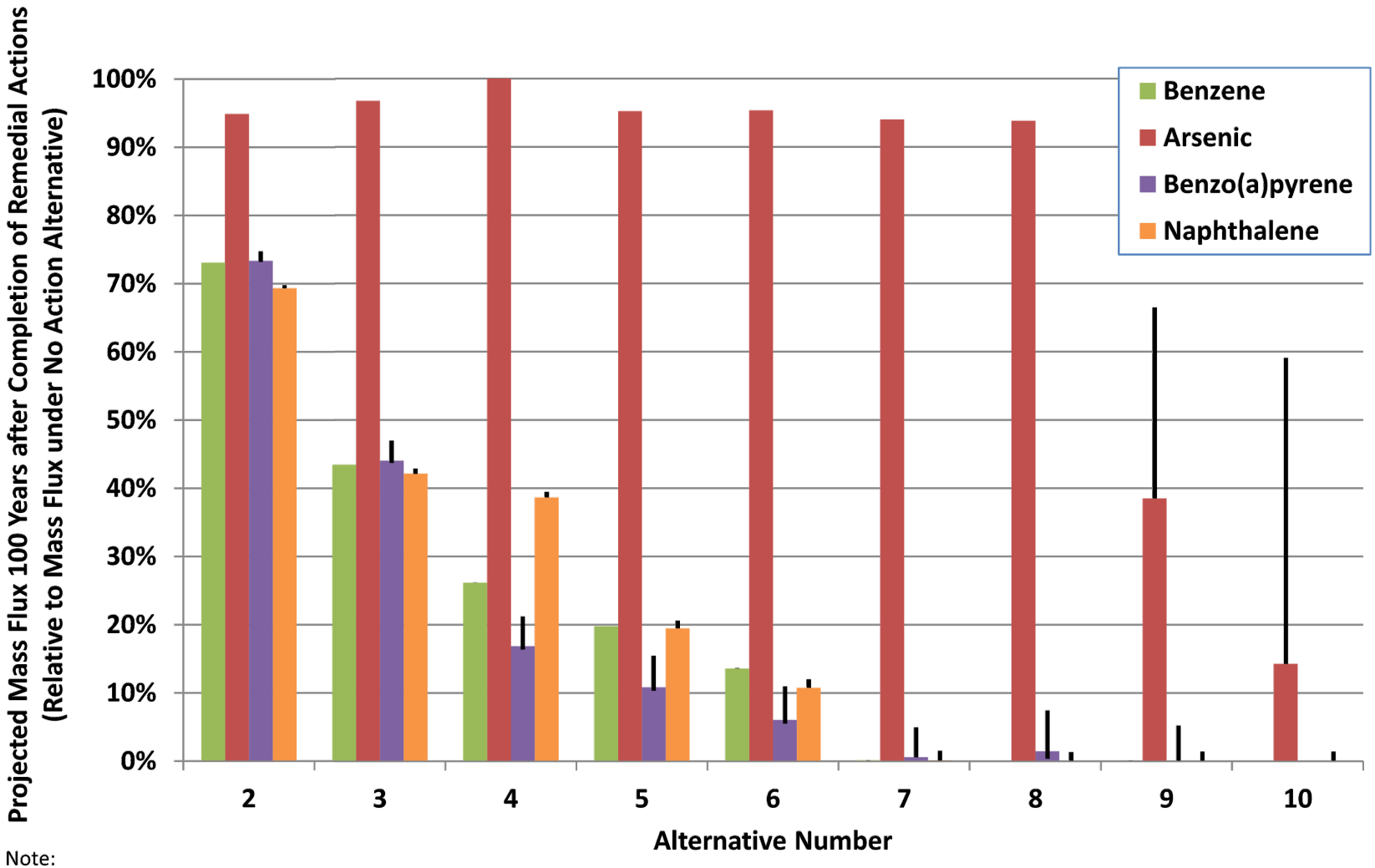
DRAFT FINAL
October 14, 2013

Estimated DNAPL Volumes Removed or Treated Under Alternative Remedial Actions

Quendall Terminals Feasibility Study Report
Renton, Washington

Aspect CONSULTING / ARCADIS	FIRM: ASPECT	DRAWN BY: JJP/SCC	FIGURE NO. ES-15

CAD Path: Q:\Quendall\020027 Quendall Terminals\2013-06 FS Draft Final Executive Summary\ES2\020027-71.dwg 7-2 || Date Saved: Oct 11, 2013 3:01pm || User: scudd



Note:

Mass Flux estimates include only mass contributed from upland contamination. See section A3.6 of Appendix A for details of mass flux calculations. Black bars for alternatives 1, 7, and 8 represent results of a sensivity analysis. Black bars for other alternatives are estimates derived from sensitivity analysis results. See Appendix A for details.

Projected Reduction in Contaminant Mass Flux to Sediments 100 Years After Implementation of Alternative Remedial Actions

Quendall Terminals Feasibility Study Report

Renton, Washington

DRAFT FINAL
October 14, 2013

Aspect CONSULTING / ARCADIS	FIRM: ASPECT	DRAWN BY: JJP/SCC	FIGURE NO. ES-16

CAD Path: Q:\Quendall\020027 Quendall Terminals\2013-06 FS Draft Final Executive Summary\ES2\020027-71.dwg 7-3 || Date Saved: Oct 11, 2013 2:51pm || User: scudd

Contents

List of Acronyms and Abbreviations ix

1 Introduction 1
1.1 Purpose 1
1.2 Report Organization 3

2 Site Description 4

3 Remedial Investigation Results and Conceptual Site Model 6
3.1 Historical Releases and Source Areas 6
3.2 Geology 7
3.3 Hydrogeology 8
3.4 Bathymetry and Sediment Characteristics 10
3.5 Nature and Extent of Contamination 10
3.6 Contaminant Fate and Transport 13
3.6.1 DNAPL Movement and Dissolution 13
3.6.2 Contaminant Transfer from DNAPL to Other Site Media 14
3.7 Baseline Risk Assessment 16
3.8 Overall Conceptual Site Model 19

4 Basis for Remedial Action 21
4.1 Applicable or Relevant and Appropriate Requirements (ARARs) 21
4.1.1 Applicability of ARARs to the Final Remedy 23
4.2 Preliminary Remedial Action Objectives (RAOs) 23
4.2.1 Source Control RAOs 24
4.2.2 Human Health Protection RAOs 24
4.2.3 Environmental Protection RAOs 25
4.3 Preliminary Remediation Goals (PRGs) 25
4.3.1 Preliminary Remediation Goals for Soil 27
4.3.2 Preliminary Remediation Goals for Groundwater 27
4.3.3 Preliminary Remediation Goals for Air and Vapor 27
4.3.4 Preliminary Remediation Goals for Surface Water/ Porewater 27
4.3.5 Preliminary Remediation Goals for Sediment 28
4.4 Site Areas and Media Targeted for Remedial Action 29
4.4.1 PRG Exceedence Areas 30
4.4.2 DNAPL Areas 32

5 Technology Identification and Screening 39
5.1 Identification of Remedial Technologies and Process Options 40
5.1.1 General Response Actions 40
5.1.2 Technologies and Process Options 41

5.2 Initial Screening of Technologies and Process Options 41
5.3 Secondary Screening of Technologies and Process Options 42
5.3.1 Technology and Process Option Screening for DNAPL 43
5.3.2 Technology and Process Option Screening for Soil 47
5.3.3 Technology and Process Option Screening for Groundwater 52
5.3.4 Technology and Process Option Screening for Sediment 57

6 Development of Alternatives 63
6.1 Assembly of Remedial Alternatives 63
6.2 Common Elements 64
6.2.1 Redevelopment of the Quendall Terminals Property 65
6.2.2 Habitat Considerations 65
6.2.3 Potential Generation of Hazardous Waste during Remediation 67
6.2.4 Modeling Tools Used in Alternative Development 68
6.3 Detailed Description of Alternatives 70
6.3.1 Alternative 1 – No Action 71
6.3.2 Alternative 2 – Containment 71
6.3.3 Alternative 3 – Containment with Targeted PTM Solidification (RR and MC DNAPL Areas) 78
6.3.4 Alternative 4 – Containment with Targeted PTM Removal (TD, QP-S, and QP-U DNAPL Areas) 86
6.3.5 Alternative 5 – Containment with Targeted PTM Solidification (RR, MC, and QP-U DNAPL Areas and ≥ 4-Foot-Thickness) and Removal (TD and QP-S DNAPL Areas) 95
6.3.6 Alternative 6 – Containment with Targeted PTM Solidification (RR and MC DNAPL Areas and ≥ 2-Foot-Thickness) and Removal (TD, QP-S, and QP-U DNAPL Areas) 97
6.3.7 Alternative 7 – Containment with PTM Solidification (Upland) and Removal (Sediment) 100
6.3.8 Alternative 8 – Containment with PTM Removal (Upland and Sediment) 102
6.3.9 Alternative 9 – Containment with Solidification and Removal of Contaminated Soil and Removal of Contaminated Sediment 106
6.3.10 Alternative 10 – Containment with Removal of Contaminated Soil and Sediment 111

7 Detailed Analysis of Alternatives 118
7.1 NCP Evaluation Criteria 118
7.1.1 Threshold Criteria 119
7.1.2 Balancing Criteria 120
7.1.3 Modifying Criteria 123
7.2 Detailed Evaluation of Alternative 1 123
7.2.1 Threshold Criteria 123
7.2.2 Balancing Criteria 123
7.3 Detailed Evaluation of Alternative 2 124
7.3.1 Overall Protection of Human Health and the Environment 124
7.3.2 Compliance with ARARs 126
7.3.3 Long-Term Effectiveness and Permanence 127
7.3.4 Reduction of Toxicity, Mobility, or Volume Through Treatment 129

7.3.5 Short-Term Effectiveness 130
7.3.6 Implementability 133
7.3.7 Cost 133
7.4 Detailed Evaluation of Alternative 3 134
7.4.1 Overall Protection of Human Health and the Environment 134
7.4.2 Compliance with ARARs 135
7.4.3 Long-Term Effectiveness and Permanence 135
7.4.4 Reduction of Toxicity, Mobility, or Volume Through Treatment 138
7.4.5 Short-Term Effectiveness 140
7.4.6 Implementability 141
7.4.7 Cost 142
7.5 Detailed Evaluation of Alternative 4 142
7.5.1 Overall Protection of Human Health and the Environment 142
7.5.2 Compliance with ARARs 144
7.5.3 Long-Term Effectiveness and Permanence 144
7.5.4 Reduction of Toxicity, Mobility, or Volume Through Treatment 146
7.5.5 Short-Term Effectiveness 147
7.5.6 Implementability 149
7.5.7 Cost 150
7.6 Detailed Evaluation of Alternative 5 150
7.6.1 Overall Protection of Human Health and the Environment 150
7.6.2 Compliance with ARARs 151
7.6.3 Long-Term Effectiveness and Permanence 152
7.6.4 Reduction of Toxicity, Mobility, or Volume Through Treatment 153
7.6.5 Short-Term Effectiveness 154
7.6.6 Implementability 155
7.6.7 Cost 156
7.7 Detailed Evaluation of Alternative 6 156
7.7.1 Overall Protection of Human Health and the Environment 156
7.7.2 Compliance with ARARs 157
7.7.3 Long-Term Effectiveness and Permanence 157
7.7.4 Reduction of Toxicity, Mobility, or Volume Through Treatment 159
7.7.5 Short-Term Effectiveness 160
7.7.6 Implementability 161
7.7.7 Cost 161
7.8 Detailed Evaluation of Alternative 7 161
7.8.1 Overall Protection of Human Health and the Environment 161
7.8.2 Compliance with ARARs 163
7.8.3 Long-Term Effectiveness and Permanence 164
7.8.4 Reduction of Toxicity, Mobility, or Volume Through Treatment 165
7.8.5 Short-Term Effectiveness 166
7.8.6 Implementability 167
7.8.7 Cost 168
7.9 Detailed Evaluation of Alternative 8 168
7.9.1 Overall Protection of Human Health and the Environment 168
7.9.2 Compliance with ARARs 169
7.9.3 Long-Term Effectiveness and Permanence 170

7.9.4 Reduction of Toxicity, Mobility, or Volume Through Treatment 171
7.9.5 Short-Term Effectiveness 172
7.9.6 Implementability 173
7.9.7 Cost 174
7.10 Detailed Evaluation of Alternative 9 174
7.10.1 Overall Protection of Human Health and the Environment 174
7.10.2 Compliance with ARARs 176
7.10.3 Long-Term Effectiveness and Permanence 177
7.10.4 Reduction of Toxicity, Mobility, or Volume Through Treatment 178
7.10.5 Short-Term Effectiveness 179
7.10.6 Implementability 180
7.10.7 Cost 181
7.11 Detailed Evaluation of Alternative 10 181
7.11.1 Overall Protection of Human Health and the Environment 181
7.11.2 Compliance with ARARs 183
7.11.3 Long-Term Effectiveness and Permanence 183
7.11.4 Reduction of Toxicity, Mobility, or Volume Through Treatment 184
7.11.5 Short-Term Effectiveness 185
7.11.6 Implementability 186
7.11.7 Cost 187

8 Comparative Analysis of Alternatives 188
8.1 Overall Protection of Human Health and the Environment 188
8.2 Compliance with ARARs 189
8.3 Long-Term Effectiveness and Permanence 190
8.3.1 Magnitude of Residual Risk 190
8.3.2 Adequacy and Reliability of Controls 192
8.3.3 Overall Long-Term Effectiveness and Permanence Ranking 193
8.4 Reduction of Toxicity, Mobility, or Volume through Treatment 195
8.5 Short-Term Effectiveness 196
8.6 Implementability 198
8.7 Cost 200
8.8 Comparative Analysis Summary 202

9 References 204

List of Tables

3-1 Chemicals of Concern by Medium

4-1 Chemical-Specific ARARs for Remedial Action at the Quendall Terminals Site

4-2 Action-Specific ARARs for Remedial Action at the Quendall Terminals Site

4-3 Location-Specific ARARs for Remedial Action at the Quendall Terminals Site

4-4 Development of PRGs for Soil

4-5 Development of PRGs for Groundwater

4-6 Development of PRGs for Surface Water/Porewater

4-7 Development of PRGs for Sediment

4-8 Summary of PRGs

5-1 Initial Screening of DNAPL Technologies and Process Options

5-2 Initial Screening of Soil Technologies and Process Options

5-3 Initial Screening of Groundwater Technologies and Process Options

5-4 Initial Screening of Sediment Technologies and Process Options

5-5 DNAPL Process Options Evaluation

5-6 Soil Process Options Evaluation

5-7 Groundwater Process Options Evaluation

5-8 Sediment Process Options Evaluation

6-1 Assembly of Alternatives - Anticipated Relationship to RAOs

6-2 Assembly of Technologies and Process Options into Remedial Alternatives

6-3 Remedial Alternative Summary

6-4 Summary of Remedial Alternative Construction Quantities

7-1 National Contingency Plan Evaluation Criteria for Detailed Analysis of Remedial Alternatives

7-2 Estimated Volumes of DNAPL Treated or Removed Under Alternative Remedial Actions

7-3 Remedial Alternative Institutional Control and Long-Term Monitoring Summary

8-1 Summary Evaluation of Remedial Alternatives

8-2 Comparative Rating of Remedial Alternatives

List of Figures

1-1 Quendall Terminals Site Location and Vicinity Map

2-1 Summary of Current Site Features

3-1 Exploration and Cross Section Location Map

3-2 Summary of Historical Site Features

3-3 Timeline of Site Operations

3-4 Geologic Cross Section A-A'

3-5 Site Plan Showing DNAPL Occurrences

3-6 Approximate Extents of Benzene, Naphthalene, cPAHs, and Arsenic in the Shallow Aquifer

3-7 Approximate Extents of Benzene, Naphthalene, and Arsenic in the Deep Aquifer

3-8 Extent of Groundwater and Porewater Exceeding PRGs along Cross Section D-D'

3-9 Surface Sediment Porewater Naphthalene Concentrations

3-10 Subsurface Sediment Porewater Naphthalene Concentrations

3-11 Surface Bulk Sediment Organic Carbon Normalized cPAH (Benzo(a)pyrene Equivalent) Concentrations

3-12 Graphic Illustration of the DNAPL Conceptual Site Model

3-13 Graphic Illustration of the Contaminant Fate and Transport Conceptual Site Model

3-14 Average Nearshore Surface Water and Sediment Porewater Concentration Profiles of Key Fate and Transport Constituents

3-15 Graphic Illustration of Human Exposure Conceptual Site Model

4-1 Areas Targeted for Remedial Action

4-2 Estimated Extent of DNAPL along Cross Section A-A'

4-3 Estimated Extent of DNAPL along Cross Section B-B'

4-4 Estimated Extent of DNAPL along Cross Section C-C'

4-5 Estimated Extent of DNAPL along Cross Section D-D’

4-6 Cumulative Thickness of DNAPL in Thiessen Polygon Areas

6-1 Alternative 2 – Remedy Components

6-2 Alternative 2 – Upland Remedy Components along Cross Section D-D’

6-3 Alternative 2 – Offshore Remedy Components along Cross Section E-E’

6-4 Alternative 3 – Remedy Components

6-5 Alternative 3 – Upland Remedy Components along Cross Section D-D'

6-6 Alternative 3 – Offshore Remedy Components along Cross Section E-E'

6-7 Alternative 4 – Remedy Components

6-8 Alternative 4 – Upland Remedy Components along Cross Section D-D’

6-9 Alternatives 4, 5, and 6 – Offshore Remedy Components along Cross Section E-E'

6-9 Alternative 5 – Remedy Components

6-10 Alternative 5 – Remedy Components

6-11 Alternative 5 – Upland Remedy Components along Cross Section B-B’

6-12 Alternative 6 – Remedy Components

6-13 Alternative 6 – Upland Remedy Components along Cross Section D-D’

6-14 Alternative 7 – Remedy Components

6-15 Alternative 7 – Upland Remedy Components along Cross Section D-D’

6-16 Alternatives 7 and 8 – Offshore Remedy Components along Cross Section E-E'

6-17 Alternative 8 – Remedy Components

6-18 Alternative 8 – Upland Remedy Components along Cross Section D-D’

6-19 Alternative 9 – Remedy Components

6-20 Alternative 9 – Upland Remedy Components along Cross Section D-D'

6-21 Alternative 9 and 10 – Offshore Remedy Components along Cross Section E-E’

6-22 Alternative 10 – Remedy Components

6-23 Alternative 10 – Upland Remedy Components along Cross Section D-D'

7-1 Projected Groundwater Restoration 100 Years After Implementation of Alternative Remedial Actions

7-2 Estimated DNAPL Volumes Removed or Treated Under Alternative Remedial Actions

7-3 Projected Reduction in Contaminant Mass Flux to Sediments 100 Years After Implementation of Alternative Remedial Actions

7-4 Potential Short-Term Impacts of Sediment Capping and Dredging

7-5 Summary of Estimated Remedy Design and Construction Durations

Appendices

A Groundwater Modeling

B Engineering Evaluations in Support of Sediment Remedial Alternatives

C Remedial Technology Screening

D Remedial Alternative Cost Estimates

E Engineering Calculations Supporting Remedial Alternatives Development and Costing

F Construction Shoring Design Considerations

List of Acronyms and Abbreviations

Anchor QEA	Anchor QEA, LLC
AOC	Administrative Settlement Agreement and Order on Consent
ARAR	applicable or relevant and appropriate requirement
Aspect	Aspect Consulting, LLC
ATSDR	Agency for Toxic Substances and Disease Registry
bgs	below ground surface
BMP	best management practice
bss	below sediment surface
BTEX	benzene, toluene, ethylbenzene, and xylene(s)
BTV	background threshold value
CAD	contained aquatic disposal
CDF	confined disposal facility
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
cm/s	centimeters per second
COC	chemical of concern
cPAHs	carcinogenic polycyclic aromatic hydrocarbons
CSM	conceptual site model
CWA	Clean Water Act
cy	cubic yards
DNAPL	dense non-aqueous phase liquid
DNR	Washington State Department of Natural Resources
DRET	dredge elutriate testing
Ecology	Washington State Department of Ecology

ECRT	ElectroChemical Remediation Technology
ELCR	excess lifetime cancer risk
ENR	enhanced natural recovery
EP	environmental protection
EPA	United States Environmental Protection Agency
ERA	ecological risk assessment
ERH	electrical resistance heating
ESA	Endangered Species Act
ESB	equilibrium-partitioning sediment benchmark
ESBQ	equilibrium-partitioning sediment benchmark quotient
FS	Feasibility Study
ft/day	feet per day
ft/ft	feet per foot
GAC	granular activated carbon
gpm	gallons per minute
GRA	general response action
HAET	highest apparent effects threshold
HDPE	high-density polyethylene
HH	human health
HHERA	human health and ecological risk assessment
HHRA	human health risk assessment
HI	hazard index
HPAH	high-molecular-weight polycyclic aromatic hydrocarbon
HQ	hazard quotient
HVAC	heating, ventilation, and air conditioning
I-405	Interstate 405
Kd	sorption coefficient
LLC	Limited Liability Company

LNAPL	light non-aqueous phase liquid
LPAH	low-molecular-weight polycyclic aromatic hydrocarbon
MCL	maximum contaminant level
MCLG	maximum contaminant level goal
Metro	Municipality of Metropolitan Seattle
mg/kg	milligram(s) per kilogram
mg/L	milligram(s) per liter
MGP	manufactured gas plant
MNA	monitored natural attenuation
MNR	monitored natural recovery
MTCA	Washington State Model Toxics Control Act
NAPL	non-aqueous phase liquid
NCP	National Contingency Plan
NPL	National Priorities List
NWQC	National Water Quality Criteria
O&M	operation and maintenance
OC	organic carbon
OHWL	ordinary high water line
OM&M	operation, maintenance, and monitoring
OMMP	operations, maintenance and monitoring plan
OSHA	Occupational Safety and Health Act
OSWER	Office of Solid Waste and Emergency Response
PAH	polycyclic aromatic hydrocarbon
PCB	polychlorinated biphenyl
PCP	pentachlorophenol
PQL	practical quantitation limit
PRB	permeable reactive barrier
PRG	preliminary remediation goal
PSE	Puget Sound Energy

PTM	principle threat material
QAC	quaternary ammonium compounds
RAO	remedial action objectives
RBC	risk-based concentrations
RBTC	risk-based threshold concentrations
RCM	reactive core mat
RCRA	Resource Conservation and Recovery Act
Respondents	Altino Properties, Inc., and J.H. Baxter & Company
RI	Remedial Investigation
ROD	Record of decision
RSET	Regional Sediment Evaluation Team
RSL	regional screening level
SC	source control
SDWA	Safe Drinking Water Act
Site	Quendall Terminals Site
SSL	soil screening levels
SVE	soil vapor extraction
SVOC	semivolatile organic compound
SWAC	surface weighted averge concentration
TBC	to be considered
TCH	thermal conduction heating
TCLP	toxicity characteristic leaching procedure
TDI	total dietary intake
TI	technical impracticability
TI guidance	guidance for technical impracticability waivers
TM	technical memorandum
TOC	total organic carbon
TRV	toxicity reference value
TU	toxic unit

U&A	Usual and Accustomed
UCL	upper confidence limit
µg/kg	microgram(s) per kilogram
µg/L	microgram(s) per liter
UIC	underground injection control
UECA	Uniform Environmental Covenants Act
USACE	U.S. Army Corps of Engineers
USCG	U.S. Coast Guard
USFWS	U.S. Fish and Wildlife Service
UT	University of Texas
UTS	Universal Treatment Standard
VOC	volatile organic compound
WAC	Washington Administrative Code
WP	wellpoint

1 Introduction

Under the direction of the United States Environmental Protection Agency (EPA), the Quendall Terminals owners (Altino Properties, Inc. and J.H. Baxter & Company; the Respondents) are conducting a Remedial Investigation (RI) and Feasibility Study (FS) at the Quendall Terminals Site (Site). The Site is located on the southeast shore of Lake Washington, in the northernmost limits of the City of Renton (City) in Washington (Figure 1-1). The RI/FS is being conducted in accordance with the requirements of the Site Administrative Settlement Agreement and Order on Consent (AOC; EPA 2003a), pursuant to the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). The RI Report (Anchor QEA and Aspect 2012) was submitted to EPA on September 25, 2012.

The Site was listed on the National Priorities List (NPL) in 2006. The Site remedial alternatives evaluation and remedy selection process are being conducted pursuant to CERCLA, the National Oil and Hazardous Substances Pollution Contingency Plan (NCP; 40 Code of Federal Regulations [CFR] 300) and relevant EPA guidance.

1.1 Purpose

This FS Report describes the development and evaluation of Site remedial alternatives. EPA, in consultation with the other agencies and with public input, will use the information in the RI and FS Reports to select a remedial action, to be documented in a Record of Decision (ROD), in accordance with the NCP (40 CFR 300). CERCLA remedy selection criteria include:

Threshold Criteria

1. Overall protection of human health and the environment;
2. Compliance with applicable or relevant and appropriate requirements (ARARs);

Balancing Criteria

3. Long-term effectiveness and permanence;
4. Reduction of toxicity, mobility, or volume through treatment;
5. Short-term effectiveness;
6. Implementability;
7. Cost;

Modifying Criteria

8. State acceptance; and
9. Community acceptance.

The goal of the remedy selection process, as stated in 40 CFR 300.430(a)(1)(i) of the NCP, is to select remedies that protect human health and the environment, maintain protection over time, and minimize untreated waste. The NCP describes six expectations that EPA shall generally consider in developing remedial alternatives (see 40 CFR 300.430[a][1][iii][A–F] of the NCP):

1. Use treatment to address the principal threats posed by the site wherever practicable;
2. Use engineering controls, such as containment, for waste that poses a low long-term threat or where treatment is impracticable;
3. Use a combination of methods, as appropriate, to achieve protection of human health and the environment;
4. Use institutional controls, such as restrictions on groundwater use , to supplement engineering controls as appropriate, for short- and long-term management to prevent or limit exposure to hazardous substances, pollutants, or contaminants;
5. Consider using innovative technologies when they offer the potential for comparable or superior treatment performance or implementability, fewer or lesser adverse impacts than other available approaches, or lower costs for similar levels of performance, than demonstrated technologies; and
6. Return usable groundwater to its beneficial uses wherever practicable, within a timeframe that is reasonable given the particular circumstances of the site.

In addition, the statutory requirements for remedial actions that must be addressed in the ROD are as follows (EPA 1988a):

- Protect human health and the environment;
- Attain ARARs or provide appropriate grounds for invoking an ARAR waiver;
- Be cost-effective;
- Use permanent solutions and alternative treatment technologies or resource recovery technologies to the maximum extent practicable; and
- Satisfy the preference for treatment to reduce toxicity, mobility, or volume to the extent practicable.

This FS also incorporates information from the Office of Solid Waste and Emergency Response (OSWER) Directive No. 9355.7-04 (EPA 1995a), which provides information on how to consider current and future land uses during development and selection of remedial alternatives.

The organization and content of this FS adhere to the *Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA, Interim Final* (EPA 1988a) as well as the *Contaminated Sediment Remediation Guidance for Hazardous Waste Sites* (EPA 2005). The FS focuses on key principles in these and other EPA guidance documents. Particularly at complex sites like this one, these principles are intended to guide EPA in selecting a cleanup alternative that is protective as well as cost-effective and consistent with the overall objectives of CERCLA and the NCP.

As described in EPA (EPA 1988a) guidance and in the NCP (40 CFR 300), the FS consists of the development and screening of remedial technologies and detailed analyses of a range of potentially viable alternatives. The following steps were used in developing the Site remedial alternatives:

1. Develop RAOs and PRGs using ARARs and risk-based criteria, and identify Site areas exceeding PRGs;
2. Develop general response actions (GRA);
3. Identify and screen technologies (including innovative technologies);
4. Identify and evaluate technology process options;
5. Assemble retained process options into remedial alternatives; and
6. Evaluate the remedial alternatives in accordance with the NCP (40 CFR 300).

1.2 Report Organization

This report consists of nine sections as follows:

- Section 1 summarizes the purpose of the FS and presents the report organization.
- Section 2 provides a Site description, including a discussion of land use.
- Section 3 summarizes background information from the RI Report including Site description and history, physical properties, geology, and hydrogeology, nature and extent of contamination, fate and transport of contaminants; and human health and ecological risks; and presents the Site conceptual site model (CSM).
- Section 4 presents ARARs, RAOs, and PRGs, and also describes the media targeted for remedial action in each Site area.
- Section 5 reviews GRAs and screens different remedial technologies and process options based on effectiveness, implementability, and cost.
- Section 6 assembles and describes a range of comprehensive remedial alternatives and provides the foundation for the detailed analysis in Section 7.
- Section 7 presents a detailed analysis of individual remedial alternatives following the specific NCP criteria, steps, and guidelines described in EPA guidance (EPA 1988a).
- Section 8 presents a comparative analysis of the range of alternatives following the specific NCP criteria, steps, and guidelines described in EPA guidance (EPA 1988a).
- Section 9 contains the publication details for the references cited throughout the FS text.

The text is supported by tables and figures, which are grouped together and presented at the end of the text. In addition, several appendices provide details supporting various technical analyses and modeling used in this FS.

2 Site Description

A detailed description of the Site, including Site history and current conditions, is provided in the RI Report (Anchor QEA and Aspect 2012). The Site is located on the southeast shore of Lake Washington, in Renton, Washington (Figure 1-1), within a former industrial area that now includes residential and commercial uses. The Site encompasses approximately 51 acres and includes the Quendall Terminals Property located at 4503 Lake Washington Boulevard North, a portion of Lake Washington immediately adjacent to the Quendall Terminals Property, and a portion of the Burlington Northern Railroad right-of-way to the east (referred to as the Railroad Property). The Site is bordered by the Puget Sound Energy (PSE) easement and the Football Northwest Property (the Seattle Seahawks Training Facility) to the north, Lake Washington Boulevard and Ripley Lane North to the east, the Conner Homes residential development (the former Barbee Mill site) to the south, and Lake Washington to the west (Figure 2-1). Access to the Site is from Lake Washington Boulevard. Interstate 405 (I-405) is located approximately 500 feet to the east.

The upland portion of the Site encompasses approximately 22 acres and is relatively flat, with approximately 1,500 feet of Lake Washington shoreline.

Shortly after the lowering of Lake Washington in 1916, the Quendall Terminals Property, including newly exposed portions of the former May Creek delta, was developed as a creosote manufacturing facility by Reilly Tar & Chemical Company. May Creek originally ran through the Site to Lake Washington but was diverted south to the Conner Homes Property prior to 1936. The creosote facility refined and processed coal tar and oil-gas tar residues that were shipped or barged to the facility. The Reilly Tar & Chemical Company sold the property to Quendall Terminals in 1971. Quendall Terminals intermittently used portions of the upland to store diesel fuel and crude/waste oils, while upland and aquatic areas were used for log storage. Fuel and oil storage operations ceased in 1983 when the last storage tanks were demolished. From approximately 1977 to 2009, the Site was primarily used for log sorting and storage.

Aquatic lands that are part of the Site (approximately 29 acres) are either owned privately or owned by the State of Washington.[1] The area of the lake on and adjacent to the Site is considered prime habitat for rearing of juvenile salmonid stocks, including Chinook salmon (Tabor et al. 2006), which are listed as threatened under the Endangered Species Act (ESA). As discussed in the RI Report (Anchor QEA and Aspect 2012), the Site is located within the Usual and Accustomed (U&A) fishing grounds used by the Muckleshoot Tribe. Recreational fishing (catch and release) also occurs offshore from the Quendall Terminals Property.

[1] Aquatic lands on the Site managed by the Washington State Department of Natural Resources (DNR) were historically leased for log rafting and vessel storage, but those leases were terminated in the 1990s.

Previous Site activities, including the operation of log sorting yards, have resulted in the accumulation of wood chips and bark materials in the central and eastern portions of the Site. The exposed Site soil is relatively fine-grained, which slows infiltration during rainy periods causing ponding in many areas.

3 Remedial Investigation Results and Conceptual Site Model

The RI Report (Anchor QEA and Aspect 2012) contains background information and presents the scope and results of the RI field investigation conducted in 2009 under the direction of EPA, as well as numerous Site investigations performed previously under the direction of the Washington State Department of Ecology (Ecology). The collective results of these investigations were used to describe the nature and extent of hazardous substances in the upland soil, sediments (including sediment porewater), surface water, and groundwater. This section summarizes the results of the RI that collectively form the CSM, including a description of historical releases and source areas (Section 3.1), geology, hydrogeology (Sections 3.2 and 3.3, respectively), bathymetry and sediment characteristics (Section 3.4), nature and extent of contamination (Section 3.5), contaminant fate and transport (Section 3.6), and human health and ecologic baseline risk assessment (Section 3.7). Figure 3-1 provides a Site map with exploration locations, as well as the locations of cross sections depicted in this FS.

3.1 Historical Releases and Source Areas

Releases resulted primarily from creosote manufacturing processes and associated activities. Creosote manufacturing is discussed in Section 2.1.2 of the RI Report, with source areas discussed in Sections 2.2 and 4.4 of that report. Creosote manufacturing was conducted at the Site from 1916 through 1969. Coal and oil-gas tar residues (collectively referred to as coal tars) were distilled into three fractions that were shipped off the Site for a variety of uses or transported to the neighboring J.H. Baxter & Co. site for use in its wood treating operations.[2] The light distillate fraction was typically used as a feedstock in chemical manufacturing. The middle distillate fraction was used in the wood-preserving industry. The bottom fraction, pitch, was used for applications such as roofing tar (Hart Crowser 1994). Releases of coal tars and distillate products to the environment occurred at Site locations where product transport, production, storage, and/or disposal were performed. Figure 3-2 shows the locations of historical Site features, and Figure 3-3 presents a timeline of Site operations.

As discussed in Section 4.4 of the RI Report, releases of coal tars and distillate products occurred in five general Site areas, as follows:

- Offshore, along the former T-Dock, coal-tar feedstock was offloaded and transferred to Site uplands through a pipeline located on the deck of the dock. A large spill (reportedly 30,000 to 40,000 gallons of coal-tar feedstock) occurred sometime between 1930 and 1940 at the western end of the T-Dock during vessel offloading. Elevated concentrations of polycyclic aromatic hydrocarbons (PAHs)

[2] This pipeline, shown on Figure 3-2, transported creosote. Although the specific years of pipeline use are not known, the J. H. Baxter & Co. site was operated as a wood treatment plant from 1955 until 1982 (Retec 2001).

in surface sediments along the main stem of the T-Dock (see Section 3.5) indicate there also may have been spills from leaks in the piping.

- Around the former Still House, coal tar was distilled, and creosote and light distillates were transferred to surrounding tanks via piping. A pipeline was present between the tanks west of the former Still House and the property to the north of the Site (formerly occupied by J.H. Baxter & Company, which operated a wood treatment plant at that location from 1955 until 1982). This pipeline was used to transport creosote for use in the wood treatment process. Reported releases include product releases directly onto the earthen floor of the Still House (CH2M Hill 1983 and Ecology 1989).
- The former Railroad Tank Car Loading Area at the railroad tracks east of the Still House was situated on a trestle built over May Creek and is a location of apparent historical spills. A solid material loading platform was located further north along the tracks.
- The former May Creek Channel, located south of the manufacturing plant and storage tanks, received wastes from historical operations. Wastes from nearby tanks were reportedly placed in the eastern portion of the former channel, and the western portion of the channel reportedly received creosote wastes discharged from the former Still House sewer outfall.
- The North and South Sumps received effluent from the former Still House cooling lines, and this effluent sometimes contained creosote and tars. Tank bottoms from nearby storage tanks were also reportedly placed west of the North Sump, where Quendall Pond is now located. Shortly after the plant was shut down, approximately 50 truckloads of material were excavated from the North Sump and disposed of at the Coal Creek Landfill. The South Sump was reportedly filled in before 1950 (Hart Crowser 1994). There were no reports that any materials were removed from the South Sump before it was filled in.

Some solid wastes produced in the manufacturing process were also disposed of at the Site. Heavy tar produced by the distillation process was cooled and solidified in pitch bays located north of the Still House. The waste pitch, also called Saturday Coke, was chiseled out and reportedly placed near the Site shoreline (CH2M Hill 1983). Solid tar products have also been observed in shallow soils around the northern railroad loading area, where solid products were loaded onto railcars.

3.2 Geology

Site geology is discussed in Section 3.1.4 of the RI Report. The Site is located within the Puget Sound Lowland, a physiographic feature dominated by repeated advances and recessions of glacial ice. Much of what is now the upland portion of the Site was formed by the lowering of Lake Washington in 1916, which exposed the alluvial delta of May Creek. Site topography has been modified over the past 90 years by filling and grading activities. Site geologic units are illustrated in cross sections on Figure 3-4. Geologic units include the following:

- **Fill.** Present at the ground surface and ranges from 1 foot to more than 10 feet thick. The Fill is a mixture of silt, sand, and gravel as well as wood debris, glass,

brick, and pitch-like materials. Wood chips and bark from former log sorting operations are common in the upper few feet.

- **Shallow Alluvium.** Extends from the base of the Fill to depths of between 30 and 50 feet below ground surface (bgs). The Shallow Alluvium was deposited as a series of gently dipping foreset beds consisting of very soft peat and organic silts interbedded with very loose, silty, fine to medium sand. As a result of their depositional history, including repeated slumping, the discontinuous layers generally slope downward toward the west and northwest.
- **Deeper Alluvium.** Extends from the base of the Shallow Alluvium to depths of between 90 and 140 feet bgs. The Deeper Alluvium generally consists of more homogeneous, coarser materials including medium-dense to dense sand and gravel. Near the top of the Deeper Alluvium, lower-permeability interbedded silt to silty sand layers are also present; these layers are most likely a transitional zone representing the continuation of the May Creek delta. Silty sand layers have been observed as deep as 83 feet, bgs at boring SWB-8.
- **Lacustrine Clay.** Beneath the Deeper Alluvium, a layer of lacustrine clay at least 10 feet thick has been encountered at depths below 90 feet bgs.

The majority of hydrocarbon contamination at the Site, including dense non-aqueous phase liquids (DNAPL), is present within the Shallow Alluvium. Evidence from field observations suggests that interbedded, low-permeability layers in the Shallow Alluvium (and, to a lesser extent, in the top portion of the Deeper Alluvium) create stratigraphic "traps" that can stop, slow, or alter migration of DNAPL. These subsurface Site conditions are critical in developing and evaluating remedial alternatives because the widespread presence of thin, discontinuous DNAPL layers separated by low-permeability materials within a heterogeneous soil matrix significantly reduces the effectiveness of many remedial technologies.

3.3 Hydrogeology

Site hydrogeology is discussed in Section 3.1.5 of the RI Report. Hydrogeologic units affected by contamination at the Site include the following:

- **Shallow Aquifer.** Occurs in the Fill and in the Shallow Alluvium to depths of approximately 30 to 50 feet bgs, with the water table typically encountered at depths of 6 to 8 feet bgs. Hydraulic conductivity estimates in the Shallow Aquifer indicate at least a two-order-of-magnitude range from 1×10^{-2} to 1×10^{-4} centimeters per second (cm/sec), with interbedded lower permeability silt and peat layers and high heterogeneity (Anchor QEA and Aspect 2012).
- **Deep Aquifer.** Occurs in the Deeper Alluvium to a depth of approximately 140 feet bgs. Hydraulic conductivity estimates for the Deep Aquifer average approximately 2×10^{-2} cm/sec (Anchor QEA and Aspect 2012).

The presence of flowing conditions in the former plant water supply well indicates a confined aquifer below the Deep Aquifer, separated by a layer of lacustrine silt/clay (termed the Artesian Aquifer). According to a former plant manager, this well is 180 feet deep (Hart Crowser 1994).

The groundwater flow system includes recharge in the upland areas east of the Site and the May Creek drainage south/southeast of the Site, with flow toward the west and discharge to Lake Washington. Site groundwater originates from precipitation on and east of the Site and recharge from alluvial deposits in the May Creek drainage immediately south of the Site. The months of July through September constitute the low-precipitation period when groundwater recharge is generally at its lowest. Conversely, the months of November through February are the rainy period when groundwater recharge is at its highest. The elevation of Lake Washington is controlled by the U.S. Army Corps of Engineers (USACE) and typically fluctuates up to 2 feet during the year. The lake level is typically lowest in the late fall and early winter, and highest during the late spring and summer.

Site groundwater generally flows horizontally across the Site in an east to west direction, ultimately discharging to Lake Washington. In the Shallow Aquifer, an average horizontal hydraulic gradient of 0.004 feet per foot (ft/ft) was measured from BH-22 to BH-24 in September 2009, when Lake Washington was near its maximum water level and groundwater elevations were in decline. In contrast, the average horizontal hydraulic gradient (measured in the same two wells) in the wetter month of November 2008 was 0.005 ft/ft. The higher hydraulic gradients occur between October and January when Lake Washington water levels are at their minimum and Site groundwater levels are rising as a result of higher precipitation recharge to the shallow groundwater system. Water level data indicate that the Deep Aquifer is similarly affected by lake levels and recharge with the maximum, wet-season gradient near the shoreline being more than double the minimum, dry-season gradient. Recent measurements indicate a seasonal horizontal gradient within the Deep Aquifer ranging from 0.002 ft/ft (September) to 0.04 ft/ft (December). Based on the observed hydraulic gradient, the estimated time for groundwater to travel through the Deep Aquifer from the eastern Quendall Terminals Property boundary (near the location of BH-30C at 33 feet bgs) to Lake Washington is approximately 5 years.

The Deep Aquifer is a semi-confined aquifer, and vertical hydraulic interaction between the Shallow and Deep Aquifers is limited by the horizontal stratification of the Shallow Alluvium and varies depending on location on the Site. Shallow groundwater in the eastern portion of the Site near the Railroad Property typically flows downward through the Shallow Aquifer into the upper portion of the Deep Aquifer (vertical gradients from -0.01 to -0.12 ft/ft). Within the central areas of the Site, groundwater flow is primarily horizontal, and vertical exchange between the Shallow Aquifer and Deep Aquifer is limited. Near the shoreline of Lake Washington, groundwater in the Deep Aquifer has an upward flow component (vertical gradients from 0.01 to 0.05 ft/ft) and travels through the Shallow Aquifer before discharging to surface water. The highest upward gradients in nearshore wells are typically observed in the fall, when recharge is low and the lake level is dropping.

Information on Site geology and hydrogeology was used as the basis for developing a three-dimensional numerical groundwater flow and contaminant fate and transport model. The groundwater model was developed to support the RI and to evaluate remedial alternatives in this FS. Documentation of the construction and calibration of the groundwater model is presented in Appendix D of the RI Report (Anchor QEA and Aspect 2012) and in Appendix A of this FS.

3.4 Bathymetry and Sediment Characteristics

From the shoreline, the lake bottom slopes gradually to the inner harbor line. At the sand spit, the elevation drop is generally 1:20 (i.e., 1 ft elevation drop over 20 ft run). At the former T-Dock, the bathymetry is approximately 1.5:20 (i.e., 1.5 ft elevation drop over 20 ft run).

Between the Site inner and outer harbor lines, the lake bottom is relatively flat and generally contains a slope of 0.5:20 (i.e., 0.5 ft elevation drop over 20 ft run). Water depths at the outer harbor line range from 26 to 31 feet (as measured at the normal high water line). The maximum water depth between the Site and Mercer Island is approximately 70 feet (Retec 1997).

The lake bottom substrate is typically a fine silt/mud, although there are several areas with a sandier bottom, including a sandspit north of the former T-Dock and sediment near the outer harbor line south of the former T-Dock. With the exception of a wood-debris area along the southern shoreline, aquatic vegetation is dominated by dense areas of Eurasian water milfoil.

3.5 Nature and Extent of Contamination

As discussed in the RI Report (Anchor QEA and Aspect 2012), the nature and extent of Site contamination have been characterized by extensive soil, groundwater, and sediment sampling and testing for a range of physical, chemical, and biological parameters. Table 3.1 provides a list of chemicals of concern (COCs) by medium[3]. The greatest COC concentrations in Site media are associated with occurrences of creosote and coal-tar DNAPL, which have been observed in six general Site areas, including both upland and offshore areas. Each of these six areas is correlated with historical releases of creosote and coal-tar products:

- In soils surrounding the former Railroad Tank Car Loading Areas, to depths of 33 feet bgs;
- In soils beneath the former May Creek Channel, to depths of 32 feet bgs;
- In soils near the former Still House, to depths of 16 feet bgs;
- In soils beneath the former North Sump and the Quendall Pond area, to depths of 22 feet bgs;
- In sediment within 100 feet offshore of the Quendall Pond area, to depths of 9 feet below the mudline; and
- In shallow near-surface sediments beneath the former T-Dock, at depths of less than 5 feet below the mudline.

DNAPL is present within an estimated 8.0 acres of the Site uplands (of the 22-acre total Site upland area) and 1.7 acres of sediment (i.e., 9.7 acres total; see Table 4.4 of the RI Report (Anchor QEA and Aspect 2012). DNAPL occurs in numerous laterally

[3] Identification of Site COCs is discussed in Section 3.7.

discontinuous thin sand or silty sand layers separated by low-permeability silt or peat. The estimated areal extent of Site DNAPL occurrences is illustrated on Figure 3-5.

Benzene, naphthalene, and carcinogenic polycyclic aromatic hydrocarbons (cPAHs), and arsenic are indicator chemicals at the Site[4]. The highest concentrations of benzene, naphthalene, and cPAHs in Site media are present in and around areas where DNAPL has been observed. DNAPL composition varies within different Site areas; for instance, DNAPL in the former May Creek Channel contains very low concentrations of benzene and is generally consistent with creosote[5], while DNAPL in the area around Quendall Pond contains much higher concentrations of benzene, which is consistent with a coal-tar source[6]. Elevated concentrations of arsenic have also been detected in groundwater in the vicinity of DNAPL occurrences; these detections are attributable to liberation of naturally occurring arsenic in soil under the highly reducing groundwater conditions encountered in these areas[7]. In addition, sodium arsenate was used for weed control over the entire upland Site for many years (CH2M Hill 1983, Hart Crowser 1994).

In groundwater and soil, the highest COC concentrations have been detected in the Shallow Aquifer, and at the top of the Deep Aquifer, within and downgradient of DNAPL. Below the upper portion of the Deep Aquifer, chemical concentrations are much lower. The areal extent of groundwater contamination for indicator chemicals in the Shallow and Deep Aquifers is illustrated on Figures 3-6 and 3-7, respectively. On Figure 3-7, the Deep Aquifer arsenic plume appears as though it may be coming from the Conner Homes property. However, as discussed in Section 5.2.2.1 of the RI Report, a significantly higher arsenic concentration was detected at well BH-21B (104 µg/L) than at BH-26B (31.8 µg/L), although BH-26B is located at the Quendall Terminals Property boundary and approximately upgradient of BH-21B. These exceedances may not be contiguous with the arsenic plumes in shallow groundwater on either the Quendall Terminals or Conner Homes properties, and may be caused by localized reducing conditions associated with peat deposits in the vicinity of both wells.

The estimated extent of groundwater contamination for indicator chemicals along a representative cross section (parallel to groundwater flow in the center of the Site) is presented on Figure 3-8. The vertical extent of these chemicals is generally delineated by groundwater data from deep monitoring wells. One exception is naphthalene, which exceeds the conservative drinking water-based PRG of 1.4 micrograms per liter (µg/L; refer to Section 4.3.2 and Table 4-5) in the deepest groundwater sample collected from well BH-30C (screened from 85 to 95 feet bgs[8]). However, elevated naphthalene

[4] Indicator chemicals are a subset of Site COCs used to characterize the nature and extent of Site contamination. Refer to Section 5.1 of the RI Report (Anchor QEA and Aspect 2012) for more information.

[5] Refer to Section 4.4.1.2 of the RI Report.

[6] Refer to Section 4.4.4.2 of the RI Report.

[7] Reducing groundwater conditions are created from microbial activity that consumes oxygen and other electron acceptors. Microbial activity is fueled from organic carbon, which at the Site is a combination of naturally occurring peat deposits and constituents of creosote and coal tar.

[8] PRGs were identified in the RI Report (Anchor QEA and Aspect 2012) based on federal or state applicable or relevant and appropriate requirements (ARARs) and risk-based criteria.

concentrations do not extend into the underlying low-permeability lacustrine silt/clay unit.

The vertical extent of cPAH concentrations (TEQ basis)[9] in groundwater was characterized using a combination of analytical data and groundwater fate and transport model simulations of contaminant transport from an historical DNAPL source (assumed to have been released 100 years ago when the creosote plant was constructed). The model-predicted extent of benzo(a)pyrene exceeding the drinking water maximum contaminant level (MCL) of 0.2 µg/L is provided in Appendix A. Based on the resolution of the model cell grid representing the Deeper Alluvium, the groundwater model simulations are rough approximations[10]. However, four soil samples containing elevated benzo(a)pyrene concentrations were detected below the deepest DNAPL occurrences at the following locations: 1.72 mg/kg at Q1-D, 1 foot below DNAPL; 0.46 mg/kg at Q2-C, 7 feet below DNAPL; 1.75 mg/kg at HC-4, 5 feet below DNAPL; and 1.51 mg/kg at HC-2, 3 feet below DNAPL. Soils at these locations are potential sources of cPAHs to groundwater.

The vertical extent of cPAHs in groundwater between well BH-20B (where it exceeded the MCL) and well BH-20C (where it did not exceed the MCL) was estimated using groundwater data collected at discrete intervals during drilling of well BH-20C (Anchor QEA and Aspect 2012). These data also revealed that groundwater arsenic concentrations exceeding the drinking water MCL of 10 µg/L are limited to depths shallower than approximately 60 feet bgs.

In sediment and sediment porewater, the highest chemical concentrations have also been detected within and downgradient of DNAPL. Sediment and sediment porewater near the shoreline are downgradient of contaminated groundwater that flows through upland DNAPL areas prior to discharging to Lake Washington. Surface sediment in areas to the north, south, and west of the T-Dock has been contaminated from historical T-Dock spills and pipeline leaks. The approximate extent of contamination in the nearshore groundwater discharge area is represented by naphthalene exceeding the conservative EPA Region 3 screening level of 1.1 µg/L (Canadian Council of Ministers of the Environment 1999) in surface and subsurface sediment porewater (Figures 3-9 and 3-10, respectively). The approximate extent of surface sediment contamination beyond the nearshore groundwater discharge area that is attributable to historical spills along the T-Dock is represented by the area exceeding the background cPAH concentrations. Two sediment background cPAH values were developed during the RI (Anchor QEA and Aspect 2012; Appendix H): 1) the Site-specific background of 6.2 milligrams per

[9] The TEQ basis refers to total cPAH concentrations expressed as benzo(a)pyrene toxicity equivalency quotients, also known as "benzo(a)pyrene equivalents." These are calculated by multiplying concentrations of the seven cPAHs by toxicity equivalency factors (TEFs) per 2009 California EPA guidance (CAEPA 2009) and summing the results. Unless otherwise noted, all references to cPAH concentrations in this document are on a TEQ basis.

[10] Model cell volumes are variable based on cell location; see Appendix A for more information.

kilogram normalized to organic carbon (OC) (mg/kg-OC; Figure 3-11)[11], which is the 90 percent upper confidence limit (UCL) of the dataset summarized in Appendix H of the RI; and 2) the replacement threshold (RT) of 27 mg/kg-OC as summarized in Appendix H of the RI. As required by EPA, and as confirmed in Appendix B (B-1), the background threshold value (BTV) of 17.5 mg/kg-OC was used in this FS to conservatively approximate the extent of sediments that may require remediation. As depicted on Figure 3-11, approximately 29.14 acres of sediments at the Site exceed the BTV.

Section 4.4 provides additional descriptions of the estimated extent of contamination in each of the Site areas targeted for remedial action.

3.6 Contaminant Fate and Transport

Contaminant fate and transport are discussed in Section 6 of the RI Report (Anchor QEA and Aspect 2012). Contaminants at the Site can migrate through the subsurface via bulk flow (advection) or chemical gradient (diffusion) processes. Contaminants can also be transferred among air, water, and soil media via various partitioning mechanisms (e.g., volatilization, dissolution, and sorption) during migration, thereby modifying the rate of movement through the subsurface. In addition, contaminant concentrations can be reduced or attenuated by various combinations of chemical (e.g., abiotic transformation), biological (e.g., biodegradation), or physical processes (e.g., dispersion and dilution). These contaminant transport, partitioning, and attenuation processes affect how the nature and extent of contamination may change over time, and provide a basis for assessing the potential effectiveness of technologies and remedial alternatives in this FS.

3.6.1 *DNAPL Movement and Dissolution*

DNAPL is present under an estimated 9.7 acres (19 percent) of the Site. Most DNAPL is located below the water table, in constant contact with groundwater, and thus contaminants are constantly leaching from DNAPL.

DNAPL moves through the soil from its original source areas based on its location-specific mobility. Mobility characteristics vary based on variations in local geology, soil structure, and chemical characteristics. The Shallow Alluvium dips toward the lake and consists of numerous permeable discrete thin sand or silty sand layers separated by low-permeability silt or peat. Because DNAPL is denser than water, it will migrate vertically downward until it becomes trapped by lower-permeability materials or the DNAPL mass is depleted. When it encounters a low-permeability layer, DNAPL may: (1) accumulate on top of the lower-permeability layers or (2) migrate laterally through seams of higher permeability until becoming trapped by other intersecting lower-permeability layers. As DNAPL migrates through soil, it leaves behind a residual coating of product on the soil grains (referred to as “residual DNAPL” or “oil-coated” soil), diminishing the available volume of mobile DNAPL. A CSM for DNAPL migration at the Site is shown on Figure 3-12

[11]OC normalization of surface sediment cPAH concentrations was performed to provide a measure of the potentially bioavailable concentration to evaluate potential human health risks resulting from consumption of aquatic organisms (Anchor QEA and Aspect 2012).

DNAPL mobility in sediment is affected by the same parameters as mobility in soil. However, additional parameters affect the mobility of DNAPL released to surface water (i.e., Lake Washington). The mobility of DNAPL in surface water resulting from spilled or leaked material is a function of the spill event (i.e., location, volume, and rate), the nature of the material, and physical conditions.

3.6.2 *Contaminant Transfer from DNAPL to Other Site Media*

Contaminants in DNAPL migrate via a variety of transport mechanisms into other media at the Site, including soil, groundwater, sediment, and air. Transport of these contaminants depends on their chemical properties including volatility, solubility, and sorption potential, and on their biotic/abiotic decay potential. A graphic illustration of the contaminant fate and transport CSM is provided on Figure 3-13. In the evaluation of Site conditions, three pathways are of particular importance in evaluating potential contaminant exposures under current and future conditions:

- The DNAPL/soil/groundwater to air pathway;
- The DNAPL/soil to groundwater to sediment/porewater pathway; and
- The groundwater to surface water pathway.

In the RI Report (Anchor QEA and Aspect 2012), migration of chemicals via these pathways was evaluated using measured Site characterization data and contaminant fate and transport model simulations, including use of numerical and analytical modeling techniques, that incorporate the transport, partitioning, and attenuation/transformation mechanisms. Descriptions of these three pathways are provided below.

3.6.2.1 DNAPL/Soil/Groundwater to Air Pathway

For the DNAPL/soil/groundwater to air pathway (also called the vapor intrusion pathway), contaminants present in the subsurface are transported via soil gas into the above-ground air. Contaminants present in DNAPL and soil in the unsaturated zone, and in groundwater at the top of the water table, volatilize into soil gas according to chemical-specific partitioning relationships. Contaminant migration in soil vapor may be retarded by sorption onto soil, and contaminant concentrations may be reduced by biodegradation. Indoor air modeling conducted in support of the Site RI indicated that exceedances of air PRGs for benzene and naphthalene are possible for future structures if vapor controls are not implemented (Bailey 2008); this was corroborated by the baseline human health risk assessment (HHRA) documented in Section 7.1 of the RI Report.

Based on the widespread occurrence of volatile contaminants in shallow Site soil and groundwater, and the results of the screening-level evaluation summarized above, it is anticipated that the design of future Site redevelopment structures would need to include an evaluation of vapor intrusion and would likely require some form of vapor intrusion mitigation, either passive or active. As discussed in Section 6, further evaluation or control of vapor intrusion has been included as a component of the remedial alternatives evaluated in this FS. The details of the evaluation and/or mitigation would depend on future development details such as the depth and type of fill placed on the Site; building locations and footprints; and building heating, ventilation, and air conditioning (HVAC) designs (e.g., negative or positive pressure systems and air exchange rates). A variety of mitigation techniques such as vapor barriers and sub-slab ventilation systems are

available and are commonly applied at redeveloped sites, usually for a small fraction of the overall building cost (ITRC 2007).

3.6.2.2 DNAPL/Soil to Groundwater to Sediment/Porewater Pathway

In this pathway, contaminants present in Site DNAPL or soil dissolve into groundwater and are transported in groundwater toward Lake Washington, where they are either discharged to the surface water or, prior to discharge, are transformed or sorbed onto sediment.

Because multiple DNAPL sources impact the Shallow Aquifer, dissolved contaminants are present at shallow depths throughout most of the Site. Dissolved contaminants enter the Deep Aquifer groundwater pathway through the Shallow Aquifer in response to downward vertical gradients. Although groundwater flow is predominantly horizontal, dissolved contaminants migrate to significant depths in the Deep Aquifer through dispersion, as indicated by Site characterization data and contaminant fate and transport modeling.

Upward groundwater flow gradients measured beneath Lake Washington and contaminant concentrations in bulk sediment and sediment porewater in the nearshore groundwater discharge area indicate that groundwater discharge is a source of contamination to sediment porewater; however, comparison of measured contaminant concentrations in groundwater and sediment porewater indicate a significant concentration reduction along the flowpath from the upland to the lake, primarily from dispersion, sorption, and degradation in the sediment. Contaminant fate and transport processes in sediment are discussed in Section 3.6.2.3.

The migration of COCs in groundwater to Lake Washington is affected by contaminant-specific mobility and degradation rates. Benzene, naphthalene, and benzo(a)pyrene (representative of the seven cPAHs; refer to Table 4-8) degrade relatively slowly under anaerobic conditions, with degradation half-lives ranging between 2 and 10 years[12]. Migration rates of these indicator chemicals in groundwater[13] were estimated in the RI Report (Anchor QEA and Aspect 2012) as follows[14]:

- Benzene has a relatively high solubility and low sorption potential, making it relatively mobile in groundwater. The groundwater flow model results presented in the RI Report estimate benzene would move across the Site in approximately 7 years.
- Naphthalene has a relatively moderate solubility and low sorption potential, making it less mobile in groundwater. The groundwater flow model results presented in the RI Report estimate naphthalene would move across the Site in approximately 40 years.

[12] Literature values compiled in the RI Report Groundwater Modeling, Appendix D (Anchor QEA and Aspect 2012).

[13] Arsenic mobility is strongly dependent on geochemical conditions and can vary locally across the Site. Because of the complexity and uncertainty in arsenic mobility, a travel time for arsenic was not estimated in the RI Report.

[14] Refer to Section 6.4.2.4 of the RI Report for discussion of these migration rate estimates

- Benzo(a)pyrene has a relatively low solubility and high sorption potential, making it relatively immobile in groundwater. The groundwater flow model results presented in the RI Report estimate benzo(a)pyrene would move across the Site in approximately 54,000 years.

Because of the higher mobility of benzene and naphthalene, these chemicals have migrated deeper (more than 110 feet bgs for naphthalene) and further downgradient (i.e., toward Lake Washington) from DNAPL source areas compared to the less mobile cPAHs.

3.6.2.3 Groundwater to Surface Water Pathway

The upper few feet of sediment represent a transition zone between Site groundwater and the surface water of Lake Washington. Compared with the Site groundwater pathways discussed above, contaminant fate and transport characteristics in this transition zone are more numerous and variable. A combination of focused sampling and analytical modeling proved useful in evaluating the various contaminant fate and transport processes occurring in the transition zone, and was used in this FS to assess the effectiveness of various sediment remediation alternatives including capping.

As discussed above, significant concentration reductions occur along the groundwater flowpath from the upland to the lake. Detailed vertical profiles of potassium and other relatively conservative "tracer" cations were performed in the upper 4 feet of the sediment to characterize the combined effects of advection, diffusion/dispersion, and hyporheic exchange with the overlying surface water within nearshore areas of the Site where contaminated groundwater discharges to surface water (see Appendix B). Modeling these physical processes (incorporating uncertainty ranges) did not, by themselves, explain the measured vertical profiles of volatile organic compounds (i.e., benzene, toluene, ethylbenzene, and xylene; collectively BTEX) and low-molecular weight PAH (LPAH) porewater concentrations measured in the nearshore groundwater discharge area (Figure 3-14). Based on the data and modeling results, bacterially mediated sulfate reduction processes may be occurring at the Site and contributing to the roughly 1,000-fold reduction in BTEX and LPAH concentrations over the last several feet of the transition zone between Site groundwater and the surface water of Lake Washington.

It is important to note that degradation rates and controlling processes along the groundwater to surface water pathway at the Site are applicable to existing conditions. Changes to Site characteristics caused by remedial actions may lead to changes in contaminant fate and transport mechanisms and/or rates. Evaluation of future attenuation characteristics is included in the detailed evaluation of alternatives (Section 7).

3.7 Baseline Risk Assessment

As discussed in Section 7.1.2 of the RI Report (Anchor QEA and Aspect 2012), a baseline human health and ecological risk assessment (HHERA) was conducted in accordance with EPA guidance[15,16]. The baseline human health risk assessment

[15] See *Section 7.1.2. – Human Health Risk Assessment Guidance* of the RI Report (Anchor QEA and Aspect 2012) for a list of EPA Guidance Documents for HHRA.

(HHRA) evaluated the following exposure scenarios, which are graphically illustrated on Figure 3-15:

- **Future Residential Exposure Scenario.** This scenario is based on potential redevelopment of the Site for residential purposes and future Site use by adults and children. The potential routes of exposure to contaminants in soil (to a depth of 15 feet bgs) and groundwater include incidental ingestion, dermal contact, and inhalation of fugitive dusts and vapors. Inhalation of vapors migrating from groundwater into future residential buildings is also possible in the absence of vapor controls.
- **Future Occupational Worker Exposure Scenario.** Adult workers could potentially be exposed to chemicals in soil (from 0 to 15 feet bgs) by incidental ingestion, dermal contact, and inhalation of ambient dust and vapors. Vapor intrusion into future non-residential buildings and exposure to groundwater by occupational workers are also possible; however, these pathways are addressed under the more health-conservative residential exposure scenario.
- **Future Construction/Excavation Worker Exposure Scenario**. Adult construction/excavation workers could potentially be exposed to chemicals in soil (from 0 to 15 feet bgs) by incidental soil ingestion, dermal contact with soil, and inhalation of ambient dusts and vapors generated during excavation activities. Potential routes of exposure to shallow groundwater for the construction/ excavation worker include dermal contact and inhalation of ambient vapors generated during excavation activities.
- **Current and Future Recreational Beach User Exposure Scenario.** The recreational beach user scenario addresses individuals engaged in recreation at the shoreline, gaining access either from the upland or via a boat. Potential routes of exposure to nearshore surface sediment (0 to 4 inches below mudline) and surface water include incidental ingestion and dermal contact.
- **Current and Future Recreational Fishing Exposure Scenario.** The recreational fishing exposure scenario addresses adult recreational anglers gaining Site access by boat or land and harvesting fish or shellfish for personal consumption using hook and line, traps, digging, or other methods. Potential exposure routes include ingestion of contaminants that may bioaccumulate in fish/shellfish tissue, and incidental ingestion of and dermal contact with sediment during angling activities.
- **Current and Future Subsistence Fishing Exposure Scenario.** Lake Washington is a U&A fishing ground for the Muckleshoot Tribe. Potential exposure routes under this scenario include ingestion of contaminants that may bioaccumulate in fish/shellfish tissue and incidental ingestion of and dermal contact with sediment during angling activities.

[16] See *Section 7.2 – Baseline Ecological Risk Assessment* of the RI Report for a list of EPA Guidance Documents for ERA.

EPA default exposure assumptions were used to evaluate these scenarios, including the Tribal subsistence fishing scenario. The HHRA evaluated potential non-cancer and cancer effects to humans. For non-cancer effects, the likelihood that a receptor would develop an adverse effect was estimated by comparing the predicted level of exposure for a particular chemical with the highest level of exposure that is considered protective. The ratio is termed the hazard quotient (HQ). When the HQ for a chemical exceeds 1, there is a concern for potential non-cancer health effects. To assess the potential for non-cancer effects posed by exposure to multiple chemicals, a hazard index (HI) approach was used in accordance with EPA guidance (EPA 1989).

The potential for cancer effects was evaluated by estimating excess lifetime cancer risk (ELCR). This risk is the incremental increase in the probability of developing cancer during one's lifetime in addition to the background probability of developing cancer (i.e., if no exposure to Site chemicals occurs)[17]. In interpreting estimates of ELCR, EPA under the Superfund program generally considers action to be warranted when the multi-chemical aggregate cancer risk for all exposure routes within a specific exposure scenario exceeds 1×10^{-4}. Action generally is not required for risks falling between 1×10^{-6} and 1×10^{-4}; however, this is judged on a case-by-case basis.

The results of the human health risk characterization indicated that the non-cancer hazard index (HI) exceed 1 for each scenario except the recreational beach user and recreational fishing scenarios. HIs exceeding 1 range from 3 (subsistence fish ingestion) to 7,995 (groundwater exposure for the future resident). ELCR estimates exceed 1×10^{-4} for the six scenarios using Site data, ranging from 2×10^{-4} (recreational fish ingestion) to greater than 8×10^{-1} (groundwater exposure for the future resident). The ELCR estimate for the residential indoor air pathway is 2×10^{-2}, with the primary risk contributors being benzene, naphthalene, and ethylbenzene.

Recreational beach user, recreational fishing, and subsistence fishing scenarios were also evaluated using a background sediment dataset. HIs were less than 1 for these three scenarios, and ELCR estimates for recreational and subsistence fish ingestion exceed 1×10^{-6}, but are less than 1×10^{-4}.

As discussed in Section 7.2 of the RI Report (Anchor QEA and Aspect 2012), the baseline Ecological Risk Assessment (ERA) was conducted following standard EPA guidance. For the ERA, the receptors potentially at risk include the animals and plants that use terrestrial and/or aquatic habitats within the Site. These receptors can generally be segregated into plants, invertebrates, reptiles and amphibians, fish and shellfish, and mammals and birds. Representative species from groups including plants, invertebrates, fish, shellfish, birds, and mammals were selected as receptors of concern and further evaluated to determine whether and to what degree they may be at risk from contaminated media at the Site.

[17] For example, an ELCR of 2×10^{-6} means that for every 1 million people exposed to the carcinogen throughout their lifetimes, the average incidence of cancer may increase by two cases of cancer.

Ecological HQs were estimated using multiple lines of evidence including comparison of bulk soil (for soil invertebrates and terrestrial plants) and surface water/porewater concentrations (for fish and aquatic plants) to screening levels and use of a multi-media exposure model approach that compared estimated total dietary intakes (TDIs) with literature toxicity reference values (TRVs). Benthic invertebrate risk was assessed directly via sediment bioassays and using the equilibrium-partitioning sediment benchmark quotient (ESBQ) approach for PAHs (EPA 2003b).

Results of the ERA indicated that risks for both terrestrial and aquatic-dependent wildlife receptors exceed an HQ of 1. The primary risk drivers are PAHs in soil, sediment, and sediment porewater.

Site sediments that pose a PAH-related risk to benthic macroinvertebrates have been delineated in the T-Dock and nearshore Site areas adjacent to Quendall Pond. Benthic toxicity measured in sediment bioassays correlated closely with porewater PAH concentrations, and are corroborated by PAH ESBQs that exceed 1.

When a cumulative ELCR of 1×10^{-4} was exceeded for a given medium, the individual chemicals that pose an ELCR of 1×10^{-6} were identified as human health COCs. Chemicals that exceeded an HQ of 1 for either human or ecological receptors were also identified as COCs. Table 3-1 provides a list of the COCs by medium. The primary human health risk drivers throughout the Site are cPAHs, naphthalene, benzene, and arsenic. The primary ecological receptors risk drivers throughout the Site are PAHs, represented as both individual chemicals and as totals (LPAHs, high-molecular-weight PAH [HPAH], total PAHs, and PAH ESBQs).

3.8 Overall Conceptual Site Model

Based on the collected chemical data, DNAPL originating as creosote and other coal-tar products is the primary source of contamination at the Site. Coal-tar products were released into the subsurface in the historical processing, storage, and offloading areas located in the upland portion of the Site. Releases of coal tar also occurred offshore in Lake Washington along the T-Dock during product offloading operations, directly impacting sediments. Although petroleum hydrocarbons (e.g., fuel oil) and light-end distillates were used or processed at the Site, light non-aqueous phase liquid (LNAPL) was not observed during Site investigations. Refer to Section 4.1.3 of the RI Report (Anchor QEA and Aspect 2012).

Occurrences of DNAPL have been identified in the shallow subsurface in much of the upland area, extending nearshore beneath Lake Washington adjacent to Quendall Pond, and in surface sediment along the location of the former T-Dock. The DNAPL tends to occur within discrete layers or thin lenses in the Shallow Alluvium rather than in continuous ‘pools’ (see Figure 3-15). The movement of DNAPL in the subsurface is influenced by the prevailing east-to-west groundwater flow direction, but the deltaic nature of the Shallow Alluvium (i.e., sloping and interbedded silt, sand, and peat layers) also plays a significant role in how DNAPL migrates in the subsurface. Boring and test pit logs indicate that DNAPL impacts approximately 9.7 acres of the Site and is present as deep as 34 feet bgs, but is most typically observed in the upper 20 feet bgs. Approximately 445,000 gallons of DNAPL are estimated to be present in the subsurface

at the Site (DNAPL volume calculations are provided in Appendix G to the RI Report [Anchor QEA and Aspect 2012]).

Contaminants in DNAPL migrate via a variety of transport mechanisms into other media at the Site, including soil, groundwater, sediment, and air (see Figure 3-13). Coal tar and indicator chemicals (i.e., benzene, naphthalene, and cPAHs) are present above PRGs in groundwater where DNAPL is present, with impacted groundwater generally extending downgradient (both horizontally and vertically) from DNAPL-impacted areas. The migration of dissolved indicator chemicals in groundwater is primarily controlled by the east-to-west groundwater flow direction and contaminant-specific mobility. Benzene and naphthalene are relatively mobile and, based on both empirical data and groundwater modeling, have likely migrated deeper (more than 110 feet bgs, impacting groundwater in the Deeper Alluvium) and further downgradient (i.e., toward Lake Washington) from DNAPL source areas compared to the less mobile cPAHs. Groundwater transport of soluble coal-tar-product constituents from the upland portion of the Site has also contributed contaminants to sediment in nearshore areas. The migration of contaminated groundwater from DNAPL source areas represents a secondary source of contamination to soil and sediment; therefore, the horizontal and vertical extent of contamination in groundwater is an indicator of the extent of impacts to these other media. Arsenic concentrations in groundwater also exceed the PRG in both the Shallow Alluvium and the Deeper Alluvium; this may be a result, at least in part, of the greater mobility of naturally occurring arsenic under reducing conditions, which occur in areas of soils containing naturally high organic carbon (e.g., peat), DNAPL, and dissolved-phase hydrocarbon contamination; refer to Section 5.2.2.1 of the RI Report (Anchor QEA and Aspect 2012).

The baseline HHRA concluded that risks posed to the human receptors evaluated exceed EPA's acceptable levels of 1×10^{-4} for cancer risk and/or an HQ of 1 for non-cancer risk. The exposure scenarios that were evaluated included future residential, worker, recreational beach user, and recreational and subsistence fishing scenarios (see Figure 3-15). The risk drivers are benzene, naphthalene, cPAHs, and arsenic.

The baseline ERA concluded that risks to terrestrial invertebrates, plants, and wildlife (birds and mammals), as well as to benthic invertebrates, aquatic plants, and aquatic-dependent wildlife, exceed an HQ of 1. The risk drivers are PAHs, represented as both individual chemicals and as totals (LPAHs, HPAHs, PAHs, and PAH ESBQs).

4 Basis for Remedial Action

As described in the RI Report (Anchor QEA and Aspect 2012) and summarized in Section 3, the Site has been characterized and is well understood for the purposes of supporting remedial alternative development, evaluation, and selection. Based on the results of the RI, this FS Report evaluates technologies and develops and screens remedial alternatives for the Site. This section presents the ARARs, RAOs, and PRGs that were used in this analysis.

Section 4.1 presents the Site ARARs that are used to evaluate and screen remedial alternatives. Section 4.2 identifies the RAOs, which describe what the proposed remedy is expected to accomplish. Section 4.3 discusses the PRGs, which are the numerical concentrations that are protective of human health and the environment and comply with chemical-specific ARARs. Section 4.4 discusses Site areas and media targeted for remedial action based on the presence of DNAPL and exceedances of the PRGs in Site media. This information is used as a basis for identifying and screening technologies (presented in Section 5) and developing a range of remedial alternatives (presented in Section 6).

4.1 Applicable or Relevant and Appropriate Requirements (ARARs)

One of the two CERCLA threshold criteria requires remedial actions to achieve ARARs, which are defined as any legally applicable or relevant and appropriate standard, requirement, criterion, or limitation that has been promulgated under federal or state law. Although a cleanup action performed under formal CERCLA authorities (e.g., a Consent Decree) would be exempt from the procedural requirements of these laws, the action must nevertheless comply with their substantive requirements. Under CERCLA 121 (e), federal, state, or local permits need not be obtained for remedial actions that are conducted entirely on-site. The NCP defines "on-site" as the "*areal extent of contamination and all suitable areas in very close proximity to the contamination necessary for implementation of the response action*" (40 CFR 300.5). Remedial activities performed off-site would require applicable permits.

According to the NCP (40 CFR 300.5), applicable requirements are those cleanup standards, standards of control, and other substantive requirements, criteria, or limitations promulgated under federal or state law that specifically address a hazardous substance, pollutant, contaminant, remedial action, location, or other circumstance identified at a CERCLA site. A requirement may not be applicable but nevertheless could be relevant and appropriate. Relevant and appropriate requirements address problems or situations sufficiently similar to those encountered at CERCLA sites that their use is well suited to the particular site.

Washington State has promulgated environmental regulations to implement certain federal programs; in cases where the state requirement is more stringent than the federal requirement, the state requirement is the controlling ARAR. In addition, some federal,

state, and local environmental and public health agencies may develop criteria, advisories, guidance documents, and proposed standards that are not legally enforceable but that contain useful information for implementing a cleanup remedy or selecting cleanup levels. These fall into the category of criteria "to be considered" (TBCs); TBCs are not mandatory requirements but may complement the identified ARARs (see EPA 1988c).

In general, there are three categories of ARARs (see EPA 1988c):

- Chemical-specific requirements;
- Action-specific requirements; and
- Location-specific requirements.

Some ARARs fit neatly into a single category, while others may fall into more than one category. Each of these categories is described below:

- Chemical-specific ARARs are laws and requirements that establish health- or risk-based numerical values or methodologies for developing such values (EPA 1988c). These ARARs are used to establish the acceptable concentration of a chemical that may remain in or be discharged to the environment. As such, chemical-specific ARARs are considered in identifying the PRGs. Chemical-specific ARARs are listed in Table 4-1.
- Action-specific ARARs are performance, design, or other requirements that may place controls or restrictions on a particular remedial action (EPA 1988c). Action-specific ARARs are typically technology- or activity-based requirements or limitations on actions, and these requirements may include chemical-specific standards or criteria that must be met as the result of an action. For remedial actions at the Site, these requirements are not necessarily triggered by the presence of specific contaminants in Site media, but rather by the specific actions that occur at the Site. Action-specific ARARs are listed in Table 4-2.
- Location-specific ARARs are requirements that are triggered based on the location of the remedial action to be undertaken (EPA 1988c). Location-specific ARARs may restrict or preclude certain remedial actions or may apply only to certain portions of the Site. Some location-specific ARARs overlap with action-specific ARARs. Location-specific ARARs are listed in Table 4-3.

EPA is currently evaluating the status of the City of Renton Shoreline Master Program (SMP) as an ARAR. The SMP, which has been approved by Ecology, establishes requirements for replacement of wetlands affected by remedial actions, and for buffers and setbacks from shorelines and wetlands. Current SMP requirements are not the same as those in effect when redevelopment project applications were filed with the City. (Washington's vested rights rule governs which SMP requirements apply in a given circumstance.) In addition, SMP requirements (both former and current) are somewhat different from the corresponding Clean Water Act 404(b)(1) requirements. Basic questions to be resolved include:

- Is the SMP an ARAR?
- If the SMP is an ARAR, which SMP requirements apply (vesting issue)?

Irrespective of the resolution of the above unresolved issues, applicable SMP requirements will be met as part of the remedial design. As described in Section 6, all alternatives (with the exception of No Action Alternative) assume a 100-foot habitat zone along the entire Lake Washington shoreline.

4.1.1 *Applicability of ARARs to the Final Remedy*

CERCLA Section 121 requires that the selected alternative must be protective of human health and the environment and meet ARARs, unless an ARAR is waived. The NCP provides that an ARAR may be waived under the circumstances provided in 40 CFR 300.430(f)(1)(ii)(C):

"*An alternative that does not meet an ARAR under federal environmental or state environmental or facility siting laws may be selected under the following circumstances:*

1. *The alternative is an interim measure and will become part of a total remedial action that will attain the applicable or relevant and appropriate federal or state requirement;*
2. *Compliance with the requirement will result in greater risk to human health and the environment than other alternatives;*
3. *Compliance with the requirement is technically impracticable from an engineering perspective;*
4. *The alternative will attain a standard of performance that is equivalent to that required under the otherwise applicable standard, requirement, or limitation through use of another method or approach;*
5. *With respect to a state requirement, the state has not consistently applied, or demonstrated the intention to consistently apply, the promulgated requirement in similar circumstances at other remedial actions within the state; or*
6. *For Fund-financed response actions only, an alternative that attains the ARAR will not provide a balance between the need for protection of human health and the environment at the site and the availability of Fund money to respond to other sites may present a threat to human health and the environment*."

The EPA OSWER Directive 9234.2-25 guidance titled, *Guidance for Evaluating Technical Impracticability of Ground-Water Restoration* (EPA 1993a) and OSWER Directive 9200.4-14 titled, *Consistent Implementation of the FY 1993 Guidance on Technical Impracticability of Ground-Water Restoration at Superfund Sites* (EPA 1995b) provide the primary guidance for technical impracticability (TI) waivers (TI guidance). The TI guidance requires a "TI evaluation", which must include the data and analyses necessary to make a TI determination. The TI guidance further states that the TI evaluation may be performed by the responsible parties at enforcement-led sites but that the TI determination will be made by EPA.

4.2 Preliminary Remedial Action Objectives (RAOs)

As described in the NCP (40 CFR 200) and in EPA's (1988b) *Guidance on Remedial Actions for Contaminated Ground Water at Superfund Site,* RAOs are medium-specific or site-specific goals for protecting human health and the environment. RAOs are

established based on the nature and extent of contamination, the receptors that are currently and potentially threatened, and the potential for human and environmental exposure. PRGs are site-specific, quantitative goals that define the extent of cleanup required to achieve the RAOs (see Section 4.3). RAOs for the Site as defined by EPA (2010) are summarized below.

One of the expectations to be generally considered by EPA is the ability of remedial alternatives to address principal threat materials to the extent practicable (see Section 1.1). Principal threat materials are those source materials considered to be highly toxic or highly mobile that generally cannot be reliably contained or would present a significant risk to human health or the environment should exposure occur (EPA 1991a). For the purposes of this FS, DNAPL, DNAPL-impacted soil, and DNAPL-impacted sediment (i.e., either oil-wetted or oil-coated materials[18]; also referred to as residual DNAPL or 'DNAPL-impacted' soil or sediment in this FS) are considered to be principal threat materials. The RAOs and remedial alternatives assembled in this FS use a wide range of removal, treatment, and containment strategies to address Site media, including principal threat materials. The NCP evaluation presented in Sections 7 and 8 of this FS Report was prepared to assist EPA in determining which remedial alternative, including containment options, can be used to treat principal threat materials to the extent practicable.

4.2.1 *Source Control RAOs*

The RAOs related to source control at the Site are:

- **SC1: Source Material as Principal Threat.** Treat or remove DNAPL in subsurface soils and groundwater to prevent contamination of groundwater above COC MCLs to the extent practicable. (as defined in 40 CFR 300.430(a)(1)(iii)(A-F) of the NCP).
- **SC2: Source Material.** Contain DNAPL in subsurface soils and groundwater where treatment or removal is not practicable (as defined in 40 CFR 300.430(a)(1)(iii)(A-F)of the NCP).
- **SC3: Source Material: Soil.** Reduce migration of COCs to groundwater from soils that exceed remediation goals for the protection of groundwater.
- **SC4: Source Material: Sediment.** Reduce migration of COCs to surface water from sediments that exceed remediation goals for the protection of surface water.

4.2.2 *Human Health Protection RAOs*

The RAOs related to the protection of human health (human health) at the Site are:

- **HH1: Groundwater.** Restore groundwater to its highest beneficial use (drinking water) by meeting COC MCLs in the Site Shallow Alluvium and Deeper Alluvium aquifers within a reasonable period of time.
- **HH2: Sediment.** Reduce to acceptable levels the risk to adults and children who ingest resident fish and shellfish taken from the Site for subsistence.

[18] Refer to Section 4.3.1 of the RI Report (Anchor QEA and Aspect 2012) for description of "oil-wetted' and "oil-coated" materials with regard to DNAPL characterization.

- **HH3: Sediment.** Reduce to acceptable levels the human health risk from playing, wading, or swimming resulting in incidental ingestion or/and dermal exposure to contaminated sediments that exceed remediation goals.
- **HH4: Surface Water.** Reduce to acceptable levels the human health risk from direct contact or incidental ingestion of surface water contaminated with COCs exceeding remediation goals (water quality standards or MCLs).
- **HH5: Vapor.** Reduce to acceptable levels the human health risk from inhalation of vapors from groundwater and/or soils contaminated with COCs exceeding soil or groundwater remediation goals.
- **HH6: Soils (Surface and Subsurface).** Reduce to acceptable levels the human health risk from direct contact or incidental ingestion of COCs in soil exceeding soil remediation goals.

4.2.3 *Environmental Protection RAOs*

The RAOs related to environmental protection at the Site are:

- **EP1: Surface Water.** Reduce to acceptable levels the risk to aquatic-dependent organisms when direct contact with surface water or incidental ingestion of COCs in surface water exceeds remediation goals (water quality standards).
- **EP2: Upland Soil.** Reduce to acceptable levels the risk to terrestrial wildlife when direct contact and incidental ingestion or consumption of soil invertebrates results in exposures to COCs that exceed remediation goals.
- **EP3: Sediment.** Reduce to acceptable levels the risk to aquatic-dependent wildlife (sediment probing birds and piscivorous mammals) where surface sediments containing COCs exceed remediation goals.
- **EP4: Sediment.** Reduce to acceptable levels the risk to benthos where surface sediments containing COCs exceed remediation goals.

4.3 Preliminary Remediation Goals (PRGs)

PRGs for groundwater, soil, air/vapor, surface water/porewater, and sediment were developed for those COCs that drive human health and/or ecological risks ("risk driver COCs") using chemical-specific ARARs, risk-based concentrations (RBCs), regional background data, and other appropriate EPA human health and ecological screening sources (EPA 2004a). For soil, surface water, and sediment, PRGs were developed for both human health and ecological exposure pathways. For groundwater and air/vapor, PRGs were developed for human health exposure only, because ecological exposures are not a risk driver for these pathways.

A detailed PRG evaluation was performed as part of the RI Report (Anchor QEA and Aspect 2012) for the purpose of determining the nature and extent of contamination. In the RI Report, PRG screening levels were identified for risk driver COCs based on the most relevant human health or ecological Site exposure pathway. For example, the development of the PRG screening levels prioritized: 1) MCLs above other ARARs or risk-based criteria; 2) groundwater criteria over surface water criteria for groundwater; and 3) surface water criteria over groundwater criteria for porewater, consistent with the RI Report (Anchor QEA and Aspect 2012).

PRGs have been identified for all risk driver COCs as the most stringent (lowest concentration) value within the following hierarchy, as directed by EPA:

- **Federal and Washington State ARARs.** If one or more chemical-specific ARARs (i.e., promulgated cleanup standards, such as an MCL) are available, the lowest value for a particular chemical and media was identified as the PRG.
- **Risk-Based Concentrations (RBCs).** To-be-considered RBCs were calculated using MTCA equations (Chapter 173-340 WAC) and using externally peer-reviewed EPA screening levels (e.g., regional screening levels [RSLs] and ecological soil screening levels [SSLs]). Potential PRGs based on carcinogenic effects were calculated for elevated cancer risks of 1×10^{-4}, 1×10^{-5}, and 1×10^{-6}. Potential PRGs based on non-carcinogenic effects were calculated for a hazard quotient (HQ) of 1. If a chemical-specific ARAR is not available, for the purposes for this FS, the lowest RBC based on an elevated cancer risk of 1×10^{-5} or HQ of 1 was selected as the PRG.

As discussed above, the results of the baseline ecological risk assessment indicate that risks to terrestrial invertebrates, plants, and wildlife (birds and mammals), as well as to benthic invertebrates, aquatic plants, and aquatic-dependent wildlife, exceed an HQ of 1. The primary contributors to unacceptable risk are PAHs, represented as both individual chemicals and as totals (LPAHs, HPAHs, total PAHs, and PAH ESBQs). While EPA surface water screening levels for ecological protection (Canadian Council of Ministers of the Environment 1999) were used in this FS to delineate sediment areas potentially requiring remediation, the PAH ESBQ dataset presented in the RI (Anchor QEA and Aspect 2012) provides a more scientifically robust means to evaluate ecological risks at the Site. Thus, a PAH ESBQ toxic unit (TU) criterion of 1 (Table 4-6) was used in this FS to determine the protectiveness of alternative sediment cleanup actions (see Section 7.2.1).

If the PRG was less than background, the PRG was adjusted to the background concentration[19]. PRGs for several soil COCs (arsenic, copper, and lead) were adjusted based on regional background concentrations (Ecology 1994). In addition, a Site-specific background value and replacement threshold for total cPAHs was developed for surface sediment in the RI. Risk-based human health sediment screening values for cPAHs in the fish consumption pathway are below Lake Washington background concentrations (Anchor QEA and Aspect 2012, Appendix H).

Potential PRGs, including ARARs, RBCs, and background concentrations, are provided in Tables 4-4 through 4-7 for soil, groundwater, surface water/porewater, and sediment, respectively. The PRGs used in this FS according to the hierarchy described above are summarized in Table 4-8. The assumptions and other considerations used to identify the PRGs for each medium are summarized in Sections 4.3.1 through 4.3.5 below.

[19] PRGs may also be adjusted to practical quantitation limits (PQLs); however, none of the PRGs for Site COCs exceeded PQLs so no adjustments based on PQLs were made.

4.3.1 *Preliminary Remediation Goals for Soil*

Soil PRGs are summarized in Table 4-4. Soil risk driver COCs for human health are the PAHs 2-methylnaphthalene, benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene, chrysene, dibenz(a,h)anthracene, indeno(1,2,3-cd)pyrene, and naphthalene; the volatile organic compound (VOC) ethylbenzene; and arsenic. RBCs used for determining soil PRGs were calculated using the exposure assumptions of the human health risk assessment (HHRA) residential scenario. These inputs and corresponding PRGs are identical to the EPA RSLs.

For ecological receptors, risk driver COCs are chromium, lead, pentachlorophenol, and HPAHs, including the individual PAHs benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene, fluoranthene, dibenz(a,h)anthracene, and indeno(1,2,3-cd)pyrene.

Arsenic RBCs for human health are lower than background; therefore, the soil PRG for arsenic is regional background.

4.3.2 *Preliminary Remediation Goals for Groundwater*

Groundwater PRGs are summarized in Table 4-5. As discussed in the RI Report (Anchor QEA and Aspect 2012), groundwater risk driver COCs for human health are as follows:

- **VOCs.** Benzene, ethylbenzene, and total xylenes;
- **SVOCs – PAHs.** 2-methylnaphthalene, acenaphthene, fluoranthene, fluorene, naphthalene, pyrene, benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene, chrysene, dibenz(a,h)anthracene, indeno(1,2,3-cd)pyrene;
- **Other SVOCs.** Dibenzofuran; and
- **Metals.** Arsenic.

RBTCs used for determining groundwater PRGs were calculated using the exposure assumptions of the HHRA residential scenario. These inputs and corresponding PRGs are identical to the EPA RSLs. Groundwater pathways are not complete to ecological receptors.

The drinking water MCL for arsenic is 10 µg/L (Table 4-5). Based on the natural background of arsenic in soil and its higher mobility under geochemically reducing conditions, naturally occurring organic materials, such as peat, can create groundwater conditions with naturally elevated arsenic concentrations.

4.3.3 *Preliminary Remediation Goals for Air and Vapor*

PRGs for indoor air and trench vapor (summarized in Table 4-8) were based on the EPA RSLs for residential air and industrial air, respectively. Indoor air and trench vapor risk driver COCs for human health are as follows:

- **VOCs.** Benzene, ethylbenzene, naphthalene, and total xylenes.

4.3.4 *Preliminary Remediation Goals for Surface Water/ Porewater*

Surface water/porewater PRGs are summarized in Table 4-6. The surface water/porewater risk driver COC for human health is as follows:

- **VOC.** Benzene, with the National Water Quality Criteria for human health (water+organism) used as the PRG.

For ecological receptors, risk driver COCs include:

- **PAHs.** 2-methylnaphthalene, acenaphthene, anthracene, benzo(a)anthracene, benzo(a)pyrene, fluoranthene, fluorene, naphthalene, phenantherene, pyrene, and PAH ESBQ TU; and
- **VOC.** Toluene.

As discussed above, ecological screening values from EPA Region 3 and EPA Region 5 were used as PRGs for individual chemicals to delineate sediment areas potentially requiring remediation. The PAH ESBQ applied in the RI (Anchor QEA and Aspect 2012) following EPA guidance (toxic unit [TU] = 1) was used in this FS to determine the protectiveness of alternative sediment cleanup actions (see Section 7.2.1).

4.3.5 *Preliminary Remediation Goals for Sediment*

Sediment PRGs are summarized in Table 4-7. Nearshore and Site-wide sediment risk drivers for human health are based on sediment exposure per the beach recreation and fishing scenarios, respectively. The human health risk driver COCs included:

- **PAHs.** Benzo(a)anthracene, benzo(a)pyrene, chrysene, dibenz(a,h)anthracene, and indeno(1,2,3-cd)pyrene.

For ecological receptors, the risk driver COCs include:

- **PAHs.** Benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthenefluoranthene, benzo(k)fluoranthene, fluoranthene, dibenz(a,h)anthracene, indeno(1,2,3-cd)pyrene, and pyrene.

As discussed in the RI Report (Anchor QEA and Aspect 2012), for the nearshore sediment, the otter was the most sensitive ecological receptor and PRGs were developed based on toxicity data for benzo(a)pyrene, total PAHs, and HPAHs. For the Site-wide sediment, the sandpiper was the most sensitive ecological receptor and PRGs were based on toxicity data for benzo(a)pyrene and total PAH. Toxicity to benthic invertebrates is also a risk driver, and the PRG is the PAH ESBQ (TU = 1).

Consumption of fish and shellfish is a risk driver for human health and ecological receptors, although this endpoint is based on modeled tissue concentrations from sediment using biota-sediment accumulation factors. The bioavailability of PAHs in sediment for uptake into fish or shellfish tissue is a function of OC content (total organic carbon [TOC] data for sediment samples are provided as a percentage and ranged from 0.178 percent up to 46.2 percent); therefore, the PRG for fish and shellfish consumption is expressed as an OC-normalized sediment concentration. The RBCs for cPAHs are lower than background sediment cPAH concentrations; therefore, the sediment PRG for cPAHs is based on regional background. As discussed above, the sediment cPAH BTV was used in this FS to conservatively approximate the extent of sediments that may require remediation to a background-based criterion.

4.4 Site Areas and Media Targeted for Remedial Action

The nature and extent of risk driver COCs in Site media is described in detail in the RI Report (Anchor QEA and Aspect 2012) and summarized in Section 3.5. For the purposes of developing alternatives for this FS (in Section 6), Site areas have been identified that have similar characteristics of contamination (e.g., type of contaminant, type of media impacted, and depth of contamination). Each remedial alternative in the FS identifies a technology (or combination of technologies) to address each Site area.

To identify Site areas to be remediated, Site areas with contaminants above PRGs in each Site media were identified based on the data presented in the RI Report (Anchor QEA and Aspect 2012). These areas were then further differentiated based on the location of contaminants relative to potential exposure pathways (e.g., surface versus subsurface soils). Figure 4-1 shows the Site areas where PRGs are exceeded (PRG Exceedence Areas). These areas, which are described in Section 4.4.1 are designated as follows:

- The Surface Soil Area;
- The Subsurface Soil and Groundwater Area; and
- The Surface and Subsurface Sediment Area.

Site areas containing principal threat materials (i.e., DNAPL; refer to Section 4.2) were also identified. Areas containing DNAPL were further differentiated by considering the following:

- **Effect on Groundwater Quality.** Because of the shallow water table, most Site DNAPL is in contact with groundwater and is a source of groundwater contamination. As a result, groundwater in the Shallow Alluvium over most of the Site exceeds drinking water MCLs. Groundwater in a portion of the Deeper Alluvium is also contaminated above MCLs, but because of Site groundwater flow patterns (groundwater flows downward on the eastern portion of the Site and upward on the western portion of the Site), only a portion of the DNAPL source significantly impacts groundwater quality in the Deeper Alluvium. Distinct Site areas were identified that contain DNAPL that significantly impacts groundwater quality in the Deeper Alluvium.
- **DNAPL Mobility.** As described in Section 4 of the RI Report (Anchor QEA and Aspect 2012) and summarized above in Section 3.2, the majority of Site DNAPL is below residual saturation (i.e., immobilized by capillary forces) and most DNAPL that is above residual saturation (i.e., DNAPL-impacted soil) is trapped by low-permeability soil layers. However, it is possible that DNAPL present above residual saturation may still move, especially if subsurface conditions were to change (e.g., as part of remediation, as a result of future development activities, or following a large seismic event). Therefore, distinct Site areas containing significant quantities[20] of DNAPL-impacted soil were identified.

[20] Thin layers of oil-wetted soil, such as have been observed in a number of Site borings, represent a lesser risk than thick layers if they are mobilized in the future because the thin layers contain less

- **DNAPL Depth.** DNAPL present at different depths may be best addressed by using different technologies. For example, remedial alternatives involving excavation of shallow DNAPL-impacted soil (e.g., in the top 10 to 15 feet) are more implementable than remedial alternatives involving excavation of deep DNAPL-impacted soil (down to 34 feet bgs). Therefore, distinct Site areas containing DNAPL at significantly deeper depths were identified.
- **DNAPL Cumulative Thickness.** Remedial technologies addressing DNAPL are often more efficiently applied in areas where DNAPL layers are thicker (i.e., more DNAPL mass in the soil column). Since a goal of remediation is to remove as much DNAPL as possible, Site areas were also differentiated with respect to DNAPL cumulative thickness.

Section 4.4.2 below discusses how these considerations were used to delineate specific areas of DNAPL.

4.4.1 *PRG Exceedence Areas*

This section describes the Site surface soil, subsurface soil and groundwater, and surface and subsurface sediment areas where PRGs are exceeded.

4.4.1.1 Surface Soil Area

The Surface Soil Area is the upland area where DNAPL has not been identified. It is that portion of the upland part of the Site not included in the DNAPL area (Figure 4-1). Although only limited surface soil sampling and analysis have been performed, the available data indicate that surface soils (i.e., soils in the 0- to 5-foot depth range) in this area exceed PRGs for at least some COCs (see Section 5.3 of the RI Report [Anchor QEA and Aspect 2012]).

The existing surface soil data were considered adequate for purposes of the RI/FS when considering the following:

- The Site is fenced and access is prohibited.
- Future Quendall Terminals Property redevelopment will require at least several feet of fill to match the adjacent property grades and to install a gravity sewer system.
- Recent log sorting yard operations deposited a significant quantity of wood debris that is not representative of prior industrial activities. Redevelopment plans will likely require that this material be removed or graded prior to paved-road construction, to minimize the potential for future settlement.
- Based on cleanup actions implemented at similar sites, and as described in more detail in later sections of this FS, the remedial alternatives will result in capping or backfilling of nearly the entire Site.
- Once the preferred remedy is identified, additional focused surface soil sampling and analysis can be completed if necessary to complete the remedial design.

DNAPL. The small amount of DNAPL in the thin layers is likely to be trapped by capillary forces if the DNAPL were to be mobilized.

The Surface Soil Area includes the upland portion of the Quendall Terminals Property and a portion of the adjacent Railroad Property. The Surface Soil Area on the Railroad Property includes the former Railroad Tank Car Loading Area and the Solid Materials Loading Area. Due diligence investigations performed by the Port of Seattle prior to purchasing the Railroad Property indicated that some Site COCs, including PAHs, arsenic, and lead, were detected outside of these areas, but at concentrations and with a PAH fingerprint that is more consistent with contamination detected elsewhere along the Railroad Property away from the Site (Pinnacle Geosciences 2009).

4.4.1.2 Subsurface Soil and Groundwater Area

The Subsurface Soil and Groundwater Area, shown on Figure 4-1 as a dashed green line, is defined by the area where soils below the 5-foot depth and/or groundwater exceeds PRGs for Site COCs. In general, the estimated lateral and vertical boundaries were delineated based on the maximum extent of naphthalene, which is the most widely detected COC above PRGs. As described in Section 3.5, the naphthalene PRG of 1.4 µg/L is slightly exceeded at wells along the north and south Quendall Terminals Property lines, at deep well BH-20C, and at background well BH-22. For purposes of the FS, the boundaries of the Subsurface Soil and Groundwater Area are assumed to be as follows:

- The north and south Quendall Terminals Property boundaries are the north and south Site boundaries. Properties to the north (Football Northwest Property) and south (Conner Homes Property) were or are being remediated and are subject to Environmental Covenants that restrict the use of groundwater.
- The eastern boundary is estimated to be the eastern boundary of the Railroad Property because groundwater flows to the west and there are no known sources to the east of the Railroad Property.
- The western boundary is estimated to be beneath Lake Washington as shown on Figure 4-1. This boundary is the maximum westerly extent of COCs exceeding PRGs (see Figure 3-6).
- The vertical extent of contamination exceeding PRGs below well BH-20C is estimated to be above the low-permeability lacustrine silt layer that bounds the Deep Aquifer. The vertical extent of the Subsurface Soil and Groundwater Area along Cross Section D-D' is approximated by the estimated extent of groundwater and porewater exceeding the naphthalene PRG on Figure 3-8.

4.4.1.3 Surface and Subsurface Sediment Area

The Surface and Subsurface Sediment Area is the area where surface sediment (0 to 4 inches below sediment surface [bss]) and subsurface sediments (deeper than 4 inches bss) exceed PRGs, as shown on Figure 4-1. The surface sediment area encompassed by cPAH PRG exceedances includes the areas that exceed naphthalene and PAH TU PRGs. Subsurface sediment areas associated with the T-Dock that exceed PRGs are encompassed by DNAPL areas. In the nearshore groundwater discharge area, subsurface sediment porewater exceeding the naphthalene PRG encompasses the area exceeding the benzene, cPAH, and PAH TU PRGs.

4.4.2 *DNAPL Areas*

This section describes how specific areas of DNAPL were delineated and differentiated based on their effect on groundwater quality, mobility, depth, and cumulative thickness. Specific DNAPL areas are generally defined based on occurrences that have a particular impact on groundwater quality, have significant DNAPL above residual saturation, are located at depths that are particularly shallow (in sediments) or deep (in the uplands), and/or have significant thicknesses of DNAPL-impacted soil. Specific areas include:

- DNAPL-impacted soil in the former Railroad Tank Car Loading Area (RR DNAPL Area);
- DNAPL-impacted soil in the former May Creek Channel (MC DNAPL Area);
- DNAPL-impacted soil around Quendall Pond (QP-U DNAPL Area);
- DNAPL-impacted sediments offshore of Quendall Pond (QP-S DNAPL Area); and
- DNAPL-impacted sediments along the former T-Dock (TD DNAPL Area).

DNAPL occurrences that were not identified as a specific area are collectively described as Other Upland DNAPL Areas (including DNAPL-impacted soil in other former process areas) or Other Aquatic DNAPL Areas.

Figures 4-2, 4-3, 4-4, and 4-5 depict cross sections for the delineated DNAPL areas shown on Figure 4-1. Refer to Figure 3-5 for boring locations discussed in this section. DNAPL depths, thicknesses, and characteristics at specific borings identified below are from Appendix G of the RI Report (Anchor QEA and Aspect 2012). The location and characteristics of each delineated DNAPL area are described below

4.4.2.1 Railroad DNAPL Area (RR DNAPL Area)

The RR DNAPL Area is located in and around the former Railroad Tank Car Loading Area where liquid products (including coal tar and creosote) were historically loaded and unloaded on a trestle above the former May Creek Channel. As discussed in the RI Report (Anchor QEA and Aspect 2012), this area was reported to “have received heavy spilling over the years”. The trestle was located on the Railroad Property but, based on historical reports and Site investigation results, released products likely migrated west along the creek channel or in subsurface soil layers onto the Quendall Terminals Property. DNAPL in this upland area is of particular concern due to its effect on groundwater quality in the Deep Aquifer, depth, and thickness.

Site investigations identified significant quantities of DNAPL in the subsurface of this area, including one boring (Q2-D) with the largest cumulative thickness (11 feet thick) of DNAPL-impacted soil that has been observed at the Site, and boring BH-30C, where the deepest occurrence of DNAPL (33.7 feet bgs) was observed. Boring BH-30C is also the only location at the Site where DNAPL has been observed in the Deeper Alluvium.

In this area, high concentrations of benzene (up to 1,600 µg/L), naphthalene (45,000 µg/L), cPAHs (2,760 µg/L[21]), and arsenic (1,690 µg/L) have been detected in groundwater in the Shallow Alluvium. The highest concentrations were detected at well Q9 (see Section 5.2 of the RI Report [Anchor QEA and Aspect 2012]). The deep DNAPL occurrences and downward hydraulic gradients in this area result in a groundwater plume extending into the Deep Aquifer (see Section 6 of the RI Report [Anchor QEA and Aspect 2012]).

The estimated lateral extent of the RR DNAPL Area is shown on Figures 4-1 and 4-3, and the vertical extent along Cross Section D-D' is shown on Figure 4-5. Based on the available data, the RR DNAPL Area appears to be contiguous with DNAPL identified in the former May Creek Channel south of the former Still House, adjacent to former storage tanks 1 through 5 (see Figure 3-5). However, DNAPL west of BH-30C (at borings HC-5, MC-20, and MC-23) was identified at shallow depths (less than 13 feet bgs) and over a smaller cumulative thickness (2.5 feet at each boring) than in BH-30C. Therefore, the western boundary of the RR DNAPL Area is estimated to be between the deep DNAPL occurrences at BH-30C and the shallow DNAPL occurrences at HC-5, west of BH-30C[22]. DNAPL occurrences west of the RR DNAPL Area are included in the "Other Upland DNAPL Areas" described in Section 4.4.2.4 below.

4.4.2.2 Former May Creek Channel DNAPL Area (MC DNAPL Area)

The MC DNAPL Area is located where wastes containing creosote were reportedly discharged from the plant through a sewer outfall to the former May Creek Channel (Roberts 1989). DNAPL in this upland area is of particular concern due to its mobility, depth, and thickness. Site investigations identified significant quantities of DNAPL, including one boring (MC-1, located adjacent to the former sewer outfall) where the greatest depth (to a maximum depth of 31.5 feet bgs) has been observed outside of the RR DNAPL Area.

DNAPL occurrences in this area extend west of the former outfall along the former channel alignment. At well BH-21A, located in the former May Creek Channel downstream of the outfall, 5.5 feet of DNAPL accumulated and returned (i.e., recovered) after purging the well, indicating that DNAPL at this location is above residual saturation (i.e., oil-wetted soil). In total, 35 gallons of creosote DNAPL were removed from this well during DNAPL recovery pilot testing in 2003 and 2004. DNAPL-impacted soil was also observed at borings MC-8 (1.5 feet thick) and MC-7 (1 foot thick), located progressively west of BH-21A. A 0.2-foot-thick layer of DNAPL-impacted soil was observed at MC-16, located west of MC-7. DNAPL has not been observed in sediment borings immediately downgradient of the MC DNAPL Area. These observations suggest that: 1) although potentially mobile DNAPL is located in this area, the amount of mobile DNAPL mass declines to the west; and 2) any "stringers" west of BH-21A are exhausted before DNAPL can reach Lake Washington surface sediments.

[21] cPAH concentrations provided in Section 4.4.2 are the total benzo(a)pyrene TEQ for all cPAHs using mammalian toxicity equivalent factors.

[22] The boundary for each area is based on the available data for the purposes of developing and comparing alternatives. Additional characterization of the actual area boundary may be performed as part of the remedial design, if necessary.

In the MC DNAPL Area, high concentrations of naphthalene (up to 2,100 µg/L) have been detected in groundwater, with the highest concentrations at well BH-21A. Benzene (up to 16 µg/L at BH-21B), cPAHs (24.6 µg/L at BH-21A), and arsenic (109 µg/L at BH-21B), have also been detected above their respective PRGs. Because of the slightly downward vertical gradient in the eastern portion of this area, contaminants are transported from the DNAPL-impacted soils near the base of the Shallow Aquifer at MC-1 into the top of the Deep Aquifer, resulting in a groundwater plume extending into the Deep Aquifer (see Section 6.4.2 of the RI Report [Anchor QEA and Aspect 2012]). Near the shoreline, groundwater flow transitions upward, resulting in an elevated concentration of naphthalene (4,100 µg/L) in offshore subsurface groundwater at wellpoint WP-21C.

The vertical extent of the MC DNAPL Area along Cross Section B-B' is shown on Figure 4-3. The MC DNAPL Area consists of three separate areas where deep DNAPL or significant thicknesses of DNAPL-impacted soil were identified: 1) near the former sewer outfall, at boring MC-1; 2) downstream of the former sewer outfall at boring HC-7, where a 6.5-foot-thick layer of DNAPL-impacted soil was observed; and 3) still further downstream at monitoring well BH-21A and borings MC-7 and MC-8. DNAPL was also observed at several adjacent locations: MC-2 (southwest of MC-1), MC-13 (north of MC-1), SP-1 (west of MC-1), and MC-16 (west of MC-8); however, occurrences of DNAPL-impacted soil were limited to very thin layers (0.5 foot thick at MC-2, 0.3 foot thick at MC-13, and 0.2 foot thick at MC-16). These more limited DNAPL occurrences are included in the Other Upland DNAPL Areas (Section 4.4.2.4).

4.4.2.3 Quendall Pond Upland DNAPL Area (QP-U DNAPL Area)

The QP-U DNAPL Area is located where tank bottoms were reportedly placed (Roberts 1989) and where contaminated fluids discharged to the North Sump may have migrated via surface or subsurface flow (see RI Report Section 4.4.4 [Anchor QEA and Aspect 2012]). DNAPL in this upland area is of particular concern due to its effect on groundwater quality and mobility.

Site investigations in this area identified DNAPL-impacted soil in the subsurface, including at two wells from which DNAPL was recovered during pilot testing in 2003 and 2004, as follows:

- **Well BH-5, located just east of Quendall Pond**. At this well, 1 foot of DNAPL-impacted soil, to a maximum depth of 19 feet bgs, was observed, and 26 gallons of DNAPL were recovered during pilot testing.
- **Well RW-QP-1, located just west of Quendall Pond.** At this well (co-located with boring SP-3), 2 feet of oil-wetted soil, to a maximum depth of 16 feet bgs, was observed, and 42 gallons of DNAPL were recovered during pilot testing.

At these locations, DNAPL may be trapped by low-permeability silt and peat layers that prevent downward migration (Anchor QEA and Aspect 2012).

DNAPL-impacted soil has also been observed at several other borings adjacent to Quendall Pond, including SP-4 (1 foot thick, to a depth of 12.5 feet bgs), SP-8 (1.4 feet thick, to a depth of 18 feet bgs), and RB-12 (0.4 foot thick, to a depth of 18 feet bgs).

In this area, high concentrations of naphthalene (up to 16,000 µg/L), benzene (up to 33,000 µg/L), and cPAHs (up to 362 µg/L) have been detected, with the highest concentrations at well BH-5. Arsenic (up to 53.8 µg/L at BH-5A) has also been detected above its PRG. The deepest DNAPL occurrence in this area (at BH-20C, where DNAPL-impacted soil was observed from 25.5 to 26.5 feet bgs) is within the Shallow Alluvium, and groundwater flow is upward at this location; however, based on contaminant transport via diffusion and dispersion and from contributions from DNAPL sources east of this area (see Section 6 of the RI Report [Anchor QEA and Aspect 2012]), concentrations of benzene and naphthalene (and to a lesser extent, arsenic) are also elevated at the top of the Deeper Alluvium.

The QP-U DNAPL Area includes the locations where oil-wetted soil was identified around Quendall Pond. DNAPL was also observed at locations north, south, east, and west of this area but because of distinguishing characteristics, these adjacent occurrences were not included in the QP-U DNAPL Area, as follows:

- **To the North.** DNAPL was not observed at well BH-19 but was identified north of BH-19 at borings SP-2, QP-1, and RB-11 and sediment cores VS2, QPN-07, and NS15. DNAPL layers to the north of Quendall Pond get progressively thinner and lower in elevation, tapering to a 0.1-foot-thick layer of DNAPL-impacted sediment 9.3 feet below mudline at NS15. These occurrences are included in the Other Upland DNAPL Areas (Section 4.4.2.4) and Other Aquatic DNAPL Areas (Section 4.4.2.7).
- **To the South.** DNAPL was identified at BH-20C, from a depth of 25.5 to 26.5 feet. However, this occurrence was characterized as oil-coated rather than oil-wetted. This occurrence is included in the Other Upland DNAPL Areas (Section 4.4.2.4).
- **To the East.** DNAPL has been identified in soil borings east of Quendall Pond, in the vicinity of the North Sump; however, the physical and chemical characteristics of DNAPL near the North Sump are distinct from the DNAPL characteristics at Quendall Pond as follows:
    - DNAPL near the North Sump is below residual saturation and was not recoverable during the DNAPL recovery pilot test.
    - DNAPL near the North Sump has a much lower concentration of benzene (approximately 0.06 percent by weight: see RI Report Table 4.2-1 [Anchor QEA and Aspect 2012]) than DNAPL near Quendall Pond (up to 1 percent by weight).
    - DNAPL near the North Sump is included in the Other Upland DNAPL Areas described in Section 4.4.2.4.
- **To the West.** DNAPL has been identified in sediment borings offshore of Quendall Pond. Because sediment remediation technologies and methods are often significantly different from upland technologies, offshore DNAPL occurrences are discussed separately. DNAPL offshore of Quendall Pond is included in the Other Aquatic DNAPL Areas described in Section 4.4.2.7.

4.4.2.4 Other Upland DNAPL Areas

The Other Upland DNAPL Areas are shown on Figure 4-1, and include all upland areas where DNAPL was observed (at any thickness) outside of the specific areas discussed above (i.e., RR DNAPL Area, MC DNAPL Area, and QP-U DNAPL Area). The Other Upland DNAPL Areas generally contain DNAPL that is shallow, thin layered, and/or below residual saturation (i.e., DNAPL-impacted soil). Based on either their location or chemical composition, these Other Upland DNAPL Areas do not significantly impact groundwater quality below the top of the Deeper Alluvium; they include DNAPL at the fringes of the specific areas discussed above and also DNAPL occurrences in other former process areas, which are discussed below.

4.4.2.4.1 DNAPL in Other Former Process Areas

Upland occurrences of DNAPL not associated with the former railroad tank car loading, May Creek channel, or Quendall Pond areas are generally associated with three other former process areas: 1) the Railroad Solid Materials Loading Area; 2) the Still House; and 3) the North Sump. Cumulative thickness of DNAPL is an important differentiator within these areas. Figure 4-6 shows the DNAPL cumulative thicknesses observed in Site borings, depicted using Thiessen polygons.[23]

DNAPL characteristics in these areas are summarized as follows:

- **Former Railroad Solid Materials Loading Area.** DNAPL in this area occurs at depths less than 22 feet bgs, primarily as oil-coated soil. It does not appear to have a significant impact on groundwater quality (as measured at wells Q1-D and BH-27), likely because of the composition of the material (i.e., a higher proportion of heavier PAH compounds than elsewhere on the Site, with no BTEX compounds detected). The largest cumulative thickness of DNAPL observed was 6 feet (at Q1-D).
- **Former Still House.** DNAPL at this location occurs at depths less than 14 feet bgs. DNAPL layer thickness observations did not exceed 2 feet except at BH-8, where a 4-foot thickness was observed from 8.5 to 12.5 feet bgs. (This was also the largest cumulative DNAPL thickness observed in this area.) Well BH-8A was installed with the screen placed at this depth interval, but no product was recorded in this well.
- **Former North Sump.** DNAPL in this area is present over a greater horizontal and vertical extent than the two "Other Former Process Areas" above, and occurs as deep as 24 feet bgs (at BH-23). However, product has not accumulated in three wells installed in this area (BH-8, BH-23, and RW-NS-1), and maximum concentrations of benzene (350 µg/L at BH-23) and naphthalene (760 µg/L at RW-NS-1) in groundwater are more than 10 times lower than in the adjacent QP-U DNAPL Area to the west. The largest cumulative thickness of DNAPL observed was 6 feet (at SP-5).

[23] The same cumulative thicknesses and Thiessen polygons were used in the RI Report (Section 4.4 and Appendix G) to estimate the cubic yards of DNAPL-impacted soil and sediment, and the gallons of DNAPL present in the subsurface at the Site.

Refer to Section 4.4 of the RI Report (Anchor QEA and Aspect 2012) for additional information regarding DNAPL characteristics in the former process areas.

The cumulative thickness of DNAPL is an important differentiator within the Other Upland DNAPL Areas. Figure 4-6 shows the DNAPL cumulative thicknesses observed in Site borings, depicted using Thiessen polygons.[24] The maximum cumulative DNAPL thickness within the Other Upland DNAPL Areas is 6 feet at Q1-D and SP-5.

4.4.2.5 Quendall Pond Sediment DNAPL Area (QP-S DNAPL Area)

This area, labeled QP-S on Figure 4-1, is located where DNAPL near Quendall Pond has migrated into subsurface sediments through permeable soil layers. DNAPL in this offshore area is of particular concern due to its effect on groundwater quality and thickness.

This area includes two sediment boring locations where DNAPL-impacted sediment has been observed: at VS-30 (5 feet thick, to a depth of 9 feet below mudline) and QPN-02 (cumulative thickness of 1.7 feet, to a depth of 7.4 feet below mudline). This area is a continuation of the QP-U DNAPL Area described above but is discussed separately because different remedial technologies may be applied to sediments than to upland soils.

Groundwater in this area contains relatively high concentrations of benzene (up to 11,000 µg/L, at wellpoints WP-19A and WP-19B) and naphthalene (up to 11,000 µg/L, at wellpoint WP-3). Concentrations of cPAHs (up to 12.5 µg/L at wellpoint WP-3) have also been detected above the PRG.

A thin layer of DNAPL-impacted sediment was also observed at three sediment borings north of this area, at QPN-07 (0.2 foot thick, to a maximum depth of 8.7 feet below mudline), VS-2 (2 inches thick, to a maximum depth of 16.3 feet below mudline), and NS-15 (0.1 foot thick, to a maximum depth of 9.3 feet below mudline). Because these DNAPL occurrences were relatively thin and below residual saturation and are located where surface sediments and groundwater porewater are below PRGs, this area is discussed under Other Aquatic DNAPL Areas described in Section 4.4.2.7.

4.4.2.6 T-Dock DNAPL Area (TD DNAPL Area)

This area, labeled TD on Figure 4-1, is located along the former T-Dock alignment where historical spills from transfer piping have resulted in DNAPL occurrences in surface and subsurface sediments. DNAPL in this area is of particular concern due to its relatively shallow depth in sediments.

DNAPL in this area has been characterized as DNAPL-impacted sediment and has generally been observed in thin (1- to 4-inch-thick) layers. The TD DNAPL Area also includes thicker sequences of DNAPL observed at two sediment borings (1 foot thick at VT-1 and 3.8 feet thick at VT-4) located west of the T-Dock cross-span, near the location of a major coal-tar release reported in the 1930s (Roberts 1989). DNAPL at these two locations was in surface sediment.

[24] The same cumulative thicknesses and Thiessen polygons were used in the RI Report (Section 4.4 and Appendix G) to estimate the cubic yards of DNAPL-impacted soil and sediment, and the gallons of DNAPL present in the subsurface at the Site.

PAHs (including naphthalene, cPAHs, and PAH TUs) were elevated above PRGs at locations TD-08 and TD-15 (at the end of the T-Dock), and at NS-12 (adjacent to boring VS-27). Midge and amphipod bioassay tests on samples from TD-08 and TD-15 resulted in mortality of the test organisms. Bioassay test samples from NS-12 were also classified as toxic.

4.4.2.7 Other Aquatic DNAPL Areas

Other Aquatic DNAPL Areas are shown on Figure 4-1 and consist of aquatic lands containing DNAPL that are not included in one of the two specific areas described above. These other areas contain relatively thin layers of DNAPL (refer to Figure 4-6), are below residual saturation, and do not impact porewater or surface water quality above PRGs. DNAPL occurrences north of the QP-S DNAPL Area and west (offshore) of the MC DNAPL Area are included in these Other Aquatic DNAPL Areas.

5 Technology Identification and Screening

This section identifies and screens potential remedial technologies that may be effective in satisfying the Site RAOs defined in Section 4.2. Identification and screening of technologies is performed for each contaminated Site medium (DNAPL, soil, groundwater, and sediment) as follows:

- Technology identification begins with a review of GRAs applicable to contaminated Site media. For each GRA, potentially applicable technologies and technology process options (different methods of implementing a particular technology are referred to as "process options" in this report) for each technology are identified.
- After technologies and process options are identified for each medium, they are screened using a two-step approach as follows:
    - An initial screening, in which each process option is first evaluated with respect to its potential applicability to Site COCs and conditions, for each Site medium.
    - A secondary screening, in which process options that pass the initial screening are evaluated relative to one another based on their potential effectiveness, implementability, and cost. Process options that meet the secondary screening criteria are then retained to be potentially included in remedial alternatives in Section 6.

In most cases, for technologies that are retained, one representative process option was selected for the purposes of developing and comparing alternatives in this FS. It is expected that after alternatives are evaluated and a remedy is selected, potential process options may be re-evaluated during design of the final remedy. Section 5.1 discusses the identification of GRAs, remedial technologies, and process options. Section 5.2, describes the initial technologies and process options screening based on their applicability to the Site. Section 5.3 includes a brief description of each technology and process option retained from the initial screening and provides the secondary screening of technologies based on effectiveness, implementability, and cost by media, as follows:

- Section 5.3.1 - DNAPL;
- Section 5.3.2 - Soil;
- Section 5.3.3 - Groundwater; and
- Section 5.3.4 - Sediment.

Detailed descriptions and evaluation of each technology and process option are presented in Appendix C.

Tables 5-1 through 5-4 summarize the different GRAs, technologies, and process options considered for this FS and the results of the initial screening. Tables 5-5 through 5-8 present a summary of the results of the secondary screening of process options, which are

evaluated based on effectiveness, implementability, and cost, in the context of Site-specific conditions and constraints.

5.1 Identification of Remedial Technologies and Process Options

This process involves a three-step hierarchical approach to identifying actions that may achieve Site RAOs (EPA 1988a). The list of technologies and process options (included in Tables 5-1 through 5-4) is the baseline upon which screening narrows the array of technologies and process options to include the most likely effective actions.

1. **Develop GRAs.** GRAs are major categories of remedial activities such as institutional controls, *in situ* containment, removal, or treatment. GRAs that might be used at a site are defined based on an understanding of site conditions and action-specific ARARs. Similar to RAOs, GRAs are medium-specific. Tables 5-1 through 5-4 include a listing of GRAs, by media, chosen for the Site.
2. **Identify Remedial Technologies.** Specific remedial technologies are identified for each GRA category. For example, technologies within the removal GRA category may include excavation or pumping.
3. **Identify Process Options.** Process options are specific variations in the way each technology can be implemented. For example, process options for pumping include pumping from vertical wells, horizontal or angled wells, or trenches.

5.1.1 *General Response Actions*

GRAs represent categories of remedial technologies that might be undertaken to satisfy the RAOs for a site and may involve, depending on site-specific circumstances, the complete elimination or destruction of hazardous substances at the site, the reduction of concentrations of hazardous substances via engineering or institutional controls, or some combination of the above. GRAs for the Site media are as follows:

- **Institutional Controls.** Institutional controls are measures undertaken to limit or prohibit activities that may interfere with a cleanup action or result in exposure to hazardous substances.
- **Monitored Natural Attenuation.** Natural attenuation is the reduction of contaminant concentrations at the point of exposure over time through natural processes, such as sedimentation, sorption, dispersion, and/or biodegradation. Monitoring documents that the processes are occurring at the desired rates. This GRA is applicable to Site groundwater and sediment. For sediment, this GRA is referred to as monitored natural recovery (MNR).
- ***In situ* Containment.** *In situ* containment involves confining hazardous substances in place through placement of physical barriers or hydraulic controls. Containment technologies can be designed to prevent contact with and/or migration of hazardous substances.
- ***In Situ* Treatment.** *In situ* treatment technologies can potentially reduce the concentration, mobility, and/or toxicity of COCs.

- **Removal.** Contaminated materials can be physically removed from the Site and treated and/or disposed of either on-site or at an off-site, permitted disposal facility.
- ***Ex Situ* Treatment.** *Ex situ* treatment technologies destroy or immobilize contaminants in media that have been removed from the subsurface.
- **Disposal.** Disposal technologies include placement of contaminated solid media in on- or off-site landfills or discharge of contaminated water to a publicly owned treatment works (POTW).

5.1.2 *Technologies and Process Options*

Technologies and process options were identified by drawing on a variety of sources including EPA guidance documents developed for application to Superfund sites, professional publications and websites, and implementation experience at similar sites. References used in the identification and screening process are provided in the detailed description of technologies and process options (Appendix C), and include:

- Presumptive Remedies for Soils, Sediments, and Sludges at Wood Treater Sites (EPA 1995c);
- Feasibility Study/Record Of Decision Analysis for Wood Treater Sites with Contaminated Soils, Sediments, and Sludges (EPA 1997);
- Presumptive Response Strategy and Ex-Situ Treatment Technologies for Contaminated Ground Water at CERCLA Sites: Final Guidance (EPA 1996a);
- Contaminated Sediment Remediation Guidance for Hazardous Waste Sites (EPA 2005); and
- Federal Remediation Technologies Roundtable (FRTR Website 2012).
- Use of Amendments for *In Situ* Remediation at Superfund Sediment Sites. U. S. Environmental Protection Agency, Office of Superfund Remediation and Technology Innovation. (EPA 2013).

Technologies and process options considered for the Site are listed, by medium, in Tables 5-1 through 5-4. As shown in columns one through three in Tables 5-1 through 5-4, several remedial technologies were identified for each GRA, and numerous technology process options often exist for each technology.

5.2 Initial Screening of Technologies and Process Options

The remedial technologies and process options are screened to reduce the number of technologies and process options to those most likely to meet RAOs and ARARs and address COCs by medium. A two-phase screening process is used. During the first phase of the screening, technologies and process options may be eliminated from further consideration on the basis of their applicability to the Site. During the second phase of the screening (Section 5.3), technologies and process options considered to be generally applicable to the Site are evaluated in greater detail.

Initial screening of remedial technologies is accomplished by using available information from the RI Site characterization on contaminant types, contaminant concentrations, and Site geology and hydrogeology, to screen out technologies and process options that

cannot be effectively implemented at the Site. Two factors that commonly influence technology effectiveness are the Site COCs targeted by the technology and the Site subsurface conditions (geology and hydrogeology). Table 3-1 summarizes the Site COCs. As indicated in the table, Site contaminant types are as follows:

- VOCs, including benzene and naphthalene;
- SVOCs, including PAHs such as benzo[a]pyrene; and
- Metals, such as arsenic.

Technologies and process options determined to be ineffective for remediating any Site COCs are eliminated from further consideration. Subsurface conditions, such as fine-grained soils, or lack of a continuous aquitard, can limit the effectiveness of many types of containment and groundwater collection technologies. Technologies that do not have demonstrated effectiveness for Site COCs or Site conditions were also eliminated from consideration. Potential applicability of technologies and process options is discussed in Appendix C. Tables 5-1 through 5-4 summarize the results of the initial screening process. Because the Site includes a range of COC types and both zones of both heterogeneous, fine-grained soils (the Shallow Alluvium) and more homogeneous, coarser-grained soils (the Deeper Alluvium), few technologies or process options were eliminated during the initial screening.

5.3 Secondary Screening of Technologies and Process Options

During the second phase of the screening, technology and process options considered to be generally applicable to the Site are evaluated in greater detail. One representative process is selected, if possible, for each technology, simplifying the subsequent assembly and evaluation of alternatives without limiting flexibility during remedial design. The representative process provides a basis for developing performance specifications during preliminary design; however, the specific process actually used to implement the remedial action at a site may not be selected until the remedial design phase. In some cases more than one process option may be selected for a technology. This may be done if two or more processes are sufficiently different in their performance that one would not adequately represent the other.

During the second screening step, process options are evaluated on the basis of effectiveness, implementability, and cost. This evaluation considers technologies and process options that are intended to satisfy specific Site areas or COCs and not to the Site as a whole. The basis for this evaluation is as follows:

- **Effectiveness Evaluation.** This evaluation is qualitative and focused on: 1) the potential effectiveness of process options in handling the estimated areas or volumes of media and meeting the remediation goals identified in the RAOs, 2) the potential impacts to human health and the environment during the construction and implementation phase, and 3) how proven and reliable the process is with respect to the contaminants and conditions at the Site.
- **Implementability Evaluation.** Implementability encompasses both the technical and administrative feasibility of implementing a process option. Technical

feasibility refers to the ability to construct, operate, maintain, and monitor the remedial action during and after construction and meet technology-specific regulations. Administrative feasibility refers to the ability to obtain permits for remedial actions and the availability of specific equipment and technical specialists.

- **Cost Evaluation.** Process options are screened on the basis of relative capital and operation, maintenance, and monitoring (OM&M) costs. Relative costs are estimated on the basis of engineering judgment. Each process is evaluated as to whether costs are high, low, or medium relative to other process options in the same GRA.

A brief description of this evaluation is provided by media in Sections 5.3.1 through 5.3.4 and summarized in Tables 5-5 through 5-8. A detailed description of this screening for each technology and process option is provided in Appendix C.

5.3.1 *Technology and Process Option Screening for DNAPL*

Technologies and process options identified in Table 5-1 as potentially effective for addressing Site DNAPL (coal tar and creosote) are screened on the basis of relative effectiveness, implementability, and cost in Table 5-5. A description of each technology and process option, organized by GRA, is provided below.

5.3.1.1 DNAPL Institutional Controls

Institutional controls limit access to contaminated material and may consist of physical restrictions, such as fences; or legal restrictions, such as use limitations recorded on the property deed. Process optiozns for institutional controls include:

- Fences and warning signs to control access to the Site or to specific areas of the Site such as the nearshore area in the vicinity of Quendall Pond;
- Deed restrictions such as restricting land use, construction, and soil excavation without EPA approval; and
- Use restrictions and monitoring requirements to prevent disturbance of caps or other engineered controls.

These institutional controls can be effective and implementable under a wide range of conditions and generally apply to the entire Site. The institutional control process options listed above were retained as representative institutional control process options.

5.3.1.2 DNAPL *In Situ* Containment

The lateral mobility of DNAPL can be controlled by installing impermeable vertical barriers across potential DNAPL flow paths. Impermeable barriers to prevent DNAPL migration are considered applicable only to upland Site areas.

Process options for impermeable vertical barriers include:

- **Slurry Wall.** Control lateral movement of DNAPL through installation of a slurry wall by excavating a trench around the DNAPL zones and backfilling with slurry of low-permeability material to provide a barrier.

- **Sheet Pile Wall.** Control lateral movement of DNAPL through installation of interlocking steel or plastic piles into the subsurface along the boundaries of the DNAPL zones.
- **Grout Curtain.** Control lateral movement of DNAPL through installation of a jet-grouted low-permeability slurry curtain.

These vertical barrier process options can be equally effective at controlling the lateral mobility of DNAPL and are implementable under a wide range of conditions. Slurry walls are the most reliable to construct and maintain (i.e., they can be installed with greater certainty of continuity than grout curtains, do not corrode or have potentially leaking joints like sheet piles) and cost-effective of these process options; slurry walls were retained as the representative *in situ* containment process option for DNAPL.

5.3.1.3 DNAPL *In Situ* Treatment

In Situ Thermal Treatment

Subsurface heating can be used to destroy or volatilize organic chemicals associated with DNAPL. This technology typically includes a network of heating or injection wells that heat the subsurface, and a network of extraction wells to remove contaminated soil vapor, groundwater, and DNAPL from the subsurface. Contaminated fluids are treated above ground, typically by a combination of physical separation (to remove DNAPL), adsorption (to remove dissolved contaminants), and thermal oxidation (to destroy contaminated vapors). Process options for *in situ* thermal treatment include:

- **Hot Water Injection.** Hot water is injected into the subsurface, decreasing DNAPL viscosity and raising the solubility of organic compounds.
- **Steam Injection.** Steam is injected into the subsurface, volatilizing or destroying (by pyrolysis) organic compounds.
- **Electrical Resistance Heating (ERH).** A voltage is applied to subsurface electrodes installed in vertical boreholes. The electrical resistivity of site soils creates heat.
- **Thermal Conduction Heating (TCH).** Vertical wells are heated, typically using in-ground electrical heaters, and the heat is transferred to subsurface soils via the soil's thermal conductivity.

Some or all of the above process options can be operated at varying temperature ranges with varying degrees of efficacy at removing COCs present as DNAPL. Operating temperatures can be varied depending on remedial action alternatives and as discussed below:

- **Low-Temperature Heating.** Heating the subsurface to temperatures less than the boiling point of water would reduce the DNAPL viscosity and increase the solubility of DNAPL constituents for enhanced physical DNAPL recovery. It would also volatilize and remove most volatile compounds. A portion of residual DNAPL would remain coated to soil after treatment. Technologies that may be effective at low temperatures are hot water injection, ERH, and TCH.
- **Mid-Temperature Heating.** Heating the subsurface to the boiling point of water improves contaminant removal when compared to low-temperature heating,

further reducing the DNAPL viscosity and increasing contaminant solubility. Many of the Site COCs, including benzene and naphthalene, would be volatilized and removed, but a significant fraction of SVOCs, such as cPAHs, would remain in soil. Residual material treated by this technology would be relatively immobile and contain compounds of lower solubility, significantly reducing the amount of contaminant leaching. Technologies that may be effective at mid-temperatures are steam, ERH, and TCH.

- **High-Temperature Heating.** In high-temperature heating, also called *in situ* thermal desorption, most volatile and SVOCs in DNAPL would be removed or destroyed *in situ*. The subsurface is heated above the boiling point of water. Variation in contaminant reduction has been observed in samples from different manufactured gas plant sites where this process option has been implemented.

In situ thermal treatment process options are expected to be more costly than other *in situ* treatment methods and more uncertain in effectiveness based on limited full-scale application. Therefore, this technology and its process options have not been retained.

In Situ Stabilization

In this technology, organic and inorganic COCs in soil are physically bound within a stabilized mass (solidification) while chemical reactions between the stabilizing agent and the contaminants reduces contaminant mobility. Potential amendments include bentonite, activated carbon, and cement. Bench testing may be needed to determine an amendment or blend of amendments to achieve performance criteria. Amendments can be mixed with soil *in situ* using large-diameter augers or jet-grouting equipment. Through this process, mobility of free-phase DNAPL and its chemical components is reduced by mixing with amendments, which reduce soil permeability and contaminant leachability.

Solidification/stabilization is potentially effective for immobilizing DNAPL in soils and is implementable, and therefore, has been retained for DNAPL in soils.

In Situ Chemical Treatment

The *in situ* chemical treatment process option for DNAPL treatment is chemical oxidation. Chemical oxidants in solution are injected into the subsurface to react with and destroy organic contaminants below the water table. Multiple injections may be required to achieve remediation goals. Common oxidants have been shown to destroy a wide range of contaminants, including PAHs, benzene, and other COCs, in soil and groundwater; however, they are generally not effective for metals. Process options for chemical oxidation include:

- Hydrogen peroxide;
- Potassium permanganate;
- Ozone; and
- Sodium persulfate.

Chemical oxidation can be moderately effective in reducing the quantity of free-phase DNAPL; however, the quantity of reagent required to oxidize free-phase DNAPL across the upland would likely be difficult and costly to inject. Other effective, implementable,

and more cost-effective *in situ* treatments of DNAPL are available. Therefore, chemical oxidation was not retained.

5.3.1.4 DNAPL Removal Technologies

DNAPL can either be removed directly as a free-phase product by pumping fluids from wells or trenches, or by removing DNAPL-impacted soil or sediment. Removal via excavation and treatment methods for DNAPL-impacted soil and sediment are discussed in Sections 5.3.2.4 and 5.3.4.5, respectively. This section discusses pumping methods of removing free-phase DNAPL. Process options are as follows:

- **Vertical Wells.** Vertical wells can be installed with carefully placed screen sections to maximize DNAPL removal from targeted zones. Wells can include sumps for collecting DNAPL if the underlying confining layer is adequately thick.
- **Horizontal or Angled Wells.** Horizontal drilling techniques have been used at some cleanup sites to install non-vertical wells that provide access to areas where the surface is inaccessible to drilling rigs or trench installation.
- **Trenches.** Trenches generally allow more effective capture of groundwater and DNAPL than individual vertical wells by providing an expanded zone of influence (capture).

These DNAPL pumping process options can be effective and implementable and generally apply to the Site. Angled wells to target relatively shallow DNAPL would provide for only minimal additional lateral capture and are more sensitive to heterogeneous soil conditions than vertical wells. Therefore, DNAPL recovery by pumping from vertical wells and trenches were retained as representative removal process options.

5.3.1.5 *Ex Situ* DNAPL Treatment Technologies

DNAPL collected from pumping or separated from other waste materials would likely be classified as a hazardous waste based on high concentrations of PAHs. If DNAPL is classified as a hazardous waste and recycling/reuse is impractical, it would likely need to be shipped to a hazardous waste treatment facility and incinerated. The process option for *ex situ* treatment of recovered DNAPL consists of incineration, in which DNAPL is heated to temperatures above 1,400°F, oxidizing and converting VOCs and SVOCs to carbon dioxide and water. Metals are not treated, though they may be volatilized and the offgas may require treatment.

Incineration, though typically expensive, can be highly effective for destruction of high concentrations of VOCs and PAHs and is implementable under a wide range of Site conditions, and, therefore, has been retained for DNAPL.

5.3.1.6 DNAPL Disposal Technologies

Recovered DNAPL may be considered for off-site management. Off-site management process options include:

- Recycling of recovered DNAPL; and

- Disposal of recovered DNAPL via incineration, where high temperatures (1,400° to 2,200° F) are used to volatilize and combust organic constituents in hazardous wastes. Offgases and combustion residuals generally require treatment.

Both DNAPL recycling and DNAPL incineration can be highly effective for managing high concentrations of VOCs and PAHs and are implementable under a wide range of site conditions, and, therefore, were retained as representative DNAPL off-site management process options.

5.3.2 *Technology and Process Option Screening for Soil*

Table 5-2 identifies technologies and process options that are potentially effective for addressing Site COCs in soil, which include:

- VOCs, including indicator chemicals benzene and naphthalene;
- SVOCs, including PAHs other than naphthalene, such as the indicator chemical benzo(a)pyrene (representative of the seven cPAHs); and
- Metals, including the indicator chemical arsenic.

Technologies and process options identified in Table 5-2 as potentially effective for Site COCs are screened on the basis of relative effectiveness, implementability, and relative cost in Table 5-6. Note that some of the technologies and process options identified in Table 5-2 were carried forward for evaluation in Table 5-6. A description of each technology and process option, organized by GRA, is provided below.

5.3.2.1 Soil Institutional Controls

Institutional controls and process options described in Section 5.3.1.1 for DNAPL are also potentially effective at preventing exposure to hazardous substances in soil. These institutional controls can be effective and implementable under a wide range of conditions and generally apply to the entire Site. The institutional control process options described in Section 5.3.1.1 were retained as a representative institutional control process options for soil.

5.3.2.2 Soil *In Situ* Containment

Exposure to contaminated soil can be controlled by placing an engineered cap over the contaminated materials. The long-term cap integrity can be maintained through implementation of appropriate institutional controls. In many cases, the clean cap may be separated from underlying potentially contaminated materials with a marker (e.g., geotextile fabric) indicating the cap boundary.

Process options for soil capping include:

- **Permeable Soil Capping.** Placing clean soil on the surface provides a barrier preventing exposure to underlying soil, controlling erosion of potentially contaminated material, while allowing stormwater to infiltrate.
- **Low-Permeability Capping.** A low-permeability cap constructed of clay or an engineered material such as asphalt or concrete prevents exposure to underlying soils, minimizes stormwater infiltration through potentially contaminated materials, reducing the mobility of contaminants located in the unsaturated soil zone, and controls erosion of potentially contaminated material. Engineered

materials can be used in areas requiring a durable surface, such as high-traffic areas.

- **Impervious Capping.** An impervious cap constructed of clay overlain by a synthetic liner provides an additional impermeable layer, preventing infiltration to underlying soils from occurring as well as preventing direct exposure and controlling erosion. A slurry wall may be constructed along the perimeter of the cap to fully contain contaminated material.

Permeable, low-permeability, and impervious caps are proven, effective, implementable, and can be designed to address Site-specific COCs and future use scenarios. Although implementation of low permeability and impervious caps are relatively more expensive then permeable caps, they may be appropriate in portions of the Site or for some future Site uses, and can be more effective than permeable caps by preventing infiltration and reducing leaching of contaminants. Permeable caps may be more cost-effective to protect against direct contact with contaminated soil in areas where leaching is not a concern. Therefore, these three process options have been retained as representative process options for capping.

5.3.2.3 Soil *In Situ* Treatment

In Situ Physical Removal and Treatment

Physical removal and treatment technologies operate *in situ* to remove VOCs and SVOCs from soil. This technology typically includes a network of extraction points for the recovery of extracted air or fluids from the subsurface. Contaminated air or fluids are treated above ground. Process options for *in situ* physical removal and treatment include:

- **Passive Venting.** Soil vapors beneath a building foundation are vented to the atmosphere either through atmospheric pressure changes or by applying a low vacuum with a ventilation fan. Vented vapors can be passed through granular activated carbon (GAC) for treatment, if necessary.
- **Soil Vapor Extraction.** Soil vapor extraction consists of a vacuum applied to subsurface soil to remove soil vapor. Volatile constituents in soil are removed in the vapor stream and are treated above ground.
- **Soil Flushing.** Soil flushing is an enhancement to groundwater extraction and treatment where a solution that enhances the solubility of organic contaminants is injected into groundwater, passed through contaminated soil to remove contaminants, and then extracted for treatment. Surfactants and alcohols are examples of flushing solutions.

These physical removal and treatment process options have limited effectiveness for Site COCs and limited implementability based on Site geology, as summarized on Table 5-6. This technology has not been retained in the final screening for alternative development.

In Situ Thermal Treatment

Subsurface heating can be used to destroy or volatilize organic chemicals, such as Site COCs (VOCs and SVOCs) present in soil. Low-temperature, mid-temperature, and high-temperature thermal technologies are described in detail in Section 5.3.1.3 for DNAPL.

The *in situ* thermal treatment process options for soil include:

- **Hot Water Injection.** Described in Section 5.3.1.3 for DNAPL.
- **Steam Injection.** Described in Section 5.3.1.3 for DNAPL.
- **Electrical Resistance Heating (ERH).** Described in Section 5.3.1.3 for DNAPL.
- **Thermal Conduction Heating (TCH).** Described in Section 5.3.1.3 for DNAPL.
- **Vitrification.** In vitrification, a strong electrical current is applied to the subsurface, heating soil to temperatures above 2,400°F to fuse it into a glassy solid. Organic compounds are destroyed or volatilized by the heating process; volatilized compounds are collected in the offgas and treated. Inorganic compounds are immobilized within the glass.

In situ thermal treatment process options were not retained for remedial alternative assembly based on limited effectiveness, implementability, and cost, or the availability of more cost-effective *in situ* treatment options, as summarized in Table 5-6.

In Situ Stabilization

In situ solidification/stabilization described in Section 5.3.1.3 for DNAPL is potentially applicable and effective for immobilizing Site COCs in soil. Solidification/stabilization is technically implementable, and of relatively moderate cost. Therefore, solidification/stabilization has been retained as a representative *in situ* stabilization process option for soil.

In Situ Chemical Treatment

Chemical treatment uses the physical and chemical properties of the contaminants to destroy/chemically convert the COCs in the soil *in situ*. Process options for *in situ* chemical treatment include:

- **Chemical Oxidation.** Discussed in Section 5.3.1.3 for DNAPL.
- **ElectroChemical Remediation Technology (ECRT).** Destroys organic contaminants *in situ* by applying an alternating current across electrodes placed in the subsurface. In theory, the applied voltage creates redox reactions that destroy constituents through oxidation-reduction mechanisms.

Bioremediation is potentially more effective and of relative equal or lesser cost than either chemical oxidation or ECRT. Therefore, *in situ* chemical treatment was not retained for soil.

Bioremediation

The activity of naturally occurring microbes is stimulated by amending soils with water-based solutions to enhance *in situ* biological degradation of organic contaminants.

This technology is most effective for VOCs, but is also effective (at a slower rate) for some SVOCs. Bioremediation is least effective for high-molecular weight (5- or 6-ring) PAHs (including benzo[a]pyrene). Bioremediation is generally not effective for metals; however, changes in groundwater chemistry, such as redox conditions, may cause some metals to form less toxic complexes or become insoluble, precipitating out of solution. Site VOCs and SVOCs degrade most efficiently using electron acceptors such as oxygen, nitrate, and sulfate. Oxygen is typically the preferred amendment, but delivery of other electron acceptors is more appropriate depending on Site redox conditions.

Process options for bioremediation include:

- **Amendment Injection.** This process option delivers amendments to the saturated zone and can be used to promote bioremediation of COCs in groundwater and saturated-zone soils. This technology can be used with groundwater pumping (i.e., recirculation) to enable amendment distribution through the subsurface.
- **Bioventing.** This process option increases oxygen in the unsaturated zone by extracting soil vapor, similar to soil vapor extraction (SVE). This process draws in atmospheric oxygen, which stimulates microbial growth.

Biodegradation is ongoing at the Site. Bioremediation has been widely demonstrated and could be implemented as a polishing technology for other more effective technologies under a variety of conditions. Bioventing has more limited applicability than amendment injection because of the shallow water table and the fact that most contaminants are located below the water table. Therefore, amendment injection was retained as a representative *in situ* bioremediation process option for soil.

5.3.2.4 Soil Removal Technologies

The process option for removal of contaminated soil consists of excavation. Excavators, backhoes, and other conventional earth moving equipment are the most common equipment used to remove contaminated soil from upland areas. Below the water table, shoring and dewatering may be required. Based on implementability and effectiveness of excavation, excavation has been retained as a representative soil removal process option.

5.3.2.5 *Ex Situ* Soil Treatment Technologies

Soil may be treated using physical, thermal, or biological technologies. *Ex situ* treatment requires excavation of soils. These technologies and process options for each technology are described below.

Physical Treatment

Physical treatment uses the physical properties of the soil and/or the contaminants to separate or immobilize the contaminants. Physical treatment process options include:

- **Solidification/Stabilization.** Excavated soil is mixed with amendments that immobilize and/or bind contaminants within the stabilized product. This process is similar to *in situ* solidification/ stabilization described above, except that soils are excavated and processed using a pug mill or similar equipment to blend in amendments.

Ex situ solidification/stabilization, though highly effective and implementable, is relatively higher in cost than equally effective *in situ* stabilization, and was not carried forward for alternative development.

Ex Situ Thermal Treatment

Ex situ thermal treatment uses heat to destroy organic contaminants. *Ex situ* thermal treatment process options for soil include:

- **Thermal Desorption.** Low-temperature thermal desorption involves heating soils to temperatures between 200°F and 600°F until volatile and semivolatile COCs such as benzene and naphthalene evaporate. This technology is effective for VOCs and SVOCs, achieving 90 to 99.7 percent destruction efficiencies for

PAHs (EPA 1999), but is not effective for metals. Exhaust gases produced by the process are typically combusted. Thermal desorption may be accomplished on-site with a mobile treatment unit or off-site at a permanent treatment facility.

- **Vitrification.** Described in Section 5.3.2.3 for *in situ* soils, the treatment process is similar for excavated soils.
- **Incineration.** Described in Section 5.3.1.5 for DNAPL.

Thermal desorption, vitrification, and incineration are highly effective for treating VOCs and SVOCs and implementable; however, thermal desorption is relatively less costly to implement. Therefore, thermal desorption has been retained as a representative *ex situ* thermal treatment process option for soil.

Ex Situ Chemical/Physical Treatment

Ex situ chemical/physical treatment separates contaminants from soil using various types of aqueous systems. Physical separation steps are often used before chemical separation to grade the soil into coarse and fine fractions. Process options for *ex situ* chemical/physical treatment include:

- **Soil Washing.** Contaminants sorbed onto fine-soil particles are separated from bulk soil in a water-based system on the basis of particle size. The aqueous solution can contain surfactants or other additives to promote contaminant dissolution. Soil washing has limited effectiveness for removing strongly hydrophobic chemicals such as PAHs, particularly from soils with a high organic content, and is not typically effective when soil is composed of large percentages of silt or clay (EPA 1999).
- **Solvent Extraction.** Solvent extraction is a variant of soil washing in which an organic solvent (rather than an aqueous solution) is put in contact with the soil to remove contaminants. This technology is more effective than soil washing at removing hydrophobic organic compounds such as PAHs.

These process options are expected to have limited effectiveness based on the high-fines content of Site soil and have not been retained. *Ex situ* chemical/physical soil treatment technology was not carried forward for alternative development.

Ex Situ Biological Treatment

Biological treatment consists of enhancing contaminant destruction or transformation by indigenous soil microbes by amending excavated soil with nutrients, moisture, and oxygen (typically provided by mixing). The process option for biological treatment consists of biotreatment. Methods of biotreatment include landfarming/composting, biopiles, and bioreactors.

Although many of the Site COCs are biodegradable and potentially amenable to biotreatment (e.g., inorganics such as arsenic would not be), the relatively recalcitrant nature of many COCs (particularly cPAHs present in fine-grained soil and DNAPL matrices) would require long treatment times, and complete degradation to achieve applicable cleanup levels for upland beneficial use of the material (i.e., avoiding landfill disposal) may not be feasible. Biotreatment requires significant space to implement (EPA 1999) and may have less effectiveness than other *ex situ* soil treatment options.

Therefore, biotreatment has not been retained and *ex situ* soil biological treatment was not carried forward for alternative development.

5.3.2.6 Soil Disposal Technologies

On-Site Beneficial Use

Excavated soils exceeding applicable cleanup standards may potentially be used on-site if they meet or can be treated to meet applicable cleanup standards. Process options for on-site beneficial use consist include:

- **Sand/Aggregate Reclamation.** Particle separation of excavated material with high sand content for use as concrete aggregate or general upland fill; and
- **Topsoil Feedstock.** Blending of excavated material with organics for use as non-organic topsoil feedstock.

On-site reuse may be appropriate for excavated soils, depending on COC concentrations and future Site use, and is of moderate relative cost. Both sand/aggregate reclamation and topsoil feedstock process options have been retained as representative on-site beneficial use process options for soil.

On-Site Confined Disposal

Excavated soils exceeding applicable cleanup standards can be disposed of on-site within a specially designed upland confined disposal facility (CDF). On-site confined disposal can be less costly than off-site confined disposal but requires long-term on-site management of contaminated materials.

An upland on-site CDF may be appropriate for disposal of excavated soils, depending on COC concentrations and future Site use, and is of moderate relative cost. Therefore, on-site upland confined disposal has been retained for soil.

Off-Site Landfill Disposal

Contaminated Site soils may be transported to an off-site, permitted disposal facility. The proper disposal facility would depend on whether the soil is classified as non-hazardous or hazardous waste. Because off-site disposal effectively removes contaminants from the Site and places them in a secure containment facility, and because it is cost-competitive when compared to on-site treatment technologies, soil disposal at both non-hazardous and hazardous landfills, as appropriate, have been retained as representative off-site landfill disposal process options for soil.

5.3.3 *Technology and Process Option Screening for Groundwater*

Table 5-3 summarizes remedial technologies and process options to address groundwater and evaluates process options for their applicability to Site COCs. Technologies and process options identified in Table 5-3 as potentially effective for Site COCs have been screened on the basis of relative effectiveness, implementability, and cost in Table 5-7. A description of each technology and process option, organized by GRA, is provided below.

5.3.3.1 Groundwater Institutional Controls

Institutional controls limit access to contaminated groundwater and may consist of legal restrictions such as use limitations recorded on the property deed. Process options for institutional controls include:

- Deed restrictions restricting use of groundwater for drinking; and
- Deed restrictions restricting use of groundwater wells.

These institutional controls can be effective and implementable under a wide range of conditions and generally apply to the entire Site. Consequently, the institutional control process options listed above were retained for groundwater.

5.3.3.2 Groundwater Monitored Natural Attenuation

Natural attenuation is the reduction of groundwater COC concentrations through a combination of naturally occurring physical, chemical, and/or biological processes. Some natural processes (e.g., sorption of hydrophobic organic contaminants to organic carbon in soil) act as containment mechanisms while others (e.g., biodegradation of contaminants by native bacteria) act as *in situ* treatment mechanisms.

The process option for monitored natural attenuation consists of groundwater monitoring to document the presence and effectiveness of natural processes in removing or containing Site COCs in groundwater.

While monitored natural attenuation may not be effective at achieving the RAOs as a stand-alone technology, it may be effective as a polishing step when combined with other treatment options. Monitored natural attenuation may be moderately effective for all COCs, is highly implementable at the Site, and has relatively low cost; therefore, groundwater monitoring was retained.

5.3.3.3 Groundwater *In Situ* Containment

Dissolved groundwater contaminant migration can be controlled by installing impermeable vertical barriers across groundwater flow paths or by altering groundwater hydraulics through groundwater pumping or stormwater controls.

Impermeable Vertical Barriers

Vertical barriers as an *in situ* containment technology described in Section 5.3.1.2 for DNAPL are potentially effective as an *in situ* containment technology for controlling the lateral migration of contaminated groundwater and are implementable under a wide range of conditions.

Process options for impermeable vertical barriers include slurry walls, sheet pile walls, and grout curtains, and are described in Section 5.3.1.2 for DNAPL; as discussed in that section, slurry walls are the most reliable to construct and cost-effective of these process options and was retained as the representative *in situ* containment process option for groundwater.

Groundwater Pumping

Groundwater pumping can be used to control the migration of groundwater contaminants by modifying hydraulic gradients and/or creating a capture zone within which groundwater flows toward the capture point. Groundwater pumping process options

include pumping from vertical wells and/or trenches. Because of its common application at other sites, implementability under a range of conditions, and its potential short-term application during construction, pumping from vertical wells and/or trenches was retained as a representative groundwater pumping process option.

Stormwater Controls

Migration of groundwater contaminants can be controlled by modifying hydraulic gradients influenced by stormwater infiltration. Process options for stormwater controls include:

- **Targeted Infiltration.** Creation of a hydraulic barrier by collecting and infiltrating stormwater and forming a local groundwater "mound."
- **Reduced Infiltration.** Reduce localized infiltration and seepage of stormwater in by implementing hydraulic controls such as an impermeable cap.

Implementation of targeted infiltration may be limited because of the seasonal variability of Site groundwater elevations. Reduced infiltration through impermeable capping is moderately effective and implementable under a variety of future Site uses; therefore, reduced infiltration has been retained as the representative stormwater control process option.

5.3.3.4 Groundwater *In Situ* Treatment

Permeable Reactive Barrier

A permeable reactive barrier can be used to limit the migration of dissolved groundwater contaminants by passively treating groundwater as it flows through the barrier. The process option for permeable reactive barriers consists of a sorptive/reactive wall. A sorptive/reactive wall consists of a trench excavacated in the upland and backfilled with permeable reactive materials. As groundwater flows through the barrier, permeable materials within the barrier sorb dissolved-phase constituents and can promote biodegradation. Sorptive/reactive walls materials applicable to coal tar/creosote Site COCs include activated carbon, organoclay, and materials with a high-organic content such as wood debris. Amendments to increase biodegradation may include calcium nitrate or other electron acceptors.

Because of its potential effectiveness for treating groundwater COCs and its implementability under a variety of Site conditions, a sorptive/reactive wall has been retained for groundwater.

In Situ Chemical Treatment

Discussed in Section 5.3.1.3 for DNAPL, *in situ* chemical treatment may be effective for reducing COC concentrations in groundwater. Chemical oxidation, the process option for *in situ* chemical treatment, is described in Section 5.3.1.3.

Implementability of chemical oxidation at the Site would be limited based on heterogeneous soils and high oxidant demand from natural organic materials. Chemical oxidation has higher relative cost than equally effective *in situ* technologies such as bioremediation. Therefore, the chemical oxidation process option was not retained and *in situ* chemical groundwater treatment technology was not carried forward for alternative development.

Bioremediation

Described in Section 5.3.2.3 for soil, bioremediation may be effective for COC reduction in groundwater.

Process options for bioremediation include:

- **Amendment Injection.** Described in Section 5.3.2.3 for soil; and
- **Biosparging.** Increases oxygen in the saturated zone by injecting atmospheric air to the subsurface.

Biodegradation of Site COCs may be effective, particularly if implemented as a polishing technology when combined with other technologies. Both amendment injection and biosparging may be effective at promoting biodegradation of Site COCs and are technically implementable, and therefore, are retained as representative bioremediation process options for groundwater.

5.3.3.5 Groundwater Removal Technologies

Discussed in Section 5.3.1.4 for DNAPL, removal via pumping may be effective for reducing and/or limiting migration of COCs in groundwater. Groundwater can be removed from the subsurface by pumping fluids from wells or trenches. A variety of pumping options are available for groundwater extraction but down-well pumps (e.g., electric submersible pumps) are most commonly used.

Groundwater extraction process options include:

- **Vertical Wells.** Described in Section 5.3.1.4 for DNAPL; and
- **Trenches.** Described in Section 5.3.1.4 for DNAPL.

Groundwater removal technologies have been implemented and are ongoing at many Superfund sites. While groundwater removal is not expected to adequately reduce source area concentrations for Site COCs that have low solubility (particularly cPAHs), it could be used as a polishing technology when combined with other technologies. Therefore, pumping from vertical wells and trenches was retained for groundwater.

5.3.3.6 *Ex Situ* Groundwater Treatment Technologies

Potentially applicable treatment technologies for extracted groundwater are described and evaluated below. Groundwater would not need treatment if it meets discharge requirements (e.g., if minimally impacted groundwater is extracted as a containment measure).

Physical/Chemical Treatment

Physical/chemical treatment technology uses the physical and chemical properties of the groundwater and/or the contaminants to separate or immobilize the contaminants. Process options include:

- **Adsorption.** Contaminated groundwater is passed through a bed of granulated media where contaminants sorb to the surface of the sorbent, reducing the concentration of COCs in the bulk liquid phase.
- **Air Stripping.** Contaminated groundwater and air are typically passed counter-currently through a tower and volatile contaminants (such as benzene and, to a

lesser extent, naphthalene) are transferred from the water to the air. The contaminant-laden air is usually treated by GAC and then discharged to the atmosphere.

- **Advanced Oxidation Processes.** Adding chemicals that directly oxidize organic groundwater contaminants, such as ozone, hydrogen peroxide (with or without catalysts such as Fenton's Reagent or ultraviolet light), and permanganate.

Adsorption is a widely used water treatment technology that is highly effective for treating VOCs, SVOCs, and arsenic in groundwater. Air stripping and advanced oxidation are highly effective for treating VOCs and to a lesser degree SVOCs, and are not effective for treating metals. Advanced oxidation is no more effective or implementable than adsorption or air stripping, and costs significantly higher, and therefore, was not carried forward for alternative development. Adsorption and air stripping were retained as representative process options for physical/chemical treatment for groundwater.

Biological Treatment

Biological treatment consists of contaminant destruction by passing contaminated groundwater through a biological reactor in which a contaminant-degrading microbial culture is maintained, generally by adding nutrients and oxygen and controlling temperature, pH, and other parameters. Types of biological reactors include bioslurry reactors, fixed-film bioreactors, and constructed wetlands.

Biological treatment is potentially highly effective for treatment of Site groundwater containing VOCs; however, the treatability of recalcitrant COCs (particularly cPAHs) would have to be demonstrated in bench-scale and/or pilot tests. Because biological treatment is likely to be effective for treating Site groundwater and is technically implementable, it has been retained for groundwater.

5.3.3.7 Groundwater Disposal Technologies

Recovered groundwater may be considered for on-site or off-site disposal. Some disposal methods may require pre-treatment depending on the quality of the extracted groundwater. Inclusion of these technologies in remedial alternatives could occur if short-term dewatering is required as part of construction.

Off-Site Management

Off-site groundwater disposal process options include:

- **Discharge to Sanitary Sewer.** Recovered groundwater is discharged to the local sanitary sewer system. Groundwater pre-treatment may not be required if COC concentrations meet discharge criteria.
- **Discharge to Surface Water.** Recovered groundwater is discharged to Lake Washington surface waters. A National Pollutant Discharge Elimination System (NPDES) permit would likely be required for discharges.

Discharge of groundwater to sanitary sewer and surface water are potentially effective, implementable, and cost-effective means for disposing of groundwater and are retained.

On-Site Management

Extracted groundwater may be discharged on-site via reintroduction to groundwater. Process options for reintroduction to groundwater include infiltration galleries or injection wells. On-site reintroduction to groundwater is often the preferred disposal method for water generated during construction at large sites, such as the Quendall Terminals Site, when practicable. Reintroduction to groundwater as a disposal method is potentially effective, implementable, and cost-effective, and therefore, has been retained.

5.3.4 *Technology and Process Option Screening for Sediment*

Technologies and process options identified in Table 5-4 as potentially effective for addressing Site sediments were screened on the basis of relative effectiveness, implementability, and cost as shown in Table 5-8. A description of each technology and process option, organized by GRA, is provided below.

5.3.4.1 Sediment Institutional Controls

Institutional controls limit access to contaminated material and may consist of physical restrictions, such as public advisories on fish consumption, or legal restrictions, such as use limitations recorded on the property deed. Process options for institutional controls include the following:

- Advisories on harvesting fish or shellfish typically implemented and enforced by the local health department;
- Monitoring and notification of waterway users to restrict specific activities to protect the remedy (e.g., restrictions on anchorage within the areas that are capped; restrictions on grounding of small vessels on the shoreline and on vessel draft, horsepower, speed, and time in area; restrictions on piling placement or removal through cap; and limits on other potential in-water construction/structures);
- Easements or restrictive covenants to limit activities which may damage the remedy or increase the potential for exposure; these can be placed on privately owned aquatic lands or on state-owned aquatic lands through a long-term agreement with the Washington State Department of Natural Resources (DNR); and
- Additionally, the locations of all subaqueous caps would be indicated on appropriate local governmental units' mapping systems.

These institutional controls are potentially effective at preventing exposure to hazardous substances and could be implemented under a wide range of conditions; however, institutional controls alone would not meet RAOs. Consequently, the institutional control process options that were retained for sediment are combined with active remedial technologies and/or are used to protect the selected remedy. These institutional controls are considered applicable to the alternatives with a cap remedy. In addition, for alternatives with a dredging component, short-term fish consumption advisories may be required due to the potential for short-term water quality and fish tissue impacts during dredging. A remedy including sediment institutional controls would need to be designed to reduce conflicts or restrictions on Tribal treaty fishing rights or other treaty-protected rights such as anchorage of Tribal fishing vessels or access to aquatic resources. The combination of monitoring, maintenance, and institutional controls; formal 5-year

reviews; and contingency actions (if required) are considered adequate for ensuring remedy integrity.

5.3.4.2 Sediment Monitored Natural Recovery

As a GRA, MNR provides monitoring to document the presence and effectiveness of natural processes in removing, reducing the risk associated with, or containing Site COCs. The key difference between monitored natural attenuation (MNA) for ground water and MNR for sediment is in the type of processes being relied upon to reduce risk. Transformation of contaminants, including biodegradation, is usually the major attenuating process for contaminated groundwater. However, often these processes are too slow for the persistent sediment contaminants and do not result in sediment remediation in a reasonable timeframe. Natural sedimentation is the process most frequently relied upon for MNR (EPA 2005).

While MNR may not effective at achieving the RAOs as a stand-alone technology, it may be effective when combined with other technologies. MNR may be moderately effective for all COCs, is implementable under a range of Site conditions, and may have a low relative cost. Therefore, MNR has been retained for sediment, primarily as a possible supplemental technology to be combined with other sediment remediation technologies.

Enhanced natural recovery (ENR) is a remedial approach that accelerates the rate of recovery by adding a thin layer of clean sand over impacted sediment (i.e., thin-layer placement). The acceleration can occur through several processes, including increased dilution through bioturbation of clean sand mixed with underlying contaminated sediment. Thin-layer placement is typically different than *in situ* isolation caps because it is not designed to provide long-term isolation of contaminants from benthic organisms. ENR has been implemented as part of a remedy at similar sites. For instance, ENR has been implemented successfully as a component of the larger remedial effort at the creosote-contaminated Wykcoff/Eagle Harbor Site on Bainbridge Island (ENVIRON and SPAWAR, 2009). Specifically, the thin-layerplacement has remained stable during 10 years of monitoring. Therefore, ENR has been retained.

5.3.4.3 Sediment *In Situ* Containment

Engineered caps as an *in situ* containment technology, described in Section 5.3.2.2 for soil, may be effective for isolating COCs in sediment.

Process options for sediment capping include:

- **Engineered Sand Cap.** Placing clean sand on the sediment surface provides a containment layer that isolates underlying sediment.
- **Post-Dredge Residuals Cap**. Placing clean materials on the dredged sediment surface provides a reduction in exposure to the residual contamination layer.

Engineered sand caps and post-dredge residuals caps are proven effective, implementable, and of low to medium relative cost; therefore, these process options have been retained for sediment.

5.3.4.4 Sediment *In Situ* Treatment

With the exception of sediment caps which include reactive media, most *in situ* treatment approaches for sediment are in the early stages of development, have not been fully demonstrated, and/or may have significant technical limitations (EPA 2005).

Physical/Chemical Treatment

Physical/chemical treatment uses the physical and chemical properties of the sediment and/or the contaminants to separate or immobilize the contaminants. Physical/chemical treatment process options include:

- **Permeable Reactive Capping.** A permeable cap is placed above contaminated sediments and a material (such as organoclay or activated carbon) is placed within the sediment cap to sorb DNAPL and/or dissolved-phase constituents, limiting migration into overlying sediment porewater and surface water.
- **Stabilization.** Described in Section 5.3.1.3 for DNAPL. In the aquatic environment, this process option is currently under development.

Stabilization of aquatic sediments *in situ* has not been demonstrated to be effective in the long-term. Therefore, stabilization was not carried forward for alternative development. Permeable reactive capping is the potentially most effective and implementable option for treating COCs *in situ* and was retained as the representative process option of *in situ* physical/chemical treatment. Reactive caps have been installed as the final remedy at many contaminated sediment sites across the United States, as described in Appendix C.

Bioremediation

Described in Section 5.3.2.3 for soil, bioremediation may be effective for reducing COC concentrations in sediment. The bioremediation process option for sediment is amendment injection. Amendment injection is an innovative technology that may not meet RAOs when implemented alone. However, it may be effective when combined with other technologies, and can potentially be implemented under a variety of Site conditions. Therefore, amendment injection was retained for future consideration as a potential sediment polishing technology, but not for stand-alone application.

5.3.4.5 Sediment Removal Technologies

Removal of sediments can be achieved by dredging (mechanical or hydraulic) or by using conventional upland excavation equipment or following dewatering.

Excavation

Process options for excavation include:

- **Upland-Based Excavation.** Use of long-reaching excavators positioned from upland staging areas to remove contaminated sediment; and
- **Cofferdam Containment.** Dry excavation of nearshore sediments may be facilitated through the installation of temporary cofferdams and lowering of the groundwater table.

The technical feasibility of dewatering and dry excavation declines rapidly with increasing excavation depth. Upland-based excavation is likely more cost-effective and significantly more implementable than cofferdam containment. Therefore, upland-based excavation was retained as a representative process option.

Dredging

Dredging is a sediment removal technology that allows for the removal of sediments without dewatering, which is required for traditional excavation methods. Process options for dredging include:

- **Hydraulic.** Removal using a cutterhead or auger, which dislodges the sediment, or plain suction. The dredged material is conveyed along with water, using a suction pipe and slurry pumps. The resulting sediment slurry is pumped to a barge or upland location for processing.
- **Mechanical.** Removal using an articulated fixed arm (e.g., backhoe) dredge, enclosed (environmental) bucket, or clamshell bucket on a barge. Environmental buckets are suitable for softer materials containing little debris. The mechanical dredge removes the sediment and transfers it into a separate barge for transport to the primary staging area.

Dredging effectiveness may be limited by resuspension, release of COCs (i.e., dissolved, particles, and sheens) to water and volatilization to air during dredging, and residual COCs remaining after dredging (USACE 2008). These effects may be reduced by use of containment (e.g., sheet piles, silt curtains, booms), best management practices (BMPs) (e.g., production rates, bucket control, etc.), and/or by equipment selection.

Both mechanical and hydraulic dredging may be applicable for sediment removal and were retained as representative dredging process options.

5.3.4.6 *Ex Situ* Sediment Treatment Technologies

Removed sediment may be treated using physical, thermal, or biological technologies. Technologies and process options for each technology are described below.

Physical Treatment

Physical treatment uses the physical properties of the soil and/or the contaminants to separate or immobilize the contaminants. Physical treatment process options include:

- **Physical Separation.** Described in Section 5.3.2.5 for soil. Excess water can be removed from sediments using process options such as gravity dewatering, filter press, or geotextile tubes, allowing for separate treatment and/or disposal of the liquid and solid fractions.
- **Solidification/Stabilization.** This process option, as applied to sediment, is similar to the description in Section 5.3.2.5 for soil. However, this process option is also an effective method of dewatering sediment prior to transport and off-site disposal.

Physical separation typically has a relatively high to moderate cost but, depending on the project, it may reduce overall treatment/disposal costs by reducing the volume of contaminanted materials requiring treatment/disposal. *Ex situ* stabilization is an effective, implementable, and relatively low-cost means of dewatering sediment for off-site disposal. Therefore, both physical separation and stabilization have been retained as representative physical treatment process options for sediment.

Ex Situ Thermal Treatment

Ex situ thermal treatment uses heat to destroy organic contaminants. *Ex situ* thermal treatment process options for sediment include:

- **Thermal Desorption.** Described in Section 5.3.2.5 for soil.
- **Vitrification.** Described in Section 5.3.2.5 for soil.
- **Incineration.** Described in Section 5.3.1.5 for DNAPL.

Thermal desorption is equally effective as vitrification and incineration in treating VOCs and SVOCs in excavated sediment but at a much lower relative cost; therefore, thermal desorption was retained as a representative *ex situ* thermal treatment process option for sediment. Thermal desorption of sediments may be less effective than for soils due to the higher moisture content of sediment and typically requires dewatering of sediments prior to treatment.

Ex Situ Biological Treatment

Ex situ biological treatment, as described in Section 5.3.2.5 for soil, may be effective for COC destruction in sediment. Biotreatment, the process option for biological treatment, is described in Section 5.3.2.5.

Although many of the Site COCs are biodegradable and potentially amenable to biotreatment, the relatively recalcitrant nature of many COCs (particularly cPAHs present in fine-grained soil and DNAPL matrices) would require long treatment times, and complete degradation to achieve applicable cleanup levels for upland beneficial use of the material (i.e., avoiding landfill disposal) may not be feasible. Therefore, biotreatment of Site sediments was not retained as a process option, and *ex situ* biological treatment was not carried forward for alternative development.

5.3.4.7 Sediment Disposal Technologies

On-Site Beneficial Use

On-site beneficial use, as described in Section 5.3.2.6 for soil, may be effective for disposal of sediment. Process options for on-site beneficial use includes:

- **Sand/Aggregate Reclamation.** Described in Section 5.3.2.6 for soil; and
- **Topsoil Feedstock.** Described in Section 5.3.2.6 for soil.

Both sand/aggregate reclamation and topsoil feedstock process options may be appropriate for dredged materials and the least costly methods of sediment disposal; therefore, both these process options have been retained for sediment.

On-Site Confined Disposal

On-site confined disposal, described in Section 5.3.2.6 for soil, may be applicable for sediment disposal. CDF process options for sediment include:

- **Confined On-site Disposal.** Described in Section 5.3.2.6 for soil.
- **Nearshore CDF.** Dredged sediments exceeding applicable cleanup standards could potentially be placed on-site in a specially designed CDF built along the shoreline.

Nearshore CDF construction would require significant filling and reduction of aquatic lands and, therefore, was not carried forward for alternative development. Placement of dredged sediment in an on-site upland CDF may be suitable for low-level concentrations of COCs in sediment, is implementable, and a relative low cost disposal option; therefore, upland CDF was retained as a representative on-site confined disposal process option for sediment.

5.3.4.8 Off-Site Landfill Disposal

Described in Section 5.3.2.6 for soil, off-site landfill disposal may be applicable for sediment disposal. The proper disposal facility would depend on whether the sediment is classified as non-hazardous or hazardous waste. Process options include a Resource Conservation and Recovery Act (RCRA) Subtitle D waste disposal facility for non-hazardous waste and a RCRA Subtitle C waste disposal facility for hazardous waste. Because off-site disposal would effectively remove contaminants from the Quendall Terminal Property and places them in a secure containment facility, and because it is cost-competitive when compared to on-site treatment technologies, disposal at both Subtitle D and Subtitle C off-site landfills have been retained for sediment.

6 Development of Alternatives

Remedial technologies and process options that were retained in Section 5 are assembled into remedial alternatives in this section. This section describes how alternatives were assembled, the remedy components for each alternative, and how the alternatives would be implemented. This section includes assumptions and conceptual design criteria used as the basis for FS-level cost estimates that are presented in Section 7 and Appendix D. Section 6.1 describes how alternatives were assembled and lists the 10 remedial alternatives developed for the Site. The alternatives include a No Action alternative (Alternative 1) to establish a baseline for comparison to the other active alternatives. Section 6.2 describes considerations and assumptions common to each alternative, and Section 6.3 describes the specific assumptions for and details of each remedial alternative carried forward for detailed evaluation in this FS.

6.1 Assembly of Remedial Alternatives

Remedial technologies and process options that were retained in Section 5 were assembled into the following alternatives. To assist the reader, descriptive titles for each numbered alternative are provided below with the areas that are the primary focus of the remedy listed in parentheses.

- **Alternative 1 – No Action**
- **Alternative 2 – Containment:** soil and sediment capping
- **Alternative 3 – Containment with Targeted Principal Threat Material (PTM)[25] Solidification (RR and MC DNAPL Areas):** treatment of deep upland PTMs via *in situ* solidification, passive groundwater treatment, and soil and sediment capping
- **Alternative 4 – Containment with Targeted PTM Removal (TD, QP-S, and QP-U DNAPL Areas):** targeted treatment of PTMs via removal/off-site disposal, passive groundwater treatment, and soil and sediment capping
- **Alternative 5 – Containment with Targeted PTM Solidification (RR, MC, and QP-U DNAPL Areas and ≥ 4-Foot-Thickness) and Removal (TD and QP-S DNAPL Areas):** targeted treatment of PTMs via *in situ* solidification and removal/off-site disposal, passive groundwater treatment, and soil and sediment capping
- **Alternative 6 – Containment with Targeted PTM Solidification (RR and MC DNAPL Areas and ≥ 2-Foot-Thickness) and Removal (TD, QP-S, and QP-U DNAPL Areas):** targeted treatment of PTMs via *in situ* solidification and

[25] PTMs for the Site include DNAPL, DNAPL-impacted soil, and DNAPL-impacted sediment (see Section 4.2). Upland PTMs include DNAPL and DNAPL-impacted soil located east of the shoreline. Sediment PTMs include DNAPL and DNAPL-impacted sediment west of the shoreline.

removal/off-site disposal, passive groundwater treatment, and soil and sediment capping

- **Alternative 7 – Containment with PTM Solidification (Upland) and Removal (Sediment):** treatment of upland PTM via *in situ* solidification; treatment of sediment PTMs via removal/off-site disposal; and soil and sediment capping
- **Alternative 8 – Containment of PTM Removal (Upland and Sediment):** treatment of upland and sediment PTMs via removal/on-site thermal desorption, and soil and sediment capping
- **Alternative 9 – Containment with Solidification and Removal of Contaminated Soil and Removal of Contaminated Sediment:** treatment of deep upland PTMs and contaminated soil via *in situ* solidification; treatment of shallow upland PTMs, sediment PTMs, and contaminated soil and sediment via removal/on-site thermal desorption; and soil and sediment capping
- **Alternative 10 – Containment with Removal of Contaminated Soil and Removal of Contaminated Sediment:** treatment of PTMs and contaminated soil and sediment via removal/on-site thermal desorption, and soil and sediment capping

The alternatives were assembled to provide a broad range of actions, including various levels of containment and treatment, consistent with EPA guidance (EPA 1988a). The focus of each alternative and whether each alternative uses containment or treatment to address each RAO (see Section 4.2) is summarized in Table 6-1.

The technologies and process options that make up each alternative (i.e., the remedy components) are summarized in Table 6-2. Table 6-3 provides summary descriptions of the alternatives, and estimated construction quantities are summarized in Table 6-4.

Not all process options that were retained in Section 5 as potentially applicable to the Site were included in the range of alternatives. Examples include *in situ* bioremediation of soil and biosparging of groundwater. While these are potentially viable polishing technologies, other viable polishing or *in situ* treatment technologies were selected for the purposes of the FS (for example, groundwater pump-and-treat in Alternative 10). It is expected that selection of the most appropriate process option would occur during remedy design.

6.2 Common Elements

This section describes considerations that are common to the alternatives, except Alternative 1 – No Action. These include assumptions regarding potential redevelopment of the Quendall Terminals Property (Section 6.2.1), future habitat considerations (Section 6.2.2), assumptions regarding the potential generation of hazardous waste during remediation (Section 6.2.3), and a summary description of predictive numerical and analytical modeling tools used to support development and evaluation of alternatives (Section 6.2.4).

6.2.1 *Redevelopment of the Quendall Terminals Property*

The Site is currently vacant and unused. The Quendall Terminals Property is likely to be redeveloped once a remedy is selected and implemented. Based on Site zoning and the most recent development plan, a future development is expected to include the following features, which were considered in developing alternatives:

- Future grade would likely be higher to meet the grades on adjacent properties and to allow installation of a gravity sewer system. As a result, excess material that may be generated during some remedies (e.g., an increase in soil volume during solidification) can likely remain on the Site.
- Site development would likely involve installation of structures such as buildings and utilities that may limit access to remedial components. If additional remedial measures are needed in the future, the presence of these structures may also limit the scope or type of remedial measures that can be implemented.

Post-remediation Site development is assumed to include impermeable engineered surfaces, such as roadways, sidewalks, parking lots, and building foundations. Future buildings would likely include deep foundation elements (e.g., driven pilings) that would be designed to ensure they are compatible with cleanup, as discussed below.

As discussed in the Site CSM (see Section 3), DNAPL in the subsurface does not appear to be actively migrating, likely because it is below residual saturation or is stratigraphically trapped. Site development construction activities have the potential to modify conditions that affect DNAPL mobility and potentially cause DNAPL to migrate, as follows:

- Reductions in stormwater infiltration from placement of impermeable caps would reduce hydraulic head and leaching, and thereby reduce DNAPL migration potential.
- Placement of fill has the potential to compress certain underlying soils such as peat, which could mobilize fluids present in those soils; however, compressible soils at the Site (e.g., peat) are low-permeability soils that limit DNAPL migration but do not contain significant quantities of DNAPL themselves. Therefore, fill placement is not expected to mobilize DNAPL.
- Installation of deep foundation elements can create preferential pathways for DNAPL migration. To limit this possibility, construction techniques that allow installation of foundation elements in a manner that does not provide preferential pathways (e.g., use of displacement pile technology) would be implemented in DNAPL areas as appropriate.

The alternatives include monitoring or active containment/treatment elements to address potential mobilization of DNAPL.

6.2.2 *Habitat Considerations*

It is anticipated that it would be necessary to fill wetlands to complete the Site cleanup and as a result, mitigation would be required pursuant to Clean Water Act (CWA) Section 404(b)(1). For purposes of evaluating FS alternatives, it is assumed that an area along the shoreline (the habitat area) would be used for mitigation following cleanup and

would remain undeveloped. This FS does not include habitat mitigation plans, but the alternatives consider this requirement and have been developed to allow future habitat mitigation to occur. Habitat mitigation pursuant to the CWA or the ESA would be included as part of the remedy.

Remedial components installed in the habitat area would need to consider potential access and use limitations, and some potential remedial components may not be compatible with future habitat areas. For example, providing periodic heavy equipment access inside the habitat area could unacceptably degrade the habitat unless the habitat area is designed to accommodate such localized disturbances. Cap designs would need to accommodate grade changes for potential wetlands and include a root zone for plants. Depending on the location of future wetland areas, the potential for contaminated groundwater to discharge into wetland habitat areas and impact biota would need to be evaluated and addressed. Potential actions could include placing impermeable reactive mats beneath wetland areas or additional overexcavation of contaminated materials. Specific requirements in the habitat area would be developed during remedy design.

The habitat needs of juvenile Chinook salmon would be an important focus during remedy design. The findings of recent research in southern Lake Washington would be used to prioritize habitat depth zones and characteristics (Tabor et. al 2006; Tabor et. al 2011).The emphasis would be on providing shallow water (less than 3 feet), sand and gravel substrate, and low gradients. In addition, opportunities for increasing shoreline complexity and increasing riparian vegetation close to shallow water habitat would be considered.

For the purposes of the FS, the following assumptions regarding habitat were made:

- The habitat area would consist of a 100-foot-wide corridor along the shoreline and be composed of a mixture of wetlands and riparian habitat. It is anticipated that only a portion of this 100-foot area would be needed for habitat mitigation pursuant to the CWA or the ESA.
- Remedial components requiring future access for monitoring or maintenance, such as permeable reactive barriers (PRBs) or groundwater extraction wells, would be placed outside the habitat area.
- Caps in the habitat area would require clean material to a minimum depth of 3 feet below current grade, to allow for potential creation of wetlands and to provide an adequate root zone for future plants.
- In-water work, such as sediment capping, dredging, backfilling, and sheet pile installation, would occur during the allowable in-water work window, which currently extends from July 16 to December 31 annually. However, dredging within sheet pile enclosures could occur outside of the in-water work window as the sheet pile isolates the dredge area from the lake.
- Remedy implementation would result in no net loss of aquatic habitat or function. For most alternatives, this is accomplished to maintain the existing location of the OHWM and the existing bathymetry near the shoreline. For alternatives with sediment caps along the shoreline, existing sediment would be removed to offset the cap thickness from the OHWM to approximately 75 feet offshore. For

comparison purposes, one alternative (Alternative 2) includes modification of the location of the OHWM without removal of existing sediments. In this alternative, the OHWM would move water ward in some locations and landward in others, yielding no net change in the area of Waters of the U.S.

6.2.3 *Potential Generation of Hazardous Waste during Remediation*

K035 RCRA wastes may be generated by remedial activities that remove soil above the water table in the footprint of the North and South Sumps. In addition, D018 RCRA wastes (benzene exceeding 0.5 mg/L toxicity characteristic leaching procedure [TCLP]) and WP01 state dangerous wastes (total PAHs exceeding 1 percent by weight) may be generated by remedial activities that remove soil or sediment containing DNAPL. For the purposes of cost estimating, the following assumptions have been made:

- Soil located above the water table within the footprint of the North and South Sumps, if removed, would designate as a K035 RCRA waste and would be disposed of at a RCRA Subtitle C landfill if transported off site.
- PTM soil, if removed, would designate as a D018 and/or WP01 waste, and would be disposed of at a RCRA Subtitle C landfill if transported off site.
- Other soil would not designate as a RCRA or Washington State dangerous waste.
- Dredged sediment would not designate as a RCRA or Washington State dangerous waste. Based on a review of available sediment data, most of the sediment has concentrations of total PAHs or benzene less than the RCRA and Washington State dangerous waste criteria.It is assumed that dredging, handling and dewatering would dilute concentrations in the removed sediment so that all material for disposal would not designate as a RCRA or Washington State dangerous waste.

Based on the maximum concentration of benzene (4.8 mg/kg at boring RB9), it is not anticipated that any soil generated would exceed 10 times the Universal Treatment Standard (UTS) of 10 mg/kg (i.e., 100 mg/kg); therefore, it is assumed that PTM soil would not require treatment prior to disposal at a RCRA Subtitle C landfill (40 CFR 268.49[c]). However, depending on the volume of material to be disposed of and other factors, it may be cost-effective to treat soils that would otherwise be designated as D018 and/or WP01 waste to remove the toxicity characteristic so they may be disposed of at a lower-cost RCRA Subtitle D landfill. This is an option that could be evaluated during remedy design.

DNAPL is often found in thin layers (i.e., stringers) that could not be “surgically” removed from surrounding soil that does not contain DNAPL. Excavation of these stringers and surrounding soil could result in either an increase (based on an increase in the volume of PTM soil) or decrease (based on the dilution of PTM soil with soil containing lower contaminant concentrations) in the hazardous waste volume. For purposes of this FS, the soil volume potentially being designated as D018 or WP01 is based on the estimated thickness of PTM soil and not adjusted based on potential dilution or inclusion of surrounding soil.

6.2.4 *Modeling Tools Used in Alternative Development*

Groundwater and sediment cap modeling were used to help develop alternatives in two ways: 1) to evaluate how site-wide alternatives could be structured to meet RAOs and 2) to provide conceptual design criteria for the purpose of developing alternatives and estimating costs. Results of the modeling completed for each alternative are provided in Section 6.2.4.2. Details of model setup, results, and sensitivity analysis are discussed in Appendices A and B. A summary of the model setup for each alternative is provided below.

6.2.4.1 Groundwater Flow and Fate and Transport Model

The numerical groundwater flow and fate and transport model described in Appendix D of the RI Report (Anchor QEA and Aspect 2012) was refined to develop and evaluate remedial alternatives in this FS. The refinements to the RI groundwater model to support its use in this FS are presented in Appendix A.

For the FS analysis, the FS groundwater model was initially set up using the same grid and input parameters used for the RI, with the following refinements:

- The grid was adjusted to accommodate particular remedy components (for example, to simulate solidified soils at a higher vertical resolution);
- Boundary conditions were adjusted and added/removed to simulate upland caps, PRBs, slurry walls, and removal of DNAPL; and
- Groundwater flow parameters were adjusted to simulate changes to aquifer properties associated with backfill placement and soil solidification.

In addition, to assist in developing alternatives, the Site-wide distribution of key indicator COCs and the effect of various remedial components were evaluated in a three-step process. First, source areas were identified as follows:

Model grid cells representing the distribution of DNAPL observed at the Site were identified as a source of contamination (referred to in Appendix A as a constant concentration boundary in the model) of benzene, naphthalene, and benzo(a)pyrene in groundwater. An average concentration[26] of naphthalene (11,000 µg/L) and benzo(a)pyrene (133 µg/L) were assigned to the model grid cells "containing" DNAPL. Because benzene concentrations vary widely in DNAPL areas based on the type of DNAPL, average concentrations were defined for each of three different areas of the Site as follows:

- 1,100 µg/L in the eastern portion of the former May Creek Channel Area, former Railroad Tank Car Loading Area, and former Still House Area (wells BH-25A[R] and Q9);
- 200 µg/L in the North Sump Area (wells BH-23 and RW-NS-1); and

[26] Average of concentrations reported on Figure 5.2-8 of the RI Report at wells within DNAPL areas: BH-5, BH-19, BH-20A, BH-21A, BH-23, BH-25A(R), Q4, Q9, RW-NS-1, and RW-QP-1. Non-detected concentrations were not included.

- 12,000 µg/L in the QP-U DNAPL Area, (wells BH-5,BH-19, BH-20A, and RW-QP-1).

Model grid cells containing DNAPL in the Solid Materials Loading Area were not identified as a constant concentration boundary because benzene, naphthalene, and benzo(a)pyrene were not detected in this area. Model grid cells around well BH-21A were also not identified as constant concentration boundaries because benzene was detected at a concentration of 4 µg/L, below the PRG. Model grid cells not containing DNAPL were similarly not identified as a constant concentration boundary.

Second, after establishing the constant concentration boundaries, the FS groundwater model was run for 100 years to simulate the potential contaminant fate and transport from hydrocarbon source areas (i.e., DNAPL) that has occurred since the beginning of Site operations.[27] This provided a model-predicted "representation" of the extent of contamination (i.e., pre-remedial action condition) of hydrocarbons across the Site.

Because no soil source of arsenic has been identified at the Site, pre-remedial action conditions for arsenic were identified based on groundwater empirical data reported in the RI Report (Anchor QEA and Aspect 2012) and are described below:

- In areas with concentrations below the MCL for arsenic (10 µg/L), the pre-remedial action condition was set at the state background concentration of 5 µg/L; and
- In areas with concentrations exceeding the MCL for arsenic (10 µg/L), as shown on Figures 3-6 and 3-7, the pre-remedial action condition was set at the average arsenic concentration[28] detected in these areas (39 µg/L).

Finally, to evaluate the effect of implementing a particular remedy component, the FS groundwater model was modified to simulate the remedial action (e.g., removal of an area of DNAPL or construction of a PRB), and then run for another 100 years to provide a model-predicted future extent of contamination (i.e., post-remedial action condition).

Because of limitations and constraints inherent in the application of predictive models to represent a physical system (e.g., simplifications of subsurface conditions, use of average source concentrations, and approximation of contaminant fate and transport parameters), the model-predicted results (e.g., extent of contamination) are approximations of actual Site conditions. While the FS groundwater model was calibrated to represent overall Site conditions, the model cannot exactly match the current Site conditions, especially on relatively small spatial scales; however, the FS groundwater model provides an appropriate basis for evaluating, on a relative basis, how a particular remedial action may

[27] As discussed in more detail in Section 7, one hundred (100) years was assumed for purposes of estimating O&M and monitoring costs.

[28] Average arsenic concentration at wells BH-5, BH-5A, BH-5B, BH19, BH-20B, BH-21B, BH-25AR, BH-26B, and BH-28B was used. The concentration detected at well Q9, 1,960 µg/L, was not included as it is suspected that the sample from this well was based on the presence and potential entrainment of DNAPL in the sample (see Section 5.2 of the RI Report, Anchor QEA and Aspect 2012).

change conditions and how different remedial actions compare. In addition to the groundwater modeling described in this section, the FS groundwater model was also used as part of this FS to evaluate and compare remedial alternatives, including estimating changes in groundwater contamination plume volume and groundwater restoration timeframe, as described in Sections 7 and 8.

6.2.4.2 Sediment Cap Modeling

The remedial alternatives include an engineered sand cap. A conceptual engineered sand cap design was developed for the FS based on assessments of cap stability and 1-dimensional numerical modeling of chemical attenuation within the cap (i.e., the model developed by Dr. Danny Reible from the University of Texas as described in Lampert and Reible 2009; hereafter referred to as the UT Model). The UT Model evaluations are discussed in detail in Appendix B. A brief summary of the UT Model is provided below.

The UT Model was used to evaluate the long-term performance of a sediment isolation cap. The UT steady-state model estimates the chemical concentrations vertically throughout a cap, including the surficial (bioturbation) layer, once steady-state conditions are achieved in the cap. As the dissolved contaminants move upward through the cap, they may undergo degradation and may partition onto the cap material. The UT Model simulates bioturbation, which mixes the surface layer, further reducing surface concentrations (Lampert and Reible 2009). The UT Model calculates the contaminant concentrations in the bioturbation layer as a balance between the flux from the underlying contaminant isolation layer, the flux associated with bioturbation processes, and the flux leaving the benthic boundary layer that enters the overlying water column.

The chemical isolation layer modeling was first applied to measured sediment porewater cation profiles at the Site, using validated Site characterization data presented in the RI Report (Anchor QEA and Aspect 2012). The model in this application provides a useful analytical framework to help differentiate the combined effects of a range of physical processes (e.g., advection and dispersion) from chemical and biological degradation processes for Site COCs.

Once calibrated, the UT Model was used to simulate the conditions for the proposed sand cap area. Predictions of nearshore seepage velocity from the FS groundwater model (Appendix A) were used as input to the sediment model. The results indicate that an isolation cap composed of 1.5 feet of sand in the nearshore area would sufficiently reduce contaminant flux such that surface sediment porewater/surface water PRGs (Table 4-6) would be achieved under steady-state conditions (Appendix B). Additional discussions of cap effectiveness are presented in Section 7.

6.3 Detailed Description of Alternatives

This section describes each of the 10 alternatives, including remedy components and how each component would be implemented. Many of the details of the alternatives (e.g., extent of excavation or solidification) presented in this section are preliminary design criteria developed using existing information. The preliminary design criteria are used to develop and compare remedial alternatives. Remedial area and material volume estimates are summarized in Table 6-4. Calculations for estimated quantities are provided in Appendix E.

Depending on the remedy ultimately selected by EPA, additional information may need to be collected during remedial design, which would be used to refine quantities and other design details. For example, additional explorations may be performed during remedial design to refine the extent of materials targeted for removal or treatment. In addition, bench- or pilot-testing may be performed during remedial design to optimize solidification amendments, PRB treatment media, and/or sediment cap designs. Additional data gathering to support remedial design would be conducted as necessary after a remedy is selected.

6.3.1 *Alternative 1 – No Action*

Per EPA guidance, this No Action alternative (Alternative 1) is included to provide a baseline for comparison to other active alternatives. Under Alternative 1, there would be no cleanup, monitoring, or associated land use actions.

6.3.2 *Alternative 2 – Containment*

Alternative 2 combines ENR of sediments, soil and sediment capping, and institutional controls to prevent exposure to contaminated media. This alternative includes maintenance of engineering controls and monitoring of ongoing natural attenuation of groundwater to confirm that exposure pathways are controlled. Specific remedial components include the following:

- ENR;
- Engineered sand cap;
- Reactive sediment caps;
- Upland cap;
- Institutional controls; and
- Monitoring.

A description of the remedial action components comprising this alternative is provided below and summarized in Table 6-2. A schematic showing the layout of alternative components is provided on Figure 6-1. Subsurface components of this alternative are illustrated along representative cross sections on Figures 6-2 and 6-3.

6.3.2.1 Alternative 2 Enhanced Natural Recovery

ENR would consist of a 6-inch (approximately 15 cm) thin sand layer placed over the sediments in the offshore area of Lake Washington to enhance ongoing recovery processes and minimize short-term impacts to the aquatic environment. ENR would provide a surface layer of clean material, resulting in an immediate reduction in surface chemical concentrations. ENR would facilitate the re-establishment of benthic organisms, minimize short-term disruption of the benthic community, and accelerate the process of physical isolation continued over time by natural sediment deposition (NRC 2003, EPA 2005).

ENR would be applied in areas of sediment where the BTV value is exceeded and DNAPL has not been observed. The shoreward extent of ENR placement (boundary with sand cap) was established by estimating the reduction in concentration of OC-normalized cPAHs in the bioturbation layer (upper 4 inches/10 cm) following placement of 6-inches

of sand. Based on an assumption that up to 3-inches of sand would mix with the underlying sediment, the ENR layer would result in an average concentration in the bioturbation layer of approximately 0.125 times the existing sediment surface concentration (i.e., reduce the surface concentration by 8 times). Most of the surface samples within the area proposed for ENR are within approximately 2 to 4 times the BTV. Two samples in the sediment area were excluded from the ENR extent and included in the reactive cap area (PTM sediment areas) because they had relatively high exceedances of the BTV (i.e., TD-14-SS and S-54 had 215 mg/kg and 799.7 mg/kg OC-normalized cPAHs).

ENR has been effectively employed as a remediation technique at many sites, including two sites within Puget Sound. At the Wyckoff/Eagle Harbor Superfund Site, a 15-cm thin sand cap was placed over sediments of "moderate concern" as defined by the sediment chemical concentration. These concentrations represented the High Apparent Effects Threshold (HAET), above which amphipod and oyster larvae exposed to sediment fail Site-specific acute toxicity tests, and benthic organisms may demonstrate chronic exposure effects (ENVIRON and SPAWAR 2009). At the Bremerton Naval Complex, 15 to 20 cm of sand was placed over sub-tidal sediments where polychlorinated biphenyl (PCB) concentrations exceeded 6 mg/kg-OC. The PCB concentration breakpoint was selected as an average concentration between the dredging related breakpoint (12 mg/kg-OC) and the 90th percentile sediment PCB concentration for the reference area sediment (ENVIRON and SPAWAR 2009). The proposed use of a surface sediment concentration to define the extent of ENR is consistent with these two regional sites. In addition, sediment remedy extent and long-term effectiveness is commonly evaluated using surface weighted average concentrations (SWACs).

The ENR material would likely consist of fine-grained to medium-grained sand and would be placed from a barge. Depending on the source of the sand material, it may be barged or trucked to the Site. Two methods of applying ENR used previously at other sites include hydraulic washing from the deck of a barge (effective for dispersing a thin-layer cap over a large area) or window placement from a split-hull hopper dredge. Specialized approaches for placing caps in thin lifts such as a spreader box may also be used. ENR may have limited, short-term water quality impacts due to the suspension of the ENR material in the water column.

As detailed in Appendix E, the estimated volume of ENR material placed would be 14,300 cy. Based on an assumed cap placement production rate of 500 cy per day, ENR would require approximately 6 weeks to implement.

6.3.2.2 Alternative 2 Engineered Sand Cap

The engineered sand cap would consist of approximately 1.5 feet of sand placed over the existing sediment surface. In addition, a geotextile layer may be placed between the sand and the existing sediment surface to demarcate clean material from underlying contaminated sediments in the nearshore area and provide separation between the cap material and the underlying soft sediment. Without a geotextile layer, the sand may initially sink into the soft sediment. A geotextile layer would also increase cap stability during and following placement. However, installation of geotextile layers in aquatic environments can be challenging and would be further evaluated in the design. For the FS, it is assumed a geotextile layer would be placed within approximately 75 feet of the

shoreline as a demarcation layer, and that a geotextile layer would not be placed under the offshore portions of the sand cap.

The sand cap would provide a clean bioturbation layer and would also reduce surface sediment porewater concentrations relative to deeper groundwater concentrations, ensuring the PRGs would be achieved in surface sediment under steady-state conditions (see cap modeling results in Appendix B). The engineered sand cap would be placed in the nearshore area, excluding the PTM sediment areas. The sand cap extent would encompass the area where porewater data exceeds PRGs (outside of the PTM areas) and where existing surface sediment concentrations are approximately greater than 8 times the BTV along the inner harbor line.

Shoreline cap sections with less than 15 feet of water depth would require erosion protection from wave energy and vessel-generated current. The estimated armor size required is material with a median diameter of 6.0 inches (i.e., rip-rap) for breaking waves (0 to 5 feet of water depth), or a median diameter of 0.6 inches (i.e., gravel) for non-breaking waves. Appendix B provides additional details regarding FS-level cap stability design calculations and conceptual material specifications for various cap layers. As an alternative to rip-rap, biotechnical stabilization (erosion protection which enhances habitat features) would be evaluated during the design. For example, a cellular confinement layer (e.g., geocell, Geoweb®, StataWeb™) and vegetation may be used to protect the sand cap surface. The use of a geocell technology generally reduces the required particle size of the armor material by providing material confinement within the cells. However, the installation of geocells in aquatic environments can be challenging and requires further evaluation in design.

From the shoreline to approximately 75 feet offshore, sediment would be removed prior to capping to maintain the existing elevation and profile of the nearshore area (i.e., 1.5 feet of sediment removal). Removal of sediment would likely be conducted using mechanical removal equipment either from a barge or from the shoreline. Sand would likely be placed using specialized capping delivery approaches such as a spreader box to provide a thin lift of material. The sand may be placed in two to three thinner lifts. To the extent practicable, nearshore erosion protection would be placed with land-based equipment. The removed sediment would be dewatered and disposed of as described in Section 6.3.3.2.

As detailed in Appendix E, the estimated volume of sediment dredged would be 2,200 cy, and the estimated volume of sand cap material placed would be 15,300 cy. Based on an assumed cap placement production rate of 500 cy per day and dredging rate of 400 cy per day, the sand cap would require approximately 7 weeks to implement.

6.3.2.3 Alternative 2 Reactive Caps

As shown on Figure 6-1, all aquatic DNAPL areas (DA-1 through DA-8) will be capped with reactive material under this alternative. These areas contain DNAPL deposits that, while currently stable, may be disturbed following a seismic or other extreme event.

Two reactive cap configurations are included in this alternative. Configuration One is a Reactive Core Mat® (RCM) layer overlain by clean sand, and Configuration Two is an amended sand cap. The amended sand cap would be installed in the QP-S DNAPL Area (DA-6), and the RCM cap in all other areas noted above.

6.3.2.3.1 Configuration One: RCM Cap

The objective of the RCM cap in this alternative is to sorb any disturbed DNAPL using a relatively thin reactive cap in areas where DNAPL is relatively limited in volume and less mobil due to weathering.(e.g., in the T-Dock area).

The RCM cap would consist of an organoclay RCM overlain by 6-inches of clean sand to provide a bioturbation layer. The RCM consists of an approximately ¼-in-thick organoclay layer sandwiched between two geotextiles layers stitched together. Along the shoreline in areas with less than 15 feet of water depth, the sand layer would require erosion protection from wave energy as described for the engineered sand cap. In addition, the RCM layer would be permanently secured on the banks using an anchoring system.

For the FS, based on the stability of the DNAPL, one layer of RCM is assumed for the reactive cap. A standard RCM includes approximately 0.8 pound of organoclay per square foot (ft^2) and is supplied in 1,500-ft^2 rolls (15 feet by 100 feet). It is assumed that a minimum of 1-ft of overlap between mats would be required. The RCM layer(s) could be placed from a barge in the offshore areas and from the shoreline using land-based equipment in the nearshore areas. RCMs initially float and then sink upon saturation with water. Sand bags may be used to accelerate RCM placement onto the sediment surface.

From the shoreline to approximately 75 feet offshore, sediment would be removed prior to capping to offset cap thickness and maintain the existing nearshore area profile (i.e., 6 inches of sediment removal). Sediment removal would likely be conducted using mechanical removal equipment either from a barge or from the shoreline. Sand would likely be placed using barge-mounted mechanical clamshell equipment. To the extent practicable, nearshore erosion protection would be placed with land-based equipment. The removed sediment would be dewatered and disposed of as described in Section 6.3.4.7.3.

As detailed in Appendix E, the estimated area of the RCM caps would be 215,000 sf, and the estimated volume of material dredged would be 600 cy. Based on an assumed RCM reactive cap placement rate of 10,000 square feet per day (including reactive material and sand) and dredging rate of 400 cy per day, RCM capping would require approximately 5 weeks to implement.

6.3.2.3.2 Configuration Two: Amended Sand Cap

The objective of the amended sand cap in this alternative is to sorb any disturbed DNAPL using a thicker reactive cap in areas where DNAPL is present in greater volume and potentially more mobil (i.e., in the QP-S DNAPL Area), and where the effect on aquatic habitat due to capping could be mitigated (e.g., along the shoreline).

The amended sand cap would consist of geosythetic layers overlain on top of the existing sediment surface, an attenuation layer of up to 24 inches of clean sand and bulk organoclay mix (90:10 by weight) over the geosythetic, a separation layer of up to 24 inches of clean sand over the attenuation layer, and 6-inches of clean sand over the separation layer for bioturbation/habitat layer. This would make the amended sand cap about 54 inches (4.5 feet) thick. Along the shoreline in areas with less than 15 feet of water depth, the amended sand cap would require erosion protection from wave energy as described above for the engineered sand cap.

The thickness of each layer in the amended sand cap presented here is estimated based on best engineering judgement. Further refinement and supporting engineering analyses would be conducted in the design. Due to the nominal amended sand cap thickness (4.5 feet), it would not be practical to dredge to, offsetthe full cap thickness and match existing bathymetry. Geotechical loading of the cap would be considered during the design, and measures would be taken to avoid the upward DNAPL migration due to consolidation in sediment caused by the weight of the amended sand cap. Reducing the overall cap thickness (and loading) as well as providing a partial offset (i.e. 1.5 feet) would also be considered during design. The nominal clean sand and bulk organoclay mix (90:10 by weight) in the attenuation layer would provide an order of magnitude greater sorptive capacity relative to the RCM cap configuration.

The amended sand cap's thickness without offset dredging would change the existing shoreline bathymetry. Therefore, it would need to be designed to enhance and improve aquatic habitat in consultation with Trustees, and in a manner that offsets loss of habitat.

The amended sand cap would likely be placed using specialized capping delivery approaches such as a spreader box to provide a thin lift of material. The sand may be placed in multiple thinner lifts. To the extent practicable, nearshore erosion protection would be placed with land-based equipment.

As detailed in Appendix E, the estimated area of amended sand capping would be 32,200 sf, and the estimated volume of material to be placed would be 6,200 cy. Based on an assumed amended sand cap placement rate of 500 cy per day, amended sand capping would require approximately 3 weeks to implement.

6.3.2.4 Alternative 2 Upland Cap

Areas where COCs exceed PRGs in surface soil would be capped to prevent direct contact with affected soil. Portions of the cap that are impermeable would also reduce infiltration, leaching from contaminated soils, and transport of contaminants into the deep aquifer.

The design of the cap would depend on habitat considerations and may vary across the Site. For the purpose of developing cost estimates, the FS assumes that the cap would be constructed prior to development, and used the following assumptions:

- The habitat area (see Section 6.2.2) would be re-contoured to allow for development of functional wetland and riparian habitat. Soil would be excavated to an average depth of 3 feet across this area, resulting in overexcavation and disposal of up to 14,800 cy of material.
- A marker fabric layer would be placed across the entire Site to delineate existing soil from future clean fill/cap materials.
- A 3-foot-thick permeable soil cap would be placed over the entire Site as shown on Figure 6-1, over an estimated 22 acres. The cap in the habitat area would be composed of a mixture of topsoil and other habitat materials as appropriate.

Construction of the upland cap is estimated to take approximately 3 months.

As described in Section 6.2.1, future Site redevelopment outside of the shoreline habitat area is expected to include placement of additional fill to raise the Site grade. The cap

placed in this area may consist of impermeable engineered materials such as concrete sidewalks or building foundations. Additionally, a small portion of the upland areas may include landscaping with permeable cap materials. The costs for installing impermeable, engineered caps or providing fill to raise the grade to support redevelopment are not considered remedial action costs and are not included in the FS cost estimates. However, because a redevelopment scenario with largely impermeable surfaces is considered the most likely long-term future Site use, the groundwater model used to evaluate alternatives in Sections 7 and 8 assumes that the upland cap outside of the habitat area would be impermeable.

6.3.2.5 Alternative 2 Institutional Controls

A combination of monitoring, maintenance, and institutional controls; formal 5-year reviews; and contingency actions (if required) would be used to ensure remedy integrity. Institutional controls that may be implemented as part of Alternative 2 are discussed below. Monitoring is discussed in Section 6.3.2.6.

Environmental covenants for the Railroad and Quendall Terminals Properties and state-owned aquatic lands would be filed with King County. Covenants may be placed on state-owned aquatic lands through a long-term agreement with the DNR. These covenants would prohibit Site activities that would interfere with the integrity of remedial actions (such as soil and sediment caps) or compromise protection of human health and the environment. Specific Site use restrictions and requirements identified in the environmental covenants may include the following:

- Protection of engineering controls such as soil and sediment caps by limiting activities which may damage the caps or increase the potential for exposure;
- Evaluation of vapor intrusion potential and/or construction of vapor controls beneath future buildings located above areas containing volatile COCs;
- Implementation of a construction management plan specifying monitoring and material management requirements for subsurface activities that would contact potentially contaminated media;
- Use of construction techniques that minimize the potential vertical mobilization of DNAPL for future deep foundation elements potentially penetrating areas of DNAPL. Such techniques may include use of displacement piles. Specific foundation elements and construction techniques would depend on geotechnical requirements for future structures; and
- Prohibition on future use of groundwater for drinking purposes and on construction of wells (other than for remediation or monitoring purposes).

In addition to environmental covenants, institutional controls for sediments may include the following:

- Enforcement and permit tools (i.e., administrative orders, consent decrees);
- Informational devices (i.e., seafood consumption advisories, education and public outreach, and site registry); and

- Monitoring and notification of waterway users:
  - Restrictive anchorage within the areas that are capped;
  - Restrictive grounding of small vessels on the shoreline;
  - Restrictions of vessel draft, horsepower, speed, and time in area; and
  - Restrictions on piling placement or removal through cap, or other potential in-water construction/structures.

6.3.2.6 Alternative 2 Monitoring

Short-term monitoring would be conducted during remedy construction. In-water work such as ENR and capping must occur during the allowable in-water work window and would require water quality control measures and water quality monitoring. Upland remedial measures that include disturbance of contaminated soil (for example, overexcavation of soil near the shoreline for habitat construction) would require a soil management plan and may require air monitoring. For each element of work, a construction quality assurance plan would be prepared following design to establish procedures for environmental monitoring during construction and to provide procedures for confirming that remedial components are constructed and documented with an appropriate level of quality assurance and quality control.

Long-term monitoring would be conducted to confirm that RAOs continue to be met after the remedy is implemented. This would include conducting periodic groundwater and sediment monitoring to verify that the area of contaminated groundwater is stable or shrinking, and that COC concentrations remain protective of Lake Washington. The operation, maintenance, and monitoring plan for the selected alternative would be written following design. The monitoring program would be developed to include specific objectives, a plan for assessing those objectives, and the methods to be used in implementing the plan. For the FS, the monitoring activities are assumed to include the following:

- Annual inspection of upland cap integrity;
- Surveys to inspect sediment cap integrity annually for 2 years, then at the 5- and 10-year marks;
- Sediment sampling and analysis in sediment cap and ENR areas annually for 2 years, then at the 5- and 10-year marks; and
- Groundwater monitoring of groundwater COCs would be conducted at a network of 20 wells quarterly for 1 year and annually thereafter.

Cap inspections would also be conducted after significant natural events, such as a large-magnitude earthquake.

6.3.3 *Alternative 3 – Containment with Targeted PTM Solidification (RR and MC DNAPL Areas)*

Alternative 3 includes a similar use of upland and sediment capping[29], monitoring, and institutional controls as Alternative 2, but also involves treatment of targeted areas of upland PTMs and additional treatment measures to further address contaminant migration near the shoreline. Additional measures include the following:

- *In situ* solidification of deep PTMs in the RR DNAPL Area and MC DNAPL Area;
- DNAPL collection trenches along the shoreline, to remove mobile DNAPL from the subsurface and further reduce the potential migration of DNAPL from the uplands to the lake sediments; and
- A PRB along the shoreline to reduce migration of contamination in groundwater from the uplands and enhance recovery of lake sediments and porewater.

A description of the remedial actions that would be taken in this alternative is provided below and summarized in Table 6-2. A schematic showing the layout of alternative components is provided on Figure 6-4. Subsurface components of this alternative are shown along representative cross sections on Figures 6-5 and 6-6. Remedial area and material volume estimates are summarized in Table 6-4.

6.3.3.1 Alternative 3 Solidification of Deep Upland PTMs

To reduce the volume of the Deep Aquifer contaminant plume, this alternative targets treatment of PTMs with the greatest potential effect on the Deep Aquifer: 1) PTMs located close to or in the Deep Aquifer; and 2) PTMs in the eastern portion of the Site, where downward groundwater gradients transport contamination from the Shallow Aquifer to the Deep Aquifer.

As described in Section 4, PTMs are present in or close to the Deep Aquifer at two locations: the RR DNAPL Area and the eastern portion of the MC DNAPL Area. To determine the area on the eastern portion of the Site (where downward gradients and therefore the potential for contaminant migration into the Deep Aquifer are greatest) that would provide the most efficient reduction in Deep Aquifer plume volume, the FS groundwater model was used to estimate the reduction in plume volume for different scenarios targeting progressively larger PTM areas on the eastern portion of the Site. Modeling assumptions are described in Appendix A and the areas addressed by each scenario are shown on Figure A-2. Three scenarios were modeled, as follows:

[29] In the QP-S DNAPL Area, a RCM cap would be installed in Alternative 3 instead of the amended sand cap assumed for Alternative 2. Refer to Section 6.3.3.6.

- Solidification of the RR DNAPL Area (Area 1 on Figure A-2), which includes the easternmost[30] and deepest (34 feet, at the top of the Deep Aquifer, at boring BH-30C) DNAPL occurrences;
- Solidification of the RR DNAPL Area and PTMs directly west of the RR DNAPL Area, including at borings MC-20, MC-23, and HC-5 (see Figure 4-3, and Areas 1 and 2 on Figure A-2); and
- Solidification of the RR DNAPL Area, PTMs directly west of the RR DNAPL Area, and additional PTMs located around borings BH-9, MC-18, and HC-4 (Areas 1, 2, and 3 on Figure A-2);

Additional scenarios involving PTM treatment west of Areas 1, 2 and 3 on Figure A-2 were not modeled because hydraulic gradients in the Deep Aquifer are primarily horizontal in the center of the Site and have an upward component near the shoreline (see Section 3.3).

The FS groundwater model predicts that removing or solidifying the RR DNAPL Area provides a significant reduction in plume volume (34 percent). Additional removal or solidification of PTMs further west results in additional reduction in groundwater contaminant plume volume, but the reduction is not proportional to the amount of soil treated. Including Areas 2 and 3 involves solidifying more than double and triple the amount of soil when compared to solidification of Area 1 but is predicted to reduce the plume volume by only an additional 8 and 14 percent, respectively. The estimated volume of soil treated and the model-predicted percent reduction in contaminant plume volume are provided in Table A-5. Based on the modeling results, solidifying Area 1, combined with solidifying deep PTMs in the MC DNAPL Area, was identified as the most efficient method of reducing groundwater plume volume.

In situ solidification was selected as the treatment method because it would be easier to implement than other methods but provides a similar level of effectiveness. The FS groundwater model (see Appendix A) was used to compare the effect, after 100 years, of implementing three potential treatment methods on plume volume: 1) excavation, off-site disposal, and replacement with clean imported fill; 2) excavation, on-site treatment, and backfill with treated soil; and 3) *in situ* solidification. The model predicted that these three treatment methods, when applied to the RR DNAPL Area, would result in a similar level of plume reduction (29 to 34 percent by volume: see Table A-4). Excavation of PTMs in this area would be difficult and expensive because of the presence of PTMs at great depth (34 feet) in the top of the Deep Aquifer, which would require substantial shoring and construction dewatering to access. Therefore, *in situ* solidification was selected as the treatment method. The extent of solidification and assumed construction methods are discussed below.

[30] DNAPL is also located further east in the Solid Materials Loading Area but DNAPL in that area has limited impact on groundwater quality (see Section 4.4.2.4) and is assumed to be a negligible contributor to contamination in the Deep Aquifer.

6.3.3.1.1 Area and Volume of Solidified Soils

In this alternative, PTMs in the RR DNAPL Area and the eastern portion of the MC DNAPL Area (polygon MC-1 on Figure 4-6) would be solidified. Soil located between or overlying layers of PTMs would also be solidified. For the purposes of this FS, it is assumed that solidification would include soil to a depth of 2 feet below the estimated bottom of PTMs. This would provide a buffer between solidified contaminated soil, which remains a potential contaminant source, and the surrounding aquifer. Figure 6-4 depicts the area of soil to be solidified and Figure 6-5 depicts a representative cross section of the vertical extent of soil to be solidified. The estimated extent of solidification includes approximately 0.4 acre to a maximum depth of 36 feet, and approximately 17,500 cy.

6.3.3.1.2 Soil Solidification Methods

Soils would be solidified *in situ* using large-diameter augers. The augers would include a mixing shaft to add amendments such as cement, soda ash, and/or bentonite to the soil. As the auger advances through the soil, cement grout (and any additives) would be pumped through the mixing shaft and out jets at the bottom of the auger. Augering would be performed in an overlapping pattern to amend the upland soils. Actual amendments and the amendment columns would be determined during remedial design. Testing would be performed to confirm that mixing is complete and that permeability and strength requirements are achieved.

In 2004, solidification was used at the adjacent former J.H. Baxter & Company site to remediate soil containing some of the same COCs (creosote-contaminated soil). Solidification was performed with 8.5-foot-diameter augers and soils were amended with 25 percent cement and 1 percent bentonite by dry weight. Solidification of Deeper Alluvium soils may require a smaller diameter auger because of the greater depth and denser materials.

Depending on the concentration of amendments added, it is estimated that the soil volume would increase between roughly 10 and 30 percent as a result of solidification (Riser-Roberts 1998.) For the purposes of this FS, it is assumed that the soil volume would increase by approximately 20 percent; this would result in a maximum increase in grade of approximately 7 feet (for solidification to a maximum depth of 36 feet). Because it is anticipated that future development would raise the overall grade of the Site (see Section 6.2.1), no removal or disposal of excess soil is assumed for the FS.

Based on a maximum estimated soil stabilization rate of 600 cy per day[31], solidification of this area is estimated to take approximately 2 months. Additional time would be required for mobilization, Site setup, and Site restoration. It is estimated that construction of this remedy component would take 4 months.

[31] This solidification rate is based on the average production rate at the Columbus, GA Site (EPA 1999). Estimated duration assumes solidification work would be conducted 5 days per week during normal working hours.

6.3.3.2 Alternative 3 DNAPL Collection Trenches

Collection trenches would be installed along the shoreline to intercept mobile DNAPL. Although DNAPL attributes at the Site indicate a low-migration potential, either because it is stratigraphically trapped by low-permeability layers in the Shallow Alluvium or because it is present below its residual saturation, the complexity of Site geology makes it difficult to fully assess potential migration pathways. DNAPL collection trenches along the shoreline would provide a means of both monitoring and removing DNAPL that has the potential to migrate from the uplands into lake sediments. However, because of its low migration potential, it is expected that only a small portion of Site DNAPL would be mobile enough to be captured by the trenches.

DNAPL collection trenches have been implemented at similar sites, such as the American Creosote (EPA 1993b), Garland Creosoting (EPA 2006), and Madisonville Creosote Works (EPA 2012) sites. DNAPL collection trenches have been constructed of gravel, organoclay, or a combination of the two. Gravel-filled trenches contain a sump to which DNAPL drains. The gravel collection trench would facilitate collection of DNAPL, which would be removed and treated. An organoclay-filled trench would adsorb and immobilize the DNAPL in place, also removing sheen and a portion of the dissolved phase. A trench can also combine both the gravel-sump and an organoclay-containing RCM along the downgradient wall. The advantage of this combination is that in addition to gravity settling of the bulk DNAPL, any sheen or DNAPL particles that are too small to settle before crossing the trench would be adsorbed to the organoclay RCM. Both the organoclay-filled trench and the combination trench would help improve performance of the groundwater treatment wall (see Section 6.3.3.3).

DNAPL collection construction methods would be analyzed and specific design details (e.g., dimensions and materials) would be determined during remedial design. For the purposes of this FS, DNAPL would be collected under this alternative using gravel-collection trenches and an organoclay RCM would be placed in trench sections that are directly adjacent to the permeable groundwater treatment wall. DNAPL collection trenches would be constructed as follows:

- Five 2-foot-wide trenches would be constructed along approximately 500 feet of shoreline where DNAPL has been identified. Trench alignments are shown on Figure 6-4. Trenches would be placed as close as practicable to the shoreline but outside the future shoreline habitat area (see Section 6.2.2) to facilitate access for O&M[32]. One trench would be constructed near the mouth of the former May Creek Channel, and four trenches would be constructed along the shoreline of the Quendall Pond Uplands area. Multiple trenches are assumed for this area to target different depths along the shoreline and to reduce the lateral distance, and required sloping, of collection piping at the base of each trench. Because the soils in this area are heterogeneous, an impermeable liner would be placed at the bottom of the trench to prevent DNAPL entering the trench from migrating into adjoining permeable soil layers.

[32] Potential methods of integrating the collection trenches with the habitat area to capture DNAPL closer to the shoreline would be considered during remedy design.

- Trenches would be excavated using an excavator and temporary sheet piling for shoring. Trenches would be keyed into the low-permeability soil layer beneath the deepest DNAPL occurrence along each alignment. An impermeable, chemically resistant high-density polyethylene (HDPE) liner and a 4-inch-diameter perforated HDPE collection pipe would be placed at the trench base. The base of each trench would be sloped to an approximately 3-foot-deep, 12-inch-diameter stainless steel collection sump.
- A 4-inch-diameter HDPE riser pipe would be installed in each sump to an access manhole at the ground surface.
- A 4-inch-diameter HDPE cleanout pipe would be installed at the end of the collection pipe opposite the sump (or at both ends if the sump is centrally located) for maintenance purposes, with an access manhole at the ground surface.
- An RCM would be used to line the downgradient trench wall adjacent to a PRB.

The trench would be backfilled with pea gravel and topped with an impermeable cap. Soil excavated during the trench installation would be stockpiled, characterized, and disposed of accordingly. For the purposes of this FS, PTM soil is assumed to be designated as a characteristic hazardous waste and/or state-only dangerous waste, and would be disposed of as a hazardous waste at a RCRA Subtitle C landfill. An estimated 926 cy of contaminated soil, including 167 cy of PTM soil, would be removed during trench installation.

Temporary dewatering from inside the trench would be performed to facilitate construction. In some areas, dewatering may also be required to depressurize the Deep Aquifer. The maximum estimated flow rate to facilitate construction of a 25-foot-deep, 100-foot-long trench along the shoreline is 50 gallons per minute (gpm; see Appendix A, Table A-10). Although additional testing and analysis would be required prior to construction design, it is assumed that water generated during construction would be treated and discharged to the sanitary sewer.

Construction of DNAPL collection trenches is estimated to take approximately 3 months.

Previous product recovery pilot testing indicated slow recovery rates from wells containing DNAPL, as Site DNAPL is generally located in thin stringers that are expected to have poor recovery characteristics; therefore, DNAPL recovery is assumed to be performed by periodically pumping sumps manually rather than by using automated pumps. Based on the pilot test results, the initial recovery rate is estimated to be less than 500 gallons per year (see calculation in Appendix E). Based on the performance of DNAPL collection trenches at other sites, the rate of recovery is likely to decline over time.

Based on the chemical characteristics of DNAPL collected during previous pilot testing, it is assumed that collected DNAPL would be a characteristic hazardous waste given the anticipated concentrations of benzene, and also a Washington State persistent dangerous waste given the anticipated concentrations of PAHs. Collected DNAPL would be placed in 55-gallon drums and temporarily stored on the Site within a secured area with secondary containment. For disposal, DNAPL would be shipped to a hazardous waste treatment facility for incineration.

6.3.3.3 Alternative 3 Permeable Reactive Barrier

A subsurface PRB would be installed along the shoreline in the Shallow Alluvium to intercept contaminated groundwater and reduce the flux of contamination toward Lake Washington. The treatment wall would be designed to enhance ongoing natural attenuation processes occurring in the nearshore sediment area (see below). It would also provide a "control plane" at which to monitor and optimize treatment.

The PRB configuration, treatment media, and construction methods would be determined as part of remedial design, which would likely need to include treatability testing and detailed hydraulic modeling. For the purposes of this FS, a conceptual design based on preliminary modeling and implementation at other sites was developed as described below.

PRB Configuration. PRBs are typically constructed in one of three general configurations:

- A continuous vertical zone "wall" of permeable treatment media. This configuration is simple to construct but uses a large volume of treatment media, and replacement or maintenance of media over the full length of the wall is costly;
- A funnel and gate, in which impermeable wall sections ("funnels") are used to divert groundwater through 'gates' filled with permeable treatment media. This configuration allows maintenance to be focused on a subset of the full-wall alignment, but requires detailed analysis during remedial design to control mounding, ensure hydraulic capture, and optimize the performance of the adjacent sediment caps; and
- A reactor system, in which groundwater is collected in a gravel trench behind an impermeable wall, directed through underground reactor vessels filled with permeable treatment media, and discharged on the other side. This system allows the most flexibility in replacing media or using different media in sequence; however, it is the most complicated in controlling hydraulics and would require the most frequent maintenance.

For this FS, a funnel and gate configuration is assumed to provide an appropriate balance between design complexity and maintenance requirements. The FS groundwater model was used to identify a funnel and gate conceptual layout that would capture groundwater with significant PRG exceedances (i.e., in and near DNAPL areas) without increasing the lateral extent of the groundwater plume (see Appendix A). The conceptual layout is shown on Figure 6-4. The FS groundwater model predicted a maximum increase in hydraulic head of 1.5 feet behind the impermeable funnel sections. Additional modeling details, including the predicted lateral and vertical extent of the plume before and after funnel and gate installation, are provided in Appendix A.

Treatment Media. The PRB would be designed to remove hydrocarbons, including benzene, naphthalene, and benzo(a)pyrene, from groundwater. Potential treatment media for these COCs include GAC, organoclay, organic materials such as peat or mulch, and biostimulants such as air (via sparging) or nutrients such as calcium nitrate. For this FS, GAC was assumed as the treatment media because it is conventionally used in

groundwater treatment for COCs associated with coal tar and creosote[33] and has been successfully applied in full scale PRBs (Niederbacher 2000; Schad et al. 2000).

Location and Dimensions. The PRB would be located immediately downgradient of the DNAPL collection trenches so that the treatment media would not get saturated from free product. Similar to the DNAPL collection trenches, the treatment wall would be located just east of the habitat area to facilitate maintenance without disturbing habitat[34]. Because groundwater velocities would be highest directly downgradient of the gates, gates would not be placed in areas upgradient of PTMs to avoid mobilizing contamination.

The treatment wall would be constructed to a depth of approximately 25 feet to intercept the majority of the Shallow Alluvium groundwater plume without extending into Deeper Alluvium. The treatment wall would likely not extend into the Deeper Alluvium for the following reasons:

- To avoid introducing potential downward migration pathways into the Deeper Alluvium for DNAPL trapped in the Shallow Alluvium;
- Construction of a PRB to depths sufficient to intercept the full vertical extent of the groundwater plume (greater than 120 feet) would be very difficult; and
- Dissolved-phase contamination in the Deeper Alluvium has a much longer flowpath for attenuation before reaching Lake Washington. Monitoring to confirm that the Deeper Alluvium plume is stable or shrinking is included in this alternative (see Section 6.3.3.9).

Construction Method. PRBs can be constructed using a variety of methods. For the purposes of this FS, the PRB is assumed to be constructed using one-pass trenching because it is a proven method of placing both permeable and impermeable materials without the need for shoring or construction dewatering.

Depending on final design analyses, localized excavation in the shoreline area offshore of the treatment gates (i.e., zones of preferential groundwater flow) may be required to ensure the long-term effectiveness of nearshore sediment caps constructed in these areas. However, the extent of nearshore sediment dredging (and backfill with clean materials) in this scenario is anticipated to be minimal.

Construction of the funnel and gate PRB is estimated to take approximately 2 months.

Maintenance Requirements. PRBs generally require minimal maintenance; typically, they only require performance monitoring. However, more substantial maintenance may be required occasionally. Because the PRB is designed to absorb contaminants passing through it, the treatment media has the potential to become saturated. Because the source

[33] GAC has limited effectiveness for treating arsenic. For the purposes of this FS, the PRB is assumed not to provide treatment of arsenic as the arsenic concentrations exceeding the MCL along the shoreline are primarily detected in the Deep Aquifer (see Figure 3-12), below the proposed PRB.

[34] Potential methods of integrating the PRB with the habitat area to treat groundwater closer to the shoreline would be considered during remedy design.

of contamination is expected to remain for a long time, it is likely that at some time in the future, the media in the treatment gates would need to be replaced to prevent contaminant breakthrough.

The lifetime of the PRB treatment gates was estimated (see Appendix E) at approximately 30 years, based on the dimensions described above and the following assumptions:

- Groundwater velocity through a treatment gate of 1.1 ft/day, based on the maximum estimated by hydraulic modeling (see Appendix A);
- Benzene being the first COC to break through, based on its high concentration and low sorption potential relative to other COCs;
- An average benzene concentration in groundwater of 7.9 mg/L, based on the concentration detected in the Shallow Alluvium at monitoring well BH-20A, located near the northern treatment gate; and
- A safety factor of 2 (i.e., the change-out frequency was assumed to be twice the frequency required based on the parameters above) to account for uncertainty in how field performance may vary from predicted performance.

Spent GAC is assumed to require disposal as a RCRA hazardous waste based on potential benzene concentrations.

6.3.3.4 Alternative 3 ENR

ENR would be implemented in areas containing surface sediments exceeding the BTV but not covered with sand or reactive sediment caps (see Sections 6.3.3.5 and 6.3.3.6, respectively, below). The ENR area covers the same footprint as described for Alternative 2 and would be constructed using the same methodologies described in Section 6.3.2.1.

6.3.3.5 Alternative 3 Engineered Sand Cap

An engineered sand cap would be placed over sediments where porewater data exceeds PRGs (outside of the PTM areas) and where existing surface sediment concentrations are approximately greater than 8 times the BTV along the inner harbor line. The cap would cover the same footprint as described for Alternative 2 and would be constructed using the same methodologies described in Section 6.3.2.2.

6.3.3.6 Alternative 3 Reactive Cap

Reactive sediment caps would be placed over sediments containing near-surface PTMs. Reactive caps would cover the same footprint as described for Alternative 2, but under Alternative 3 all reactive caps would be RCMs (Configuration One as described in Section 6.3.2.3). As detailed in Appendix E, the estimated area of the RCM caps would be 247,000 sf, and the estimated volume of material dredged would be 1,000 cy. Based on an assumed RCM reactive cap placement rate of 10,000 square feet per day (including reactive material and sand) and dredging rate of 400 cy per day, RCM capping would require approximately 6 weeks to implement.

6.3.3.7 Alternative 3 Upland Cap

Areas where COCs exceed PRGs in surface soil would be covered with an engineered cap to prevent direct contact with affected soil. The cap would be constructed as described in Alternative 2 (see Section 6.3.2.4 above).

6.3.3.8 Alternative 3 Institutional Controls

Institutional controls for Alternative 3 would be the same as for Alternative 2 (see Section 6.3.2.5), and would include environmental covenants for the Railroad and Quendall Terminals Properties and state-owned aquatic lands, advisories on harvesting fish or shellfish issued by the local health department, and notification of waterway users to restrict specific activities to protect the engineered sand cap and reactive caps.

6.3.3.9 Alternative 3 Monitoring

Short-term monitoring would be conducted during remedy construction, and long-term monitoring would be conducted to confirm that natural attenuation continues and RAOs continue to be met after the remedy is implemented. Monitoring would be conducted as described in Alternative 2 (see Section 6.3.2.6).

6.3.4 *Alternative 4 – Containment with Targeted PTM Removal (TD, QP-S, and QP-U DNAPL Areas)*

Alternative 4 includes the same remedies as Alternative 3, but instead of treating deep upland PTMs to reduce groundwater contaminant plume volume, Alternative 4 includes targeted removal of PTMs in the Quendall Pond (QP) and T-Dock (TD) DNAPL Areas. As described in Section 4, the TD DNAPL Area contains sediments with the highest toxicity, based on the presence of DNAPL in relatively shallow sediments. The QP DNAPL Area includes potentially mobile DNAPL close to Lake Washington, including in upland soil adjacent to the shoreline (QP-U DNAPL Area) and in shallow sediments (QP-S DNAPL Area). The purpose of targeting these areas is to remove PTMs with the greatest future exposure risk.

Alternative 4 includes the following components:

- Upland PTM removal in the QP-U DNAPL Area;
- DNAPL collection trenches;
- PRB;
- ENR;
- Engineered sand cap;
- Reactive sediment cap;
- Sediment PTM removal in the QP-S and TD DNAPL Areas;
- Upland cap;
- Institutional controls; and
- Monitoring.

The areas addressed by different components of Alternative 4 (not including upland capping which, for clarity, is shown on the Alternative 3 plan view [Figure 6-5] but not

on the plan views of subsequent alternatives) are shown on Figure 6-7. Representative cross sections illustrating this alternative's subsurface components are provided on Figures 6-8 and 6-9. Each component is discussed below.

6.3.4.1 Alternative 4 Removal of Upland PTMs (QP-U DNAPL Area)

In this alternative, PTMs in the QP-U DNAPL Area would be excavated, disposed of off site, and replaced with clean imported fill. Excavation and off-site disposal was selected rather than: 1) excavation, on-site treatment, and backfill with treated soil or 2) *in situ* solidification based on the following constructability and cost considerations:

- This alternative also includes removal of sediments in the adjacent QP-S DNAPL Area. Removal of the two areas in tandem could allow for construction efficiencies.
- For the estimated soil volume to be removed (12,700 cy), on-site treatment is not expected to be cost-effective compared to disposal based on economies of scale for mobilizing and operating on-site treatment equipment.

The extent of soil removal and assumed construction methods are discussed below.

6.3.4.1.1 Areas and Volumes of Soil to be Removed

The lateral and vertical extent of the QP-U DNAPL Area is described in Section 4.4.2.3 and includes layers of potentially mobile DNAPL of significant thickness within 100 feet of the shoreline. Removal of adjacent sediment PTMs is described in Section 6.3.4.6.

Figure 6-7 depicts the area of soil to be removed, and Figure 6-8 depicts a representative cross section of the vertical extent of soil to be removed. Approximately 0.5 acre to a maximum depth of 19 feet would be removed, resulting in removal of 15,600 cy of upland soil.

6.3.4.1.2 Soil Removal Methods

Excavation below the water table can be performed "in the dry" or "in the wet". Wet excavation, similar to dredging, leaves behind residual contamination, as discussed in Section 5.3.4.5, leading to very long timeframes for groundwater restoration. However, dry excavation can require substantial dewatering and depressurization of the Deep Aquifer, which raises cost and can mobilize contamination below the excavation prism before it is removed.

For Alternative 4, contaminated residuals resulting from wet excavation would be left behind and managed through backfilling. However, to the extent that dewatering can be conducted in a cost-efficient manner, dry excavation is still preferred for a number of reasons, including:

- More efficient removal of material. For variable depth excavations, sidewall slopes would likely be much less steep (resulting in additional volume removed) under saturated conditions;
- Less handling and processing of excavated material to remove water;
- Easier field verification of excavation extent and performance; and
- Fewer contaminated residuals.

To excavate material in this Site area, both excavation methods would require temporary shoring to achieve target depths and prevent sidewall sloughing. Shoring (discussed in Section 6.3.4.1.3) would be provided with temporary sheet piles surrounding the excavation area. In addition, an excavation that is accompanied by dewatering may require Deep Aquifer depressurization to maintain excavation stability. The Quendall Pond area would requires dewatering and depressurization whether excavation is performed wet or dry based on requirements for tieback installation as part of the shoring design (see Appendix F). Dewatering assumptions and shoring construction are discussed in Section 6.3.4.1.4.

After soils are removed from the cell, clean imported fill would be used to restore the original Site grade. Areas excavated in the wet would be backfilled with a material such as 1-inch rock that can be adequately compacted under saturated conditions. Fill would be placed in lifts and compacted. After the grade is restored, the sheet pile wall segments would be removed.

Based on a maximum estimated rate of 400 cy[35] per day for excavation and backfilling, removal of this area is estimated to take approximately 2 months. Additional time would be required for mobilization, Site setup, shoring and dewatering installation, and Site restoration. It is estimated that construction of this remedy component would take 8 months.

6.3.4.1.3 Shoring

Impermeable shoring walls would be installed around the excavation perimeter to prevent sidewall sloughing and to reduce the construction dewatering rate. Without shoring, unstable sidewall sloughing would require removal and disposal of contaminated material outside the targeted excavation area. In particular, shoring walls along the shoreline would be required to separate removal activities from Lake Washington.

Process options for impermeable shoring walls include sheet pile walls, secant pile walls, and cutterhead soil mixing walls. Each of these options could potentially be implemented at the Site. For the purposes of this FS, temporary sheet pile walls (which could be removed and reused) were identified as the likely least costly option. Conceptual design criteria for a sheet pile wall for a 19-foot-deep excavation include one row of tieback anchors and a minimum embedment depth of approximately 35 feet. Preliminary shoring design considerations are described in Appendix F. The sheet pile shoring wall perimeter is shown on Figure 6-7, and the estimated embedment depth is shown on Figure 6-8.

6.3.4.1.4 Construction Dewatering and Water Treatment

For the purposes of this FS, it is assumed that Deep Aquifer depressurization is necessary to perform excavation whether done wet or dry. To excavate PTMs in the vicinity of Quendall Pond, depressurization flow rates of 590 gpm are estimated to be needed to excavate in the dry, while wet excavation could be accomplished with a depressurization rate of 207 gpm (Cell 7: see Appendix A, Tables A-9 and A-10). For the QP-U DNAPL

[35] This type of removal and fill was performed at the former Barbee Mill site in 2006 (Aspect 2006). The Barbee Mill average removal and fill rate was used in this study because it accounts for area-specific hauling and working hour constraints.

area addressed by this alternative, wet excavation can be accomplished with a depressurization rate of 120 gpm (see Table A-9). Additional testing during design would be needed to ensure that dewatering and groundwater modeling assumptions are accurate.

Groundwater removed during dewatering activities would be treated and discharged. The level of treatment would depend on where treated water would be discharged, which could be one of the following:

- To the City of Renton sanitary sewer system, under a City of Renton and/or King County Metro sewer discharge permit. Discharged water would be treated by the King County sewer treatment plant or pretreated at the Site per the sewer discharge conditions;
- To groundwater via a new Underground Injection Control (UIC) well (Class V well) installed on the Site. Water would be treated to comply with WAC 173-200 Water Quality Standards for Groundwater of State of Washington; or
- To Lake Washington after treatment. The substantive requirements of a temporary NPDES permit would need to be defined with Ecology and could potentially allow for a mixing zone.

For the estimated maximum flow rate under this alternative, discharge to the City of Renton sanitary sewer system is anticipated to be the most cost-effective option. An on-site treatment system would be required to reduce COC concentrations to appropriate discharge limits.

The treatment system is assumed to include the following major components:

- Decant tank to remove DNAPL;
- Equalization/sedimentation tank to provide storage capacity and remove solids;
- Chemical precipitation mixing tank and clarifier to remove iron and manganese;
- Air stripper to remove VOCs, including benzene;
- Vapor-phase GAC adsorption units, to treat air-stripper offgas;
- Liquid-phase GAC adsorption units, to remove PAHs; and
- Sand filters upstream of the liquid-phase GAC adsorption units, to reduce fouling.

Based on the maximum concentration of arsenic detected in the QP-U DNAPL Area (51 µg/L in BH-20B) and the typical King Country Metro discharge limit for arsenic (1 mg/L), no treatment to address arsenic is assumed necessary.

6.3.4.1.5 Management of Removal Soil

Excavated soil would be segregated based on its potential waste designation. In this area of the Site, RCRA-listed wastes are not expected to be encountered; however, PTM soil may be designated as a characteristic RCRA waste based on the presence of benzene or a state-only dangerous waste based on the presence of PAHs. Segregated soil would be stockpiled and tested. Free liquids draining from soil stockpiles would be collected and treated using the construction dewatering treatment system (see Section 6.3.4.1.4). After

testing, soil would be loaded into trucks and transported to an appropriate facility as follows:

- Soil containing benzene less than 5 mg/L by TCLP extraction and less than 1 percent by weight PAHs would be transported to a Subtitle D landfill for disposal.
- Soil exceeding 5 mg/L benzene via TCLP extraction or 1 percent by weight PAHs would be transported to a RCRA Subtitle C landfill for disposal.

6.3.4.2 Alternative 4 DNAPL Collection Trenches

Collection trenches would be installed along the shoreline to intercept potentially mobile DNAPL. DNAPL collection trenches along the shoreline would provide a means of both monitoring and removing DNAPL that has the potential to migrate from the uplands into lake sediments. This alternative assumes DNAPL collection trenches would be constructed as described in Alternative 3 (see Section 6.3.3.2 above).

6.3.4.3 Alternative 4 Permeable Reactive Barrier

A PRB would be installed along the shoreline in the Shallow Alluvium to intercept contaminated groundwater and reduce the flux of contamination toward Lake Washington. The treatment wall would assist ongoing natural attenuation to protect potential sediment and surface water receptors and enhance recovery of the sediments and porewater. This alternative assumes the PRB would be constructed as described in Alternative 3 (see Section 6.3.3.3 above), except that the northern treatment gate would be moved upgradient of the soil excavation and backfill area. Placing the gate in this location would reduce groundwater flow velocities through PTMs remaining near the shoreline.

6.3.4.4 Alternative 4 ENR

ENR would be implemented in areas containing surface sediments exceeding the BTV but not covered with sand or reactive sediment caps (see 6.3.4.5 and 6.3.4.6, respectively, below). The ENR area covers the same footprint as described for Alternative 2 and would be constructed using the same methodologies described in Section 6.3.2.1.

6.3.4.5 Alternative 4 Engineered Sand Cap

An engineered sand cap would be placed over sediments where porewater data exceeds PRGs (outside of the PTM areas) and where existing surface sediment concentrations are approximately greater than 8 times the BTV along the inner harbor line. The cap would cover the same footprint as described for Alternative 2 and would be constructed using the same methodologies described in Section 6.3.2.2.

6.3.4.6 Alternative 4 Reactive Cap

The reactive capping approach for Alternative 4 is the same as described in Section 6.3.3.6 for Alternative 3, except the extent of reactive capping is reduced in Alternative 4. Alternative 4 includes placing reactive caps over aquatic DNAPL areas DA-3, DA-4, DA-5, DA-7, and DA-8. All reactive caps would be RCMs (Configuration One as described in Section 6.3.2.3). The remaining aquatic DNAPL areas would be dredged as described below in Section 6.3.4.7. As detailed in Appendix E, the estimated area of reactive cap would be 86,000 sf, and the estimated volume of material dredged would be 600 cy. Based on an assumed reactive cap placement rate of 10,000 sf per day (including

reactive material and sand) and dredging rate of 400 cy per day, reactive capping would require approximately 2 weeks to implement.

6.3.4.7 Alternative 4 Sediment Removal

The areas proposed for dredging in Alternative 4 include the TD DNAPL Area (DA-1 and DA-2) and the QP-S DNAPL Area (DA-6). These areas contain near-surface DNAPL deposits that while currently stable, may be potentially disturbed following a large seismic event. As described in Section 4.4.2.6, the TD DNAPL Area contains sediments with the highest toxicity, based on the presence of DNAPL in relatively shallow sediments. The purpose of targeting these areas is to remove the highest toxicity sediments.

The effectiveness of dredging these areas may be limited by short-term impacts during dredging (i.e., resuspension of sediments; release of dissolved COCs, particles, and sheens to water; and COC volatilization to air) and by residual COCs remaining after dredging (USACE 2008 and Bridges et al. 2010). The dredge areas contain DNAPL, which increases the potential for water quality impacts during dredging. These effects may be reduced by use of engineering controls (e.g., sheet piles, silt curtains, booms), BMPs (e.g., production rates, bucket control, etc.) and/or by equipment selection. In addition, all dredging work would occur prior to capping work to reduce the potential for recontamination of capping areas that are adjacent to dredging areas. The extent and methods of dredging are described below.

6.3.4.7.1 Areas and Volumes of Sediment to be Removed

Figure 6-7 depicts the area of sediment to be removed, and Figure 6-9 depicts a representative cross section of the vertical extent of sediment to be removed. Removal depths correspond with observed depths of DNAPL. These dredge areas assume 2 horizontal to 1 vertical (2H: 1V) side-slopes to reduce sloughing and failure of adjacent sediments. A shallower slope (3H: 1 V) may be required in some areas where sediments are relatively soft or in deeper dredge areas. An overdredge allowance of 1-foot deeper than the target dredge depth was included in volume calculations. Calculations, including depths and areas of individual dredge areas and associated sediment core reference locations, are provided in Appendix E.

The estimated extent of sediment removal includes approximately 12,200 cy of offshore sediment and 11,000 cy of nearshore sediment for a total of 23,200 cy not including sediment removed for offsetting the cap thickness.

6.3.4.7.2 Sediment Removal Methods

Hydraulic Dredging. Offshore PTMs in the TD DNAPL Area (DA-1 and DA-2) would be removed by hydraulic dredging. DA-1 and DA-2 have relatively shallow target dredge depths which would allow use of hydraulic dredges designed for environmental dredging (e.g., SedVac® by Terra Contracting or the VicVac™ by Brennan). These have the potential for greater control of resuspension and releases than larger navigational hydraulic dredges (USACE 2008). In addition to using environmental dredging equipment, the potential short-term impacts may be further reduced by containing dredge areas within oil-sorbent booms and/or silt curtains. Because hydraulic dredges are not effective at handling debris, relic offshore structures would be removed prior to dredging. It is estimated that approximately three dolphin buoys of five piles each would need to be pulled to allow dredging in DA-2. A portion of DA-2 overlaps the existing DNR Dry

Dock Cap and a small portion of the remaining concrete ballast and wood hulls of the former dry docks (Figure 6-7). Because previous attempts to remove the hulls proved challenging, DNR left the structures in place and placed approximately 6-inches of clean sand over the structures. Portions of this cap would be dredged while dredging underlying PTMs. A small portion of DA-2 that contains the dry dock hulls would remain in place. The dredged material would be conveyed directly to an upland staging area in a pipeline.

Mechanical Dredging. Nearshore PTMs in the QP-S DNAPL Area (DA-6) would be removed by mechanical dredging. A temporary sheet pile enclosure would be installed around DA-6 to isolate the dredging activities from the lake and to support removal of sediments to greater than 9 feet bss. If there is substantial debris located within the footprint of the sheet pile enclosure, then this debris would require removal prior to installation of sheet pile. Mechanical dredging equipment may consist of a crane-mounted bucket or an articulated bucket (barge-mounted excavator). In areas free from debris, an environmental bucket may be used to minimize sediment resuspension during dredging operations. Where debris is present, a clamshell or conventional bucket would be required. For environmental dredging, bucket sizes are typically within the range of 3 to 10 cy (USACE 2008). Debris located within the dredge area/sheet pile wall would be removed during dredging operations, segregated, stockpiled, and disposed of off site. Dredged material would be placed into an enclosed barge and transported to an offloading area adjacent to the shoreline for transfer to an upland staging area.

The type and specifications of hydraulic and mechanical dredging equipment, as well as the extent of the use of hydraulic and mechanical dredging techniques, and specification of dredging equipment would be determined during design or bidding, based on the detailed dredge design. Real-time positioning systems would be used on the dredges to accurately control position, monitor inventory, and track dredging progress in real-time.

Based on an assumed sheet pile installation rate of 20 linear feet (lf) per day, sheet pile removal rate of 30 lf per day, dredging rate of 400 cy per day and a backfilling rate of 500 cy/day, sediment removal would require approximately 29 weeks to implement.

6.3.4.7.3 Management of Removed Sediment

Excavated and dredged materials including debris would be shipped off site for disposal at a permitted landfill as described in Section 6.2.3. Given the high moisture content of sediments, on-site dewatering would be conducted to meet the transportation and disposal requirements (i.e., no free water) and to reduce disposal mass. For mechanical dredging, free liquid would be decanted from the barge prior to offloading the sediments to the upland staging area. Dewatering of the mechanically dredged sediments may consist of gravity dewatering followed by addition of a solidification agent (e.g., cement products, lime, or diatomaceous earth). Dewatering of the hydraulically dredged materials would require additional processes such as vacuum boxes due to the higher water content. An upland staging area would be located on a portion of the upland area of the Site and would be used for sediment dewatering prior to loading into trucks for off-site transport and disposal.

Supernatant/decant water from dewatering would be treated using a temporary on-site water treatment facility. For this FS, it is assumed that discharge would occur to Lake Washington, under the substantive requirements of a NPDES discharge permit. Actual

treatment methods would depend on permit conditions and supernatant chemical concentrations; however, for costing purposes, treatment is assumed to consist of storage tanks, filtration, and GAC prior to discharge to the lake.

Following verification that dredge depths have been met, residuals management and backfilling would be completed. Residuals generated by dredging would be managed using a post-dredge residuals cover. A reactive residuals cover (composed of a 6-inch layer of 10 percent organoclay and 90 percent coarse sand by weight) would be placed in the dredged areas to address anticipated DNAPL and sediment residuals. Following placement of the residuals cover, these areas would be backfilled with sand. For the cost estimate, it is assumed the dredge areas are backfilled to the existing grade. In offshore dredge areas, the need to backfill to existing grade would be further evaluated in design. Backfill may be placed to an elevation below existing grade in offshore areas.Residuals cover and backfill material may be placed using a crane-mounted clamshell bucket or using the mechanical dredging equipment (following decontamination).

6.3.4.7.4 Sediment Removal Sheet Pile Enclosure

To provide sediment resuspension control, a temporary sheet pile enclosure would be constructed prior to nearshore sediment removal. The enclosure wall alignment is shown on Figure 6-7. The wall would be approximately 700 feet long. In addition to resuspension control, the wall would also serve as excavation support along areas where removal depths are relatively deep. The wall would tie into the shoreline at both ends and would isolate the sediment removal area from the rest of the lake. Groundwater seepage could potentially occur underneath the structure if a gradient existed; however, gradients are expected to be small and therefore seepage is not considered a concern. The contractor would be required to manage the water level within the enclosure to keep water level differentials small. Water level management would limit seepage and would also limit the hydrostatic load on the sheet pile wall to allow for an economical sheet pile design. To further reduce the potential for seepage, the sheet pile interlocks would be sealed. During design, a sealant would be selected that is chemically compatible with the contaminants anticipated within the enclosure.

Based on preliminary calculations and assuming small water level differentials, a cantilevered wall constructed using regular Z-type sheet pile sections would be feasible. The wall would be designed to withstand a combination of loads, including wave load, wind load, hydrostatic load due to water level differential, lateral earth pressures, and barge impact from barges operating inside the enclosure. Based on the preliminary calculations, an AZ17 sheet pile section distributed in the United States by Skyline Steel (or similar section by another vendor with the same section modulus) would be adequate to withstand stresses within the sheet piles and limit deflections. The sheet piles would need to be embedded deep enough into the subsurface soils to provide adequate stability. A minimum embedment into the underlying deeper alluvium of 10 feet is recommended. Based on the preliminary calculations, the sheet piles would need to be approximately 50 feet long. The sizing of the sheet piles would be refined during design. Design optimization may result in the use of more than one sheet pile size and length along the wall alignment.

Due to the relatively dense nature of the deeper alluvium, an impact hammer would be needed to drive the sheet piles into the deeper soil deposits. Pile driving using an impact

hammer generates significant noise (e.g., more than using a vibratory hammer) both above and underwater, which potentially may disturb nearby residences, fish and wildlife.

Some water quality impacts are anticipated to occur due to sediment resuspension during impact driving. Water quality would be monitored during enclosure construction, and modifications to the sheet pile installation and BMPs would be made as necessary to reduce water quality impacts. It is anticipated that a barge-mounted crane would be required for enclosure installation.

After dredging, backfilling, and allowing adequate settling time for resuspended sediments within the enclosure, the enclosure wall would be removed. For sheet pile removal, a vibratory hammer is expected to be adequate.

6.3.4.8 Alternative 4 Upland Cap

Areas where COCs exceed PRGs in surface soil would be covered with an engineered cap to prevent direct contact with affected soil. Portions of the cap that are impermeable would also reduce infiltration, leaching from contaminated soils, and transport of contaminants into the Deep Aquifer. The cap would be constructed as described in Alternative 2 (see Section 6.3.2.4).

6.3.4.9 Alternative 4 Institutional Controls

Institutional controls for Alternative 4 would be the same as for Alternative 2 (see Section 6.3.2.5), and would include environmental covenants for the Railroad and Quendall Terminals Properties and state-owned aquatic lands, advisories on harvesting fish or shellfish issued by the local health department, and notification of waterway users to restrict specific activities to protect the engineered sand cap and reactive caps. Short-term fish consumption advisories may be required for Alternative 4 due to the potential for short-term water quality and fish tissue impacts during dredging.

6.3.4.10 Alternative 4 Monitoring

Short-term monitoring would be conducted during remedy construction, and long-term monitoring would be conducted to confirm that natural attenuation continues and RAOs continue to be met after the remedy is implemented. Monitoring would be conducted as described in Alternative 2 (see Section 6.3.2.6). Additional short-term monitoring for Alternative 4 would include monitoring of sheet pile installation and dredging activities and associated short-term water quality impacts and odors and air emissions. In addition, sound monitoring, potentially including underwater monitoring, may be required during installation of the sheet piles using an impact hammer.

For the purposes of the FS, it is assumed that the dredging, residuals cover, and backfilling would result in a final remedy which does not require long-term monitoring for the dredge areas.

6.3.5 *Alternative 5 – Containment with Targeted PTM Solidification (RR, MC, and QP-U DNAPL Areas and ≥ 4-Foot-Thickness) and Removal (TD and QP-S DNAPL Areas)*

Alternative 5 incorporates the same upland remedial technologies as Alternative 3[36] to treat groundwater and restore a portion of the Deep Aquifer, and the same offshore remedial technologies as Alternative 4 to remove PTMs in shallow sediments. In addition, this alternative expands the area of upland soil solidification to also include the QP-U DNAPL Area, to target potentially mobile DNAPL located adjacent to Lake Washington, and areas containing at least 4 feet cumulative thickness of PTM soil in the top 20 feet of soil column, to efficiently treat the greatest volume of accessible PTMs.

The greatest cumulative thicknesses of PTM soil have been observed in the vicinity of two historical Site features where DNAPL releases have been documented: 1) the North Sump and 2) at the former sewer outfall in the former May Creek Channel. Soils in these areas would be treated using *in situ* solidification, as in Alternative 4, because *in situ* treatment is expected to be less costly than removal. Areas to be treated were identified based on locations where 4 feet or more (cumulative thickness) of PTM soil have been observed in the upper 20 feet[37].

Alternative 5 includes the following components:

- Targeted solidification of upland PTMs, including the QP-U DNAPL Area, deep PTMs in the RR and MC DNAPL Areas, and areas with PTM soil greater than 4-feet cumulative thickness in the top 20 feet of soil column;
- PRB;
- ENR;
- Engineered sand cap;
- Reactive sediment cap;
- Sediment PTM removal in the QP-S and TD DNAPL Areas;
- Upland cap;
- Institutional controls; and
- Monitoring.

The areas addressed by different components of Alternative 5 are shown on Figure 6-10, and a representative cross section for upland components is provided on Figure 6-11. Sediment components are the same as for Alternative 4; therefore, refer to Figure 6-9 for

[36] Alternative 5 includes the upland components of Alternative 3 except without DNAPL collection trenches. Areas targeted for DNAPL collection trenches in Alternative 3 are targeted for solidification in Alternative 5.

[37] Refer to Sheet E-12 in Appendix E and Figure 4-6 for specific areas. DNAPL depth intervals are provided in Tables G-1 and G-2 of the RI Report (Anchor QEA and Aspect 2012).

illustration of components along a sediment cross section. Each component remedy is discussed below.

6.3.5.1 Alternative 5 Targeted Solidification of Upland PTMs

In this alternative, deep PTMs would be solidified as described under Alternative 3 (see Section 6.3.3.1). In addition, PTMs in the QP-U DNAPL Area and upland areas containing 4 feet or more (cumulative thickness) of PTM soil in the upper 20 feet would also be solidified.

Soil in these areas located between or overlying PTM layers would also be solidified. For the purposes of this FS, it is assumed that solidification outside of deep PTM areas would include soil up to a depth of 20 feet. Additional vertical delineation of shallow PTM in these areas would be performed as part of the design to determine the required solidification depth for PTMs above 20 feet.

Figure 6-10 depicts the soil area to be solidified, and Figure 6-11 depicts a representative cross section of the vertical extent of soil to be solidified. The estimated extent of solidification is approximately 2.3 acres to a maximum depth of 20 feet for a total volume of approximately 79,000 cy.

Soils would be solidified *in situ* using large-diameter augers as described in Alternative 3 (see Section 6.3.3.1).

Based on a maximum estimated soil solidification rate of 600 cy per day, solidification of this area is estimated to take approximately 4 months. Additional time would be required for mobilization, Site setup, and demobilization. It is estimated that construction of this remedy component would take 7 months.

6.3.5.2 Alternative 5 Permeable Reactive Barrier

A PRB would be installed along the shoreline in the Shallow Alluvium to intercept contaminated groundwater and reduce the flux of groundwater contamination toward Lake Washington. The PRB would enhance ongoing natural attenuation in the nearshore sediment area. This alternative assumes the PRB would be constructed as described in Alternative 3 (see Section 6.3.3.3).

6.3.5.3 Alternative 5 ENR

ENR would be implemented in areas containing surface sediments exceeding the BTV but not dredged or covered with sand or reactive sediment caps (see Sections 6.3.5.4 and 6.3.5.5, respectively, below). The ENR area covers the same footprint as described for Alternative 2 and would be constructed using the same methodologies described in Section 6.3.2.1.

6.3.5.4 Alternative 5 Engineered Sand Cap

An engineered sand cap would be placed over sediments where porewater data exceeds PRGs (outside of PTM areas) and where existing surface sediment concentrations are approximately greater than 8 times the BTV along the inner harbor line. The cap would cover the same footprint as described for Alternative 2 and would be constructed using the same methodologies described in Section 6.3.2.2.

6.3.5.5 Alternative 5 Reactive Cap

Reactive sediment caps would be placed over sediments containing near-surface PTMs outside of dredged areas. The reactive caps would cover the same footprint as described for Alternative 4 (see Section 6.3.4.6), and would be constructed using the same methodologies.

6.3.5.6 Alternative 5 Sediment Removal

The extent and methods of sediment removal for Alternative 5 is the same as for Alternative 4 (see Section 6.3.4.7), and includes targeted PTMs in the offshore TD DNAPL Area (DA-1 and DA-2) and the nearshore QP-S DNAPL Area (DA-6). As in Alternative 4, offshore areas would be dredged using hydraulic dredging methods and the nearshore area would be dredged using mechanical dredging methods with sheet pile containment. Following dredging a reactive residuals cover (composed of a 6-inch layer of 10 percent organoclay and 90 percent coarse sand by weight) would be placed, and then the dredge areas would be backfilled to original grade.

6.3.5.7 Alternative 5 Upland Cap

Areas where COCs exceed PRGs in surface soil would be covered with an engineered cap to prevent direct contact with affected soil. Portions of the cap that are impermeable would also reduce infiltration, leaching from contaminated soils, and transport of contaminants into the Deep Aquifer. The cap would be constructed as described in Alternative 2 (see Section 6.3.2.4 above).

6.3.5.8 Alternative 5 Institutional Controls

Institutional controls for Alternative 5 would be the same as for Alternative 4 (see Section 6.3.4.9) and would include environmental covenants for the Railroad and Quendall Terminals Properties and state-owned aquatic lands, advisories on harvesting fish or shellfish issued by the local health department, and notification of waterway users to restrict specific activities to protect the engineered sand cap and reactive caps. Short-term fish consumption advisories may be required for Alternative 5 due to the potential for short-term water quality and fish tissue impacts during dredging.

6.3.5.9 Alternative 5 Monitoring

Short-term monitoring would be conducted during remedy construction, and long-term monitoring would be conducted to confirm that natural attenuation continues and RAOs continue to be met after the remedy is implemented. Monitoring would be conducted as described in Alternative 4 (see Section 6.3.4.10).

6.3.6 *Alternative 6 – Containment with Targeted PTM Solidification (RR and MC DNAPL Areas and ≥ 2-Foot-Thickness) and Removal (TD, QP-S, and QP-U DNAPL Areas)*

Alternative 6 incorporates the same remedy components as Alternative 4, except without DNAPL collection trenches[38]. Alternative 6 also includes targeted solidification of deep

[38] Areas identified for DNAPL collection trenches in Alternative 4 are targeted for solidification in Alternative 6.

PTMs (as in Alternatives 3 and 5) to reduce groundwater plume volume and solidification of shallow PTM soil exceeding 2 feet of cumulative thickness in the top 20 feet of soil column to provide additional treatment of PTMs.

Alternative 6 includes the following components:

- Targeted solidification of upland PTMs, including deep PTMs in the RR and MC DNAPL Areas and areas containing greater than a 2-foot cumulative thickness of PTM soil in the top 20 feet of soil column;
- Upland PTM removal in the QP-U DNAPL Area;
- Targeted removal of sediment PTMs in the QP-S and TD DNAPL Areas;
- PRB;
- Reactive sediment cap;
- Non-reactive sediment cap;
- Upland cap;
- Institutional controls; and
- Monitoring.

The areas addressed by different components of Alternative 6 are shown on Figure 6-12, and upland components along a representative cross section are shown on Figure 6-13. Sediment components are the same as for Alternative 4; therefore, refer to Figure 6-9 for illustration of components along a sediment cross section. Each component remedy is discussed below.

6.3.6.1 Alternative 6 Targeted Solidification of Upland PTMs

In this alternative, deep PTMs would be solidified as described under Alternative 3 (see Section 6.3.3.1) to reduce groundwater plume volume. For Alternative 6, soil in the upper 20 feet containing 2 feet or more cumulative thickness of DNAPL would also be solidified to provide additional treatment of PTMs.

Soil in these areas located between or overlying layers of PTM soil would also be solidified. For the purposes of this FS, it is assumed that solidification outside of deep PTM areas would include soil up to a depth of 20 feet. Additional vertical delineation of shallow PTMs in these areas would be performed as part of the design to determine the required solidification depth for PTMs above 20 feet.

Figure 6-12 depicts the soil area to be solidified, and Figure 6-13 depicts a representative cross section of the vertical extent of soil to be solidified. The estimated extent of solidification includes approximately 4.2 acres to a maximum depth of 20 feet for a total volume of approximately 143,000 cy.

Soils would be solidified *in situ* using large-diameter augers as described in Alternative 3 (see Section 6.3.3.1.2).

Based on a maximum estimated soil stabilization rate of 600 cy per day, solidification of this area is estimated to take approximately 7 months. Additional time would be required

for mobilization, Site setup, and demobilization. It is estimated that construction of this remedy component would take 10 months.

6.3.6.2 Alternative 6 Permeable Reactive Barrier

A PRB would be installed along the shoreline in the Shallow Alluvium to intercept contaminated groundwater and reduce the flux of contamination toward Lake Washington. The treatment wall would assist ongoing natural attenuation to protect potential sediment and surface water receptors and enhance recovery of the sediments and porewater. This alternative assumes the PRB would be constructed as described in Alternative 3 (see Section 6.3.3.3) except the PRB alignment would follow the eastern edge of the QP-U DNAPL Area and the northern treatment gate would be installed south of the QP-U DNAPL Area.

6.3.6.3 Alternative 6 ENR

ENR would be implemented in areas containing surface sediments exceeding the BTV but not dredged or covered with sand or reactive sediment caps (see Sections 6.3.6.4 and 6.3.6.5, respectively, below). The ENR area covers the same footprint as described for Alternative 2 and would be constructed using the same methodologies described in Section 6.3.2.1.

6.3.6.4 Alternative 6 Engineered Sand Cap

An engineered sand cap would be placed over sediments where porewater data exceeds PRGs (outside of PTM areas) and where existing surface sediment concentrations are approximately greater than 8 times the BTV along the inner harbor line. The cap would cover the same footprint as described for Alternative 2 and would be constructed using the same methodologies described in Section 6.3.2.2.

6.3.6.5 Alternative 6 Reactive Cap

Reactive sediment caps would be placed over sediments containing near-surface PTMs outside of dredged areas. The reactive caps would cover the same footprint as described for Alternative 4 (see Section 6.3.4.6), and would be constructed using the same methodologies.

6.3.6.6 Alternative 6 Sediment Removal

The extent and methods of sediment removal for Alternative 6 is the same as for Alternative 4 (see Section 6.3.4.7), and includes targeted PTM areas in the offshore TD DNAPL Area (DA-1 and DA-2) and the nearshore QP-S DNAPL Area (DA-6). As in Alternative 4, offshore areas would be dredged using hydraulic dredging methods and the nearshore area would be dredged using mechanical dredging methods with sheet pile containment. Following dredging a reactive residuals cover (composed of a 6-inch layer of 10 percent organoclay and 90 percent coarse sand by weight) would be placed, and then the dredge areas would be backfilled to original grade.

6.3.6.7 Alternative 6 Upland Cap

Areas where COCs exceed PRGs in surface soil would be covered with an engineered cap to prevent direct contact with affected soil. Portions of the cap that are impermeable would also reduce infiltration, leaching from contaminated soils, and transport of contaminants into the deep aquifer. The cap would be constructed as described in Alternative 2 (see Section 6.3.2.4 above).

6.3.6.8 Alternative 6 Institutional Controls

Institutional controls for Alternative 6 would be the same as for Alternative 4 (see Section 6.3.4.9), and would include environmental covenants for the Railroad and Quendall Terminals Properties and state-owned aquatic lands, advisories on harvesting fish or shellfish issued by the local health department, and notification of waterway users to restrict specific activities to protect the engineered sand cap and reactive caps. Short-term fish consumption advisories may be required for Alternative 6 due to the potential for short-term water quality and fish tissue impacts during dredging.

6.3.6.9 Alternative 6 Monitoring

Short-term monitoring would be conducted during remedy construction, and long-term monitoring would be conducted to confirm that natural attenuation continues and RAOs continue to be met after the remedy is implemented. Monitoring would be conducted as described in Alternative 4 (see Section 6.3.4.10).

6.3.7 *Alternative 7 – Containment with PTM Solidification (Upland) and Removal (Sediment)*

Alternative 7 involves solidification of upland PTMs and removal and on-site treatment of sediment PTMs. The primary objective of this alternative is to treat the PTM on the Site. Containment measures described in Alternative 2 are also included in this alternative to maintain protectiveness.

Alternative 7 includes the following components:

- Solidification of all upland PTMs;
- Removal of all sediment PTMs;
- ENR;
- Engineered sand cap;
- Upland cap;
- Institutional controls; and
- Monitoring.

The areas addressed by different components of Alternative 7 are shown on Figure 6-14, and representative cross sections are provided on Figures 6-15 and 6-16. Each remedy component is discussed below.

6.3.7.1 Alternative 7 Solidification of Upland PTMs

In this alternative, PTMs and overlying soil would be solidified *in situ*. With solidification, there is the potential for contaminant plume spreading from the reduction in post-solidification permeability and resultant diversion of groundwater around solidified areas. Because the altered groundwater flow path can potentially carry contaminants into previously uncontaminated areas, modeling was performed to determine the effect of solidification on the plume. Modeling predicts that the contaminant plume would shrink after solidification (see Appendix A).

The extent of soil removal and assumed construction methods are discussed below.

6.3.7.1.1 Treatment Areas and Volumes

The lateral and vertical extent of PTMs is described in Section 3.5. As described for Alternative 3 (see Section 6.3.3.1), the extent of solidification is assumed to extend approximately 2 feet below the deepest PTM in each area to provide a buffer between solidified PTMs and the surrounding aquifer.

Figure 6-14 depicts the area of solidification, and Figure 6-15 depicts a representative cross section of the vertical extent of solidification. The estimated extent of solidification includes approximately 9.7 acres to a maximum depth of 36 feet for a total volume of 241,000 cy of upland soil.

6.3.7.1.2 Solidification Methods

Solidification would be performed *in situ* using large-diameter augers. The augers would mix in solidifying amendments in an overlapping pattern as described in Section 6.3.3.1.2. This process would occur in all Site upland areas containing PTMs.

Based on a maximum estimated rate of 600 cy per day, solidification of this area is estimated to take approximately 14 months. Additional time would be required for mobilization, Site setup, and Site restoration. It is estimated that construction of this remedy component would take 24 months.

6.3.7.2 Alternative 7 ENR

ENR would be implemented in areas containing surface sediments exceeding the BTV but not dredged or covered with sand or reactive sediment caps (see Sections 6.3.7.3 and 6.3.7.4, respectively, below). The ENR area covers the same footprint as described for Alternative 2 and would be constructed using the same methodologies described in Section 6.3.2.1.

6.3.7.3 Alternative 7 Engineered Sand Cap

An engineered sand cap would be placed over sediments where porewater data exceeds PRGs (outside of PTM areas) and where existing surface sediment concentrations are approximately greater than 8 times the BTV along the inner harbor line. The cap would cover the same footprint as described for Alternative 2 and would be constructed using the same methodologies described in Section 6.3.2.2

6.3.7.4 Alternative 7 Removal of Sediment PTMs

The sediment removal approach for Alternative 7 is the same as described in Section 6.3.4.7.2 for Alternative 4, except for the extent of dredging. Alternative 7 includes dredging of the offshore (DA-1 through DA-5) and nearshore (DA-6 through DA-8) sediment PTM areas. Following dredging a reactive residuals cover (composed of a 6-inch layer of 10 percent organoclay and 90 percent coarse sand by weight) would be placed, and then the dredge areas would be backfilled to original grade. As described in Section 6.3.4.7.2, sediment removal would be performed by hydraulic dredging and nearshore sediment removal would be performed by mechanical dredging within a sheet pile enclosure. Removal depths correspond with observed depths of PTMs. An overdredge allowance of 1-ft deeper than the target dredge depth was included in volume calculations. Calculations, including depths and areas of individual dredge areas and associated sediment core reference locations, are provided in Appendix E. A representative cross section displaying the extent of sediment to be removed through the central portion of the Site is shown on Figure 6-16.

The sheet pile enclosure for Alternative 7 would be similar to the one described for Alternative 4 in Section 6.3.4.7.4. The main differences are the alignment, length of the wall, and length of the sheet piles. The enclosure wall for Alternative 7 would be 1,260 feet long. The wall alignment is shown on Figure 6-14. Based on preliminary calculations, the sheet pile sections would be AZ24. The sheet piles would need to be approximately 50 feet long to provide adequate stability.

Based on an assumed sheet pile installation rate of 20 lf per day, sheet pile removal rate of 30 lf per day, and dredging rate of 400 cy per day, Alternative 7 sediment removal and backfilling would require approximately 64 weeks to implement.

6.3.7.5 Alternative 7 Upland Cap

Areas where COCs exceed PRGs in surface soil would be covered with an engineered cap to prevent direct contact with affected soil. Portions of the cap that are impermeable would also reduce infiltration, leaching from contaminated soils, and transport of contaminants into the Deep Aquifer. The cap would be constructed as described in Alternative 2 (see Section 6.3.2.4).

6.3.7.6 Alternative 7 Institutional Controls

Institutional controls for Alternative 7 would be the same as for Alternative 4 (see Section 6.3.4.9), and would include environmental covenants for the Railroad and Quendall Terminals Properties and state-owned aquatic lands, advisories on harvesting fish or shellfish issued by the local health department, and notification of waterway users to restrict specific activities to protect the engineered sand cap and reactive caps. Short-term fish consumption advisories may be required for Alternative 7 due to the potential for short-term water quality and fish tissue impacts during dredging.

6.3.7.7 Alternative 7 Monitoring

Short-term monitoring would be conducted during remedy construction, and long-term monitoring would be conducted to confirm that natural attenuation continues and RAOs continue to be met after the remedy is implemented. Monitoring would be conducted as described in Alternative 4 (see Section 6.3.4.10).

6.3.8 *Alternative 8 – Containment with PTM Removal (Upland and Sediment)*

Alternative 8 involves removal and on-site treatment of upland and sediment PTMs. The primary objective of this alternative is to treat all PTMs on the Site. Containment measures described in Alternative 2, except reactive sediment capping[39], are also included in this alternative to maintain protectiveness and provide additional source control.

Alternative 8 includes the following components:

- Upland PTM removal;
- Sediment PTM removal;

[39] Reactive sediment capping is not included in Alternative 8 because sediment PTMs are removed.

- ENR;
- Engineered sand cap;
- Upland cap; and
- Institutional controls and monitoring.

The areas addressed by different components of Alternative 8 are shown on Figure 6-17, and a representative cross section of upland components is provided on Figure 6-18. Sediment components are the same as for Alternative 7; therefore, refer to Figure 6-16 for illustration of components along a sediment cross section. Each component remedy is discussed below.

6.3.8.1 Removal of Upland PTMs

In this alternative, PTMs and overlying soil would be excavated, treated on-site, and reused as backfill. Excavation and on-site treatment was selected rather than excavation and off-site treatment based on the potential cost savings driven in large part by the expected designation of excavated soil as a RCRA hazardous wastes (which may include PTM soil containing benzene, based on its characteristics, and soil generated within the footprints of the North and South Sumps potentially containing RCRA-listed waste). *In situ* solidification of upland PTMs, which offers benefits and drawbacks compared to excavation, is described and evaluated in Alternative 7 (see Section 6.3.7).

The extent of soil removal and assumed construction methods are discussed below.

6.3.8.1.1 Areas and Volumes of Soil Removal

The lateral and vertical extent of PTMs is described in Section 3.5.

Figure 6-17 depicts the area of soil to be removed, and Figure 6-18 depicts a representative cross section of the vertical extent of soil to be removed. The estimated extent of removal includes approximately 9.7 acres to a maximum depth of 34 feet for a total volume of 210,000 cy of upland soil.

6.3.8.1.2 Soil Removal Methods

Excavation would be performed as described in Alternative 4 (see Section 6.3.4.1.2) with excavation accomplished in the dry where possible using limited shoring and dewatering to facilitate construction, but deeper excavations may be performed in the wet to avoid extensive shoring and dewatering that may be required to depressurize the Deep Aquifer. Shoring and dewatering methods are discussed in Sections 6.3.4.1.3 and 6.3.4.1.4, respectively.

Because of the large area and variable depth of PTMs, the removal area would be divided into several discrete cells so that localized deeper PTMs may be removed by focusing more extensive shoring, dewatering, and/or wet excavation in these areas, and to maintain adequate area for stockpiling and construction support operations. Excavation cells and maximum excavation depths are shown on Figures 6-17 and 6-18.

Based on a maximum estimated rate of 400 cy per day for excavation and backfilling, removal of this area is estimated to take approximately 1.5 years. Additional time would be required for mobilization, Site setup, shoring and dewatering installation, and Site

restoration. It is estimated that construction of this remedy component would take 2.5 years.

6.3.8.1.3 Shoring

Impermeable shoring walls would be installed around the perimeter of each excavation cell to prevent sidewall sloughing and to reduce the rate of construction dewatering. As described in Alternative 4 (see Section 6.3.4.1.3), it was assumed that temporary sheet pile walls (which could be removed and reused) would be required. The conceptual design criteria for sheet pile walls are described in Appendix F. Assumptions are summarized as follows for various excavation depths:

- **Up to 15 Feet Deep.** Cantilevered sheet pile walls with no tiebacks and a minimum embedment depth of approximately 35 feet (50 feet total depth);
- **Between 15 and 22 Feet Deep.** Anchored sheet pile walls with one row of tiebacks and a minimum embedment depth of approximately 20 feet (up to 42 feet total depth); and
- **Between 25 and 34 Feet Deep.** Anchored sheet pile walls with two rows of tiebacks and a minimum embedment depth of approximately 26 feet (up to 60 feet total depth).

The shoring wall cell perimeters are shown on Figure 6-17, and the estimated embedment depths are shown on Figure 6-18.

6.3.8.1.4 Construction Dewatering and Water Treatment

Soil excavation under Alternative 8 would be performed to minimize the need for construction dewatering; however, some dewatering would be needed to allow construction of shoring walls, and could also be performed where cost-effective to realize the advantages of dry excavation described in Section 6.3.4.1.2. Based on confined groundwater elevations in the Deep Aquifer, depressurization is required when dewatering to maintain excavation stability (e.g., prevent blow out of excavation bottom). A minimum depth to water of 19 feet is estimated to be required to install tiebacks for a 34-foot-deep excavation (see Appendix F). Additional detailed remedial design analyses to determine dewatering requirements would be performed after the ROD. Dewatering assumptions for this FS are as follows:

- **Cells less than 16 Feet Deep**. Shoring walls would be installed into the Deep Aquifer; however, no tieback anchors would be needed. Depressurization of the Deep Aquifer would not be necessary.
- **Cells greater than 16 Feet Deep.** Depressurization of the Deep Aquifer would be required to lower the aquifer to allow for installation of tieback anchors and maintain excavation stability. Depressurization would be conducted using dewatering wells screened in the Deep Aquifer and located inside the sheet pile cell.

Estimated cell depressurization flow rates are summarized in Appendix A. The maximum dewatering rate (Cell 7) is estimated to be 210 gpm. The estimates are for the flow rate required to maintain a depressurization at steady state, and initial flow rates may be initially higher. Dewatering estimates are preliminary for cost estimate purposes; additional testing and analysis are required prior to construction design.

Groundwater removed during dewatering activities would be treated and discharged, as described in Section 6.3.4.1.4.

For the estimated maximum flow rate under this alternative, discharge to Lake Washington is anticipated to be the most cost-effective option. It may also be necessary to treat arsenic in groundwater to meet surface water discharge requirements.

6.3.8.1.5 Management of Removed Soil

Excavated soil would be treated on site using thermal desorption. Because much of the soil to be treated is expected to have high organic content from organic silt, peat, and wood debris and high water content because of the shallow water table, additional testing would be needed to verify the effectiveness of thermal desorption at achieving soil PRGs. For the purposes of this FS, it is assumed that thermal desorption would remove DNAPL but that the treated soil could still exceed PRGs and require containment (such as capping).

Thermal desorption would be performed on site using propane-fired equipment. Contaminants in the offgas would be incinerated.

Treated soil would be used as Site backfill. Because soil that would be treated is predominantly fine-grained, it could not be placed in saturated conditions. Rather, imported backfill that can be compacted in saturated conditions (e.g., 1-inch rock) overlain with geotextile would be placed in cells not completely dewatered.

6.3.8.2 Alternative 8 ENR

ENR would be implemented in areas containing surface sediments exceeding the BTV but not dredged or covered with sand or reactive sediment caps (see Sections 6.3.8.3 and 6.3.8.4, respectively, below). The ENR area covers the same footprint as described for Alternative 2 and would be constructed using the same methodologies described in Section 6.3.2.1.

6.3.8.3 Alternative 8 Engineered Sand Cap

An engineered sand cap would be placed over sediments where porewater data exceeds PRGs (outside of PTM areas) and where existing surface sediment concentrations are approximately greater than 8 times the BTV along the inner harbor line. The cap would cover the same footprint as described for Alternative 7 and would be constructed using the same methodologies described in Section 6.3.2.2.

6.3.8.4 Alternative 8 Removal of Sediment PTMs

Sediment removal for Alternative 8 is the same as described in Section 6.3.7.4 for Alternative 7. Alternative 8 includes dredging of the offshore (DA-1 through DA-5) and nearshore PTM areas (DA-6 through DA-8). Following dredging a reactive residuals cover (composed of a 6-inch layer of 10 percent organoclay and 90 percent coarse sand by weight) would be placed, and then the dredge areas would be backfilled to original grade.

6.3.8.5 Alternative 8 Upland Cap

Areas where COCs exceed PRGs in surface soil would be covered with an engineered cap to prevent direct contact with affected soil. Portions of the cap that are impermeable would also reduce infiltration, leaching from contaminated soils, and transport of

contaminants into the deep aquifer. The cap would be constructed as described in Alternative 2 (see Section 6.3.2.4).

6.3.8.6 Alternative 8 Institutional Controls

Institutional controls for Alternative 8 would be the same as for Alternative 4 (see Section 6.3.4.9) and would include environmental covenants for the Railroad and Quendall Terminals Properties and state-owned aquatic lands, advisories on harvesting fish or shellfish issued by the local health department, and notification of waterway users to restrict specific activities to protect the engineered sand cap and reactive caps. Short-term fish consumption advisories may be required for Alternative 8 due to the potential for short-term water quality and fish tissue impacts during dredging.

6.3.8.7 Alternative 8 Monitoring

Short-term monitoring would be conducted during remedy construction, and long-term monitoring would be conducted to confirm that natural attenuation continues and RAOs continue to be met after the remedy is implemented. Monitoring would be conducted as described in Alternative 4 (see Section 6.3.4.10).

6.3.9 *Alternative 9 – Containment with Solidification and Removal of Contaminated Soil and Removal of Contaminated Sediment*

Alternative 9 includes removal or treatment of soil and sediment that is likely to act as a long-term source of groundwater contamination above MCLs, including PTMs and soils and sediments contaminated with recalcitrant compounds (e.g., arsenic and benzo[a]pyrene). Low-permeability soils are present in much of the Shallow Alluvium; therefore, this alternative includes removal of Shallow Alluvium soils within the area where MCLs are exceeded[40], excluding benzene[41]. As described in Section 3.2, low-permeability soil layers are also present in the upper portion of the Deeper Alluvium, to a depth of at least 83 feet (as observed at boring SWB-8). Removal of low-permeability layers in the Deeper Alluvium is not included based on constructability concerns[42]. Containment measures described in Alternative 2 are also included in this alternative to maintain protectiveness.

Shallow upland soils (those that can be removed without extensive dewatering or shoring) would be removed. *In situ* solidification would be used to treat the deeper upland soils.

The objective of Alternative 9 is to remove or treat PTMs and to restore groundwater to the maximum extent possible. *In situ* solidification of deep soils was selected rather than

[40] There is no naphthalene MCL and the naphthalene PRG is not based on an ARAR. As a result, groundwater exceeding the naphthalene PRG would not be targeted for treatment.

[41] Based on contaminant fate and transport modeling, benzene in fine-grained soils could biodegrade in less than 100 years, although the rate of biodegradation at the Site is uncertain. See Appendix A.

[42] Removal of soil in the Deeper Alluvium located within the arsenic plume would require excavation of soil and sediment near the shoreline to a depth of approximately 60 feet (see Figure 3-8).

excavation to reduce cost and improve implementability. However, solidified soil may present a long-term source of groundwater contamination via leaching. Active polishing treatment (such as pump-and-treat) was considered to address this, but was not included in this alternative since it could result in indefinite operation with little overall benefit. (Polishing treatment is included in Alternative 10.)

Alternative 9 includes the following components:

- Shallow contaminated soil removal;
- Deep contaminated soil solidification;
- Contaminated sediment removal;
- Groundwater treatment;
- ENR;
- Engineered sand cap;
- Upland cap;
- Institutional controls; and
- Monitoring.

The areas addressed by different components of Alternative 9 are shown on Figure 6-19 and representative cross sections are provided on Figures 6-20 and 6-21. Each component of the remedy is discussed below.

6.3.9.1 Areas and Volumes of Contaminated Soil

The area of soil to be removed or treated is shown on Figure 6-19. This area was estimated to include the following:

- The area of groundwater and porewater in the Shallow Alluvium exceeding MCLs for COCs (excluding benzene). All PTMs in the Shallow Alluvium would be addressed;
- The area of PTMs in the Deeper Alluvium (i.e., at BH-30); and
- The estimated area of benzo(a)pyrene exceeding its MCL in the Deeper Alluvium, as described in Section 3.5.

A representative cross section of the vertical extent of soil and sediment to be removed or treated is shown on Figure 6-20. Along this cross section, which is located in the middle of the Site, the majority of Shallow Alluvium soil would be removed or treated. In some areas south and north of this cross section where PTM, benzo(a)pyrene, and arsenic occurrences do not extend into the Deeper Alluvium, the lower portion of the Shallow Alluvium would not be treated. Average estimated excavation and solidification depths in different portions of the removal area are included in the volume calculations in Appendix E.

6.3.9.2 Alternative 9 Removal of Shallow Contaminated Soil

Alternative 9 assumes that upland Source Area soils are excavated to a depth of 15 feet.[43] Shallower soils would be excavated rather than solidified *in situ* for the following reasons:

- Removal of soil to 15 feet bgs would remove most of the upland PTMs and associated contaminant mass. By removing most of the upland PTMs rather than solidifying them, there is a greater likelihood that groundwater RAOs would be achieved.
- The expected unit cost of removal at shallow depths is expected to be similar to solidification because minimal shoring and dewatering would be required.

Figure 6-20 depicts a representative cross section of the vertical extent of soil to be removed. It is estimated that 340,000 cy of upland soils would be excavated under this alternative.

Soils above the static water table could be excavated using conventional earth-moving equipment, with little or no excavation dewatering required. Excavation sidewalls would be appropriately sloped to prevent sloughing and to preclude the need for shoring.

Soil excavation below the static water table would be accomplished by constructing temporary excavation cells, which would be sequentially dewatered, excavated, and backfilled. Conceptual design criteria for a sheet pile wall to facilitate a 15-foot-deep excavation include one row of tieback anchors and an embedment depth of approximately 35 feet bgs.

In some Site areas, particularly to the east away from the lake, it may be possible to excavate in the dry to 15 feet without the aid of shoring or cutoff walls; however, the preliminary construction dewatering analysis (see Appendix A) indicates the following:

- Without an impermeable perimeter wall around an excavation cell, predicted dewatering flow rates for a 1-acre cell range from approximately 100 gpm on the east side of the Site to more than 1,000 gpm at the shoreline; and
- With an impermeable perimeter wall, the predicted steady-state dewatering flow rate for a 1-acre cell is approximately 14 gpm.

Predicted flow rates for larger cells range from roughly 28 gpm for a 2-acre cell to roughly 56 gpm for a 4-acre cell.

For Alternative 9, it was determined that an average upland cell size of approximately 4 acres would minimize the amount of temporary shoring needed and would also maintain a reasonable dewatering flow rate, allowing sufficient room to conduct soil handling and stockpiling operations. Figure 6-19 shows the upland areas in which excavation cells are assumed to be constructed in Alternative 9, along with a conceptual layout of individual cells.

[43] This is the estimated depth to which excavation is possible without dewatering to depressurize the Deeper Alluvium.

Because relatively low dewatering rates are anticipated, it is expected dewatering wells would not be required; rather, sumps and trenches would be installed at the base of the excavation to capture water draining from soils within the excavation area and seeping up from the base of the excavation.

Higher short-term flow rates would be needed to dewater soil to be removed (i.e., storage depletion) and to remove precipitation that falls within the excavation cell. For a 4-acre cell, a 2-inch rain event over a 24-hour period would result in approximately 150 gpm of additional flow. Temporary stormwater detention areas could be provided to reduce capacity needs from precipitation. The average dewatering flow rate for a 4-acre upland excavation cell, including precipitation and storage, is estimated to be approximately 70 gpm. Dewatering would need to be implemented during the entire duration of the excavation, solidification, and backfilling activities.

Groundwater removed during dewatering activities would be treated and discharged as described in Section 6.3.8.1.4. For the purposes of this FS, temporary discharge to Lake Washington is anticipated to be the most cost-effective option.

Construction would be sequenced with excavation starting on the eastern (upgradient) side of the Site and progressing west to avoid recontamination of remediated areas. The estimated construction timeframe for soil removal and backfill is approximately 8 years, broken down as follows:

- Design: 3 years;
- Material and equipment mobilization and construction of the groundwater treatment plant: 2 years; and
- Removal, treatment, and backfill of upland soils: 2.5 years, based on an estimated removal, treatment, and fill rate of 400 cy per day.

The total estimated water volume to be treated, based on the estimated duration of excavation and solidification and the average flow rate from each cell, is approximately 800 million gallons.

6.3.9.3 Alternative 9 Solidification of Deep Contaminated Soil

Upland Source Area soils below 15-foot depth would be solidified *in situ* in Alternative 9.

Figure 6-20 depicts a representative cross section of the vertical extent of soil to be solidified.

The estimated soil volume requiring solidification is approximately 360,000 cy. Calculations are provided in Appendix E.

6.3.9.3.1 Soil Solidification Methods

Soils would be solidified *in situ* using large-diameter augers as described in Section 6.3.3.1.2 for Alternative 3. After solidification of a cell is complete, the remainder of the cell would be backfilled to restore the Site grade.

The estimated construction timeframe for soil stabilization is approximately 1.5 years, based on an estimated treatment rate of 600 cy per day.

6.3.9.4 Alternative 9 ENR

ENR would be implemented in areas containing surface sediments exceeding the BTV but not dredged or covered with sand or reactive sediment caps (see Sections 6.3.9.5 and 6.3.9.6, respectively, below). The ENR area covers the same footprint as described for Alternative 2 and would be constructed using the same methodologies described in Section 6.3.2.1.

6.3.9.5 Alternative 9 Engineered Sand Cap

An engineered sand cap would be placed over sediments where surface sediment concentrations are approximately greater than 8 times the BTV along the inner harbor line following sediment dredging. The cap would cover a smaller footprint than described for Alternative 2 because of additional nearshore dredging (see Section 6.3.9.6 below). The cap would be constructed using the same methodologies described in Section 6.3.2.2.

6.3.9.6 Alternative 9 Removal of Contaminated Sediment

The sediment removal approach for Alternative 9 is the same as described in Section 6.3.7.4 for Alternative 7, except for the extent of dredging. Alternative 9 includes dredging of all the aquatic DNAPL areas (DA-1 through DA-8) and additional nearshore sediment area where sediment is potentially contributing to MCL exceedances. Following dredging a reactive residuals cover (composed of a 6-inch layer of 10 percent organoclay and 90 percent coarse sand by weight) would be placed, and then the dredge areas would be backfilled to original grade. The extent of sediment to be removed through the central portion of the Site is shown on Figure 6-19. The estimated extent of removal was calculated as described in Appendix E and includes approximately:

- 4.7 acres of mechanically dredged nearshore sediments, to a maximum depth of 27 feet below mudline;
- 3.3 acres of dredged sediments, to a maximum depth of 5.7 feet below mudline;
- 172,300 cy of sediment removal including:
    - 148,600 cy of nearshore sediments within the sheet pile wall; and
    - 23,700 cy of hydraulically dredged sediments.

As described in Section 6.3.4.7.2, sediment removal would be performed by hydraulic dredging and nearshore sediment removal would be performed by mechanical dredging within a sheet pile enclosure. Removal depths for Alternative 9 extend deeper than the PTMs. In the offshore aquatic DNAPL areas (DA-1 through DA-4), the target dredge depth is 2 feet below the observed PTM depth (i.e., 2 feet deeper than Alternatives 4 through 8).

In the nearshore areas (DA-6 through DA-8), the lateral dredge area was expanded to include the estimated area of groundwater and porewater in the Shallow Alluvium exceeding the benzo(a)pyrene MCL, which encompasses the extents of other Site COCs (excluding benzene) exceeding MCLs. The area of PTMs in the Shallow Alluvium is also encompassed within this area, with the exception of DA-7, which would also be excavated as part of this alternative. The nearshore target dredge elevation is generally the bottom of the Shallow Alluvium layer and the dredge depth varies with the thickness of this layer. The maximum nearshore dredge depth would be approximately 27 feet bss

in approximately 15 feet of water, which is still within the capability (i.e., 50 feet) of most types of mechanical dredges.

The sheet pile enclosure for Alternative 9 would generally be similar to the one described for Alternative 4 in Section 6.3.4.7.4. However, due to considerably larger dredge depths for Alternative 9, significantly heavier sheet pile sections and slightly longer sheet piles would be required. Other significant differences are the wall alignment and length. The wall alignment is shown on Figure 6-19. The enclosure wall for Alternative 9 would be 1,500 feet long. Based on preliminary calculations, an AZ50 sheet pile section distributed in the United States by Skyline Steel (or similar section by another vendor with the same section modulus) would be adequate to withstand stresses within the sheet piles and limit deflections. The sheet piles would need to be embedded deep enough into the subsurface soils to provide adequate stability. Based on the preliminary calculations, the sheet piles would need to be approximately 60 feet long. The sheet piles and installation methods are assumed to be the same as for Alternative 2.

Based on an assumed sheet pile installation rate of 20 lf per day, sheet pile removal rate of 30 lf per day, and dredging rate of 400 cy per day, Alternative 7 sediment removal and backfilling would require approximately 153 weeks to implement.

6.3.9.7 Alternative 9 Upland Cap

Areas where COCs exceed PRGs in surface soil would be covered with an engineered cap to prevent direct contact with affected soil. The cap would be constructed as described in Alternative 2 (see Section 6.3.2.4 above).

6.3.9.8 Alternative 9 Institutional Controls

Institutional controls for Alternative 9 would be the same as for Alternative 4 (see Section 6.3.4.9), and would include environmental covenants for the Railroad and Quendall Terminals Properties and state-owned aquatic lands, advisories on harvesting fish or shellfish issued by the local health department, and notification of waterway users to restrict specific activities to protect the engineered sand cap and reactive caps. Short-term fish consumption advisories may be required for Alternative 9 due to the potential for short-term water quality and fish tissue impacts during dredging.

6.3.9.9 Alternative 9 Monitoring

Short-term monitoring would be conducted during remedy construction, and long-term monitoring would be conducted to confirm that natural attenuation continues and RAOs continue to be met after the remedy is implemented. Monitoring would be conducted as described in Alternative 4 (see Section 6.3.4.10).

6.3.10 *Alternative 10 – Containment with Removal of Contaminated Soil and Sediment*

The purpose of Alternative 10, similar to Alternative 9, is to treat PTMs and to restore groundwater to the maximum extent possible.

Alternative 10 includes removal of soil and sediment that is likely to act as a source of groundwater contamination above MCLs, including PTMs and soils contaminated with recalcitrant compounds (e.g., arsenic and benzo[a]pyrene). Contaminated soil and groundwater in the Deeper Alluvium would be treated by groundwater pump and treat to

speed restoration timeframe. Containment measures described in Alternative 2 are also included in this alternative to maintain protectiveness.

Alternative 10 includes the following components:

- Contaminated soil removal;
- Contaminated sediment removal;
- Groundwater treatment;
- ENR;
- Engineered sand cap;
- Upland cap;
- Institutional controls; and
- Monitoring.

The areas addressed by different components of Alternative 10 are shown on Figure 6-22, and a representative cross section of upland components is provided on Figure 6-23. Sediment components are the same as for Alternative 9; therefore, refer to Figure 6-21 for illustration of components along a sediment cross section. Each component of the remedy is discussed below.

6.3.10.1 Alternative 10 Removal of Contaminated Soil

Removal would be conducted in the dry where practicable to minimize residual contamination. Contaminated soil excavation would require extensive shoring and dewatering. The extent of excavation is described below in Section 6.3.10.1.1.

6.3.10.1.1 Areas and Volumes of Contaminated Soil

The area of soil to be removed is shown on Figure 6-22. This area was estimated to include the following:

- The area of groundwater and porewater in the Shallow Alluvium exceeding MCLs for COCs (excluding benzene). All PTMs in the Shallow Alluvium would be addressed;
- The area of PTMs in the Deeper Alluvium (i.e., at BH-30); and
- The estimated area of benzo(a)pyrene exceeding its MCL in the Deeper Alluvium, as described in Section 3.5

A representative cross section of the vertical extent of soil and sediment to be removed is shown on Figure 6-23. Along this cross section, which is located in the middle of the Site, the majority of Shallow Alluvium soil would be removed. In some areas south and north of this cross section where PTMs, benzo(a)pyrene, and arsenic occurrences do not extend into the Deeper Alluvium, the lower portion of the Shallow Alluvium would not be removed. Average estimated excavation depths in different portions of the removal area are included in the volume calculations in Appendix E.

The estimated extent of each area of excavation was calculated as described in Appendix E, and includes approximately 14 acres of upland soils, to a maximum depth of 40 feet bgs for a total volume of 705,000 cy of upland soils.

6.3.10.1.2 Soil Excavation above the Static Water Table

Soils above the static water table would most likely be excavated using conventional earth-moving equipment, with little or no excavation dewatering required. Excavation sidewalls would be appropriately sloped to prevent sloughing and to preclude the need for shoring.

6.3.10.1.3 Upland Excavation Cells

In-the-dry excavation of upland soils below the static water table would be accomplished by constructing temporary excavation cells, which would be sequentially dewatered, excavated, and backfilled. An excavation cell's perimeter would consist of an impermeable wall. The wall would serve the following two purposes:

- To shore the excavation sidewalls (i.e., prevent sidewall sloughing); and
- To limit water flow into the excavation cell, reducing the amount of dewatering needed to maintain dry conditions.

For the purposes of evaluating this alternative, temporary sheet pile walls (which can be removed and reused) were identified as the likely least-cost option. Sheet pile wall conceptual design criteria for a 40-foot-deep excavation include three rows of tieback anchors[44] and a minimum embedment depth of approximately 65 feet bgs. Preliminary shoring design considerations are described in Appendix F.

Conventional land-based excavation equipment would likely operate inside the excavation cells; therefore, the cells must be large enough (in areal extent) to accommodate this equipment. In addition, larger cells translate into fewer linear feet of temporary sheet pile wall that must be installed and subsequently removed; however, dewatering requirements place a practical limit on cell size (i.e., dewatering flow rate increases with increased cell size). The rate at which groundwater must be pumped from the cell to maintain conditions needed for in-the-dry excavation can be reduced by increasing the sheet pile wall embedment depth, but that also has practical limits as well as significant cost implications. A preliminary cost-benefit analysis (see Appendix E) was performed using the hydraulic groundwater flow model described in Appendix A to estimate required dewatering flow rates for a range of cell areas and sheet pile embedment depths. This analysis identified a cell size of approximately 1 acre and a sheet pile embedment depth of 95 feet (30 feet deeper than the average depth required for shoring purposes) as the most economical design. Sheet piles of this length are non-standard and would require special transport and handling considerations. Additionally, vibratory hammer and/or high-pressure jetting at the toe of the piles may be required to achieve the target depth.

[44] Whalers and struts could also be used to brace the sheet piling; however, the relatively large cell size would likely make tiebacks more cost-effective.

Figure 6-22 shows the upland area in which excavation cells would be constructed in Alternative 10, along with a conceptual layout of individual cells. A cross section showing conceptual shoring wall embedment of a representative cell is provided on Figure 6-23. The cells would be large enough so that ramps could be constructed inside the cells to allow excavated soil to be direct-loaded into trucks for transport out of the cell. This method would likely be used to remove most of the soil from a cell. During the final stages of cell excavation, however, internal ramps would no longer be an option. It is assumed that a crane would then be used to place an excavator inside the cell. Soil could then be transported out of the cell using a clamshell bucket or conveyor belts. A temporary working surface such as a structural mat would likely be required at the base of the excavation because of the soft Site soils.

After source area soils/sediments are removed from the cell, clean fill (either treated Site soil/sediment or imported material) would be used to restore the original Site grade. Each cell would be backfilled only after excavation of the entire cell is complete, to minimize the risk of recontaminating clean fill. Fill would be placed in lifts and compacted. After the grade inside the cell is restored, the sheet pile wall segments that do not form a portion of a subsequent (adjacent) cell wall would be removed and reused elsewhere on the Site.

Construction would be sequenced with excavation starting on the eastern (upgradient) side of the Site and progressing west to avoid recontamination of remediated areas. The estimated construction timeframe for soil removal and backfill is approximately 10 years, broken down as follows:

- Design: 3 years;
- Material and equipment mobilization and construction of the groundwater treatment plant: 2 years; and
- Removal, treatment, and backfill of upland soils: 5 years, based on an estimated removal, treatment, and fill rate of 400 cy per day.

6.3.10.1.4 Cell Dewatering and Water Management

To allow for in-the-dry excavation, a dewatering system would be installed within each excavation cell. The dewatering system would consist of the following:

- Sumps and trenches at the base of the excavation, to capture water draining from soils within the excavation area; and
- Dewatering wells, to lower the water table within the cell to below the base of the excavation. The wells would be screened in the Deeper Alluvium.

As the excavation deepens, dewatering wells would need to be either protected or decommissioned and reinstalled. The number of wells and required flow rates would vary based on the cell location as well as the stage of excavation (excavation depth) within the cell. Groundwater removed during dewatering activities would be treated and discharged as described for Alternative 8 in Section 6.3.8.1.4. For the purposes of this FS, temporary discharge to Lake Washington is anticipated to be the most cost-effective option.

The maximum estimated dewatering flow rate for an upland excavation cell is approximately 280 gpm for a 1-acre cell at the shoreline. Additional capacity would be

needed to allow for initial cell drawdown and to treat precipitation falling within a cell. Dewatering volume calculations are provided in Appendix A. The total estimated water volume to be treated, based on the estimated dewatering duration and average estimated flow rate of 220 gpm in the upland, is 600 million gallons.

6.3.10.1.5 Management of Removed Soil

Excavated soil would be treated on-site using thermal desorption as described in Section 6.3.8.1.5 for Alternative 8. Treated soil would be used as Site backfill. Because much of the soil to be treated is expected to have high organic content from organic silt, peat, and wood debris and high water content because of the shallow water table, additional testing would be needed to verify the effectiveness of thermal desorption at achieving PRGs in soil and groundwater. For the purposes of this FS, it is assumed that thermal desorption would remove DNAPL and achieve levels protective of groundwater, but that the treated soil may still exceed soil PRGs and require containment (such as capping).

For the purposes of this FS, it is assumed that thermal desorption would be performed on-site using propane-fired equipment. Contaminants in the offgas would be incinerated.

6.3.10.2 Alternative 10 Groundwater Treatment

Groundwater pump and treat technology would be implemented to address contamination remaining at depth below the excavated areas after removal of contaminated soils and sediments is completed. The objectives of the pump and treat system would be to increase flushing of the Deeper Alluvium and reduce the Deep Aquifer restoration timeframe.

The pump and treat system would consist of a groundwater extraction system, an on-site treatment plant, and a means of handling the treated water (e.g., reinjection or discharge to Lake Washington). A conceptual design and proposed implementation strategy for groundwater extraction is discussed in Section 6.3.10.2.1. Elements of extracted groundwater management are discussed in Section 6.3.10.2.2.

6.3.10.2.1 Groundwater Extraction

To develop a conceptual design for the groundwater extraction system, the Site groundwater hydraulic model and contaminant fate and transport model were used. The groundwater model and the development of the conceptual design for the Alternative 10 groundwater extraction (pump and treat) system are described in Appendix A. A summary is as follows:

- The hydraulic model was used to determine the minimum flow rate, and a conceptual layout of pumping wells was developed that would capture groundwater within the upland portion of the groundwater plume.
- The hydraulic model was used to evaluate the pumping system's ability to capture the plume beneath the lake by increasing flow rates and observing the resulting capture zones.
- The contaminant fate and transport model assessed representative heterogeneous layers of the Deeper Alluvium and evaluated the pumping system's ability to reduce restoration timeframe in these layers by increasing flow rates. This was performed by observing the effect of increasing flow rates on the predicted time

to achieve MCLs at representative points in the upland and offshore portions of the Deeper Alluvium.

Preliminary modeling results were used to optimize the conceptual design of the Alternative 10 groundwater extraction system as follows:

- Extracting a total of approximately 90 gpm from six extraction wells would capture the upland area of groundwater exceeding MCLs.
- The capture zone for the proposed pumping system is predicted to extend to a maximum of 100 feet offshore.
- Increasing the total flow rate slightly reduces the restoration timeframe within permeable layers of the Deeper Alluvium but does not significantly increase the offshore capture of the groundwater plume or reduce the Site overall restoration timeframe.

The estimated time to construct the pump and treat system is 6 months. Monitoring would be performed after pump and treat performance monitoring indicates remediation goals in the upland and sediment areas are achieved and the pump and treat system is turned off. Groundwater and porewater monitoring would be performed at monitoring wells in the Shallow Alluvium and Deeper Alluvium to evaluate whether groundwater concentrations rebound above cleanup levels. For cost estimating purposes in the FS, the assumed duration of pump-and-treat system operation is 100 years.

6.3.10.2.2 Management of Extracted Groundwater

The treatment system would be similar to that described for the construction dewatering program, except no DNAPL separation would be required as all free-phase DNAPL is assumed to have been removed during excavation. In addition, equipment capacities would be less, as the estimated system flow rate is less than the maximum flow rate needed for construction dewatering.

6.3.10.3 Alternative 10 ENR

ENR would be implemented in areas containing surface sediments exceeding the BTV but not dredged or covered with an engineered sand cap (see Section 6.3.10.4 below). The ENR area covers the same footprint as described for Alternative 2 and would be constructed using the same methodologies described in Section 6.3.2.1.

6.3.10.4 Alternative 10 Engineered Sand Cap

An engineered sand cap would be placed over sediments where surface sediment concentrations are approximately greater than 8 times the BTV along the inner harbor line following sediment dredging. The cap would be placed over the same areas as for Alternative 9 (see Section 6.3.9.5). The cap would be constructed using the same methodologies described in Section 6.3.2.2.

6.3.10.5 Alternative 10 Removal of Contaminated Sediment

Sediments containing PTMs and potentially contributing to MCL exceedances would be removed. The sediment removal extent and approach for Alternative 10 is the same as described in Section 6.3.9.6 for Alternative 9.

6.3.10.6 Alternative 10 Upland Cap

Areas where COCs exceed PRGs in surface soil would be covered with an engineered cap to prevent direct contact with affected soil. The cap would be constructed as described in Alternative 2 (see Section 6.3.2.4 above).

6.3.10.7 Alternative 10 Institutional Controls

Institutional controls for Alternative 10 would be the same as for Alternative 4 (see Section 6.3.4.9), and would include environmental covenants for the Railroad and Quendall Terminals Properties and state-owned aquatic lands, advisories on harvesting fish or shellfish issued by the local health department, and notification of waterway users to restrict specific activities to protect the engineered sand cap. Short-term fish consumption advisories may be required for Alternative 9 due to the potential for short-term water quality and fish tissue impacts during dredging.

6.3.10.8 Alternative 10 Monitoring

Short-term monitoring would be conducted during remedy construction, and long-term monitoring would be conducted to confirm that natural attenuation continues and RAOs continue to be met after the remedy is implemented. Monitoring would be conducted as described in Alternative 4 (see Section 6.3.4.10).

7 Detailed Analysis of Alternatives

This section presents the detailed analysis of the alternatives that were developed in Section 6. Each alternative was evaluated against the NCP threshold and balancing criteria. The NCP evaluation criteria and the general methodology used to perform the evaluations are summarized in Section 7.1. Sections 7.2 through 7.11 present the detailed analysis of Alternatives 1 through 10, respectively. The results of this detailed analysis were used to perform the comparative analysis of the alternatives presented in Section 8.

7.1 NCP Evaluation Criteria

CERCLA and the NCP require that each remedial alternative be evaluated against nine criteria listed in 40 CFR 300.430(e)(9). These evaluations support identification of the most appropriate alternative for implementation at the Site. The nine evaluation criteria listed below include two threshold, five balancing, and two modifying criteria established by EPA (1988a and 2005) to address the requirements of CERCLA and the NCP.

Threshold Criteria

1. Overall Protection of Human Health and the Environment; and
2. Compliance with ARARs.

Balancing Criteria

3. Long-Term Effectiveness and Permanence;
4. Reduction of Toxicity, Mobility, or Volume Through Treatment;
5. Short-Term Effectiveness;
6. Implementability; and
7. Cost.

Modifying Criteria

8. State (Support Agency) Acceptance; and
9. Community Acceptance.

Table 7-1 lists FS analysis factors for each evaluation criterion, as stated in EPA's RI/FS guidance document (EPA 1988a). The first seven criteria serve as the basis for the detailed analysis of alternatives in the FS. The two modifying criteria are evaluated by EPA at a later stage in the CERCLA process (Section 7.1.3). The NCP evaluation criteria and the general methodology used to perform the evaluations are discussed in detail below.

7.1.1 *Threshold Criteria*

This section discusses the CERCLA requirement that remedies selected for implementation must meet two threshold criteria: 1) be protective of human health and the environment and 2) comply with ARARs.

7.1.1.1 Overall Protection of Human Health and the Environment

The NCP states that, "*alternatives shall be assessed to determine whether they can adequately protect human health and the environment, in both the short- and long-term, from unacceptable risks posed by hazardous substances, pollutants, or contaminants present at the site by eliminating, reducing, or controlling exposures to levels established during development of remediation goals consistent with 40 CFR 300.430(e)(2)(i).*" This criterion describes how the risks associated with the exposure pathways delineated in the RAOs for protection of human health and the environment (Sections 4.2.2 and 4.2.3, respectively) are eliminated, reduced, or controlled through treatment, engineering, or institutional controls. The overall assessment under this criterion draws on the assessments conducted under other evaluation criteria, especially long-term effectiveness and permanence, short-term effectiveness, and compliance with ARARs.

7.1.1.2 Compliance with ARARs

This criterion assesses whether the alternative complies with the chemical-specific, action-specific, and location-specific ARARs and other "To Be Considered" criteria, advisories, and guidance (TBCs) identified in Section 4 (see Tables 4-1 through 4-3). CERCLA requires that remedial actions comply with the substantive provisions of federal and state promulgated ARARs. If it is not technically practicable to comply with an ARAR, EPA may waive the ARAR under certain circumstances, as listed in 40 CFR 300.430(f)(1)(ii)(C) of the NCP.

As discussed in Section 4.3, chemical-specific ARARs, RBCs, regional background data, and other appropriate EPA human health and ecological screening sources were considered in developing the Site-specific PRGs summarized in Table 4-8. The remedial alternatives (excluding the No Action alternative) were then developed specifically to address RAOs and comply with the PRGs, but it was determined that none of the alternatives are anticipated to achieve groundwater MCLs (under the Safe Drinking Water Act [SDWA]) for all COCs within a reasonable restoration timeframe. This may be the case for even the most aggressive groundwater restoration alternatives. Therefore, evaluation of remedial alternatives with respect to compliance with ARARs focuses on the progress likely to be made under each alternative toward achieving MCLs for each COC.

As discussed in Section 6.2.2, habitat restoration pursuant to CWA 404(b)(1) or the ESA would be included as part of the remedy, although this FS does not include habitat restoration plans. If sediment capping changes existing bathymetry because existing sediments would not be removed before cap placement, or if placement of a cap would relocate the shoreline and the OHWL waterward in some locations, these impacts would be offset by equal areas of cut backs in the shoreline to ensure that there would be no net loss of area of Waters of the United States. These design considerations would ensure compliance with Section 404 of the CWA. The compatibility of remedial components with potential future habitat scenarios is considered under this criterion.

The remedial alternatives (with the exception of the No Action alternative) are expected to comply with all other ARARs because the required engineering design and agency review process would include steps to ensure compliance. These other ARARs may affect implementation, but they do not have a significant effect on whether a remedial alternative is fundamentally viable. The means of compliance with other ARARs would be documented in the remedial design, remedial action work plan components (e.g., environmental protection plan; construction quality control plan; waste management, transportation, and disposal plan; stormwater pollution and spill prevention plan and BMPs), and other preconstruction documentation to be prepared during design.

7.1.2 *Balancing Criteria*

The five balancing criteria represent the main technical criteria upon which the alternative evaluation is based. Factors to be evaluated under each of the balancing criteria are discussed below.

7.1.2.1 Long-Term Effectiveness and Permanence

This criterion focuses on evaluating the risk remaining at the Site after the response objectives have been met. The components of this criterion include the following:

- Magnitude of residual risk[45]; and
- Adequacy and reliability of controls.

The magnitude of residual risk was evaluated in terms of the extent to which each alternative would achieve RAOs (Section 4.2.1). The following metrics were considered in this evaluation:

- Removal/treatment technologies employed (e.g., on-site thermal desorption is considered more effective than *in situ* solidification at reducing residual risk because, under *in situ* solidification, high concentrations of contaminants, although immobilized, would remain on the Site);
- Extent of removal/treatment (evaluated primarily based on estimated volume of DNAPL removed or treated; however, the predicted reduction in contaminant mass flux in lakebed sediments 100 years after implementation of the alternative was also considered); and
- Future exposure risk of contamination left in place (varies based on the location, potential mobility, and toxicity of the contaminated materials; i.e., near-surface and potentially mobile PTMs with high benzene and/or PAH concentrations generally represent a greater future exposure risk). As discussed in the introduction to Section 6.3.4, PTMs in the QP-U, QP-S, and TD DNAPL Areas have been identified as having the greatest future exposure risk; therefore, removal/treatment of PTMs in these areas provides for increased long-term

[45] The extent to which each alternative would achieve the human health and environmental protection RAOs is discussed under the *Overall Protection of Human Health and the Environment* evaluation criterion. Defined as risks that remain after remedy implementation is complete (EPA 1991b).

effectiveness by reducing the magnitude of residual risk versus the removal/treatment of PTMs elsewhere on the Site.

The volume of DNAPL removed or treated in each alternative was estimated using the Thiessen polygon areas shown on Figure 4-6. Consistent with Appendix G of the RI Report (Anchor QEA and Aspect 2012), DNAPL volume calculations for each polygon were based on the cumulative thickness of PTM soil addressed by the alternative, and assumed a soil density of 1.6 tons/cy and a total hydrocarbon concentration of 34,000 milligrams per kilogram of PTM soil. Refer to engineering calculation sheets E-7 through E-15 in Appendix E of this FS for detailed calculations. Resulting DNAPL volumes, broken out by upland versus aquatic areas and by removal/treatment technologies, are summarized in Table 7-2. Site-wide DNAPL removal/treatment volumes for each alternative are presented on Figure 7-2 in the form of a bar chart. Table 7-2 also shows DNAPL removal/treatment estimates as a percentage of the total estimated DNAPL volume in the upland and aquatic areas, and Site-wide.

The adequacy and reliability of controls (e.g., containment systems and institutional controls) were evaluated based on the likelihood for re-exposure to contained materials, considering their location and the specific controls used. Controls in upland areas are generally considered more reliable than controls in aquatic areas because access and use of upland areas would be more easily controlled and enforced, and would be easier to access for monitoring and maintenance. Controls that rely on treatment (e.g., PRBs) are considered to have a greater risk of failure than physical barriers (e.g., non-reactive caps), since treatment media can lose effectiveness over time.

7.1.2.2 Reduction of Toxicity, Mobility, or Volume Through Treatment

This criterion addresses the degree to which an alternative reduces the toxicity, mobility, or volume of chemical constituents through treatment. CERCLA has a statutory preference for remedial actions that use treatment technologies to address the principal threats posed by a site, wherever practicable (40 CFR 300.430(a)(1)(iii)(A)). Analysis factors considered under this criterion include the following:

- Treatment processes used and materials treated;
- Amount of hazardous materials destroyed or treated (discussed in terms of volume of DNAPL destroyed or treated because the vast majority of COC mass exists as DNAPL);
- Degree of expected reductions in toxicity, mobility, and volume;
- Degree to which treatment is irreversible; and
- Type and quantity of residuals remaining after treatment.

Four types of PTM treatment are employed in the range of alternatives: 1) off-site incineration of mobile DNAPL accumulating in collection trenches, 2) *in situ* solidification of upland PTMs, 3) on-site thermal desorption of PTMs, and 4) absorption of DNAPL by organoclay sediment caps. In addition, PRBs or pump and treat systems are employed to treat groundwater along the Lake Washington shoreline

in several of the alternatives,and reactive sediment capping would reduce mobility of DNAPL should DNAPL migrate due to a seismic or other exteme event.

Contamination addressed by off-site disposal is not considered for this criterion, since the criterion is based on the statutory preference for treatment.

7.1.2.3 Short-Term Effectiveness

This criterion assesses effects and risks to human health and the environment until response objectives are achieved. Analysis factors considered under this criterion include the following:

- Protection of community during remedial actions;
- Protection of workers during remedial actions;
- Environmental impacts; and
- Time until RAOs are achieved.

7.1.2.4 Implementability

This criterion evaluates the ease or difficulty of implementing the remedial alternative by considering technical feasibility, administrative feasibility, and availability of services and materials required for implementation. Analysis factors considered under this criterion include the following:

- Technical feasibility (ability to construct and operate the technology; reliability of the technology; ease of undertaking additional remedial actions, if necessary; and ability to monitor effectiveness of remedy);
- Administrative feasibility (ability to obtain approvals from other agencies, and coordination with other agencies); and
- Availability of services and materials (availability of off-site treatment, storage, and disposal services and capacity; availability of necessary equipment and specialists; and availability of prospective technologies).

Appendix C (detailed technology/process option screening) evaluates the technical feasibility of implementing various Site remedial technology process options. In general, the selected process options included in the remedial alternatives are implementable on a stand-alone basis. When comprehensive alternatives consist of a combination of active remedial process options (e.g., dredging, excavation, and on-site treatment), the size and complexity of the project can affect overall implementation.

7.1.2.5 Cost

This criterion includes all direct and indirect capital costs as well as OM&M costs incurred over the life of the project (100-year project life assumed for cost estimating purposes). Appendix D provides detailed cost estimates for Alternatives 2 through 10. Two costs were calculated for each alternative: one using Net Present Value (NPV)

analysis[46] assuming a discount rate of 1.6 percent, and one with no discount rate for future costs. NPV analysis allows costs for remedial alternatives to be compared on the basis of a single figure by discounting all future costs to a common base year. The NPV of a project represents the dollar amount which, if invested in the initial year of the remedy and disbursed as needed, would be sufficient to cover all costs associated with the remedial action. As stated in the RI/FS guidance (EPA 1988a), these estimated costs are expected to provide an accuracy of plus 50 percent to minus 30 percent but do not account for post-FS changes in the scope of the remedial alternatives. Refer to Appendix D for additional information.

7.1.2.6 Alternative Rating with Respect to the Balancing Criteria

In the detailed evaluation of each alternative in Section 7.2, the first four balancing criteria (all except "Cost") will be rated "low," "moderate," or "high," depending on the degree to which the alternative is judged to satisfy the criterion. A brief justification for the rating is also provided.

7.1.3 *Modifying Criteria*

State (Support Agency) Acceptance assesses the technical and administrative issues raised by the supporting agencies about the alternatives.

Community Acceptance assesses issues and concerns raised by interested persons in the community about the potential remedial alternative. Note that these modifying criteria were not evaluated in this FS; they will be evaluated by EPA after compilation of public comments and input received on the Site Proposed Plan.

7.2 Detailed Evaluation of Alternative 1

The No Action alternative reflects the baseline Site conditions. The No Action alternative does not include any active remediation, monitoring, or institutional controls. Contamination would be left in place.

7.2.1 *Threshold Criteria*

The No Action alternative is not protective of human health and the environment. The baseline risk assessments (see Section 3.7) identified unacceptable risks to both human and ecological receptors associated with Site contamination. All current risks would remain unabated under this alternative; therefore, the No Action alternative does not meet the threshold criterion of achieving RAOs, which include reducing human health and ecological risks to acceptable levels.

7.2.2 *Balancing Criteria*

Because the No Action alternative does not include remedial actions, residual risks are undiminished from the baseline condition, with any future changes occurring only through natural processes. Institutional controls and monitoring would not be implemented, and there would be no reduction of contaminant toxicity, mobility, or volume through treatment. Because no actions are implemented, there would be no short-term risks to workers, community, or the environment from construction activities;

[46] NPV analysis is referred to as present worth analysis in the RI/FS guidance (EPA 1988a).

however, RAOs would not be achieved indefinitely. Alternative 1 would be easy to implement and would have no associated costs because no action is taken.

7.3 Detailed Evaluation of Alternative 2

Alternative 2 combines ENR of sediments, soil and sediment capping, and institutional controls to prevent exposure to contaminated media. This alternative includes maintenance of engineering controls and monitoring of ongoing natural attenuation of groundwater to confirm that exposure pathways are controlled. Refer to Section 6.3.2 for a detailed description.

7.3.1 *Overall Protection of Human Health and the Environment*

Alternative 2 would eliminate, reduce, or control the risks associated with the exposure pathways delineated in the RAOs for protection of human health and the environment (see Sections 4.2.2 and 4.2.3, respectively) as follows:

HH1: Groundwater. The restoration of groundwater to its highest beneficial use (drinking water) under Alternative 2, would occur slowly over time as a result of natural attenuation processes. Figure 7-1 shows projected groundwater volumes exceeding the MCLs for benzene, arsenic, benzo(a)pyrene, and the aggregate plume (considering all three COCs simultaneously) 100 years after completion of remedial actions. Note that the volumes shown for Alternative 2 are somewhat lower than for Alternative 1 (No Action). This is because, as discussed in Appendix A, the groundwater model base case assumed a permeable upland surface, whereas modeling for Alternatives 2 through 10 assumed a largely impermeable surface (the likely Site development scenario).

The groundwater model predicted that MCLs would not be achieved throughout the aquifers (after 100 years) for any of the COCs. Human health risk related to potential future groundwater use would be addressed by an institutional control that would prohibit use of groundwater for drinking purposes and construction of wells for any purpose other than remediation or monitoring. This institutional control would remain in effect until all COC MCLs are achieved. As discussed in the RI Report (Anchor QEA and Aspect 2012, Section 3.3.2), Site facilities and the entire surrounding community are currently serviced by public water systems, which have sources outside the Site The only private wells identified in the area are located upgradient and outside the influence of the Site. Additionally, the King County Comprehensive Plan does not allow for new, individual private water supply wells to be permitted within municipal water supply service area boundaries, which include the Site.

HH2: Sediment. Human health risk from ingestion of resident fish and shellfish taken from the Site for subsistence would be reduced to acceptable levels. Alternative 2 would reduce COC concentrations in surface sediments which, in turn, would reduce the levels of COCs in resident fish and shellfish, through a combination of sediment capping (reactive and engineered sand caps) and ENR. No actions would be taken to reduce the toxicity or volume of sediment contaminants. The institutional controls (health department advisories on fish/shellfish harvesting, controls to protect the caps), monitoring, and cap inspection/repair program would remain in place to ensure continued protection.

HH3: Sediment. Human health risk from playing, wading, or swimming resulting in incidental ingestion and/or dermal exposure to contaminated sediments would be reduced to acceptable levels. Alternative 2 would reduce COC concentrations in surface sediments through a combination of sediment capping and ENR. No actions would be taken to reduce the toxicity or volume of sediment contaminants. The institutional controls (health department advisories on fish/shellfish harvesting, controls to protect the caps), monitoring, and cap inspection/repair program would remain in place to ensure continued protection.

HH4: Surface Water. Human health risk from direct contact or incidental ingestion of surface water contaminated with COCs would be reduced to acceptable levels. Alternative 2 would reduce COC concentrations in surface sediments, which in turn would reduce the levels of COCs in surface water, through a combination of sediment capping and ENR. No actions would be taken to reduce the toxicity or volume of sediment contaminants. The institutional controls (health department advisories on fish/shellfish harvesting, controls to protect the caps), monitoring, and cap inspection/repair program would remain in place to ensure continued protection. In addition, Lake Washington is no longer available for consumptive appropriation because it was closed in 1979 to further withdrawals under Chapter 173-508 WAC.

HH5: Vapor. Human health risk from inhalation of vapors from groundwater and/or soils contaminated with COCs would be reduced to acceptable levels primarily by an institutional control that would require evaluation of vapor intrusion potential and/or construction of vapor controls beneath future buildings located above areas containing volatile COCs. By providing a clean soil buffer, soil capping would marginally reduce the likelihood that vapor controls would be needed in a given building. However, since this alternative does not include any soil or groundwater treatment/removal, building vapor controls would likely still be required in some cases.

HH6: Soils (Surface and Subsurface). Human health risk from direct contact or incidental ingestion of COCs in soil would be reduced to acceptable levels through a combination of soil capping (3-foot thickness assumed over the entire upland Site), institutional controls to protect the cap and manage invasive activities (e.g., utility installation) that may otherwise result in exposures, and periodic inspection/repair to ensure long-term cap integrity. No actions would be taken to reduce the toxicity, mobility, or volume of soil contaminants. The institutional controls and cap inspection/repair program would remain in place to ensure continued protection.

EP1: Surface Water. Risk to aquatic-dependent organisms when direct contact with surface water or incidental ingestion of COCs in surface water exceeds remediation goals (water quality standards) would be reduced to acceptable levels. Alternative 2 would reduce COC concentrations in surface sediments, which in turn would reduce the levels of COCs in surface water, through a combination of sediment capping and ENR. No actions would be taken to reduce the toxicity or volume of sediment contaminants. The institutional controls (health department advisories on fish/shellfish harvesting, controls to protect the caps), monitoring, and cap inspection/repair program would remain in place to ensure continued protection.

EP2: Upland Soil. Risk to terrestrial wildlife when direct contact and incidental ingestion or consumption of soil invertebrates results in exposures to COCs would be reduced to acceptable levels through the same combination of actions and controls as discussed above under HH6.

EP3: Sediment. Risk to aquatic-dependent wildlife (sediment probing birds and piscivorous mammals) where surface sediments containing COCs exceed remediation goals would be reduced to acceptable levels. Alternative 2 would reduce COC concentrations in surface sediments through a combination of sediment capping and ENR. No actions would be taken to reduce the toxicity or volume of sediment contaminants. Following completion of remedial actions, contaminated sediments that are contained beneath the caps and ENR would be subject to long-term institutional controls (health department advisories on fish/shellfillshellfish harvesting, controls to protect the caps) and monitoring.

EP4: Sediment. Risk to benthos where surface sediments containing COCs exceed remediation goals would be reduced to acceptable levels. Alternative 2 would reduce COC concentrations in surface sediments through a combination of sediment capping and ENR. No actions would be taken to reduce the toxicity or volume of sediment contaminants. The institutional controls (health department advisories on fish/shellfish harvesting, controls to protect the caps), monitoring, and cap inspection/repair program would remain in place to ensure continued protection.

7.3.2 *Compliance with ARARs*

As discussed in Section 7.1.1.2, Alternative 2 would comply with the chemical-specific, action-specific, and location-specific ARARs and TBCs identified in Section 4 (see Tables 4-1 through 4-3) with the exception of the SDWA, which requires achievement of groundwater MCLs throughout the Site. The extent to which MCLs would be achieved in this alternative is discussed below.

7.3.2.1 Aquifer Restoration

The groundwater flow and contaminant fate and transport model described in Section 6.2.4.1 and Appendix A was used to predict the approximate aquifer volume that may contain groundwater with COC concentrations exceeding MCLs 100 years after completion of remedial construction. A sensitivity analysis of key FS groundwater model input assumptions that contribute to model prediction uncertainty was also performed, including evaluation of the range of assumed values for the partition coefficient, biodegradation decay rate, and initial source concentration to help bound the degree of uncertainty in model aquifer restoration predictions. The groundwater model was used as a relative tool to compare alternatives with respect to progress toward achieving MCLs.

Figure 7-1 shows model results for restoration of all Site groundwater (Shallow and Deep Aquifers). Projected groundwater volumes exceeding MCLs for the individual COCs benzene, benzo(a)pyrene, and arsenic were predicted, as well as the volume of the aggregate plume exceeding MCLs for these COCs. One hundred years after remedial construction completion for Alternative 2, the groundwater volume exceeding MCLs in the aggregate was predicted to decrease by 13 percent relative to the No Action alternative. Among the individual COCs modeled, benzene was predicted to decrease by 13 percent, while negligible reductions were predicted for benzo(a)pyrene and arsenic.

The vertical black bars shown on Figure 7-1 depict the approximate uncertainty in predicted aquifer restoration for the remedial alternative, based on a sensitivity analysis performed on key groundwater model input assumptions. Other factors, such as soil heterogeneity, introduce additional uncertainty into the model predictions (beyond the vertical bars depicted on the figures). Due to the high degree of uncertainty, model predictions should only be interpreted in a relative sense for comparative analysis of alternatives.

7.3.3 *Long-Term Effectiveness and Permanence*

The long-term effectiveness and permanence of Alternative 2 is evaluated in this section with respect to magnitude of residual risks and adequacy/reliability of controls.

7.3.3.1 Magnitude of Residual Risks

In this subsection, residual risks associated with source material are discussed in terms of the extent to which Alternative 2 would achieve the source control RAOs (see Section 4.2.1). Residual risks to human health and the environment are discussed under the *Overall Protection of Human Health and the Environment* evaluation criterion.

SC1: Treat or Remove DNAPL in Subsurface Soils and Groundwater. This alternative does not treat or remove DNAPL in subsurface soils or groundwater to prevent contamination of groundwater above MCLs.

SC2: Contain DNAPL in Subsurface Soils and Groundwater. Reactive sediment caps would be installed in sediment DNAPL areas to prevent DNAPL migration to Lake Washington. As noted in Section 6.3.2.3, the DNAPL deposits in these areas are currently stable but could potentially be mobilized by a seismic or other extreme event. The greatest potential for this type of mobilization is in QP-S DNAPL Area, due to its nearshore location and greater DNAPL thickness. Alternative 2 includes actions that would address this area with an amended sand cap, while RCM caps would be installed in the other sediment DNAPL areas. Both types of reactive sediment caps would meet the primary objectives of a subaqeuous cap (EPA 2005), which are as follows:

- Physical isolation of the contaminated sediment sufficient to reduce exposure through direct contact and to reduce the ability of burrowing organisms to move contaminants to the cap surface;
- Stabilization of contaminated sediment and erosion protection of the sediment and cap, sufficient to reduce resuspension and transport of contaminants into the water column; and
- Chemical isolation sufficient to prevent unacceptable risks of exposure to sediment contaminants that may be transported through the cap material and into the water column (e.g., via diffusion or groundwater advection).

For both types of cap, the stabilization objective would be met through appropriate armoring. The amended sand cap would provide more chemical isolation because it is thicker and would last longer. However, the amended sand cap would be heavier than the RCM cap; therefore, consolidation-induced DNAPL migration would need to be addressed by increasing the DNAPL sorptive-isolation capacity. In addition, the amended sand cap's thickness would change the existing shoreline bathymetry. Therefore, caps

would need to be designed in consultation with the Trustees in a manner that offsets potential loss of habitat. Institutional controls would be implemented to protect the caps, and long-term monitoring would confirm that DNAPL is contained.

SC3: Reduce COC Migration from Soils to Groundwater. This alternative does not include any remedial actions that would reduce migration of soil contaminants to groundwater.

SC4: Reduce COC Migration from Sediments to Surface Water. This alternative includes reactive capping over aquatic and nearshore PTM areas to sorb migrating DNAPL and limit migration of DNAPL into overlying sediment porewater and surface water.

7.3.3.2 Adequacy and Reliability of Controls

Controls in Alternative 2 include an upland cap, sediment caps (engineered sand cap and reactive sediment cap), ENR, and institutional controls. The adequacy and reliability of each of these controls are discussed below.

Upland Cap. An upland cap would be adequate and reliable in preventing direct contact with contaminated soils and reducing risk to terrestrial wildlife. Institutional controls would be needed to prevent exposure to and migration of COCs. Long-term monitoring and maintenance/repair on an as-needed basis would be needed to ensure long-term cap integrity.

Sediment Caps. The adequacy and reliability of sediment capping are dependent on the caps physical stability and their ability to control COC migration from the underlying sediments into the water column over the long term. Caps would be designed and constructed in accordance with EPA guidance to provide long-term chemical isolation and stability (EPA 2005). Institutional controls would be needed to limit activities that could damage the caps. Long-term monitoring would be needed to evaluate whether damage has occurred and to determine if/when repairs are needed. In addition, reactive caps may lose their effectiveness when the reactive material becomes saturated. Therefore, for continued effectiveness, a reactive cap would need to be designed to either achieve an operating lifetime that is longer than the projected restoration timeframe or include a mechanism to allow for replacement of reactive media as needed. Proper design and installation would eliminate the need for routine periodic maintenance. In the event that damage to the caps occurs, affected areas would be identified during monitoring and subsequently addressed.

ENR. ENR would be adequate and reliable in facilitating the re-establishment of benthic organisms and accelerating the process of physical isolation by natural sediment deposition. Long-term monitoring and placement of additional sand on an as-needed basis would ensure that contaminant concentrations in surface sediments remain at acceptable levels. Because the area to which the ENR would be applied is based on a background cPAH value, evaluation of cPAH concentrations over time and the contributions from regional background inputs would be part of tracking achievement of the cPAH PRG.

Institutional Controls. Table 7-3 lists the institutional controls and associated long-term monitoring that may be implemented in Alternative 2. Institutional controls could help

reduce exposure risks to both human and ecological receptors. The adequacy and reliability of institutional controls depends upon how they are implemented and maintained and on how the institutional controls would be enforced by the relevant agency or government entity. Consideration must be given as to whether the implementing entities have the inherent resources and capacity to plan for, implement, maintain, and enforce institutional controls[47].

The remedy would include institutional controls to limit activities that could compromise cap integrity (such as dredging). As part of the CERCLA 5-year review, EPA would require periodic review of the status and effectiveness of the institutional controls implemented at the Site.

Monitoring. CERCLA requires that a site be reviewed every 5 years if a remedy results in contaminant concentrations remaining above levels that allow for unrestricted use and unlimited exposure. Because Alternative 2 would result in contaminant concentrations remaining above such levels, it would include monitoring associated with 5-year reviews.

7.3.3.3 Alternative 2 Rating with Respect to this Criterion

Alternative 2 is rated "low" with respect to long-term effectiveness and permanence because of its reliance on capping and institutional controls to provide long-term protection, particularly with respect to aquatic PTMs and upland PTMs along the shoreline (TD, QP-S, and QP-U DNAPL Areas) which represent the greatest residual risk at the Site.

7.3.4 *Reduction of Toxicity, Mobility, or Volume Through Treatment*

Alternative 2 includes reactive sediment capping to reduce DNAPL mobility through treatment. The objective of the reactive cap is to sorb DNAPL should DNAPL migrate upward through the sediment due to a future seismic or other exteme event. Organoclay is the active treatment component.

7.3.4.1 Amount of Hazardous Materials Destroyed or Treated

The majority of contaminant mass at the Site is present as DNAPL or DNAPL-impacted soil or sediment (i.e., PTMs). Therefore, this consideration is primarily evaluated based on the amount of PTMs (as volume of DNAPL contained in those PTMs) that is treated.

The amount of DNAPL treated by the reactive sediment caps would be expected to be low under current and long-term conditions. Nearshore and aquatic DNAPL is currently stable at the Site. Active DNAPL seeps have not been observed under current Site conditions. Reactive caps are included in this alternative as a control should DNAPL migration occur due to a seismic or other extreme event.

---

[47] EPA has set forth a strategy for ensuring that institutional controls are successfully implemented at cleanup sites. The strategy includes gathering and entering information in the Institutional Controls Tracking System, evaluating data generated through the system, prioritizing and conducting Site-specific follow-up activities, building the capacity to better manage and review information, and coordinating with other interested parties (EPA 2004b). This strategy is expected to increase the long-term effectiveness of institutional controls at cleanup sites.

7.3.4.2 Degree of Expected Reductions in Toxicity, Mobility, and Volume

The reactive sediment caps would be expected to be 100 percent effective at preventing DNAPL migration from underlying sediments into Lake Washington.

Reduction in Contaminant Mass Flux to Sediments. The groundwater flow and contaminant fate and transport model described in Section 6.2.4.1 and Appendix A was used (as a relative tool) to predict the degree to which contaminant mass flux to sediments would be reduced, relative to mass flux under the No Action alternative, 100 years after completion of remedial construction. Only mass contributed from upland contamination was considered. Figure 7-3 shows the groundwater model results for the individual COCs benzene, arsenic, benzo(a)pyrene, and naphthalene. One hundred years after remedial construction for Alternative 2 was complete, projected mass flux reduction was roughly 30 percent for the organic COCs, whereas projected arsenic mass flux reduction was less than 10 percent relative to the No Action alternative.

7.3.4.3 Degree to which Treatment is Irreversible

Reactive caps containing organoclay are included in this alternative as a control should DNAPL migration occur due to a seismic or other extreme event. Research indicates that organoclays are capable of irreversibly sorbing large amounts of organic matter (Bullock 2009).

7.3.4.4 Type and Quantity of Residuals Remaining after Treatment

If organoclay caps become saturated with DNAPL, the material would be removed and replaced. DNAPL-saturated organoclay would likely be treated by incineration. The FS cost estimate conservatively assumes that 25 percent of the reactive sediment cap area would periodically be replaced; however, the quantity of organoclay that becomes "spent" over time would be expected to be low.

7.3.4.5 Alternative 2 Rating with Respect to this Criterion

Alternative 2 is rated "low" with respect to reduction of toxicity, mobility, or volume through treatment. This alternative reduces contaminant mobility through a slight reduction in groundwater mass flux and reduces the potential mobility of DNAPL in sediments. However, only a negligible amount of the Site contamination would be treated.

7.3.5 *Short-Term Effectiveness*

7.3.5.1 Protection of Community during Remedial Actions

The primary potential community risks during construction would occur through short-term air pollution and "quality of life" impacts. Quality of life impacts generally refer to the potential for an alternative to impact aesthetics, odor and dust, traffic, noise, and recreation. In general, remedial alternatives with longer durations would have larger community quality of life impacts. Based on previous CERCLA evaluations of these impacts, such as for the Hudson River PCBs Superfund Site (Ecology and Environment, Inc. 2004), the following quality of life concerns were evaluated:

- **Aesthetics.** Remedial construction activities could cause visual impacts; this is particularly true for the more aggressive alternatives. Although remedial construction would most likely occur during the day, any nighttime construction

may cause localized light impacts. Impacts would be greater for the longer-duration alternatives.

- **Odors and Dust.** Remedial construction activities would result in diesel emissions from equipment and truck traffic. Soil and/or sediment removal and stockpiling may produce hydrocarbon and anoxic (e.g., sulfide) odors with the potential to migrate past Site boundaries, depending on prevailing winds. Near stockpile and truck loading areas, dust emissions may occur but remedial designs would include BMPs to mitigate or reduce the dust impacts. Impacts could be greater for longer-duration alternatives and for the more-aggressive alternatives that involve more removal and transport of soils and/or sediments off site.

- **Traffic.** Remedial construction would cause increased truck traffic. Generally, impacts would be greater for alternatives with longer durations and greater excavation and off-site disposal volumes.

- **Noise.** Remedial construction would result in noise. Although remedial construction would most likely occur during the day, any nighttime construction would result in localized noise impacts of greater consequence and a corresponding impact on the quality of life. Impacts would be greater for longer-duration alternatives.

- **Recreation.** Areas surrounding the Site are used for a variety of water-based (e.g., boating/fishing) and shoreline recreational activities. Under each remedial alternative, construction-related effects and safety restrictions may temporarily restrict water-based recreational activities near the Site. Impacts would be greater for the longer-duration alternatives.

The amount of capping material that would be imported to the Site in Alternative 2 (more than 100,000 cy estimated for the upland cap alone) is substantial, requiring over 5,000 truck trips (nominal 20-cy truck capacity assumed). Truck routes and delivery schedules would need to be established to minimize disturbance to the local residential community. Engineering controls would be used to protect the community from dust, vapors, and noise during cap construction.

With respect to aquatic activities, a plan would be developed to manage increased waterborne traffic. Signs would be posted to alert recreational boaters of in-water construction activities. Primary impacts would be associated with temporary increases in dissolved COCs in surface water during dredging (minimal in this alternative) to maintain the existing profile in nearshore cap areas.

Relative to the other alternatives, Alternative 2 would have a low potential for community impacts.

7.3.5.2 Protection of Workers during Remedial Actions

Short-term risk exposures and general worker safety concerns (e.g., those associated with the use of heavy equipment) are inherent in any remedial construction activity and can generally be mitigated using standard BMPs required by state and federal occupational safety and health regulations.

Potential risks to workers during Site clearing, grading, and cap construction would be mitigated by adherence to Site-specific health and safety plans and use of engineering controls. (DNAPL is located below the maximum anticipated depth of disturbance for cap construction.) Potential risks during sediment cap construction and limited shoreline dredging would be similarly mitigated/controlled.

The potential for worker impacts would increase with the scope of construction; refer to Section 6.3.2 for a description of the Alternative 2 scope. Because Alternative 2 would include only a limited potential for contact with contaminated media, it would have a low potential for worker exposures.

7.3.5.3 Environmental Impacts

Impacts to the environment would be minimal during upland cap construction, assuming implementation of adequate erosion and sedimentation control measures. Potential short-term impacts of sediment capping and dredging are summarized on Figure 7-4. The limited shoreline dredging to offset cap construction would result in extremely localized, short-term acute water quality criteria exceedances. Monitoring would be performed to document turbidity levels and modify BMPs as necessary. Short-term impacts associated with cap placement would include possible minor effects on water quality. As shown on Figure 7-4, these impacts primarily consist of turbidity due to suspended clean capping materials and a relatively small potential for resuspension of existing sediments near the sediment surface. ENR sand placement would have similar short-term impacts to cap placement.

Cap material placement would in some cases provide desirable habitat substrates (e.g., beach gravel) and in many other cases the larger cap armor types would fill in with the deposition of sand and silt-sized materials similar to those currently present at the same locations across the Site. These new surfaces (i.e., the mixtures that often mimic existing Site sediments) would provide suitable substrate for the benthic invertebrate community. Studies completed in similar regional environments indicate that recolonization after sediment disturbance (e.g., initial placement of the cap) usually occurs within several months when suitable substrate is present (McCabe et al. 1998).

Alternative 2 would involve relatively little construction and a correspondingly low overall potential for environmental impacts.

7.3.5.4 Time until Remedial Action Objectives are Achieved

Estimated remedy design and construction durations for Alternative 2 are shown on Figure 7-5. Remedial construction and establishment of institutional controls would be expected to be completed within 2 years from initiation of remedial activities; however, not all RAOs would be achieved at the end of the construction period (refer to Sections 7.3.1 and 7.3.3.1).

7.3.5.5 Alternative 2 Rating with Respect to this Criterion

Alternative 2 is rated “high” with respect to short-term effectiveness because it would involve relatively modest construction activities with limited in-water work (limited sediment dredging to offset cap placement) and would likely result in only moderate community impacts from construction noise, traffic, and odor.

7.3.6 *Implementability*

7.3.6.1 Technical Feasibility

Constuction of upland and sediment caps (as well as ENR) in Alternative 2 would be technically feasible, with no unusual technical challenges. Placing sediment cap material on slopes would require a material with sufficient strength (e.g., higher percentage of coarse/medium-grained sand material) and a placement method that would maintain cap stability. Cap stability could be accomplished by starting at the toe of the slope, using a toe berm when necessary, and building upward. The cap thickness should be designed not only for isolation but also to minimize or eliminate future Site use restrictions related to Tribal treaty rights. Environmental considerations, such as protection of fish migration windows, could be readily incorporated into the implementation schedule during design.

7.3.6.2 Administrative Feasibility

Alternative 2 is administratively feasible. Property owners would need to agree to use restrictions for each parcel on which institutional controls are established. Access would need to be provided for periodic inspection and maintenance if vapor intrusion mitigation systems are installed in future buildings. Approvals associated with the substantive requirements of in-water work permitting would require coordination with state agencies. Long-term coordination with the DNR and the U.S. Coast Guard (USCG) would likely be required for off-property aquatic cap maintenance. Monitoring and notification of waterway users to restrict specific activities to protect the aquatic caps would be conducted through applicable state agencies. The Washington State Department of Health fish consumption advisories for Lake Washington, because of PCB and mercury contamination, would likely remain in place for the foreseeable future.

The implementability of environmental covenants has been improved with the State of Washington's 2007 adoption of the Uniform Environmental Covenants Act (UECA.). The UECA addresses the limitations of common law restrictive covenants by creating a system for maintaining permanent records of environmental covenants, and contains procedural requirements for how such covenants are recorded, monitored, and enforced. The UECA allows EPA to enforce restrictive covenants without taking a proprietary interest prohibited by CERCLA Section 113(j).

7.3.6.3 Availability of Services and Materials

Necessary engineering and construction services are readily available with multiple experienced contractors procurable through competitive bidding. Sufficient sand and gravel mine production capacity exists within 20 miles of the Site to supply the capping material.

7.3.6.4 Alternative 2 Rating with Respect to this Criterion

Alternative 2 is rated "high" with respect to implementability because it would present no unusual technical challenges, and necessary engineering and construction services are readily available.

7.3.7 *Cost*

The estimated present worth cost of Alternative 2 is $26 million, including a projected $18 million for capital construction and $7.6 million (present worth) for OM&M.

7.4 Detailed Evaluation of Alternative 3

Alternative 3 includes a similar use of upland and sediment capping[48], monitoring, and institutional controls as Alternative 2, but also involves treatment of targeted areas of upland PTMs and additional treatment measures to further address contaminant migration near the shoreline. Additional measures include the following:

- *In situ* solidification of deep PTMs in the RR DNAPL Area and MC DNAPL Area;
- DNAPL collection trenches along the shoreline, to remove mobile DNAPL from the subsurface and further reduce the potential migration of DNAPL from the uplands to the lake sediments; and
- A PRB along the shoreline to reduce migration of contamination in groundwater from the uplands and enhance recovery of lake sediments and porewater.

Refer to Section 6.3.3 for a detailed description.

7.4.1 *Overall Protection of Human Health and the Environment*

Alternative 3 would eliminate, reduce, or control the risks associated with the exposure pathways delineated in the RAOs for protection of human health and the environment (see Sections 4.2.2 and 4.2.3, respectively) as follows:

HH1: Groundwater. In Alternative 3, *in situ* solidification of some PTM soils (in the RR DNAPL Area and the eastern portion of the MC DNAPL Area) and the funnel-and-gate PRB system would contribute to groundwater restoration. Restoration would occur slowly over time as a result of the combined effects of these remedial components and natural attenuation processes. Figure 7-1 shows projected groundwater volumes exceeding the MCLs for benzene, arsenic, benzo(a)pyrene, and the aggregate plume 100 years after completion of remedial actions. The contribution of these remedial components is the difference between projected volumes under Alternative 3 and those under Alternative 2 (natural attenuation processes only). Remediation in Alternative 3 would contribute to groundwater restoration to a modest degree.

The groundwater model predicted that MCLs would not be achieved throughout the aquifers (after 100 years) for any of the COCs. Human health risk related to potential future groundwater use would be addressed by an institutional control that would prohibit use of groundwater for drinking purposes and construction of wells for any purpose other than remediation or monitoring. This institutional control would remain in effect until all COC MCLs are achieved. Refer to Section 7.3.1 discussion of existing restrictions on private water supply wells.

HH2, HH3, and HH4. These RAOs would be addressed in this alternative using the same combination of actions and controls as in Alternative 2; refer to Section 7.3.1 discussion.

[48] In the QP-S DNAPL Area, a RCM cap would be installed in Alternative 3 instead of the amended sand cap assumed for Alternative 2. Refer to Section 6.3.3.6.

HH5: Vapor. Human health risk from inhalation of vapors from groundwater and/or soils contaminated with COCs would be reduced to acceptable levels primarily by an institutional control that would require evaluation of vapor intrusion potential and/or construction of vapor controls beneath future buildings located above areas containing volatile COCs. By providing a clean soil buffer, soil capping would marginally reduce the likelihood that vapor controls would be needed in a given building. In addition, the limited amount of contaminated soil solidification and removal included in this alternative would reduce vapor intrusion potential in some areas of the Site.

HH6: Soils (Surface and Subsurface). Human health risk from direct contact or incidental ingestion of COCs in soil would be reduced to acceptable levels primarily through a combination of soil capping (3-foot thickness assumed over the entire upland Site), institutional controls to protect the cap and manage invasive activities that may otherwise result in exposures, and periodic inspection/repair to ensure long-term cap integrity. Risk reduction would be supplemented by *in situ* solidification of an estimated 15,000 cy of soil and removal of an estimated 2,900 cy of soil during construction of the DNAPL collection trenches and the funnel and gate systems. The institutional controls and cap inspection/repair program would remain in place to ensure continued protection.

EP1 through EP4. These RAOs would be addressed in this alternative using the same combination of actions and controls as in Alternative 2; refer to Section 7.3.1 discussion.

7.4.2 *Compliance with ARARs*

As discussed in Section 7.1.1.2, Alternative 3 would comply with the chemical-specific, action-specific, and location-specific ARARs and TBCs identified in Section 4 (see Tables 4-1 through 4-3) with the exception of the SDWA, which requires achievement of groundwater MCLs throughout the Site. The extent to which MCLs would be achieved in this alternative is discussed below.

7.4.2.1 Aquifer Restoration

Refer to Section 7.3.2.1 and Appendix A for discussion of the groundwater modeling performed to predict progress toward achieving MCLs under each remedial alternative. Groundwater modeling results are shown on Figure 7-1. One hundred years after remedial construction completion for Alternative 3, the groundwater volume exceeding MCLs in the aggregate was predicted to decrease by 33 percent relative to the No Action alternative. Among the individual COCs modeled, predictions ranged from a 5 percent decrease for arsenic to a 37 percent decrease for benzene.

7.4.3 *Long-Term Effectiveness and Permanence*

The long-term effectiveness and permanence of Alternative 3 is evaluated in this section with respect to magnitude of residual risks and adequacy/reliability of controls.

7.4.3.1 Magnitude of Residual Risks

In this subsection, residual risks associated with source material are discussed in terms of the extent to which Alternative 3 would achieve the source control RAOs (see Section 4.2.1). Residual risks to human health and the environment are discussed under the *Overall Protection of Human Health and the Environment* evaluation criterion.

SC1: Treat or Remove DNAPL in Subsurface Soils and Groundwater. Alternative 3 includes *in situ* solidification of PTM soil in the RR DNAPL Area and the eastern portion

of the MC DNAPL Area. Together these two locations are estimated to treat roughly 10 percent (by volume) of the total Site DNAPL. *In situ* solidification has been applied to address highly contaminated soils and DNAPL at similar sites and has been shown to be effective for SVOCs and metals (EPA 2009); however, there are potential uncertainties associated with the effectiveness of this technology that need to be considered during design, including the following:

- Some organic compounds have a detrimental effect on the solidification process, including benzene (EPA 2004). In general, solidification of soils containing VOCs such as benzene is less effective (EPA 2009).
- Solidification of PTM soils can be incomplete, even when DNAPL is present as thin stringers, based on the formation of oily occlusions within the amended matrix (Stolzenburg 2010). High concentrations of oils may prevent hydration of cement (Wilk 2003).
- The permanence of solidification over the very long term is uncertain. In some cases, solidified soils may gradually erode through physical or chemical degradation processes (EPA 2009).

The uncertainties associated with long-term effectiveness can be addressed by performing appropriate mix design testing and by preparing suitable construction specifications. With respect to mix design, high oil and water content can be addressed by increasing cement content or including other mix amendments, such as organophilic clay. With respect to the formation of oily inclusions, the specification for the adjacent J.H. Baxter & Company *in situ* solidification work (RETEC 2004) included: 1) the installation of test columns to ensure performance requirements were being achieved, 2) a required minimum of two passes with the auger during installation, and 3) performance monitoring throughout construction. Performance criteria for the project included no visible aqueous phase liquid and thorough mixing for grout and soil in cores extracted for monitoring, in addition to quantitative hydraulic conductivity and strength criteria. Long-term testing of *in situ* solidification effectiveness has been performed for a MGP site in Columbus, Georgia *(*EPRI 2003). This testing has demonstrated that the solidified mass is structurally sound and effective at immobilizing contaminants 10 years after installation.

DNAPL would be removed in Alternative 3 by DNAPL collection trenches constructed along the shoreline. Recovered DNAPL would be incinerated off site. Collection trenches are proven technologies to contain and recover DNAPL; however, they rely on lateral DNAPL migration through the soil matrix. Because of its low migration potential, only a small portion of Site DNAPL, estimated at less than 1 percent of the total Site DNAPL, would have sufficient mobility to ultimately be captured by the trenches. The DNAPL removal rate would be expected to decline sharply over time as mobile DNAPL upgradient of the trench is captured. However, the trenches would remain effective in the long term at preventing upland DNAPL from migrating to sediments (see DNAPL containment discussion below).

A small amount of DNAPL removal would also be achieved in Alternative 3 during excavation for construction of the DNAPL collection trenches and the funnel and gate system. The DNAPL volume removed in this manner is estimated at 1 to 2 percent of the total Site DNAPL. PTM soil would be disposed of off site.

Figure 7-2 shows the estimated volumes of DNAPL that would be removed (via off-site disposal and incineration) or treated (by solidification) in Alternative 3. An estimated 12 percent of the total Site DNAPL would be removed or treated in this alternative.

SC2: Contain DNAPL in Subsurface Soils and Groundwater. As discussed above, DNAPL collection trenches constructed along the shoreline would remove mobile DNAPL that has the potential to migrate from the uplands into Lake Washington sediments. As discussed in Section 6.3.3.2, it is assumed that the trenches would be placed upland of the future shoreline habitat area to facilitate access for O&M. Potentially mobile DNAPL located between the trenches and the lake would not be captured.

RCM caps would be installed in all sediment DNAPL areas to prevent DNAPL migration to Lake Washington. Refer to Section 7.3.3.1 discussion of RCM caps.

SC3: Reduce COC Migration from Soils to Groundwater. The *in situ* solidification of PTM soil and COC-impacted soil within the DNAPL footprint (e.g., between and above PTM soil layers) would reduce migration of soil contaminants to groundwater. As discussed in Section 6.3.3.1, soil solidification in the RR DNAPL Area would be expected to provide a significant reduction in impacted groundwater plume volume.

SC4: Reduce COC Migration from Sediments to Surface Water. As in Alternative 2, sediment caps would achieve reduction in contaminant migration from sediments to surface water. Refer to Section 7.3.3.1.

7.4.3.2 Adequacy and Reliability of Controls

Controls in Alternative 3 include an upland cap, DNAPL collection trenches, a PRB (funnel and gate system), sediment caps (engineered sand cap and reactive sediment cap), ENR, and institutional controls. The adequacy and reliability of each of these controls are discussed below.

Upland Cap. Refer to Section 7.3.3.2.

DNAPL Collection Trenches. Properly designed DNAPL collection trenches would be adequate and reliable in limiting DNAPL migration from the upland portion of the Site to the lake, and in protecting the downgradient PRB treatment media. An environmental covenant limiting activities that could cause trench damage would be adequate for protecting the collection trenches. PRB performance monitoring results would provide evidence of a potential DNAPL breach if it occurred, indicating the need for trench maintenance.

PRB (Funnel and Gate System). A properly designed funnel and gate system would be expected to be adequate and reliable in removing hydrocarbons, including benzene, naphthalene, and PAHs, from groundwater approaching the shoreline. An environmental covenant limiting activities that could cause PRB damage would be adequate for protecting the PRB. Long-term monitoring would be necessary to evaluate PRB performance and determine whether media replacement or other maintenance is needed.

Sediment Caps. Refer to Section 7.3.3.2. The RCM cap in the QP-S DNAPL Area would be the most likely to require maintenance due to the amount of DNAPL in this area and its nearshore location.

ENR. Refer to Section 7.3.3.2.

Institutional Controls. Table 7-3 lists the institutional controls and associated long-term monitoring that may be implemented in Alternative 3; refer to Section 7.3.3.2.

7.4.3.3 Alternative 3 Rating with Respect to this Criterion

Alternative 3 is rated "low" with respect to long-term effectiveness and permanence because of its heavy reliance on capping and institutional controls to provide long-term protection, particularly with respect to aquatic PTMs and upland PTMs along the shoreline.

7.4.4 *Reduction of Toxicity, Mobility, or Volume Through Treatment*

Treatment processes that would be used in Alternative 3 include reactive sediment capping, upland DNAPL/soil solidification, off-site incineration of DNAPL recovered in the collection trenches, and PRB treatment of groundwater.

Reactive Sediment Capping. Discussion of this technology with respect to this evaluation criterion is the same as in Alternative 2; refer to Section 7.3.4.

Upland DNAPL/Soil Solidification. Section 6.3.3.1 discusses upland DNAPL/soil solidification in Alternative 3, including a discussion of the treatment process and the materials that would be treated.

Incineration of Collection Trench DNAPL. As discussed in Section 6.3.3.2, it is assumed that DNAPL removed from the collection trenches would be shipped to a hazardous waste treatment facility for incineration.

PRB Treatment of Groundwater. Section 6.3.3.3 discusses PRB treatment of groundwater in Alternative 3, including a discussion of the treatment process and the materials that would be treated. For the purposes of this FS it is assumed that the PRB would be designed to remove hydrocarbons, including benzene, naphthalene, and PAHs, from groundwater, and GAC is assumed as the treatment media. GAC is anticipated to be effective at removing all hydrocarbon COCs; its ability to remove arsenic from groundwater is uncertain.

7.4.4.1 Amount of Hazardous Materials Destroyed or Treated

The majority of contaminant mass treated is DNAPL. Refer to Table 7-2 and Figure 7-2 for estimated DNAPL treatment volumes. Under this alternative, approximately 12 percent of PTMs would be treated.

Reactive Sediment Capping. As in Alternative 2, the reactive sediment cap would be expected to absorb a negligible amount of DNAPL; refer to Section 7.3.4.

Upland DNAPL/Soil Solidification. An estimated 45,000 gallons of DNAPL would be treated by solidification in this alternative.

Incineration of Collection Trench DNAPL. It is estimated that approximately 1,300 gallons of DNAPL would be removed from the collection trenches and subsequently incinerated in this alternative.

PRB Treatment of Groundwater. The PRB is designed for treatment of dissolved contaminants only. Because the vast majority of contaminant mass at the Site is present as DNAPL, the relative contaminant mass present in the dissolved phase that would be treated by the PRB is negligible.

7.4.4.2 Degree of Expected Reductions in Toxicity, Mobility, and Volume

Reactive Sediment Capping. As in Alternative 2, the reactive sediment cap would immobilize a negligible amount of DNAPL; refer to Section 7.3.4.

Upland DNAPL/Soil Solidification. Solidification would reduce the mobility of DNAPL and COCs in soil. As noted in Section 6.3.3.1.2, soil volume would increase by an estimated 10 to 30 percent as a result of solidification.

Incineration of Collection Trench DNAPL. Incineration volatilizes and destroys organic compounds, which would reduce toxicity, mobility, and volume.

PRB Treatment of Groundwater. Based on the assumed use of GAC as the treatment media, the PRB would be effective at reducing the mobility of dissolved organic contaminants in Shallow Aquifer groundwater that passes through it. Its effectiveness at treating arsenic is uncertain.

The combination of solidification and PRB treatment would reduce the volume and mobility of contaminated groundwater. Groundwater modeling results showing predicted reductions in plume volume and mass flux are shown on Figure 7-1 and Figure 7-3, respectively. One hundred years after remedial construction completion for Alternative 3, the overall reduction in contaminated groundwater volume is projected to be 33 percent. A mass flux reduction of roughly 60 percent is projected for the organic COCs, whereas the projected arsenic mass flux reduction is less than 10 percent relative to the No Action alternative.

7.4.4.3 Degree to which Treatment is Irreversible

Reactive Sediment Capping. As in Alternative 2, sorption of DNAPL by the reactive sediment cap would be expected to be irreversible; refer to Section 7.3.4.

Upland DNAPL/Soil Solidification. Refer to Section 7.4.3.1 discussion. Long-term structural and chemical integrity of the solidified matrix is a crucial consideration in developing the amendment mix and solidification process design. Properly designed and executed, solidification treatment would be expected to be essentially irreversible. Due to lack of performance data, however, the potential for long-term matrix degradation, which could result in future COC releases, cannot be entirely discounted.

Solidified materials generally have a very low permeability but materials below the water table would still contain some groundwater, and that groundwater would exceed MCLs. Gradual leaching of COCs that are not completely immobilized, such as benzene, would also potentially result in MCL exceedances at the edges of the solidified soil. Bench studies at a coal-tar site in Tacoma, Washington, indicated leaching of benzene and low-molecular-weight PAHs would continue over hundreds of years (EPA 1989). More recent laboratory studies have indicated that amendments such as activated carbon, organoclay, or sodium silicates can reduce benzene and PAH leaching from solidified soil, although thorough testing is necessary to evaluate potential interactions between contaminants, amendments, and other binders such as bentonite or cement (Environment Agency 2004).

Incineration of Collection Trench DNAPL. Organic contaminants woud be destroyed in the incineration process.

PRB Treatment of Groundwater. Organic contaminants would effectively adsorb onto GAC until the GAC becomes loaded. Groundwater monitoring would be conducted periodically to predict when GAC maintenance or replacement would be required.

7.4.4.4 Type and Quantity of Residuals Remaining after Treatment

Reactive Sediment Capping. As in Alternative 2, a small amount of DNAPL would remain immobilized in the cap. Portions of the cap may be periodically replaced and the DNAPL in those portions would likely be destroyed by incineration; refer to Section 7.3.4.

Upland DNAPL/Soil Solidification. DNAPL stabilized in the soil matrix would remain on site (refer to Table 6-4 for construction quantities). For the purposes of this FS, it is assumed that the soil volume would increase by approximately 20 percent.

Incineration of Collection Trench DNAPL. No residuals would remain on site.

PRB Treatment of Groundwater. Spent GAC used to treat groundwater would be transported off site for reactivation or disposal.

7.4.4.5 Alternative 3 Rating with Respect to this Criterion

Alternative 3 is rated "low" with respect to reduction of toxicity, mobility, or volume through treatment. DNAPL mobility in sediments would be reduced by the reactive cap. Treatment of PTMs in the RR and MC DNAPL Areas would moderately reduce the volume of contaminated groundwater, and the PRB would significantly reduce contaminant mass flux to sediments. However, only a small portion of PTMs would be treated.

7.4.5 *Short-Term Effectiveness*

7.4.5.1 Protection of Community during Remedial Actions

Alternative 3 would require protective measures in addition to those defined in Alternative 2; refer to Section 7.3.5.1 for a discussion of community protection in Alternative 2. Alternative 3 would require additional construction as a result of: 1) *in situ* solidification of a relatively modest volume of PTM soils, 2) DNAPL collection trenches, and 3) the funnel and gate systems. These construction elements would entail additional truck traffic (e.g., to export excavated impacted soils and import solidification amendments and trench backfill materials) and the potential for additional noise, dust, odors, and visual impacts. Nonetheless, with appropriate planning and controls, Alternative 3 would be expected to have a relatively low potential for community impacts.

7.4.5.2 Protection of Workers during Remedial Actions

Alternative 3 would be expected to require additional measures to protect workers, in addition to those defined under Alternative 2; refer to Section 7.3.5.2 for a discussion of worker protection in Alternative 2. *In situ* solidification of PTM soils and the construction of DNAPL collection trenches and the funnel and gate systems in this alternative would result in additional exposure and general safety risks to workers. Potential risks to workers would be mitigated by adherence to Site-specific health and

safety plans and use of engineering controls. The potential for worker impacts would increase with the scope of construction; refer to Section 6.3.3 for a description of the Alternative 3 scope. Because this alternative would have relatively little construction, it would be expected to have a relatively low potential for worker impacts.

7.4.5.3 Environmental Impacts

Refer to Section 7.3.5.3 for a discussion of potential environmental impacts associated with upland and sediment capping. Environmental impacts associated with *in situ* solidification of PTM soil and construction of the DNAPL collection trenches and the funnel and gate systems would be minimal, assuming implementation of adequate erosion and sedimentation control measures. Therefore, Alternative 3 would be expected to have a low overall potential for environmental impacts.

7.4.5.4 Time until Remedial Action Objectives are Achieved

Estimated remedy design and construction durations for Alternative 3 are shown on Figure 7-5. Remedial construction and establishment of institutional controls would be expected to be completed roughly 3 years after initiation of remedial activities; however, not all RAOs would be achieved at the end of the construction period (refer to Sections 7.4.1 and 7.4.3.1).

7.4.5.5 Alternative 3 Rating with Respect to this Criterion

Alternative 3 is rated "high" with respect to short-term effectiveness because it would involve relatively modest construction activities with limited in-water work (no sediment dredging, and would likely result in only moderate community impacts from construction noise, traffic, and odor.

7.4.6 *Implementability*

7.4.6.1 Technical Feasibility

Refer to Section 7.3.6.1 for a discussion of the technical feasibility of capping. DNAPL collection trenches and the funnel and gate systems are considered technically mature, proven technologies, and their construction in this alternative is technically feasible. The *in situ* solidification of PTM soils in this alternative is technically feasible based on Site conditions, pending the results of bench and pilot testing.

7.4.6.2 Administrative Feasibility

Refer to Section 7.3.6.2 for a discussion of the administrative feasibility of capping and institutional controls.

7.4.6.3 Availability of Services and Materials

Necessary engineering and construction services are readily available, with multiple experienced contractors procurable through competitive bidding. Sufficient sand and gravel mine production capacity exists within 20 miles of the Site to supply the capping material requirement.

7.4.6.4 Alternative 3 Rating with Respect to this Criterion

Alternative 3 is rated "high" with respect to implementability because it would present no unusual technical challenges, and necessary engineering and construction services are readily available.

7.4.7 *Cost*

The estimated present worth cost of Alternative 3 is $31 million, including a projected $22 million for capital construction and $9.2 million (present worth) for OM&M.

7.5 Detailed Evaluation of Alternative 4

Alternative 4 includes the same remedies as Alternative 3, but instead of treating deep upland PTMs to reduce groundwater contaminant plume volume, Alternative 4 includes targeted removal of PTMs in the Quendall Pond (QP) and TD DNAPL Areas. Refer to Section 6.3.4 for a detailed description.

As described in Section 4, the TD DNAPL Area contains sediments with the highest risk of exposure based on the presence of DNAPL in relatively shallow sediments. The QP DNAPL Area includes potentially mobile DNAPL close to Lake Washington, including in upland soil adjacent to the shoreline (QP-U DNAPL Area) and in shallow sediments (QP-S DNAPL Area). The purpose of targeting these areas is to remove PTMs with the greatest potential to impact Lake Washington and reduce the magnitude of residual risk.

7.5.1 *Overall Protection of Human Health and the Environment*

Alternative 4 would eliminate, reduce, or control the risks associated with the exposure pathways delineated in the RAOs for protection of human health and the environment (see Sections 4.2.2 and 4.2.3, respectively) as follows:

HH1: Groundwater. In Alternative 4, removal of some PTM soils (in the QP-U DNAPL Area) and the funnel-and-gate PRB system would contribute to groundwater restoration. Restoration would occur slowly over time as a result of the combined effects of these remedial components and natural attenuation processes. Figure 7-1 shows projected groundwater volumes exceeding the MCLs for benzene, arsenic, benzo(a)pyrene, and the aggregate plume 100 years after completion of remedial actions. The contribution of these remedial components is the difference between projected volumes under Alternative 4 and those under Alternative 2 (natural attenuation processes only). Remediation in Alternative 4 would contribute to groundwater restoration to only a small degree.

The groundwater model predicted that MCLs would not be achieved throughout the aquifers (after 100 years) for any of the COCs. Human health risk related to potential future groundwater use would be addressed primarily by an institutional control that would prohibit use of groundwater for drinking purposes and construction of wells for any purpose other than remediation or monitoring. This institutional control would remain in effect until all COC MCLs are achieved. Refer to Section 7.3.1 discussion of existing restrictions on private water supply wells.

HH2: Sediment. Human health risk from ingestion of resident fish and shellfish taken from the Site for subsistence would be reduced to acceptable levels. Alternative 4 would reduce COC concentrations in surface sediments which, in turn, would reduce the levels of COCs in resident fish and shellfish, through a combination of sediment dredging (removal of an estimated 26,000 cy from PTM areas), sediment capping (reactive and engineered sand caps), and ENR. The institutional controls (health department advisories on fish/shellfish harvesting, controls to protect the caps), monitoring, and cap inspection/repair program would remain in place to ensure continued protection.

HH3: Sediment. Human health risk from playing, wading, or swimming resulting in incidental ingestion and/or dermal exposure to contaminated sediments would be reduced to acceptable levels. Alternative 4 would reduce COC concentrations in surface sediments through a combination of sediment dredging, sediment capping, and ENR. The institutional controls (health department advisories on fish/shellfish harvesting, controls to protect the caps), monitoring, and cap inspection/repair program would remain in place to ensure continued protection.

HH4: Surface Water. Human health risk from direct contact or incidental ingestion of surface water contaminated with COCs would be reduced to acceptable levels. Alternative 4 would reduce COC concentrations in surface sediments which, in turn, would reduce the levels of COCs in surface water, through a combination of sediment dredging, sediment capping, and ENR. The institutional controls (health department advisories on fish/shellfish harvesting, controls to protect the caps), monitoring, and cap inspection/repair program would remain in place to ensure continued protection.

HH5: Vapor. Human health risk from inhalation of vapors from groundwater and/or soils contaminated with COCs would be reduced to acceptable levels primarily by an institutional control that would require evaluation of vapor intrusion potential and/or construction of vapor controls beneath future buildings located above areas containing volatile COCs. By providing a clean soil buffer, soil capping would marginally reduce the likelihood that vapor controls would be needed in a given building. In addition, the limited amount of contaminated soil removal included in this alternative would reduce vapor intrusion potential in some areas of the Site.

HH6: Soils (Surface and Subsurface). Human health risk from direct contact or incidental ingestion of COCs in soil would be reduced to acceptable levels primarily through a combination of soil capping (3-foot thickness assumed over the entire upland Site), institutional controls to protect the cap and manage invasive activities that may otherwise result in exposures, and periodic inspection/repair to ensure long-term cap integrity. Risk reduction would be supplemented by removal of an estimated 16,000 cy of soil from the QP-U DNAPL Area and an additional 2,900 cy during construction of the DNAPL collection trenches and the funnel and gate system. The institutional controls and cap inspection/repair program would remain in place to ensure continued protection.

EP1: Surface Water. Risk to aquatic-dependent organisms when direct contact with surface water or incidental ingestion of COCs in surface water exceeds remediation goals (water quality standards) would be reduced to acceptable levels. Alternative 4 would reduce COC concentrations in surface sediments, which in turn would reduce the levels of COCs in surface water, through a combination of sediment dredging, sediment capping (reactive and engineered sand caps and reactive residuals cover), and ENR. The institutional controls (health department advisories on fish/shellfish harvesting, controls to protect the caps), monitoring, and cap inspection/repair program would remain in place to ensure continued protection.

EP2: Upland Soil. Risk to terrestrial wildlife when direct contact and incidental ingestion or consumption of soil invertebrates results in exposures to COCs would be reduced to acceptable levels through the same combination of actions and controls as discussed above under HH6.

EP3: Sediment. Risk to aquatic-dependent wildlife (sediment-probing birds and piscivorous mammals) where surface sediments containing COCs exceed remediation goals would be reduced to acceptable levels. Alternative 4 would reduce COC concentrations in surface sediments through a combination of sediment dredging, sediment capping, and ENR. The institutional controls (health department advisories on fish/shellfish harvesting, controls to protect the caps), monitoring, and cap inspection/repair program would remain in place to ensure continued protection.

EP4: Sediment. Risk to benthos where surface sediments containing COCs exceed remediation goals would be reduced to acceptable levels. Alternative 4 would reduce COC concentrations in surface sediments through a combination of sediment dredging, sediment capping, and ENR. The institutional controls (health department advisories on fish/shellfish harvesting, controls to protect the caps), monitoring, and cap inspection/repair program would remain in place to ensure continued protection.

7.5.2 *Compliance with ARARs*

As discussed in Section 7.1.1.2, Alternative 4 would comply with the chemical-specific, action-specific, and location-specific ARARs and TBCs identified in Section 4 (see Tables 4-1 through 4-3) with the exception of the SDWA, which requires achievement of groundwater MCLs throughout the Site. The extent to which MCLs would be achieved in this alternative is discussed below.

7.5.2.1 Aquifer Restoration

Refer to Section 7.3.2.1 and Appendix A for discussion of the groundwater modeling performed to predict progress toward achieving MCLs under each remedial alternative. Groundwater modeling results are shown on Figure 7-1. One hundred years after remedial construction completion for Alternative 4, the groundwater volume exceeding MCLs in the aggregate plume was predicted to decrease by 19 percent relative to the No Action alternative. Among the individual COCs modeled, predictions ranged from a 2 percent decrease for arsenic to a 20 percent decrease for benzene.

7.5.3 *Long-Term Effectiveness and Permanence*

The long-term effectiveness and permanence of Alternative 4 is evaluated in this section with respect to magnitude of residual risks and adequacy/reliability of controls.

7.5.3.1 Magnitude of Residual Risks

In this subsection, residual risks associated with source material are discussed in terms of the extent to which Alternative 4 would achieve the source control RAOs(see Section 4.2.1). Residual risks to human health and the environment are discussed under the *Overall Protection of Human Health and the Environment* evaluation criterion.

SC1: Treat or Remove DNAPL in Subsurface Soils and Groundwater. This alternative includes removal of DNAPL with the greatest future exposure risk as follows:

- **Excavation of PTM Soil.** DNAPL in the QP-U DNAPL Area that would be removed in this manner is estimated at 8 percent of the total Site DNAPL. PTM soil would be disposed of off site. Whether excavation is performed “in the wet” or “in the dry,” some amount of residual contamination would remain at the base of the excavation. As discussed in Section 6.3.4.1.2, excavation “in the dry” would result in fewer contaminated residuals. The extent to which “in the dry”

excavation is feasible would be evaluated during design. In any case, the potential for direct exposure to any residual contamination would be eliminated through placement of backfill and the upland cap. As discussed in Appendix A (Section A5.1.2.), however, residual contamination may significantly increase the groundwater restoration timeframe.

- **Hydraulic Dredging of PTM Sediment.** DNAPL in the TD DNAPL Area that would be removed in this manner is estimated at 8 percent of the total Site DNAPL. PTM sediment would be disposed of off site. As discussed in Appendix C, Section C5.3.2, approximately 2 to 11 percent of the solids dredged during the last dredge production cut accumulates as a post-dredge residual layer. The hydraulic dredging proposed for the aquatic DNAPL areas would provide a high level of control and residual solids would be expected to be towards the low end of the overall range. Exposure to any residual contamination layer would be eliminated through placement of a post-dredge residuals cap.
- **Mechanical Dredging of PTM Sediment.** DNAPL in the QP-S DNAPL Area that would be removed in this manner is estimated at 6 percent of the total Site DNAPL. PTM sediment would be disposed of off site. As discussed in Appendix C, Section C5.3.2, approximately 2 to 11 percent of the solids mass dredged during the last dredge production cut accumulates as a post-dredge residual layer. The mechanical dredging proposed for the nearshore DNAPL areas would provide a low level of control and residual solids would be expected to be towards the high end of the overall range. However, exposure to any residual contamination layer would be eliminated through placement of a post-dredge residuals cap.

Figure 7-2 shows the estimated DNAPL volumes that would be removed (via off-site disposal and incineration) in Alternative 4. An estimated 22 percent of the total Site DNAPL (and, as shown in Table 7-2, 88 percent of sediment DNAPL) would be removed in this alternative, including upland and aquatic DNAPL with the greatest future exposure risk.

SC2: Contain DNAPL in Subsurface Soils and Groundwater. As in Alternative 3, DNAPL collection trenches constructed along the shoreline would remove mobile DNAPL that has the potential to migrate from the uplands into Lake Washington sediments; refer to Section 7.4.3.1. RCM caps would be installed in sediment DNAPL areas not dredged in this alternative (i.e., Areas DA-3, DA-4, DA-7, and DA-8) to prevent DNAPL migration to the lake. Refer to Section 7.3.3.1 discussion of RCM caps.

SC3: Reduce COC Migration from Soils to Groundwater. The excavation and off-site disposal of PTM soil discussed above would reduce migration of soil contaminants to groundwater.

SC4: Reduce COC Migration from Sediments to Surface Water. The dredging and off-site disposal of PTM sediments discussed above would achieve reduction in contaminant migration from sediments to surface water. In other areas of impacted sediments, sediment caps would achieve this objective; refer to Section 7.3.3.1.

7.5.3.2 Adequacy and Reliability of Controls

Controls in Alternative 4 include an upland cap, DNAPL collection trenches, a PRB (funnel and gate system), sediment caps (engineered sand cap and reactive sediment cap), reactive residuals cover, ENR, and institutional controls. The adequacy and reliability of each of these controls are discussed below.

Upland Cap. Refer to Section 7.3.3.2.

DNAPL Collection Trenches. Refer to Section 7.4.3.2.

PRB (Funnel and Gate System). Refer to Section 7.4.3.2.

Sediment Caps. Refer to Section 7.4.3.2.

Reactive Residuals Cover. Similar to a reactive sediment cap, a reactive residuals cover would be adequate and reliable in preventing direct contact with contaminated sediments, providing a clean bioturbation layer, protecting surface water resources, and preventing DNAPL migration to Lake Washington. Institutional controls would be needed to limit activities that could damage the cover. Long-term monitoring and maintenance/repair on an as-needed basis would be needed to evaluate whether damage has occurred and ensure long-term cover integrity.

ENR. Refer to Section 7.3.3.2.

Institutional Controls. Table 7-3 lists the institutional controls and associated long-term monitoring that may be implemented in Alternative 4; refer to Section 7.3.3.2.

7.5.3.3 Alternative 4 Rating with Respect to this Criterion

Alternative 4 is rated “moderate” with respect to long-term effectiveness and permanence, primarily because it would address aquatic PTMs and upland PTMs along the shoreline using a combination of removal and capping/institutional controls. PTMs presenting the most significant risk for re-exposure (shallow sediments and potentially mobile DNAPL near the shoreline) would be removed.

7.5.4 *Reduction of Toxicity, Mobility, or Volume Through Treatment*

Treatment processes used in Alternative 4 would include reactive sediment capping, reactive residuals cover, off-site incineration of DNAPL recovered in the collection trenches, and PRB treatment of groundwater. Refer to Table 7-2 and Figure 7-2 for estimated DNAPL treatment volumes. Under this alternative, less than 1 percent of DNAPL would be treated.

The amount of hazardous materials treated; the degree of expected reduction in contaminant toxicity, mobility, and volume; the irreversibility of treatment; and the type and quantity of residuals treated for each of the treatment technologies used in Alternative 4 is the same as discussed for previous alternatives except as described below.

Incineration of Collection Trench DNAPL. Discussion of this technology with respect to this evaluation criterion is the same as in Alternative 3; refer to Section 7.4.4.

Reactive Sediment Capping. Discussion of this technology with respect to this evaluation criterion is the same as in Alternative 2; refer to Section 7.3.4.

Reactive Residuals Cover. As discussed in Section 6.3.4.7.3, a reactive residuals cover composed of a 6-inch layer of 10 percent organoclay and 90 percent coarse sand by weight would be placed in dredged areas in Alternative 4. This treatment process has essentially the same objective as reactive sediment capping (DNAPL sequestration), and relies on the same active treatment component (organoclay); therefore, refer to the Section 7.3.4 discussion of reactive sediment capping.

PRB Treatment of Groundwater. Discussion of this technology with respect to this evaluation criterion is the same as in Alternative 3; refer to Section 7.4.4.

PRB treatment would reduce the volume and mobility of contaminated groundwater. Groundwater modeling results showing predicted reductions in plume volume and mass flux are shown on Figure 7-1 and Figure 7-3, respectively. One hundred years after remedial construction completion for Alternative 4, the overall reduction in contaminated groundwater volume is projected to be 19 percent. A mass flux reduction of roughly 60 to 80 percent is projected for the organic COCs, whereas projected reduction in arsenic mass flux is negligible relative to the No Action alternative.

7.5.4.1 Alternative 4 Rating with Respect to this Criterion

Alternative 4 is rated “low” with respect to reduction of toxicity, mobility, or volume through treatment. Mobility of DNAPL remaining in sediments after dredging would be reduced by reactive sediment caps and dredging residual covers. The PRB would slightly reduce contaminated groundwater volume and significantly reduce contaminant mass flux of organic COCs to sediments. However, only a very small portion of PTMs would be treated.

7.5.5 *Short-Term Effectiveness*

7.5.5.1 Protection of Community during Remedial Actions

Alternative 4 would require protective measures in addition to those defined under Alternative 2; refer to Section 7.3.5.1 for a discussion of community protection in Alternative 2. Alternative 4 would also include construction of DNAPL collection trenches and the funnel and gate systems, excavation of a modest volume of PTM soils, and dredging of PTM sediments in selected areas (refer to Table 6-4 for construction quantity estimates). Dredged sediments would be dewatered on site prior to being trucked, along with excavated impacted soils, to an off-site landfill disposal facility. The potential for dust, vapor, noise, and traffic impacts to the community generally increases with the scope and duration of construction. Because Alternative 4 would include a moderate amount of construction occurring over several years (Figure 7-5), its overall impact on the community would be expected to be moderate.

7.5.5.2 Protection of Workers during Remedial Actions

Alternative 4 would require additional measures to protect workers, in addition to those defined under Alternative 2; refer to Section 7.3.5.2 for a discussion of worker protection in Alternative 2. Removal of PTM soils and sediments in this alternative would result in significant additional exposure risks to workers. Exposure potential would be mitigated by adherence to Site-specific health and safety plans and use of engineering controls. The

potential for worker impacts would increase with the scope of construction; refer to Section 6.3.4 for a description of the Alternative 4 scope. Because this alternative would have a moderate amount of construction, it would be expected to have a moderate potential for worker impacts.

7.5.5.3 Environmental Impacts

Refer to Section 7.3.5.3 for a discussion of potential environmental impacts associated with upland and sediment capping. Environmental impacts associated with construction of the DNAPL collection trenches and the funnel and gate systems would be expected to be minimal, assuming implementation of adequate erosion and sedimentation control measures.

Disturbance of PTM soils along the shoreline and PTM sediments would have the potential to mobilize DNAPL and result in significant environmental impacts to the aquatic environment. Potential short-term impacts of sediment capping and dredging are summarized on Figure 7-4. Alternatives that include removal of these materials would be expected to have the highest overall potential for environmental impacts. In general, the potential for impacts would increase with the scope of the removal action.

Under the alternatives involving removal of PTM soils along the shoreline (i.e., Alternatives 4, 6, 8, 9, and 10) and PTM sediment (i.e., Alternatives 4 through 10), the time to achieve environmental protection varies depending on the size (volume and duration) and complexity of the project and is generally more uncertain than for sediment capping because of resuspension, release, and residuals. Based on detailed studies performed at a range of environmental dredging sites which included silt curtains or similar technologies, approximately 2 to 4 percent of the mass of hydrophobic contaminants such as cPAHs that are dredged are released into the water column, with most of the release being in the bioavailable dissolved form (Bridges et al. 2010). Sealed-sheet pile walls provide the greatest isolation of contaminants from the water body during dredging; however, there is also the potential for release of dissolved contaminants, DNAPL, and suspended solids during sheet pile installation.

The relatively shallow sediments would be removed using environmental hydraulic dredges as discussed in Section 6. These dredges have greater control of resuspension than conventional hydraulic or mechanical dredges. In addition, any short-term impacts would be reduced by containing the aquatic dredge areas within oil-sorbent booms and/or silt curtains (if necessary).

The deeper nearshore sediments would be removed using a mechanical dredge with an environmental bucket. A temporary sheet pile enclosure would be installed around the nearshore removal area to isolate the dredging activities from the lake as well as support removal of sediments at depth.

Near-surface porewater and surface water column samples collected from the Site during the RI indicated that current conditions are generally less than or very close to PRGs that would ensure protection of aquatic resources. However, even with controls, unavoidable resuspension and release of COCs from more deeply buried higher-concentration sediment deposits during sediment removal may result in short-term increases in surface water COC concentrations.

In areas where dredging occurs, the fish habitat and benthic community would be significantly altered and/or eliminated in the short term; however, where acceptable concentrations could be achieved in dredge areas (e.g., through placement of post-dredge covers), recolonization would be expected within several months (McCabe et al. 1998).

Because Alternative 4 would include a moderate amount of PTM shoreline soil and sediment removal, it would be expected to have a moderate overall potential for environmental impacts.

7.5.5.4 Time until Remedial Action Objectives are Achieved

Estimated remedy design and construction durations for Alternative 4 are shown on Figure 7-5. Remedial construction and establishment of institutional controls would be expected to be completed roughly 4 years from initiation of remedial activities; however, not all RAOs would be achieved at the end of the construction period (refer to Sections 7.5.1 and 7.5.3.1).

7.5.5.5 Alternative 4 Rating with Respect to this Criterion

Alternative 4 is rated "moderate" with respect to short-term effectiveness because it would involve moderate construction activities, including significant sediment dredging, and would have the potential for significant community impacts from construction noise, traffic, and odor.

7.5.6 *Implementability*

7.5.6.1 Technical Feasibility

Refer to Section 7.3.6.1 for a technical feasibility discussion of capping, and Section 7.4.6.1 for a discussion of DNAPL collection trenches and funnel and gate systems. Removal of PTM soils and sediments in Alternative 4 by a combination of upland-based excavation along the shoreline, mechanical dredging, and hydraulic dredging, is technically feasible. However, it is not technically feasible to eliminate contaminated residuals at the excavation base when excavating DNAPL in wet conditions. Technologies associated with handling, transportation, and off-site disposal of contaminated soils and sediments are considered technically feasible, and regional landfills are permitted to receive these materials.

Alternatives that emphasize removal (4 through 10) have longer construction periods and would likely be more complex to implement than containment alternatives. Longer construction durations have greater potential for technical problems such as extreme weather events leading to schedule delays. An additional challenge would be proper project sequencing and contractor coordination, due to the number of construction elements and potential contractors (upland excavation, two separate sediment-dredging methods and capping, etc.) and the need to provide access for mobilization/demobilization and staging.

Of the two methods of dredging proposed in this alternative, environmental hydraulic dredging is smaller scale and simpler to inplement than mechanical dredging. Environmental hydraulic dredging transports the sediment to the processing site within a pipeline and dewaters the sediment in a contained vacuum box. Mechanical dredging transports the sediment in a barge and requires rehandling and additional space for transloading and dewatering on site. The mechanical dredging of nearshore sediment

would also require sheet pile procurement, shipping, staging, installation, and removal, making it more challenging to effectively implement.

7.5.6.2 Administrative Feasibility

Refer to Section 7.3.6.2 for an administrative feasibility discussion of capping and institutional controls. Removal of PTM soils and sediments in this alternative by a combination of upland-based excavation along the shoreline, mechanical dredging, and hydraulic dredging is administratively feasible. Approvals associated with the substantive requirements of in-water work permitting would require coordination with state agencies. Dredging would require ESA consultation and substantive compliance with Sections 401 and 404 of the CWA.

7.5.6.3 Availability of Services and Materials

Necessary engineering and construction services are readily available, with multiple experienced contractors procurable through competitive bidding. Sufficient sand and gravel mine production capacity exists within 20 miles of the Site to supply the capping material requirement. Sufficient regional landfill capacity exists to receive contaminated soils and sediments generated in this alternative.

7.5.6.4 Alternative 4 Rating with Respect to this Criterion

Alternative 4 is rated "moderate" with respect to implementability because of the technical and administrative challenges associated with dredging PTM sediments.

7.5.7 *Cost*

The estimated present worth cost of Alternative 4 is $44 million, including a projected $40 million for capital construction and $4.8 million (present worth) for OM&M.

7.6 Detailed Evaluation of Alternative 5

Alternative 5 incorporates the same upland remedial technologies as Alternative 3[49] to treat groundwater and restore a portion of the Deep Aquifer, and the same aquatic remedial technologies as Alternative 4 to remove PTMs in shallow sediments. In addition, this alternative expands the area of upland soil solidification to also include the QP-U DNAPL Area, to target potentially mobile DNAPL located adjacent to Lake Washington, and areas containing at least 4-feet cumulative thickness of DNAPL-impacted soil, to efficiently treat the greatest volume of accessible PTMs. Refer to Section 6.3.5 for a detailed description.

7.6.1 *Overall Protection of Human Health and the Environment*

Alternative 5 would eliminate, reduce, or control the risks associated with the exposure pathways delineated in the RAOs for protection of human health and the environment (see Sections 4.2.2 and 4.2.3, respectively) as follows:

HH1: Groundwater. In Alternative 5, *in situ* solidification of some PTM soils and the funnel-and-gate PRB system would contribute to groundwater restoration. Restoration

[49] Alternative 5 includes the upland components of Alternative 3 except without DNAPL collection trenches. Areas targeted for DNAPL collection trenches in Alternative 3 are targeted for solidification in Alternative 5.

would occur slowly over time as a result of the combined effects of these remedial components and natural attenuation processes. Figure 7-1 shows projected groundwater volumes exceeding the MCLs for benzene, arsenic, benzo(a)pyrene, and the aggregate plume 100 years after completion of remedial actions. The contribution of these remedial components is the difference between projected volumes under Alternative 5 and those under Alternative 2 (natural attenuation processes only). Remediation in Alternative 5 would contribute to groundwater restoration to a modest degree.

The groundwater model predicted that MCLs would not be achieved throughout the aquifers (after 100 years) for any of the COCs. Human health risk related to potential future groundwater use would be addressed primarily by an institutional control that would prohibit groundwater use for drinking purposes and construction of wells for any purpose other than remediation or monitoring. This institutional control would remain in effect until all COC MCLs are achieved. Refer to Section 7.3.1 for a discussion of existing restrictions on private water supply wells.

HH2, HH3, and HH4. These RAOs would be addressed in this alternative using the same combination of actions and controls as in Alternative 4; refer to Section 7.5.1.

HH5: Vapor. Human health risk from inhalation of vapors from groundwater and/or soils contaminated with COCs would be reduced to acceptable levels primarily by an institutional control that would require evaluation of vapor intrusion potential and/or construction of vapor controls beneath future buildings located above areas containing volatile COCs. By providing a clean soil buffer, soil capping would marginally reduce the likelihood that vapor controls would be needed in a given building. In addition, the significant amount of contaminated soil solidification and removal included in this alternative would reduce vapor intrusion potential in some areas of the Site.

HH6: Soils (Surface and Subsurface). Human health risk from direct contact or incidental ingestion of COCs in soil would be reduced to acceptable levels primarily through a combination of soil capping (3-foot thickness assumed over the entire upland Site), institutional controls to protect the cap and manage invasive activities that may otherwise result in exposures, and periodic inspection/repair to ensure long-term cap integrity. Risk reduction would be supplemented by *in situ* solidification of an estimated 79,000 cy of soil and removal of an additional 1,100 cy during construction of the funnel and gate systems. The institutional controls and cap inspection/repair program would remain in place to ensure continued protection.

EP1 through EP4. These RAOs would be addressed in this alternative using the same combination of actions and controls as in Alternative 4; refer to Section 7.5.1.

7.6.2 *Compliance with ARARs*

As discussed in Section 7.1.1.2, Alternative 5 would comply with the chemical-specific, action-specific, and location-specific ARARs and TBCs identified in Section 4 (see Tables 4-1 through 4-3) with the exception of the SDWA, which requires achievement of groundwater MCLs throughout the Site. The extent to which MCLs would be achieved in this alternative is discussed below.

7.6.2.1 Aquifer Restoration

Refer to Section 7.3.2.1 and Appendix A for discussion of the groundwater modeling performed to predict progress toward achieving MCLs under each remedial alternative. Groundwater modeling results are shown on Figure 7-1. One hundred years after remedial construction completion for Alternative 5, the groundwater volume exceeding MCLs in the aggregate plume was predicted to decrease by roughly 35 percent relative to the No Action alternative. Among the individual COCs modeled, predictions ranged from an 8 percent decrease for arsenic to a 40 percent decrease for benzene.

7.6.3 *Long-Term Effectiveness and Permanence*

The long-term effectiveness and permanence of Alternative 5 is evaluated in this section with respect to magnitude of residual risks and adequacy/reliability of controls.

7.6.3.1 Magnitude of Residual Risks

In this subsection, residual risks associated with source material are discussed in terms of the extent to which Alternative 5 would achieve the source control RAOs (see Section 4.2.1). Residual risks to human health and the environment are discussed under the *Overall Protection of Human Health and the Environment* evaluation criterion.

SC1: Treat or Remove DNAPL in Subsurface Soils and Groundwater. This alternative includes treatment or removal of DNAPL as follows:

- ***In situ* Solidification of PTM Soil.** The DNAPL volume treated through solidification is estimated at approximately 47 percent of the total Site DNAPL, and includes upland DNAPL with the greatest future exposure risk (i.e., the QP-U DNAPL Area). Refer to Section 7.4.3.1 for a discussion of the long-term effectiveness of *in situ* solidification of PTM soil.

- **Excavation of PTM Soil.** The DNAPL volume removed in this manner is estimated at 1 percent of the total Site DNAPL. PTM soil would be disposed of off site. Refer to Section 7.5.3.1 for a discussion of the long-term effectiveness of upland excavation of PTM soil.

- **Hydraulic Dredging of PTM Sediment.** DNAPL in the TD DNAPL Area that would be removed in this manner is estimated at 8 percent of the total Site DNAPL. PTM sediment would be disposed of off site. Refer to Section 7.5.3.1 for a discussion of the long-term effectiveness of hydraulic dredging of PTM soil.

- **Mechanical Dredging of PTM Sediment.** DNAPL in the QP-S DNAPL Area that would be removed in this manner is estimated at 6 percent of the total Site DNAPL. PTM sediment would be disposed of off site. Refer to Section 7.5.3.1 for a discussion of the long-term effectiveness of mechanical dredging of PTM soil.

Figure 7-2 shows the estimated DNAPL volumes that would be treated (via solidification) or removed (via off-site disposal) in Alternative 5. An estimated 62 percent of the total Site DNAPL (and, as shown in Table 7-2, 88 percent of sediment DNAPL) would be treated or removed in this alternative, including upland and aquatic DNAPL with the greatest future exposure risk.

SC2: Contain DNAPL in Subsurface Soils and Groundwater. As in Alternative 4, RCM caps would be installed in sediment DNAPL areas not dredged in this alternative (i.e., Areas DA-3, DA-4, DA-7, and DA-8) to prevent DNAPL migration to the lake. Refer to Section 7.3.3.1 for a discussion of RCM caps.

SC3: Reduce COC Migration from Soils to Groundwater. The *in situ* solidification and excavation/off-site disposal of PTM soil discussed above would reduce migration of soil contaminants to groundwater.

SC4: Reduce COC Migration from Sediments to Surface Water. The dredging and off-site disposal of PTM sediments discussed above would achieve reduction in contaminant migration from sediments to surface water. In other areas of impacted sediments, sediment caps would achieve this objective; refer to Section 7.3.3.1.

7.6.3.2 Adequacy and Reliability of Controls

Controls in Alternative 5 include an upland cap, a PRB (funnel and gate system), sediment caps (engineered sand cap and reactive sediment cap), reactive residuals cover, ENR, and institutional controls. The adequacy and reliability of each of these controls are discussed below.

Upland Cap. Refer to Section 7.3.3.2.

PRB (Funnel and Gate System). Refer to Section 7.4.3.2.

Sediment Caps. Refer to Section 7.4.3.2.

Reactive Residuals Cover. Refer to Section 7.5.3.2.

ENR. Refer to Section 7.3.3.2.

Institutional Controls. Table 7-3 lists the institutional controls and associated long-term monitoring that may be implemented in Alternative 5; refer to Section 7.3.3.2.

7.6.3.3 Alternative 5 Rating with Respect to this Criterion

Alternative 5 is rated “moderate with respect to long-term effectiveness and permanence, primarily because it would addresse aquatic PTMs and upland PTMs along the shoreline using a combination of removal, treatment, and capping/institutional controls. PTMs presenting the most significant risk for re-exposure (shallow sediments and potentially mobile DNAPL near the shoreline) would be removed or treated.

7.6.4 *Reduction of Toxicity, Mobility, or Volume Through Treatment*

Treatment processes used in Alternative 5 would include reactive sediment capping, reactive residuals cover, upland DNAPL/soil solidification, and PRB treatment of groundwater. Refer to Table 7-2 and Figure 7-2 for estimated DNAPL treatment volumes. Under this alternative, approximately 46 percent of DNAPL would be treated.

The amount of hazardous materials treated; the degree of expected reduction in contaminant toxicity, mobility, and volume; the irreversibility of treatment; and the type and quantity of residuals treated for each of the treatment technologies implemented under this alternative is the same as discussed for previous alternatives except as described below.

Reactive Sediment Capping. Discussion of this technology with respect to this evaluation criterion is the same as in Alternative 2; refer to Section 7.3.4.

Reactive Residuals Cover. Discussion of this technology with respect to this evaluation criterion is the same as in Alternative 4; refer to Section 7.5.4.

Upland DNAPL/Soil Solidification. Discussion of this technology with respect to this evaluation criterion is the same as in Alternative 3, except for the volume of DNAPL treated; refer to Section 7.4.4. An estimated 211,000 gallons of DNAPL would be treated by solidification in this alternative.

PRB Treatment of Groundwater. Discussion of this technology with respect to this evaluation criterion is the same as in Alternative 3; refer to Section 7.4.4.

The combination of PTM solidification and PRB treatment would reduce the volume and mobility of contaminated groundwater. Groundwater modeling results showing predicted reductions in plume volume and mass flux are shown on Figure 7-1 and Figure 7-3, respectively. One hundred years after remedial construction completion for Alternative 5, the overall reduction in contaminated groundwater volume is projected to be 35 percent. A mass flux reduction of roughly 80 to 90 percent is projected for the organic COCs, whereas projected reduction in arsenic mass flux is less than 10 percent relative to the No Action alternative.

7.6.4.1 Alternative 5 Rating with Respect to this Criterion

Alternative 5 is rated “moderate” with respect to reduction of toxicity, mobility, or volume through treatment. Mobility of DNAPL remaining in sediments after dredging would be reduced by reactive sediment caps and dredging residual covers. A moderate percentage of Site PTMs would be treated by solidification to greatly reduce mobility The volume of contaminated groundwater would be moderately reduced, and mass flux of organic COCs to sediments would be reduced significantly over time.

7.6.5 *Short-Term Effectiveness*

7.6.5.1 Protection of Community during Remedial Actions

Alternative 5 would require protective measures in addition to those defined under Alternative 2; refer to Section 7.3.5.1 for a discussion of community protection in Alternative 2. Alternative 5 would also include *in situ* solidification of a moderate volume of PTM soils, construction of the funnel and gate systems, and dredging of PTM sediments in selected areas (refer to Table 6-4 for construction quantity estimates). Dredged sediments would be dewatered on site prior to being trucked to an off-site landfill disposal facility. The potential for dust, vapor, noise, and traffic impacts to the community generally would increase with the scope and duration of construction. Because Alternative 5 would include a considerable amount of construction occurring over several years (Figure 7-5), its overall impact on the community would be expected to be moderate to high.

7.6.5.2 Protection of Workers during Remedial Actions

Alternative 5 would require additional measures to protect workers, in addition to those defined under Alternative 2; refer to Section 7.3.5.2 for a discussion of worker protection in Alternative 2. *In situ* solidification of PTM soils and removal of PTM sediments in

this alternative would result in significant additional exposure risks to workers. Exposure potential would be mitigated by adherence to Site-specific health and safety plans and use of engineering controls. The potential for worker impacts would increase with the scope of construction; refer to Section 6.3.5 for a description of the Alternative 5 scope. Because this alternative would have a moderate amount of construction, it would have a moderate potential for worker impacts.

7.6.5.3 Environmental Impacts

Refer to Section 7.3.5.3 for a discussion of potential environmental impacts associated with upland and sediment capping. Environmental impacts associated with *in situ* solidification of PTM soil and construction of the funnel and gate systems would be expected to be minimal, assuming implementation of adequate erosion and sedimentation control measures. This alternative also would include dredging of PTM sediments in areas DA-1, DA-2, DA-5, and DA-6. As discussed in Section 7.5.5.3, this activity would be expected to have the highest overall potential for environmental impacts, and the potential for impacts generally would increase with the scope of the removal action. Because Alternative 5 would include a moderate amount of PTM sediment removal (but, unlike Alternatives 4 and 6, no removal of PTM soils along the QP-U DNAPL Area shoreline), it would be expected to have a moderate overall potential for environmental impacts.

7.6.5.4 Time until Remedial Action Objectives are Achieved

Estimated remedy design and construction durations for Alternative 5 are shown on Figure 7-5. Remedial construction and establishment of institutional controls would be expected to be completed roughly 4 years from initiation of remedial activities; however, not all RAOs would be achieved at the end of the construction period (refer to Sections 7.6.1 and 7.6.3.1).

7.6.5.5 Alternative 5 Rating with Respect to this Criterion

Alternative 5 is rated “moderate” with respect to short-term effectiveness because it would involve moderate construction activities, including significant sediment dredging, and would have the potential for significant community impacts from construction noise, traffic, and odor.

7.6.6 *Implementability*

7.6.6.1 Technical Feasibility

Refer to Section 7.3.6.1 for a technical feasibility discussion of capping, Section 7.4.6.1 for a discussion of funnel and gate systems and *in situ* solidification of PTM soils, and Section 7.5.6.1 for a discussion of removal of PTM sediments.

7.6.6.2 Administrative Feasibility

Refer to Section 7.3.6.2 for an administrative feasibility discussion of capping and institutional controls, and Section 7.5.6.2 for a discussion of removal of PTM sediments.

7.6.6.3 Availability of Services and Materials

Necessary engineering and construction services are readily available, with multiple experienced contractors procurable through competitive bidding. Sufficient sand and gravel mine production capacity exists within 20 miles of the Site to supply the required

capping material. Sufficient regional landfill capacity exists to receive contaminated sediments generated in this alternative.

7.6.6.4 Alternative 5 Rating with Respect to this Criterion

Alternative 5 is rated "moderate" with respect to implementability because of the technical and administrative challenges associated with dredging PTM sediments.

7.6.7 *Cost*

The estimated present worth cost of Alternative 5 is $47 million, including a projected $42 million for capital construction and $4.1 million (present worth) for OM&M.

7.7 Detailed Evaluation of Alternative 6

Alternative 6 incorporates the same remedy components as Alternative 4, except without DNAPL collection trenches[50]. Alternative 6 also includes targeted solidification of deep PTMs (as in Alternatives 3 and 5) to reduce groundwater plume volume and solidification of shallow DNAPL-impacted soil exceeding 2-feet cumulative thickness to provide additional treatment of PTMs. Refer to Section 6.3.6 for a detailed description.

7.7.1 *Overall Protection of Human Health and the Environment*

Alternative 6 would eliminate, reduce, or control the risks associated with the exposure pathways delineated in the RAOs for protection of human health and the environment (see Sections 4.2.2 and 4.2.3, respectively) as follows:

HH1: Groundwater. In Alternative 6, *in situ* solidification of some PTM soils, removal of some PTM soils, and the funnel-and-gate PRB system would contribute to groundwater restoration. Restoration would occur slowly over time as a result of the combined effects of these remedial components and natural attenuation processes. Figure 7-1 shows projected groundwater volumes exceeding the MCLs for benzene, arsenic, benzo(a)pyrene, and the aggregate plume 100 years after completion of remedial actions. The contribution of these remedial components is the difference between projected volumes under Alternative 6 and those under Alternative 2 (natural attenuation processes only). Remediation in Alternative 6 would contribute to groundwater restoration to a moderate degree.

The groundwater model predicted that MCLs would not be achieved throughout the aquifers (after 100 years) for any of the COCs. Human health risk related to potential future groundwater use would be addressed primarily by an institutional control that would prohibit use of groundwater for drinking purposes and construction of wells for any purpose other than remediation or monitoring. This institutional control would remain in effect until all COC MCLs are achieved. Refer to Section 7.3.1 for a discussion of existing restrictions on private water supply wells.

HH2, HH3, and HH4. These RAOs would be addressed in this alternative using the same combination of actions and controls as in Alternative 4; refer to Section 7.5.1.

[50] Areas identified for DNAPL collection trenches in Alternative 4 are targeted for solidification in Alternative 6.

HH5: Vapor. Human health risk from inhalation of vapors from groundwater and/or soils contaminated with COCs would be reduced to acceptable levels primarily by an institutional control that would require evaluation of vapor intrusion potential and/or construction of vapor controls beneath future buildings located above areas containing volatile COCs. By providing a clean soil buffer, soil capping would marginally reduce the likelihood that vapor controls would be needed in a given building. In addition, the considerable amount of contaminated soil solidification and removal included in this alternative would reduce vapor intrusion potential in some areas of the Site.

HH6: Soils (Surface and Subsurface). Human health risk from direct contact or incidental ingestion of COCs in soil would be reduced to acceptable levels primarily through a combination of soil capping (3-foot thickness assumed over the entire upland Site), institutional controls to protect the cap and manage invasive activities that may otherwise result in exposures, and periodic inspection/repair to ensure long-term cap integrity. Risk reduction would be supplemented by *in situ* solidification of an estimated 140,000 cy of soil and removal of an additional 15,000 cy during excavation of the QP-U DNAPL Area and construction of the funnel and gate systems. The institutional controls and cap inspection/repair program would remain in place to ensure continued protection.

EP1 through EP4. These RAOs would be addressed in this alternative using the same combination of actions and controls as in Alternative 4; refer to Section 7.5.1 discussion.

7.7.2 *Compliance with ARARs*

As discussed in Section 7.1.1.2, Alternative 6 would comply with the chemical-specific, action-specific, and location-specific ARARs and TBCs identified in Section 4 (see Tables 4-1 through 4-3) with the exception of the SDWA, which requires achievement of groundwater MCLs throughout the Site. The extent to which MCLs would be achieved in this alternative is discussed below.

7.7.2.1 Aquifer Restoration

Refer to Section 7.3.2.1 and Appendix A for discussion of the groundwater modeling performed to predict progress toward achieving MCLs under each remedial alternative. Groundwater modeling results are shown on Figure 7-1. One hundred years after remedial construction completion for Alternative 6, the groundwater volume exceeding MCLs in the aggregate plume was predicted to decrease by roughly 50 percent relative to the No Action alternative. Among the individual COCs modeled, predictions ranged from a 12 percent decrease for arsenic to a 56 percent decrease for benzene.

7.7.3 *Long-Term Effectiveness and Permanence*

The long-term effectiveness and permanence of Alternative 6 is evaluated in this section with respect to magnitude of residual risks and adequacy/reliability of controls.

7.7.3.1 Magnitude of Residual Risks

In this subsection, residual risks associated with source material are discussed in terms of the extent to which Alternative 6 would achieve the source control RAOs (see Section 4.2.1). Residual risks to human health and the environment are discussed under the *Overall Protection of Human Health and the Environment* evaluation criterion.

SC1: Treat or Remove DNAPL in Subsurface Soils and Groundwater. This alternative includes DNAPL treatment or removal as follows:

- ***In situ* Solidification of PTM Soil.** The DNAPL volume treated through solidification is estimated at 70 percent of the total Site DNAPL, and includes upland DNAPL with the greatest future exposure risk (i.e., the QP-U DNAPL Area). Refer to Section 7.4.3.1 for a discussion of the long-term effectiveness of *in situ* solidification of PTM soil.

- **Excavation of PTM Soil.** The DNAPL volume removed in this manner is estimated at 7 percent of the total Site DNAPL. PTM soil would be disposed of off site. Refer to Section 7.5.3.1 for a discussion of the long-term effectiveness of upland excavation of PTM soil.

- **Hydraulic Dredging of PTM Sediment.** DNAPL in the TD DNAPL Area that would be removed in this manner is estimated at 8 percent of the total Site DNAPL. PTM sediment would be disposed of off site. Refer to Section 7.5.3.1 for a discussion of the long-term effectiveness of hydraulic dredging of PTM soil.

- **Mechanical Dredging of PTM sediment.** DNAPL in the QP-S DNAPL Area that would be removed in this manner is estimated at 6 percent of the total Site DNAPL. PTM sediment would be disposed of off site. Refer to Section 7.5.3.1 for a discussion of the long-term effectiveness of mechanical dredging of PTM soil.

Figure 7-2 shows the estimated volumes of DNAPL that would be treated (via solidification) or removed (via off-site disposal) in Alternative 6. An estimated 91 percent of total site DNAPL (and, as shown on Table 7-2, 88 percent of sediment DNAPL) would be treated or removed in this alternative, including upland and aquatic DNAPL with the greatest future exposure risk.

SC2: Contain DNAPL in Subsurface Soils and Groundwater. As in Alternative 4, RCM caps would be installed in sediment DNAPL areas not dredged in this alternative (i.e., Areas DA-3, DA-4, DA-7, and DA-8) to prevent DNAPL migration to the lake. Refer to Section 7.3.3.1 discussion of RCM caps.

SC3: Reduce COC Migration from Soils to Groundwater. The *in situ* solidification and excavation/off-site disposal of PTM soil discussed above would reduce migration of soil contaminants to groundwater.

SC4: Reduce COC Migration from Sediments to Surface Water. The dredging and off-site disposal of PTM sediments discussed above would achieve reduction in contaminant migration from sediments to surface water. In other areas of impacted sediments, sediment caps would achieve this objective; refer to Section 7.3.3.1.

7.7.3.2 Adequacy and Reliability of Controls

Controls in Alternative 6 include an upland cap, a PRB (funnel and gate system), sediment caps (engineered sand cap and reactive sediment cap), reactive residuals cover, ENR, and institutional controls. The adequacy and reliability of each of these controls are discussed below.

Upland Cap. Refer to Section 7.3.3.2.

PRB (Funnel and Gate System). Refer to Section 7.4.3.2.

Sediment Caps. Refer to Section 7.4.3.2.

Reactive Residuals Cover. Refer to Section 7.5.3.2.

ENR. Refer to Section 7.3.3.2.

Institutional Controls. Table 7-3 lists the institutional controls and associated long-term monitoring that may be implemented in Alternative 6; refer to Section 7.3.3.2.

7.7.3.3 Alternative 6 Rating with Respect to this Criterion

Alternative 6 is rated "moderate" with respect to long-term effectiveness and permanence, primarily because it addresses aquatic PTMs and upland PTMs along the shoreline using a combination of removal, treatment, and capping/institutional controls. PTMs presenting the most significant risk for re-exposure (shallow sediments and potentially mobile DNAPL near the shoreline) would be removed.

7.7.4 *Reduction of Toxicity, Mobility, or Volume Through Treatment*

Treatment processes used in Alternative 6 include reactive sediment capping, reactive residuals cover, upland DNAPL/soil solidification, and PRB treatment of groundwater. Refer to Table 7-2 and Figure 7-2 for estimated DNAPL treatment volumes. Under this alternative, approximately 68 percent of DNAPL would be treated.

The amount of hazardous materials treated; the degree of expected reduction in contaminant toxicity, mobility, and volume; the irreversibility of treatment; and the type and quantity of residuals treated for each of the treatment technologies is the same as discussed for previous alternatives except as described below.

Reactive Sediment Capping. Discussion of this technology with respect to this evaluation criterion is the same as in Alternative 2; refer to Section 7.3.4.

Reactive Residuals Cover. Discussion of this technology with respect to this evaluation criterion is the same as in Alternative 4; refer to Section 7.5.4.1.

Upland DNAPL/Soil Solidification. Discussion of this technology with respect to this evaluation criterion is the same as in Alternative 3, except for the volume of DNAPL treated; refer to Section 7.4.4. An estimated 311,000 gallons of DNAPL would be treated by solidification in this alternative.

PRB Treatment of Groundwater. Discussion of this technology with respect to this evaluation criterion is the same as in Alternative 3; refer to Section 7.4.4.

The combination of PTM solidification and PRB treatment would reduce the volume and mobility of contaminated groundwater. Groundwater modeling results showing predicted reductions in plume volume and mass flux are shown on Figure 7-1 and Figure 7-3, respectively. One hundred years after remedial construction completion for Alternative 6, the overall reduction in contaminated groundwater volume is projected to be 50 percent. A mass flux reduction of approximately 90 percent was projected for the organic COCs, whereas projected reduction in arsenic mass flux was less than 10 percent relative to the No Action alternative.

7.7.4.1 Alternative 6 Rating with Respect to this Criterion

Alternative 6 is rated "moderate" with respect to reduction of toxicity, mobility, or volume through treatment. Mobility of DNAPL remaining in sediments after dredging would be reduced by reactive sediment caps and dredging residual covers. A moderate amount of Site PTMs would be treated, resulting in a moderate reduction in contaminated groundwater volume. The mass flux of organic COCs to sediments would be reduced significantly over time.

7.7.5 *Short-Term Effectiveness*

7.7.5.1 Protection of Community during Remedial Actions

Alternative 6 would require protective measures in addition to those defined under Alternative 2; refer to Section 7.3.5.1 for a discussion of community protection in Alternative 2. Alternative 6 would also include *in situ* solidification of a relatively large volume of PTM soils, construction of the funnel and gate systems, excavation of a modest volume of PTM soils, and dredging of PTM sediments in selected areas (refer to Table 6-4 for construction quantity estimates). Dredged sediments would be dewatered on site prior to being trucked, along with excavated impacted soils, to an off-site landfill disposal facility. The potential for dust, vapor, noise, and traffic impacts to the community generally would increase with the scope and duration of construction. Because Alternative 6 would include a considerable amount of construction occurring over several years (Figure 7-5), its overall impact on the community would be expected to be moderate to high.

7.7.5.2 Protection of Workers during Remedial Actions

Alternative 6 would require additional measures to protect workers, in addition to those defined under Alternative 2; refer to Section 7.3.5.2 for a discussion of worker protection in Alternative 2. *In situ* solidification of PTM soils and removal of PTM soils and sediments in this alternative would result in significant additional exposure risks to workers. Exposure potential would be mitigated by adherence to Site-specific health and safety plans and use of engineering controls. The potential for worker impacts would increase with the scope of construction; refer to Section 6.3.6 for a description of the Alternative 6 scope. Because this alternative would have a moderate amount of construction, it would have a moderate potential for worker impacts.

7.7.5.3 Environmental Impacts

Refer to Section 7.3.5.3 for a discussion of potential environmental impacts associated with upland and sediment capping. Environmental impacts associated with *in situ* solidification of PTM soil and construction of the funnel and gate systems would be expected to be minimal, assuming implementation of adequate erosion and sedimentation control measures. This alternative also includes excavation of PTM soils along the QP-U DNAPL Area shoreline and dredging of PTM sediments in areas DA-1, DA-2, DA-5, and DA-6. As discussed in Section 7.5.5.3, these activities would be expected to have the highest overall potential for environmental impacts, and the potential for impacts generally would increase with the scope of the removal action. Because Alternative 6 would include a moderate amount of PTM shoreline soil and sediment removal (identical to Alternative 4), it would be expected to have a moderate overall potential for environmental impacts.

7.7.5.4 Time until Remedial Action Objectives are Achieved

Estimated remedy design and construction durations for Alternative 6 are shown on Figure 7-5. Remedial construction and establishment of institutional controls would be expected to be completed roughly 5 years from initiation of remedial activities; however, not all RAOs would be achieved at the end of the construction period (refer to Sections 7.7.1 and 7.7.3.1).

7.7.5.5 Alternative 6 Rating with Respect to this Criterion

Alternative 6 is rated "moderate" with respect to short-term effectiveness because it would involve moderate construction activities, including significant sediment dredging, and would have the potential for significant community impacts from construction noise, traffic, and odor.

7.7.6 *Implementability*

7.7.6.1 Technical Feasibility

Refer to Section 7.3.6.1 for a technical feasibility discussion of capping, Section 7.4.6.1 for a discussion of funnel and gate systems and *in situ* solidification of PTM soils, and Section 7.5.6.1 for a discussion of removal of PTM soils and sediments.

7.7.6.2 Administrative Feasibility

Refer to Section 7.3.6.2 for an administrative feasibility discussion of capping and institutional controls, and Section 7.5.6.2 for a discussion of removal of PTM soils and sediments.

7.7.6.3 Availability of Services and Materials

Necessary engineering and construction services are readily available, with multiple experienced contractors procurable through competitive bidding. Sufficient sand and gravel mine production capacity exists within 20 miles of the Site to supply the required capping material. Sufficient regional landfill capacity exists to receive contaminated soils and sediments generated in this alternative.

7.7.6.4 Alternative 6 Rating with Respect to this Criterion

Alternative 6 is rated "moderate" with respect to implementability because of the technical and administrative challenges associated with dredging PTM sediments.

7.7.7 *Cost*

The estimated present worth cost of Alternative 6 is $61 million, including a projected $57 million for capital construction and $4.1 million (present worth) for OM&M.

7.8 Detailed Evaluation of Alternative 7

Alternative 7 involves solidification of upland PTMs and removal and on-site treatment of sediment PTMs. Containment measures described in Alternative 2 are also included in this alternative to maintain protectiveness. Refer to Section 6.3.7 for a detailed description. The primary objective of this alternative is to treat the PTM on the Site.

7.8.1 *Overall Protection of Human Health and the Environment*

Alternative 7 would eliminate, reduce, or control the risks associated with the exposure pathways delineated in the RAOs for protection of human health and the environment (see Sections 4.2.2 and 4.2.3, respectively) as follows:

HH1: Groundwater. In Alternative 7, *in situ* solidification of all PTM soils would contribute to groundwater restoration. Restoration would occur slowly over time as a result of the combined effects of this remedial component and natural attenuation processes. Figure 7-1 shows projected groundwater volumes exceeding the MCLs for benzene, arsenic, benzo(a)pyrene, and the aggregate plume 100 years after completion of remedial actions. The contribution of this remedial component is the difference between projected volumes under Alternative 7 and those under Alternative 2 (natural attenuation processes only). Remediation in Alternative 7 would contribute to groundwater restoration to a large degree for benzene and benzo(a)pyrene, but to only a small degree for arsenic.

The groundwater model predicted that MCLs would not be achieved throughout the aquifers (after 100 years) for any of the COCs. Human health risk related to potential future groundwater use would be addressed primarily by an institutional control that would prohibit use of groundwater for drinking purposes and construction of wells for any purpose other than remediation or monitoring. This institutional control would remain in effect until all COC MCLs are achieved. Refer to Section 7.3.1 for a discussion of existing restrictions on private water supply wells.

HH2: Sediment. Human health risk from ingestion of resident fish and shellfish taken from the Site for subsistence would be reduced to acceptable levels. Alternative 7 would reduce COC concentrations in surface sediments which, in turn, would reduce the COC levels in resident fish and shellfish, through a combination of sediment dredging (removal of an estimated 58,000 cy from PTM areas), sediment capping (engineered sand caps and reactive residuals cover), and ENR. The institutional controls (health department advisories on fish/shellfish harvesting, controls to protect the caps), monitoring, and cap inspection/repair program would remain in place to ensure continued protection.

HH3: Sediment. Human health risk from playing, wading, or swimming resulting in incidental ingestion and/or dermal exposure to contaminated sediments would be reduced to acceptable levels. Alternative 7 would reduce COC concentrations in surface sediments through a combination of sediment dredging, sediment capping, and ENR. The institutional controls (health department advisories on fish/shellfish harvesting, controls to protect the caps), monitoring, and cap inspection/repair program would remain in place to ensure continued protection.

HH4: Surface Water. Human health risk from direct contact or incidental ingestion of surface water contaminated with COCs would be reduced to acceptable levels. Alternative 7 would reduce COC concentrations in surface sediments which, in turn, would reduce the levels of COCs in surface water, through a combination of sediment dredging, sediment capping, and ENR. The institutional controls (health department advisories on fish/shellfish harvesting, controls to protect the caps), monitoring, and cap inspection/repair program would remain in place to ensure continued protection.

HH5: Vapor. All PTM soils and overlying contaminated soils would be solidified *in situ*. In addition, soil capping would provide a clean soil buffer over the entire upland Site. Thus, vapor intrusion potential would be greatly reduced in this alternative. However, it cannot be assumed that *in situ* solidification would sufficiently reduce contaminant

volatilization such that vapor intrusion would not be a concern. For this reason, this alternative would include an institutional control applicable to the entire upland Site that would require evaluation of vapor intrusion potential and/or construction of vapor controls beneath future buildings; this would ensure vapor inhalation risk reduction to acceptable levels. However, given the physical characteristics of solidified soil, it would be unlikely that vapor controls would be needed for buildings constructed over areas of the Site treated by *in situ* solidification.

HH6: Soils (Surface and Subsurface). Human health risk from direct contact or incidental ingestion of COCs in soil would be reduced to acceptable levels primarily through a combination of soil capping (3-foot thickness assumed over the entire upland Site), institutional controls to protect the cap and manage invasive activities that may otherwise result in exposures, and periodic inspection/repair to ensure long-term cap integrity. Risk reduction would be supplemented by *in situ* solidification of an estimated 240,000 cy of soil, including all PTM soil. The institutional controls and cap inspection/repair program would remain in place to ensure continued protection.

EP1: Surface Water. Risk to aquatic-dependent organisms when direct contact with surface water or incidental ingestion of COCs in surface water exceeds remediation goals (water quality standards) would be reduced to acceptable levels. Alternative 7 would reduce COC concentrations in surface sediments, which in turn would reduce the COC levels in surface water, through a combination of sediment dredging, sediment capping, and ENR. The institutional controls (health department advisories on fish/shellfish harvesting, controls to protect the caps), monitoring, and cap inspection/repair program would remain in place to ensure continued protection.

EP2: Upland Soil. Risk to terrestrial wildlife when direct contact and incidental ingestion or consumption of soil invertebrates results in exposures to COCs would be reduced to acceptable levels through the same combination of actions and controls as discussed above under HH6.

EP3: Sediment. Risk to aquatic-dependent wildlife (sediment probing birds and piscivorous mammals) where surface sediments containing COCs exceed remediation goals would be reduced to acceptable levels. Alternative 7 would reduce COC concentrations in surface sediments through a combination of sediment dredging, sediment capping, and ENR. The institutional controls (health department advisories on fish/shellfish harvesting, controls to protect the caps), monitoring, and cap inspection/repair program would remain in place to ensure continued protection.

EP4: Sediment. Risk to benthos where surface sediments containing COCs exceed remediation goals would be reduced to acceptable levels. Alternative 7 would reduce COC concentrations in surface sediments through a combination of sediment dredging, sediment capping, and ENR. The institutional controls (health department advisories on fish/shellfish harvesting, controls to protect the caps), monitoring, and cap inspection/repair program would remain in place to ensure continued protection.

7.8.2 *Compliance with ARARs*

As discussed in Section 7.1.1.2, Alternative 7 would comply with the chemical-specific, action-specific, and location-specific ARARs and TBCs identified in Section 4 (see Tables 4-1 through 4-3) with the exception of the SDWA, which requires achievement of

groundwater MCLs throughout the Site. The extent to which MCLs would be achieved in this alternative is discussed below.

7.8.2.1 Aquifer Restoration

Refer to Section 7.3.2.1 and Appendix A for discussion of the groundwater modeling performed to predict progress toward achieving MCLs under each remedial alternative. Groundwater modeling results are shown on Figure 7-1. One hundred years after remedial construction completion for Alternative 7, the groundwater volume exceeding MCLs in the aggregate was predicted to decrease by roughly 79 percent relative to the No Action alternative. Among the individual COCs modeled, predictions ranged from a 21 percent decrease for arsenic to a 97 percent decrease for benzene.

7.8.3 *Long-Term Effectiveness and Permanence*

The long-term effectiveness and permanence of Alternative 7 is evaluated in this section with respect to magnitude of residual risks and adequacy/reliability of controls.

7.8.3.1 Magnitude of Residual Risks

In this subsection, residual risks associated with source material are discussed in terms of the extent to which Alternative 7 would achieve the source control RAOs (see Section 4.2.1). Residual risks to human health and the environment are discussed under the *Overall Protection of Human Health and the Environment* evaluation criterion.

SC1: Treat or Remove DNAPL in Subsurface Soils and Groundwater. This alternative includes DNAPL treatment or removal as follows:

- ***In situ* Solidification of all PTM Soil.** The DNAPL volume treated through solidification is estimated at 85 percent of the total Site DNAPL. Refer to Section 7.4.3.1 for a discussion of the long-term effectiveness of *in situ* solidification of PTM soil.
- **Hydraulic Dredging of PTM Sediment.** The DNAPL volume removed in this manner is estimated at 8 percent of the total Site DNAPL. PTM sediment would be disposed of off site. Refer to Section 7.5.3.1 for a discussion of the long-term effectiveness of hydraulic dredging of PTM soil.
- **Mechanical Dredging of PTM Sediment.** The DNAPL volume removed in this manner is estimated at 7 percent of the total Site DNAPL. PTM sediment would be disposed of off site. Refer to Section 7.5.3.1 for a discussion of the long-term effectiveness of mechanical dredging of PTM soil.

Figure 7-2 shows the estimated volumes of DNAPL that would be treated (via solidification) or removed (via off-site disposal) in Alternative 7. Essentially complete treatment/removal of DNAPL would be achieved in this alternative.

SC2: Contain DNAPL in Subsurface Soils and Groundwater. This source control RAO is not applicable to Alternative 7 because all PTM soil and sediment would be treated or removed.

SC3: Reduce COC Migration from Soils to Groundwater. The *in situ* solidification of PTM soil discussed above would reduce migration of soil contaminants to groundwater.

SC4: Reduce COC Migration from Sediments to Surface Water. The dredging and off-site disposal of PTM sediments discussed above would achieve reduction in contaminant migration from sediments to surface water. In other areas of impacted sediments, sediment caps would achieve this objective; refer to Section 7.3.3.1.

7.8.3.2 Adequacy and Reliability of Controls

Controls in Alternative 7 include an upland cap, engineered sand caps, reactive residuals cover, ENR, and institutional controls. The adequacy and reliability of each of these controls are discussed below.

Upland Cap. Refer to Section 7.3.3.2.

Engineered Sand Caps. Refer to Section 7.3.3.2 discussion of sediment caps.

Reactive Residuals Cover. Refer to Section 7.5.3.2.

ENR. Refer to Section 7.3.3.2.

Institutional Controls. Table 7-3 lists the institutional controls and associated long-term monitoring that may be implemented in Alternative 7; refer to Section 7.3.3.2.

7.8.3.3 Alternative 7 Rating with Respect to this Criterion

Alternative 7 is rated "high" with respect to long-term effectiveness and permanence because of its reliance on treatment and removal technologies to address all PTMs.

7.8.4 *Reduction of Toxicity, Mobility, or Volume Through Treatment*

Treatment processes used in Alternative 7 include a reactive residuals cover and upland DNAPL/soil solidification. Refer to Table 7-2 and Figure 7-2 for estimated DNAPL treatment volumes. The amount of hazardous materials treated; the degree of expected reduction in contaminant toxicity, mobility, and volume; the irreversibility of treatment; and the type and quantity of residuals treated for each of the treatment technologies is the same as discussed for previous alternatives except as described below.

Reactive Residuals Cover. Discussion of this technology with respect to this evaluation criterion is the same as in Alternative 4. Refer to Section 7.5.4.1.

Upland DNAPL/Soil Solidification. Discussion of this technology with respect to this evaluation criterion is the same as in Alternative 3, except for the volume of DNAPL treated; refer to Section 7.4.4. An estimated 377,000 gallons of DNAPL would be treated by solidification in this alternative.

DNAPL/soil solidification would reduce the volume and mobility of contaminated groundwater. Groundwater modeling results showing predicted reductions in plume volume and mass flux are shown on Figure 7-1 and Figure 7-3, respectively. One hundred years after remedial construction completion for Alternative 7, the overall reduction in contaminated groundwater volume is projected to be 79 percent. A mass flux reduction of nearly 100 percent was projected for the organic COCs, whereas projected reduction in arsenic mass flux was less than 10 percent relative to the No Action alternative.

7.8.4.1 Alternative 7 Rating with Respect to this Criterion

Alternative 7 is rated "high" with respect to reduction of toxicity, mobility, or volume through treatment because a large fraction of PTMs would be treated. The volume of contaminated groundwater and mass flux of organic COCs to sediments would be greatly reduced over time.

7.8.5 *Short-Term Effectiveness*

7.8.5.1 Protection of Community during Remedial Actions

Alternative 7 would require protective measures in addition to those defined under Alternative 2; refer to Section 7.3.5.1 for a discussion of community protection in Alternative 2. Alternative 7 would also include *in situ* solidification of a large volume of PTM soils and dredging of a large volume of PTM sediments (refer to Table 6-4 for construction quantity estimates). Dredged sediments would be dewatered on site prior to being trucked to an off-site landfill disposal facility. The potential for dust, vapor, noise, and traffic impacts to the community generally would increase with the scope and duration of construction. Because Alternative 7 would include a large amount of construction occurring over several years (Figure 7-5), its overall impact on the community would be expected to be high.

7.8.5.2 Protection of Workers during Remedial Actions

Alternative 7 would require additional measures to protect workers, in addition to those defined under Alternative 2; refer to Section 7.3.5.2 for a discussion of worker protection in Alternative 2. *In situ* solidification of PTM soils and removal of PTM sediments in this alternative would result in significant additional exposure risks to workers. Exposure potential would be mitigated by adherence to Site-specific health and safety plans and use of engineering controls. The potential for worker impacts would increase with the scope of construction; refer to Section 6.3.7 for a description of the Alternative 7 scope. Because this alternative would have a large construction component, it would have a relatively high potential for worker impacts.

7.8.5.3 Environmental Impacts

Refer to Section 7.3.5.3 for a discussion of potential environmental impacts associated with upland and sediment capping. Environmental impacts associated with *in situ* solidification of PTM soil would be expected to be low, assuming implementation of adequate erosion and sedimentation control measures. This alternative also includes dredging of PTM sediments in areas DA-1 through DA-8. As discussed in Section 7.5.5.3, this activity would be expected to have the highest overall potential for environmental impacts, and the potential for impacts generally would increase with the scope of the removal action. Because Alternative 7 would include a large amount of PTM sediment removal, it would be expected to have a relatively high overall potential for environmental impacts.

7.8.5.4 Time until Remedial Action Objectives are Achieved

Estimated remedy design and construction durations for Alternative 7 are shown on Figure 7-5. Completion of remedial construction and establishment of institutional controls would be expected roughly 7 years from initiation of remedial activities; however, not all RAOs would be achieved at the end of the construction period (refer to Sections 7.8.1 and 7.8.3.1).

7.8.5.5 Alternative 7 Rating with Respect to this Criterion

Alternative 7 is rated "low" with respect to short-term effectiveness because it would involve extensive construction activities occurring over a multi-year period, including a large in-water construction component, and would have the potential for significant community impacts from construction noise, traffic, and odor.

7.8.6 *Implementability*

7.8.6.1 Technical Feasibility

The technical feasibility of the remedial components used in Alternative 7 was evaluated for previous alternatives. Refer to Section 7.3.6.1 for a technical feasibility discussion of capping, Section 7.4.6.1 for a discussion of *in situ* solidification of PTM soils, and Section 7.5.6.1 for a discussion of removal of PTM sediments. While the remedial components are the same as in previous alternatives, the large scale and volume of materials removed or treated under Alternative 7 would introduce additional technical and logistical challenges. These challenges would make it difficult to effectively implement this alternative and call into question whether this alternative's goals could be met.

A primary goal of this alternative would be to remove or treat all PTMs. As described in Section 3.8, DNAPL tends to occur within descrete layers or thin lenses rather than in continuous "pools," and DNAPL migration is influenced by the deltaic nature of the Shallow Alluvium. Identification of all DNAPL occurences, even after conducting supplementary design investigations, would be unlikely. As a result, the ability to fully delineate the lateral and vertical extent of DNAPL to provide complete *in situ* treatment of PTM soils and to remove PTM sediments would be major technical challenges.

An *in situ* solidification project of this magnitude (over 240,000 cy of soil to be solidified) would involve the transport of significant materials (e.g. cement) to the Site over a extended period of time.

Dredging of 58,000 cy of sediment in DNAPL-impacted areas would involve significant challenges in controlling potential water quality impacts during construction and avoiding or minimizing leaving residual contamination following construction, particularly in the QP DNAPL Area given the highly stratified subsurface conditions and lenticular nature of the DNAPL source.

Alternative 7 would also be would more difficult to implement based on its longer construction duration, due to the potential for technical problems such as extreme weather events leading to schedule delays.

7.8.6.2 Administrative Feasibility

Refer to Section 7.3.6.2 for an administrative feasibility discussion of capping and institutional controls and Section 7.5.6.2 for a discussion of removal of PTM sediments. Because of the extent of dredging, substantial coordination with regulatory agencies would be required to address potential water quality impacts.

Alternative 7 may require more administrative coordination based on its longer construction duration.

7.8.6.3 Availability of Services and Materials

Necessary engineering and construction services are readily available, with multiple experienced contractors procurable through competitive bidding. Sufficient sand and gravel mine production capacity exists within 20 miles of the Site to supply the required capping material. Sufficient regional landfill capacity exists to receive contaminated sediments generated in this alternative.

7.8.6.4 Alternative 7 Rating with Respect to this Criterion

Alternative 7 is rated "moderate with respect to implementability because an *in situ* solidification and dredging project of this magnitude would present significant technical challenges.

7.8.7 *Cost*

The estimated present worth cost of Alternative 7 is $80 million, including a projected $78 million for capital construction and $2.7 million (present worth) for OM&M.

7.9 Detailed Evaluation of Alternative 8

Alternative 8 involves removal and on-site treatment of upland and sediment PTMs. Containment measures described in Alternative 2, except reactive sediment capping[51], are also included in this alternative to maintain protectiveness and provide additional source control. Refer to Section 6.3.8 for a detailed description. The primary objective of this alternative is to treat all PTMs on the Site.

7.9.1 *Overall Protection of Human Health and the Environment*

Alternative 8 would eliminate, reduce, or control the risks associated with the exposure pathways delineated in the RAOs for protection of human health and the environment (see Sections 4.2.2 and 4.2.3, respectively) as follows:

HH1: Groundwater. In Alternative 8, removal of all PTM soils would contribute to groundwater restoration. Restoration would occur slowly over time as a result of the combined effects of this remedial component and natural attenuation processes. Figure 7-1 shows projected groundwater volumes exceeding the MCLs for benzene, arsenic, benzo(a)pyrene, and the aggregate plume 100 years after completion of remedial actions. The contribution of this remedial component is the difference between projected volumes under Alternative 8 and those under Alternative 2 (natural attenuation processes only). Remediation in Alternative 8 would contribute to groundwater restoration to a large degree for benzene, to a moderate degree for benzo(a)pyrene, and to a small degree for arsenic.

The groundwater model predicted that the MCL for benzene would be achieved throughout the aquifers after 100 years, but not the MCLs for arsenic or benzo(a)pyrene. Human health risk related to potential future groundwater use would be addressed primarily by an institutional control that would prohibit use of groundwater for drinking purposes and construction of wells for any purpose other than remediation or monitoring.

[51] Reactive sediment capping is not included in Alternative 8 because sediment PTMs are removed.

This institutional control would remain in effect until all COC MCLs are achieved. Refer to Section 7.3.1 discussion of existing restrictions on private water supply wells.

HH2, HH3, and HH4. These RAOs would be addressed in this alternative using the same combination of actions and controls as in Alternative 7; refer to Section 7.8.1.

HH5: Vapor. All PTM soils and overlying contaminated soils would be excavated, treated on site by thermal desorption, and used as Site backfill. In addition, soil capping would provide a clean soil buffer over the entire upland Site. Thus, vapor intrusion potential would be greatly reduced in this alternative. As discussed in Section 6.3.8.1.5, however, it is assumed for the purposes of this FS that the thermally desorbed soil may still exceed PRGs. For this reason, this alternative would include an institutional control applicable to the entire upland Site that would require evaluation of vapor intrusion potential and/or construction of vapor controls beneath future buildings. This institutional control would ensure vapor inhalation risk reduction to acceptable levels. However, given the fact that thermal desorption is particularly effective at treating volatile contaminants, it is unlikely that vapor controls would be needed for buildings constructed over areas backfilled with thermally desorbed soils.

HH6: Soils (Surface and Subsurface). Human health risk from direct contact or incidental ingestion of COCs in soil would be reduced to acceptable levels primarily through a combination of soil capping (3-foot thickness assumed over the entire upland Site), institutional controls to protect the cap and manage invasive activities that may otherwise result in exposures, and periodic inspection/repair to ensure long-term cap integrity. Risk reduction would be supplemented by removal of an estimated 210,000 cy of soil, including all PTM soil. The institutional controls and cap inspection/repair program would remain in place to ensure continued protection.

EP1 through EP4. These RAOs would be addressed in this alternative using the same combination of actions and controls as in Alternative 7; refer to Section 7.8.1.

7.9.2 *Compliance with ARARs*

As discussed in Section 7.1.1.2, Alternative 8 would comply with the chemical-specific, action-specific, and location-specific ARARs and TBCs identified in Section 4 (see Tables 4-1 through 4-3) with the exception of the SDWA, which requires achievement of groundwater MCLs throughout the Site. The extent to which MCLs would be achieved in this alternative is discussed below.

7.9.2.1 Aquifer Restoration

Refer to Section 7.3.2.1 and Appendix A for discussion of the groundwater modeling performed to predict progress toward achieving MCLs under each remedial alternative. Groundwater modeling results are shown on Figure 7-1. One hundred years after remedial construction completion for Alternative 8, the groundwater volume exceeding MCLs in the aggregate was predicted to decrease by roughly 75 percent relative to the No Action alternative. Among the individual COCs modeled, predictions ranged from an 11 percent decrease for arsenic after 100 years, to complete aquifer restoration for benzene 28 years after remedy construction is complete.

7.9.3 *Long-Term Effectiveness and Permanence*

The long-term effectiveness and permanence of Alternative 8 is evaluated in this section with respect to magnitude of residual risks and adequacy/reliability of controls.

7.9.3.1 Magnitude of Residual Risks

In this subsection, residual risks associated with source material are discussed in terms of the extent to which Alternative 8 would achieve the source control RAOs (see Section 4.2.1). Residual risks to human health and the environment are discussed under the *Overall Protection of Human Health and the Environment* evaluation criterion.

SC1: Treat or Remove DNAPL in Subsurface Soils and Groundwater. This alternative includes removal of DNAPL as follows:

- **Excavation of All PTM Soil.** The DNAPL volume removed in this manner is estimated at 85 percent of the total Site DNAPL. Refer to Section 7.5.3.1 for a discussion of the long-term effectiveness of upland excavation of PTM soil.
- **Hydraulic Dredging of PTM Sediment.** The DNAPL volume removed in this manner is estimated at 8 percent of the total Site DNAPL. Refer to Section 7.5.3.1 for a discussion of the long-term effectiveness of hydraulic dredging of PTM soil.
- **Mechanical Dredging of PTM Sediment.** The DNAPL volume removed in this manner is estimated at 7 percent of the total Site DNAPL. Refer to Section 7.5.3.1 for a discussion of the long-term effectiveness of mechanical dredging of PTM soil.

All removed soil and sediment would be treated on site by thermal desorption. The assumed treatment effectiveness of thermal desorption is discussed in Section 6.3.8.1.5. Treated material would be used as backfill at the Site.

Figure 7-2 shows the estimated volume of DNAPL that would be removed (and treated via thermal desorption) in Alternative 8. Given the complexity of Site conditions and the scale of removal/treatment under this alternative, there is a potential for residual risk associated with residual contamination.

SC2: Contain DNAPL in Subsurface Soils and Groundwater. This source control RAO is not applicable to Alternative 8 because all PTM soil and sediment would be removed.

SC3: Reduce COC Migration from Soils to Groundwater. The excavation and on-site thermal desorption of PTM soil discussed above would reduce migration of soil contaminants to groundwater.

SC4: Reduce COC Migration from Sediments to Surface Water. The dredging and on-site thermal desorption of PTM sediments discussed above would achieve reduction in contaminant migration from sediments to surface water. In other areas of impacted sediments, sediment caps would achieve this objective; refer to Section 7.3.3.1.

7.9.3.2 Adequacy and Reliability of Controls

Controls in Alternative 8 include an upland cap, engineered sand caps, reactive residuals cover, ENR, and institutional controls. The adequacy and reliability of each of these controls are discussed below.

Upland Cap. Refer to Section 7.3.3.2.

Engineered Sand Caps. Refer to Section 7.3.3.2 discussion of sediment caps.

Reactive Residuals Cover. Refer to Section 7.5.3.2.

ENR. Refer to Section 7.3.3.2.

Institutional Controls. Table 7-3 lists the institutional controls and associated long-term monitoring that may be implemented in Alternative 8; refer to Section 7.3.3.2.

7.9.3.3 Alternative 8 Rating with Respect to this Criterion

Alternative 8 is rated "high" with respect to long-term effectiveness and permanence because of its reliance on removal technologies to address all PTMs.

7.9.4 *Reduction of Toxicity, Mobility, or Volume Through Treatment*

Treatment processes used in Alternative 8 include reactive residuals cover and on-site thermal desorption.

Reactive Residuals Cover. Discussion of this technology with respect to this evaluation criterion is the same as in Alternative 4. Refer to Section 7.5.4.1.

On-site Thermal Desorption. Section 6.3.8.1.5 discusses on-site thermal desorption in Alternative 8, including a discussion of the treatment process and the materials treated. The amount of hazardous materials treated; the degree of expected reduction in contaminant toxicity, mobility, and volume; the irreversibility of treatment; and the type and quantity of residuals treated for thermal desorption is described below.

7.9.4.1 Amount of Hazardous Materials Destroyed or Treated

On-site Thermal Desorption. Refer to Table 7-2 and Figure 7-2 for estimated DNAPL treatment volumes. An estimated 445,000 gallons of DNAPL would be treated on site by thermal desorption in this alternative. The intent of this alternative is to treat all PTMs at the Site. However it is likely that some residual contamination would remain given the complexity of the Site and volume of treatment involved under this alternative.

7.9.4.2 Degree of Expected Reductions in Toxicity, Mobility, and Volume

On-site Thermal Desorption. Thermal desorption volatilizes organic compounds, which reduces toxicity, mobility, and volume. Thermal desorption effectiveness for arsenic is uncertain. Pilot-scale testing would be completed to optimize treatment parameters such as desorption temperature and residence time, and to determine the reduction in concentrations that could be achieved. For the purposes of this FS, it is assumed that thermal desorption would remove DNAPL but that the treated soil may still exceed PRGs and require containment (such as capping).

DNAPL/soil treatment by thermal desorption would reduce the volume and mobility of contaminated groundwater. Groundwater modeling results showing predicted reductions

in plume volume and mass flux are shown on Figure 7-1 and Figure 7-3, respectively. One hundred years after remedial construction completion for Alternative 8, the overall reduction in contaminated groundwater volume is projected to be 75 percent. A mass flux reduction of nearly 100 percent was projected for the organic COCs, whereas projected reduction in arsenic mass flux was less than 10 percent relative to the No Action alternative.

7.9.4.3 Degree to which Treatment is Irreversible

On-site Thermal Desorption. Organic contaminant treatment in the thermal desorption process is irreversible. Thermal desorption volatilizes organic compounds, which reduces toxicity, mobility, and volume. Organic contaminant treatment in the thermal desorption process is irreversible.

7.9.4.4 Type and Quantity of Residuals Remaining after Treatment

On-site Thermal Desorption. Treated soils would remain on site (refer to Table 6-4 for construction quantities). Residual contaminant concentrations in soil would be expected to be low but may exceed PRGs depending on the effectiveness of treatment.

7.9.4.5 Alternative 8 Rating with Respect to this Criterion

Alternative 8 is rated "high" with respect to reduction of toxicity, mobility, or volume through treatment. Essentially all PTMs would be treated to greatly reduce toxicity and mobility of contaminants. The volume of contaminated groundwater and the contaminant mass flux to sediments would be greatly reduced over time.

7.9.5 *Short-Term Effectiveness*

7.9.5.1 Protection of Community during Remedial Actions

Alternative 8 would require protective measures in addition to those defined under Alternative 2; refer to Section 7.3.5.1 for a discussion of community protection in Alternative 2. Alternative 8 would also include excavation of a large volume of PTM soils and dredging of a large volume of PTM sediments (refer to Table 6-4 for construction quantity estimates). Sediments would be dewatered on site, followed by on-site thermal desorption of all removed soils and sediments. The potential for dust, vapor, noise, and traffic impacts to the community generally would increase with the scope and duration of construction. Because Alternative 8 would include a large amount of construction occurring over several years (Figure 7-5), its overall impact on the community would be expected to be high.

7.9.5.2 Protection of Workers during Remedial Actions

Alternative 8 would require additional measures to protect workers, in addition to those defined under Alternative 2; refer to Section 7.3.5.2 for a discussion of worker protection in Alternative 2. Removal and on-site thermal desorption of PTM soils and sediments in this alternative would result in significant additional exposure risks to workers. Exposure potential would be mitigated by adherence to Site-specific health and safety plans and use of engineering controls. The potential for worker impacts would increase with the scope of construction; refer to Section 6.3.8 for a description of the Alternative 8 scope. Because this alternative would have a large construction component, it would have a relatively high potential for worker impacts.

7.9.5.3 Environmental Impacts

Refer to Section 7.3.5.3 for a discussion of potential environmental impacts associated with upland and sediment capping. This alternative also includes excavation of PTM soils along the shoreline and dredging of PTM sediments in areas DA-1 through DA-8. As discussed in Section 7.5.5.3, these activities would be expected to have the highest overall potential for environmental impacts, and the potential for impacts generally would increase with the scope of the removal action. Because Alternative 8 would include a large amount of PTM sediment removal, it would be expected to have a relatively high overall potential for environmental impacts.

7.9.5.4 Time until Remedial Action Objectives are Achieved

Estimated remedy design and construction durations for Alternative 8 are shown on Figure 7-5. Completion of remedial construction and establishment of institutional controls would be expected roughly 8 years from initiation of remedial activities; however, not all RAOs would be achieved at the end of the construction period (refer to Sections 7.9.1 and 7.9.3.1).

7.9.5.5 Alternative 8 Rating with Respect to this Criterion

Alternative 8 is rated "low" with respect to short-term effectiveness because it would involve extensive construction activities occurring over a multi-year period, including a large in-water construction component, and would have the potential for significant community impacts from construction noise, traffic, and odor.

7.9.6 *Implementability*

7.9.6.1 Technical Feasibility

With the exception of thermal desorption, the technical feasibility of the remedial components used in Alternative 8 was evaluated for previous alternatives. Refer to Section 7.3.6.1 for a technical feasibility discussion of capping, and Section 7.5.6.1 for a discussion of removal of PTM soils and sediments. The deep excavations for PTM removal in Alternative 8 would require extensive, robust shoring and dewatering systems. Also note that a primary goal of this alternative is to remove all PTM present at the Site. As discussed in Section 7.8.6.1, full delineation of the lateral and vertical extent of DNAPL to provide complete removal of both upland and sediment PTM would be expected to be a significant technical challenge.

Thermal desorption is technically feasible for treatment of organic compounds, pending the results of bench and pilot testing; however, it is possible that treatment would not achieve PRGs in soil because of treatability limitations for wet, high-organic soils as are found at the Site. Capping of treated soils is included in this alternative to address potential residuals. On-site thermal treatment would require air emissions controls and monitoring.

Given the complexity and magnitude of this project, there is a high potential for problems to be encountered that delay construction schedule and/or increase costs. An excavation/dredging/thermal desorption project of this magnitude would present significant technical challenges (refer to Table 6-4 for estimated construction quantities).

Alternative 8 may be more difficult to implement based on its longer construction duration, due to the potential for technical problems such as extreme weather events

leading to schedule delays. An additional challenge would be proper project sequencing and contractor coordination, due to the number of construction elements and potential contractors (upland excavation, sediment dredging and capping, sheet pile installation, sediment processing, thermal desorption, etc.) and the need to provide access for mobilization/demobilization and egress to remove treatment residuals.

7.9.6.2 Administrative Feasibility

Refer to Section 7.3.6.2 for an administrative feasibility discussion of capping and institutional controls and Section 7.5.6.2 for a discussion of removal of PTM soils and sediments. A project of this magnitude that includes a large on-site thermal treatment component and has potential for significant impacts to air and water quality over an extended construction period would require extensive coordination with local and federal agencies and present significant administrative challenges.

Alternative 8 may require more administrative coordination based on its longer construction duration.

7.9.6.3 Availability of Services and Materials

The local availability of vendors and equipment for on-site thermal treatment are limited, which would present a bidding and procurement challenge. Some specialized equipment and custom materials (e.g., sheet piles for excavation) would likely require long lead times between design and construction and may pose transportation challenges.

7.9.6.4 Alternative 8 Rating with Respect to this Criterion

Alternative 8 is rated "low" with respect to implementability because an excavation/dredging/thermal desorption project of this magnitude would likely present major technical and administrative challenges.

7.9.7 *Cost*

The estimated present worth cost of Alternative 8 is $140 million, including a projected $137 million for capital construction and $2.7 million (present worth) for OM&M.

7.10 Detailed Evaluation of Alternative 9

Alternative 9 includes removal or treatment of soil and sediment that is likely to act as a long-term source of groundwater contamination above MCLs, including PTMs and soils and sediments contaminated with recalcitrant compounds (e.g., arsenic and benzo[a]pyrene). Refer to Section 6.3.9 for a detailed description. The objective of Alternative 9 is to remove or treat PTMs and to restore groundwater to its highest beneficial use (drinking water) to the maximum extent possible.

7.10.1 *Overall Protection of Human Health and the Environment*

Alternative 9 would eliminate, reduce, or control the risks associated with the exposure pathways delineated in the RAOs for protection of human health and the environment (see Sections 4.2.2 and 4.2.3, respectively) as follows:

HH1: Groundwater. In Alternative 9, removal of all shallow contaminated soils and *in situ* solidification of all deep contaminated soils would contribute to groundwater restoration. Restoration would occur slowly over time as a result of the combined effects of these remedial components and natural attenuation processes. Figure 7-1 shows

projected groundwater volumes exceeding the MCLs for benzene, arsenic, benzo(a)pyrene, and the aggregate plume 100 years after completion of remedial actions. The contribution of these remedial components is the difference between projected volumes under Alternative 9 and those under Alternative 2 (natural attenuation processes only). Remediation in Alternative 9 would contribute to groundwater restoration to a large degree for benzene and benzo(a)pyrene (assuming no or limited residual contamination remains following construction), but to only a small degree for arsenic.

The groundwater model predicted that MCLs would not be achieved throughout the aquifers (after 100 years) for any of the COCs. Human health risk related to potential future groundwater use would be addressed primarily by an institutional control that would prohibit use of groundwater for drinking purposes and construction of wells for any purpose other than remediation or monitoring. This institutional control would remain in effect until all COC MCLs are achieved. Refer to Section 7.3.1 discussion of existing restrictions on private water supply wells.

HH2: Sediment. Human health risk from ingestion of resident fish and shellfish taken from the Site for subsistence would be reduced to acceptable levels. Alternative 9 would reduce COC concentrations in surface sediments which, in turn, would reduce the levels of COCs in resident fish and shellfish, through a combination of sediment dredging (removal of an estimated 173,000 cy from PTM areas and areas with porewater PRG exceedances), sediment capping (engineered sand caps and reactive residuals cover), and ENR. The institutional controls (health department advisories on fish/shellfish harvesting, controls to protect the caps), monitoring, and cap inspection/repair program would remain in place to ensure continued protection.

HH3: Sediment. Human health risk from playing, wading, or swimming resulting in incidental ingestion and/or dermal exposure to contaminated sediments would be reduced to acceptable levels. Alternative 9 would reduce COC concentrations in surface sediments through a combination of sediment dredging, sediment capping, and ENR. The institutional controls (health department advisories on fish/shellfish harvesting, controls to protect the caps), monitoring, and cap inspection/repair program would remain in place to ensure continued protection.

HH4: Surface Water. Human health risk from direct contact or incidental ingestion of surface water contaminated with COCs would be reduced to acceptable levels. Alternative 9 would reduce COC concentrations in surface sediments which, in turn, would reduce the levels of COCs in surface water, through a combination of sediment dredging, sediment capping, and ENR. The institutional controls (health department advisories on fish/shellfish harvesting, controls to protect the caps), monitoring, and cap inspection/repair program would remain in place to ensure continued protection.

HH5: Vapor. All shallow contaminated soils (above approximately 15 feet bgs) would be excavated, treated on site by thermal desorption, and used as Site backfill, and deeper contaminated soils would be treated by *in situ* solidification. In addition, soil capping would provide a buffer of clean surface soil. As discussed in Section 6.3.8.1.5, it is assumed for the purposes of this FS that the thermally desorbed soil may still exceed PRGs. For this reason, this alternative would include an institutional control requiring evaluation of vapor intrusion potential and/or construction of vapor controls beneath

future buildings as a precautionary measure. This institutional control would ensure vapor inhalation risk reduction to acceptable levels. However, given the fact that thermal desorption is particularly effective at treating volatile contaminants, it is unlikely that building vapor controls would ever be needed in this alternative.

HH6: Soils (Surface and Subsurface). All shallow contaminated soils (above approximately 15 feet bgs) would be excavated, treated on site by thermal desorption, and used as Site backfill. As discussed in Section 6.3.8.1.5, it is assumed for the purposes of this FS that the treated soil may still exceed PRGs. Human health risk from direct contact or incidental ingestion of residual COCs in soil would be addressed through a combination of soil capping (3-foot thickness assumed over the entire upland Site), institutional controls to protect the cap and manage invasive activities that may otherwise result in exposures, and periodic inspection/repair to ensure long-term cap integrity. The institutional controls and cap inspection/repair program would remain in place to ensure continued protection.

EP1: Surface Water. Risk to aquatic-dependent organisms when direct contact with surface water or incidental ingestion of COCs in surface water exceeds remediation goals (water quality standards) would be reduced to acceptable levels. Alternative 9 would reduce COC concentrations in surface sediments, which in turn would reduce the levels of COCs in surface water, through a combination of sediment dredging, sediment capping, and ENR. The institutional controls (health department advisories on fish/shellfish harvesting, controls to protect the caps), monitoring, and cap inspection/repair program remain in place to ensure continued protection.

EP2: Upland Soil. Risk to terrestrial wildlife when direct contact and incidental ingestion or consumption of soil invertebrates results in exposures to COCs would be reduced to acceptable levels through excavation and on-site treatment (by thermal desorption) of all shallow contaminated soils (above approximately 15 feet bgs). Treated soils would be used as Site backfill. In addition, soil capping would provide a clean surface soil buffer.

EP3: Sediment. Risk to aquatic-dependent wildlife (sediment probing birds and piscivorous mammals) where surface sediments containing COCs exceed remediation goals would be reduced to acceptable levels. Alternative 9 would reduce COC concentrations in surface sediments through a combination of sediment dredging, sediment capping, and ENR. The institutional controls (health department advisories on fish/shellfish harvesting, controls to protect the caps), monitoring, and cap inspection/repair program would remain in place to ensure continued protection.

EP4: Sediment. Risk to benthos where surface sediments containing COCs exceed remediation goals would be reduced to acceptable levels. Alternative 9 would reduce COC concentrations in surface sediments through a combination of sediment dredging, sediment capping, and ENR. The institutional controls (health department advisories on fish/shellfish harvesting, controls to protect the caps), monitoring, and cap inspection/repair program would remain in place to ensure continued protection.

7.10.2 *Compliance with ARARs*

As discussed in Section 7.1.1.2, Alternative 9 would comply with the chemical-specific, action-specific, and location-specific ARARs and TBCs identified in Section 4 (see

Tables 4-1 through 4-3) with the exception of the SDWA, which requires achievement of groundwater MCLs throughout the Site. The extent to which MCLs would be achieved in this alternative is discussed below.

7.10.2.1 Aquifer Restoration

Refer to Section 7.3.2.1 and Appendix A for discussion of the groundwater modeling performed to predict progress toward achieving MCLs under each remedial alternative. Groundwater modeling results are shown on Figure 7-1. One hundred years after remedial construction completion for Alternative 9, the groundwater volume exceeding MCLs in the aggregate was predicted to decrease by roughly 78 percent relative to the No Action alternative. Among the individual COCs modeled, predictions ranged from a 21 percent decrease for arsenic to a 97 percent decrease for benzene.

7.10.3 *Long-Term Effectiveness and Permanence*

The long-term effectiveness and permanence of Alternative 9 is evaluated in this section with respect to the magnitude of residual risks and adequacy/reliability of controls.

7.10.3.1 Magnitude of Residual Risks

In this subsection, residual risks associated with source material are discussed in terms of the extent to which Alternative 9 would achieve the source control RAOs (see Section 4.2.1). Residual risks to human health and the environment are discussed under the *Overall Protection of Human Health and the Environment* evaluation criterion.

SC1: Treat or Remove DNAPL in Subsurface Soils and Groundwater. This alternative includes DNAPL treatment or removal as follows:

- ***In situ* solidification of PTM Soil.** The DNAPL volume treated through solidification is estimated at 23 percent of the total Site DNAPL. Refer to Section 7.4.3.1 for a discussion of the long-term effectiveness of *in situ* solidification of PTM soil.

- **Excavation of PTM Soil.** The DNAPL volume removed in this manner is estimated at 61 percent of the total Site DNAPL. Refer to Section 7.5.3.1 for a discussion of the long-term effectiveness of upland excavation of PTM soil.

- **Hydraulic Dredging of PTM Sediment.** The DNAPL volume removed in this manner is estimated at 8 percent of the total Site DNAPL. Refer to Section 7.5.3.1 for a discussion of the long-term effectiveness of hydraulic dredging of PTM soil.

- **Mechanical Dredging of PTM Sediment.** The DNAPL volume removed in this manner is estimated at 7 percent of the total Site DNAPL. Refer to Section 7.5.3.1 for a discussion of the long-term effectiveness of mechanical dredging of PTM soil.

All removed soil and sediment would be treated on site by thermal desorption. The assumed treatment effectiveness of thermal desorption is discussed in Section 6.3.8.1.5. Treated material would be used as backfill at the Site.

Figure 7-2 shows the estimated DNAPL volume that would be treated (by *in situ* solidification) or removed (and treated via thermal desorption) in Alternative 9. Essentially complete treatment/removal of DNAPL would be achieved in this alternative.

SC2: Contain DNAPL in Subsurface Soils and Groundwater. This source control RAO is not applicable to Alternative 9 because all PTM soil and sediment would be treated or removed.

SC3: Reduce COC Migration from Soils to Groundwater. The *in situ* solidification and excavation/thermal desorption of PTM soil discussed above would reduce migration of soil contaminants to groundwater.

SC4: Reduce COC Migration from Sediments to Surface Water. The dredging and on-site thermal desorption of PTM sediments discussed above would achieve reduction in contaminant migration from sediments to surface water. In other areas of impacted sediments, sediment caps would achieve this objective; refer to Section 7.3.3.1.

7.10.3.2 Adequacy and Reliability of Controls

Controls in Alternative 9 include an upland cap, engineered sand caps, reactive residuals cover, ENR, and institutional controls. The adequacy and reliability of each of these controls are discussed below.

Upland Cap. Refer to Section 7.3.3.2.

Engineered Sand Caps. Refer to Section 7.3.3.2 for a discussion of sediment caps.

Reactive Residuals Cover. Refer to Section 7.5.3.2.

ENR. Refer to Section 7.3.3.2.

Institutional Controls. Table 7-3 lists the institutional controls and associated long-term monitoring that may be implemented in Alternative 9; refer to Section 7.3.3.2.

7.10.3.3 Alternative 9 Rating with Respect to this Criterion

Alternative 9 is rated “high” with respect to long-term effectiveness and permanence because of its reliance on treatment and removal technologies to address contaminated soil and sediment, including all PTMs.

7.10.4 *Reduction of Toxicity, Mobility, or Volume Through Treatment*

Treatment processes used in Alternative 9 include a reactive residuals cover, upland DNAPL/soil solidification, and on-site thermal desorption. Refer to Table 7-2 and Figure 7-2 for estimated DNAPL treatment volumes. This alternative would treat all PTMs at the Site.

The amount of hazardous materials treated; the degree of expected reduction in contaminant toxicity, mobility, and volume; the irreversibility of treatment; and the type and quantity of residuals treated for each of the treatment technologies is the same as discussed for previous alternatives except as described below.

Reactive Residuals Cover. Discussion of this technology with respect to this evaluation criterion is the same as in Alternative 4; refer to Section 7.5.4.1.

Upland DNAPL/Soil Solidification. Discussion of this technology with respect to this evaluation criterion is the same as in Alternative 3, except for the volume of DNAPL treated; refer to Section 7.4.4. An estimated 104,000 gallons of DNAPL would be treated by solidification in this alternative.

On-site Thermal Desorption. Discussion of this technology with respect to this evaluation criterion is the same as in Alternative 8, except for the volume of DNAPL treated; refer to Section 7.9.4. An estimated 273,000 gallons of DNAPL would be treated by on-site thermal desorption in this alternative.

Refer to Section 7.3.4.3 for a discussion of the groundwater modeling performed to predict reduction in contaminant mass flux to sediments under each remedial alternative.

DNAPL/soil treatment by thermal desorption would reduce the volume and mobility of contaminated groundwater. Groundwater modeling results showing predicted reductions in plume volume and mass flux are shown on Figure 7-1 and Figure 7-3, respectively. One hundred years after remedial construction completion for Alternative 9, the overall reduction in contaminated groundwater volume was projected to be 78 percent. Mass flux for the organic COCs was projected to be negligible (essentially 100 percent reduction), whereas projected reduction in arsenic mass flux was roughly 60 percent relative to the No Action alternative.

7.10.4.1 Alternative 9 Rating with Respect to this Criterion

Alternative 9 is rated “high” with respect to reduction of toxicity, mobility, or volume through treatment because the vast majority of the Site contamination would be treated, including all PTMs.

7.10.5 *Short-Term Effectiveness*

7.10.5.1 Protection of Community during Remedial Actions

Alternative 9 would require protective measures in addition to those defined under Alternative 2; refer to Section 7.3.5.1 for a discussion of community protection in Alternative 2. Alternative 9 would also include *in situ* solidification of a large volume of deep contaminated soils, excavation of a large volume of shallow contaminated soils, and dredging of a large volume of PTM sediments (refer to Table 6-4 for construction quantity estimates). Sediments would be dewatered on site, followed by on-site thermal desorption of all removed soils and sediments. The potential for dust, vapor, noise, and traffic impacts to the community generally would increase with the scope and duration of construction. Because Alternative 9 would include large-scale construction occurring over many years (Figure 7-5), its overall impact on the community would be expected to be very high.

7.10.5.2 Protection of Workers during Remedial Actions

Alternative 9 would require additional measures to protect workers, in addition to those defined under Alternative 2; refer to Section 7.3.5.2 for a discussion of worker protection in Alternative 2. *In situ* solidification of deep impacted soils and removal/on-site thermal desorption of soils and sediments in this alternative would result in significant additional exposure risks to workers. Exposure potential would be mitigated by adherence to Site-specific health and safety plans and use of engineering controls. The potential for worker impacts would increase with the scope of construction; refer to Section 6.3.9 for a

description of the Alternative 9 scope. Because this alternative would have a very large construction component, it would have a high potential for worker impacts.

7.10.5.3 Environmental Impacts

Refer to Section 7.3.5.3 for a discussion of potential environmental impacts associated with upland and sediment capping. Environmental impacts associated with *in situ* solidification of PTM soil would be expected to be low, assuming implementation of adequate erosion and sedimentation control measures. This alternative also includes excavation of PTM soils along the shoreline and dredging of PTM sediments in areas DA-1 through DA-8. As discussed in Section 7.5.5.3, this activity to be expected to have the highest overall potential for environmental impacts, and the potential for impacts generally would increase with the scope of the removal action. Because Alternative 9 would include a large amount of PTM sediment removal, it would be expected to have a relatively high overall potential for environmental impacts.

7.10.5.4 Time until Remedial Action Objectives are Achieved

Estimated remedy design and construction durations for Alternative 9 are shown on Figure 7-5. Completion of remedial construction and establishment of institutional controls would be expected roughly 13 years from initiation of remedial activities; however, not all RAOs would be achieved at the end of the construction period (refer to Sections 7.10.1 and 7.10.3.1).

7.10.5.5 Alternative 9 Rating with Respect to this Criterion

Alternative 9 is rated "low" with respect to short-term effectiveness because it would involve extensive construction activities occurring over a multi-year period, including a large in-water construction component, and would have the potential for significant community impacts from construction noise, traffic, and odor.

7.10.6 *Implementability*

7.10.6.1 Technical Feasibility

The technical feasibility of the remedial components used in Alternative 9 was evaluated for previous alternatives. Refer to Section 7.3.6.1 for a technical feasibility discussion of capping, Section 7.4.6.1 for a discussion of *in situ* solidification of PTM soils, Section 7.5.6.1 for a discussion of removal of PTM soils and sediments, and Section 7.9.6.1 for a discussion of thermal desorption. A primary goal of this alternative is to remove or treat *in situ* all PTM present at the Site. As discussed in Section 7.8.6.1, full delineation of the lateral and vertical extent of DNAPL to provide complete treatment/removal of all PTM would be expected to be a significant technical challenge.

The shallow excavations for PTM removal in Alternative 9 involve removal, handling, and treatment of a very large quantity of materials would require complex shoring and dewatering systems. As discussed in Section 7.9.6.1, thermal desorption is technically feasible for treatment of organic compounds, pending the results of bench and pilot testing; however, it is possible that treatment would not achieve PRGs in soil because of treatability limitations for wet, high-organic soils as are found at the Site.

Given the complexity and magnitude of this project, there is a high potential for problems to be encountered that delay construction schedule and/or increase costs. A project of this scale, with the volume of soil to be treated by *in situ* solidification (354,000 cy) and

removal/thermal treatment (516,000 cy of soil and sediment) has never before been implemented. An excavation/dredging/solidification/thermal desorption project of this magnitude would present major technical challenges (refer to Table 6-4 for estimated construction quantities).

7.10.6.2 Administrative Feasibility

Refer to Section 7.3.6.2 for an administrative feasibility discussion of capping and institutional controls, and Section 7.5.6.2 for a discussion of removal of PTM soils and sediments. A project of this magnitude that includes a large on-site thermal treatment component and has potential for significant impacts to air and water quality over an extended construction period would require extensive coordination with local and federal agencies and present significant administrative challenges

7.10.6.3 Availability of Services and Materials

The local availability of vendors and equipment for on-site thermal treatment are limited, which would present a bidding and procurement challenge. Some specialized equipment and custom materials (e.g., sheet piles for excavation) would likely require long lead times between design and construction and may pose transportation challenges.

7.10.6.4 Alternative 9 Rating with Respect to this Criterion

Alternative 9 is rated "low" with respect to implementability because an excavation/dredging/solidification/thermal desorption project of this magnitude would likely present major technical and administrative challenges.

7.10.7 *Cost*

The estimated present worth cost of Alternative 9 is $262 million, including a projected $259 million for capital construction and $2.7 million (present worth) for OM&M.

7.11 Detailed Evaluation of Alternative 10

Alternative 10 includes removal of soil and sediment that is likely to act as a source of groundwater contamination above MCLs, including PTMs and soils contaminated with recalcitrant compounds (e.g., arsenic and benzo[a]pyrene). Contaminated soil and groundwater in the Deeper Alluvium would be treated by groundwater pump and treat to accelerate the groundwater restoration timeframe. Containment measures described in Alternative 2 are also included in this alternative to maintain protectiveness. Refer to Section 6.3.10 for a detailed description. The purpose of Alternative 10 is to remove PTMs and to restore groundwater to the maximum extent possible.

7.11.1 *Overall Protection of Human Health and the Environment*

Alternative 10 would eliminate, reduce, or control the risks associated with the exposure pathways delineated in the RAOs for protection of human health and the environment (see Sections 4.2.2 and 4.2.3, respectively) as follows:

HH1: Groundwater. In Alternative 10, removal of all contaminated soils would contribute to groundwater restoration. Restoration would occur slowly over time as a result of the combined effects of this remedial component and natural attenuation processes. Figure 7-1 shows projected groundwater volumes exceeding the MCLs for benzene, arsenic, benzo(a)pyrene, and the aggregate plume 100 years after completion of remedial actions. The contribution of this remedial component is the difference between

projected volumes under Alternative 10 and those under Alternative 2 (natural attenuation processes only). Remediation in Alternative 10 would contribute to groundwater restoration to a large degree for benzene and benzo(a)pyrene, and to a moderate degree for arsenic.

The groundwater model predicted that the MCLs for benzene and benzo(a)pyrene (assuming complete removal with no residual contamination remaining) would be achieved throughout the aquifers after 100 years, but not the MCL for arsenic. The groundwater model predicted that the benzo(a)pyrene concentration in groundwater would exceed the MCL after 100 years if residual contamination remained following construction. Human health risk related to potential future groundwater use would be addressed primarily by an institutional control that would prohibit use of groundwater for drinking purposes and construction of wells for any purpose other than remediation or monitoring. This institutional control would remain in effect until all COC MCLs are achieved. Refer to Section 7.3.1 for a discussion of existing restrictions on private water supply wells.

HH2, HH3, and HH4. These RAOs would be addressed in this alternative using the same combination of actions and controls as in Alternative 9; refer to Section 7.10.1.

HH5: Vapor. All contaminated soils would be excavated, treated on site by thermal desorption, and used as Site backfill. In addition, groundwater would be pumped from below excavated areas and treated, and soil capping would provide a clean soil buffer. As discussed in Section 6.3.8.1.5, it is assumed for the purposes of this FS that the thermally desorbed soil may still exceed PRGs. For this reason, this alternative would include an institutional control requiring evaluation of vapor intrusion potential and/or construction of vapor controls beneath future buildings as a precautionary measure. This institutional control would ensure vapor inhalation risk reduction to acceptable levels. However, given the fact that thermal desorption is particularly effective at treating volatile contaminants, it is unlikely that building vapor controls would ever be needed in this alternative.

HH6: Soils (Surface and Subsurface). All contaminated soils would be excavated, treated on site by thermal desorption, and used as Site backfill. As discussed in Section 6.3.8.1.5, it is assumed for the purposes of this FS that the treated soil may still exceed PRGs. Human health risk from direct contact or incidental ingestion of residual COCs in soil would be addressed through a combination of soil capping (3-foot thickness assumed over the entire upland Site), institutional controls to protect the cap and manage invasive activities that may otherwise result in exposures, and periodic inspection/repair to ensure long-term cap integrity. The institutional controls and cap inspection/repair program would remain in place to ensure continued protection.

EP1, EP3, and EP4. These RAOs would be addressed in this alternative using the same combination of actions and controls as in Alternative 9; refer to Section 7.10.1.

EP2: Upland Soil. Risk to terrestrial wildlife when direct contact and incidental ingestion or consumption of soil invertebrates results in exposures to COCs would be reduced to acceptable levels through excavation and on-site treatment (by thermal desorption) of all contaminated soils. Treated soils would be used as Site backfill. In addition, soil capping would provide a clean soil buffer.

7.11.2 *Compliance with ARARs*

As discussed in Section 7.1.1.2, Alternative 10 would comply with the chemical-specific, action-specific, and location-specific ARARs and TBCs identified in Section 4 (see Tables 4-1 through 4-3) with the exception of the SDWA, which requires achievement of groundwater MCLs throughout the Site. The extent to which MCLs would be achieved in this alternative is discussed below.

7.11.2.1 Aquifer Restoration

Refer to Section 7.3.2.1 and Appendix Afor a discussion of the groundwater modeling performed to predict progress toward achieving MCLs under each remedial alternative. Groundwater modeling results are shown on Figure 7-1.

One hundred years after remedial construction completion for Alternative 10, the groundwater volume exceeding MCLs in the aggregate plume was predicted to decrease by roughly 91 percent relative to the No Action alternative. Among the individual COCs modeled, the model predicted a 65 percent decrease for arsenic after 100 years, complete aquifer restoration for benzene 14 years after remedy construction, and complete aquifer restoration for benzo(a)pyrene upon completion of construction. However, the model assumed no residuals were present following construction because the quantity of residuals is difficult to quantify. A sensitivity analysis using the groundwater model indicated that residuals would result in exceedances of the MCL for benzo(a)pyrene for more than 100 years following implementation of Alternative 10. The presence of residuals following removal is considered the more likely scenario even when employing BMPs during a removal action. The extent to which the benzo(a)pyrene plume exceeding the MCL would be reduced depends to a large extent on the amount of residual contamination following completion of the remedy.

7.11.3 *Long-Term Effectiveness and Permanence*

The long-term effectiveness and permanence of Alternative 10 is evaluated in this section with respect to magnitude of residual risks and adequacy/reliability of controls.

7.11.3.1 Magnitude of Residual Risks

In this subsection, residual risks associated with source material are discussed in terms of the extent to which Alternative 10 would achieve the source control RAOs (see Section 4.2.1). Residual risks to human health and the environment are discussed under the *Overall Protection of Human Health and the Environment* evaluation criterion.

SC1: Treat or Remove DNAPL. This alternative addresses PTM soil and sediment in the same manner as Alternative 8; refer to Section 7.9.3.1.

SC2: Contain DNAPL. This source control RAO is not applicable to Alternative 10 because all PTM soil and sediment would be removed.

SC3: Reduce COC Migration from Soils to Groundwater. The excavation and on-site thermal desorption of PTM soil discussed above would reduce migration of soil contaminants to groundwater.

SC4: Reduce COC Migration from Sediments to Surface Water. The dredging and on-site thermal desorption of PTM sediments discussed above would achieve reduction in

contaminant migration from sediments to surface water. In other areas of impacted sediments, sediment caps would achieve this objective; refer to Section 7.3.3.1.

7.11.3.2 Adequacy and Reliability of Controls

Controls in Alternative 10 include an upland cap, engineered sand caps, reactive residuals cover, ENR, and institutional controls. The adequacy and reliability of each of these controls are discussed below.

Upland Cap. Refer to Section 7.3.3.2.

Engineered Sand Caps. Refer to Section 7.3.3.2 for a discussion of sediment caps.

Reactive Residuals Cover. Refer to Section 7.5.3.2.

ENR. Refer to Section 7.3.3.2.

Institutional Controls. Table 7-3 lists the institutional controls and associated long-term monitoring that may be implemented in Alternative 10; refer to Section 7.3.3.2.

7.11.3.3 Alternative 10 Rating with Respect to this Criterion

Alternative 10 is rated "high" with respect to long-term effectiveness and permanence because of its reliance on removal technologies to address contaminated soil and sediment, including all PTMs.

7.11.4 *Reduction of Toxicity, Mobility, or Volume Through Treatment*

Treatment processes used in Alternative 10 include a reactive residuals cover, on-site thermal desorption, and treatment of extracted groundwater. This alternative would treat all PTMs at the Site. Refer to Table 7-2 and Figure 7-2 for estimated DNAPL treatment volumes. The amount of hazardous materials treated; the degree of expected reduction in contaminant toxicity, mobility, and volume; the irreversibility of treatment; and the type and quantity of residuals treated for each of the treatment technologies is the same as discussed for previous alternatives except as described below.

Reactive Residuals Cover. Discussion of this technology with respect to this evaluation criterion is the same as in Alternative 4; refer to Section 7.5.4.1.

On-site Thermal Desorption. Discussion of this technology with respect to this evaluation criterion is the same as in Alternative 8, except that additional volumes of contaminated soil and sediment would be treated; refer to Section 7.9.4. An estimated 445,000 gallons of DNAPL would be treated by on-site thermal desorption in this alternative.

Treatment of Extracted Groundwater. Section 6.3.4.1.4 discusses water treatment associated with construction dewatering. Treatment of extracted groundwater in Alternative 10 would be similar except that no DNAPL separation would be required as all free-phase DNAPL is assumed to have been removed during excavation.

7.11.4.1 Amount of Hazardous Materials Destroyed or Treated

Treatment of Extracted Groundwater. The groundwater treatment system would be designed for treatment of dissolved contaminants only, not DNAPL. Because the vast majority of contaminant mass at the Site is present as DNAPL, the relative contaminant

mass present in the dissolved phase that would be treated via groundwater treatment would be negligible. Organic contaminants would effectively adsorb onto GAC until the GAC becomes loaded. Treatment system monitoring would be conducted to determine when GAC replacement is required. GAC replacement would generate spent carbon, which would be transported off site for reactivation or disposal.

DNAPL/soil treatment by thermal desorption and groundwater extraction would reduce the volume and mobility of contaminated groundwater. Groundwater modeling results showing predicted reductions in plume volume and mass flux are shown on Figure 7-1 and Figure 7-3, respectively. One hundred years after remedial construction completion for Alternative 8, the overall reduction in contaminated groundwater volume was projected to be 91 percent. Mass flux for the organic COCs was projected to be negligible (essentially 100 percent reduction), whereas projected reduction in arsenic mass flux was nearly 90 percent relative to the No Action alternative.

7.11.4.2 Alternative 10 Rating with Respect to this Criterion

Alternative 10 is rated "high" with respect to reduction of toxicity, mobility, or volume through treatment. The vast majority of the Site contamination would be treated, including all PTMs.

7.11.5 *Short-Term Effectiveness*

7.11.5.1 Protection of Community during Remedial Actions

Alternative 10 would require protective measures in addition to those defined under Alternative 2; refer to Section 7.3.5.1 for a discussion of community protection in Alternative 2. Alternative 10 would also include excavation of a very large volume of contaminated soils and dredging of a large volume of PTM sediments (refer to Table 6-4 for construction quantity estimates). Sediments would be dewatered on site, followed by on-site thermal desorption of all removed soils and sediments. The potential for dust, vapor, noise, and traffic impacts to the community generally would increase with the scope and duration of construction. Because Alternative 10 would include large-scale construction occurring over many years (Figure 7-5), its overall impact on the community would be expected to be very high.

7.11.5.2 Protection of Workers during Remedial Actions

Alternative 10 would require additional measures to protect workers, in addition to those defined under Alternative 2; refer to Section 7.3.5.2 for a discussion of worker protection in Alternative 2. Removal and on-site thermal desorption of soils and sediments in this alternative would result in significant additional exposure risks to workers. Exposure potential would be mitigated by adherence to Site-specific health and safety plans and use of engineering controls. The potential for worker impacts would increase with the scope of construction; refer to Section 6.3.10 for a description of the Alternative 10 scope. Because this alternative would have a very large construction component, it would have a high potential for worker impacts.

7.11.5.3 Environmental Impacts

Refer to Section 7.3.5.3 for a discussion of potential environmental impacts associated with upland and sediment capping. This alternative also includes excavation of PTM soils along the shoreline and dredging of PTM sediments in areas DA-1 through DA-8. As discussed in Section 7.5.5.3, these activities would be expected to have the highest

overall potential for environmental impacts, and the potential for impacts generally increases with the scope of the removal action. Because Alternative 10 would include a large amount of PTM sediment removal, it would be expected to have a high overall potential for environmental impacts.

7.11.5.4 Time until Remedial Action Objectives are Achieved

Estimated remedy design and construction durations for Alternative 10 are shown on Figure 7-5. Completion of remedial construction and establishment of institutional controls would be expected roughly 15 years from initiation of remedial activities; however, not all RAOs would be achieved at the end of the construction period (refer to Sections 7.11.1 and 7.11.3.1).

7.11.5.5 Alternative 10 Rating with Respect to this Criterion

Alternative 10 is rated "low" with respect to short-term effectiveness because it would involve extensive construction activities occurring over a multi-year period, including a large in-water construction component, and would have the potential for significant community impacts from construction noise, traffic, and odor.

7.11.6 *Implementability*

7.11.6.1 Technical Feasibility

The technical feasibility of the remedial components used in Alternative 10 was evaluated for previous alternatives. Refer to Section 7.3.6.1 for a technical feasibility discussion of capping, Section 7.5.6.1 for a discussion of removal of PTM soils and sediments, and Section 7.9.6.1 for a discussion of thermal desorption. A primary goal of this alternative is to remove all PTM present at the Site. As discussed in Section 7.8.6.1, full delineation of the lateral and vertical extent of DNAPL to provide complete removal of both upland and sediment PTM would be expected to be a significant technical challenge.

The very deep excavations for PTM removal in Alternative 10 involve removal, handling, and treatment of a very large quantity of materials that would require extensive, robust shoring and dewatering systems. As discussed in Section 7.9.6.1, thermal desorption is technically feasible for treatment of organic compounds, pending the results of bench and pilot testing; however, it is possible that treatment would not achieve PRGs in soil.

Given the complexity and magnitude of this project, there would be a high potential for problems to be encountered that delay the construction schedule and/or increase costs. A project of this scale, with the volume of soil and sediment to be treated by removal/thermal treatment (879,000 cy of soil and sediment) has never before been implemented. An excavation/dredging/thermal desorption project of this magnitude would present major technical challenges (refer to Table 6-4 for estimated construction quantities).

7.11.6.2 Administrative Feasibility

Refer to Section 7.3.6.2 for an administrative feasibility discussion of capping and institutional controls, and Section 7.5.6.2 for a discussion of removal of PTM soils and sediments. A project of this magnitude that would include a large on-site thermal treatment component and would have the potential for significant impacts to air and

water quality over an extended construction period would require extensive coordination with local and federal agencies and would present significant administrative challenges.

7.11.6.3 Availability of Services and Materials

The local availability of vendors and equipment for on-site thermal treatment are limited, which would present a bidding and procurement challenge. Some specialized equipment and custom materials (e.g., sheet piles for excavation shoring, with conceptual design lengths up to 95 feet) would be difficult to transport, would likely require long lead times between design and construction, and may pose transportation challenges.

7.11.6.4 Alternative 10 Rating with Respect to this Criterion

Alternative 10 is rated "low" with respect to implementability because an excavation/dredging/thermal desorption project of this magnitude would likely present major technical and administrative challenges.

7.11.7 *Cost*

The estimated present worth cost of Alternative 10 is $409 million, including a projected $380 million for capital construction and $29 million (present worth) for OM&M (primarily associated with the groundwater pump-and-treat system).

8 Comparative Analysis of Alternatives

In Section 7, each of the Site remedial alternatives were evaluated in detail using seven of the nine NCP evaluation criteria. The results of those evaluations are used in this section to compare the alternatives by identifying the advantages and disadvantages of each alternative relative to one another, consistent with EPA (1988a) guidance.

The comparative analysis presented in this section is summarized in Table 8-1. Consistent with 40 CFR300.430, each alternative is first evaluated using the threshold criteria of overall protection and ARAR compliance (defined in Section 7.1.1). The alternatives are evaluated further with respect to the NCP balancing criteria: long-term effectiveness and permanence; reduction of toxicity, mobility, or volume through treatment; short-term effectiveness; implementability; and cost (defined in Section 7.1.2).

This comparative analysis includes a summary of the factors considered for each criterion, which are described in more detail in Section 7. This analysis then identifies the key differentiating factors between alternatives. For threshold criteria, each alternative is identified as meeting or not meeting the criteria. For balancing criteria except cost, each alternative is evaluated using a qualitative scale to rate the relative degree (i.e., low, moderate, high) to which an alternative meets the criteria requirements. For cost, the evaluation is based on estimated capital and long-term (OM&M) costs[52]. A summary of the comparative rating of the alternatives is provided in Table 8-2.

The comparative analysis is presented below.

8.1 Overall Protection of Human Health and the Environment

This criterion addresses the overall ability of each alternative to eliminate, reduce, or control potential exposures to hazardous substances in both the short and long term, and evaluates whether the alternative achieves the RAOs for protection of human health and the environment. As discussed in Section 4.3, EPA developed PRGs to address unacceptable Site risks, COCs, and potential exposure pathways; those PRGs are used in this FS to determine whether each alternative provides adequate overall protection of human health and the environment. If an alternative is projected to achieve PRGs or otherwise effectively control exposure to Site media exceeding PRGs, then that alternative meets this NCP criterion.

As discussed in Section 7, with the exception of the baseline No Action alternative (Alternative 1), all of the remedial alternatives are protective of human health and the environment. For the purposes of retaining alternatives, this threshold criterion was evaluated only on the basis of whether the criterion was met in accordance with EPA guidance (EPA 1988a). All alternatives include containment technologies (including

[52] Note that the cost effectiveness of the remedial alternatives is not evaluated in the FS but will be considered during selection of a preferred remedy.

capping), ENR, institutional controls, and monitoring to achieve the required protectiveness. In addition, Alternatives 3 through 10 include progressively increased treatment and/or removal of contaminated materials and rely less on maintenance of containment measures to ensure protectiveness.

In general, differences in overall protectiveness between the alternatives are a function of the degree of PTM treatment/removal and location on the Site relative to the potential for future exposure. Alternatives that include treatment/removal of contaminated materials—particularly in sensitive areas of the Site (e.g., along the shoreline)—would reduce the reliance on institutional controls to manage the long-term risk by providing more permanent reductions in toxicity, mobility, and/or volumes of contaminants. However, those more aggressive alternatives would have a higher cost and lower short-term effectiveness, would be more difficult to implement and, due to the complexity of the Site, in all likelihood would leave residual contamination which would still necessitate reliance on institutional controls. Evaluation of the differences in long-term and short-term effectiveness of alternatives is provided in Sections 8.3 and 8.5, respectively.

In summary, all alternatives except Alternative 1 (No Action) would meet PRGs or otherwise effectively control exposure to Site media exceeding PRGs, and they therefore protect human health and the environment.

8.2 Compliance with ARARs

This criterion assesses whether each alternative would attain the identified chemical-, action-, and location-specific ARARs and other "To Be Considered" (TBC) criteria, advisories, and guidance presented in Section 4.1. As discussed in Section 7.1.1.2, it would be expected that all alternatives, except Alternative 1 (No Action), would comply with all ARARs except the SDWA, which requires achievement of groundwater MCLs throughout the Site.

To assess compliance with the SDWA, groundwater modeling was used to predict the volumes of contaminated groundwater exceeding the MCLs for benzene, benzo(a)pyrene, and arsenic 100 years following implementation of each alternative. Results are provided on Figure 7-1 and are summarized below:

- Benzene was predicted to exceed its MCL after 100 years for Alternatives 1 through 7 and 9. Assuming no residual soil contamination, benzene was predicted to achieve its MCL after 28 years for Alternative 8 and after 14 years for Alternative 10[53]. The model sensitivity analysis results indicate that the presence of residuals following construction for Alternatives 8 and 10 does not significantly increase the timeframe to achieve the MCL for benzene in groundwater.

[53] Note that timeframes listed are based on the time after remedy construction is complete; therefore, the predicted time to achieve MCLs is somewhat greater, based on the duration of the remedy design and construction (see Figure 7-5). The total time to achieve the benzene MCL under Alternatives 8 and 10 would be 35 and 29 years, respectively.

- Benzo(a)pyrene was predicted to exceed its MCL in groundwater after 100 years for all alternatives. In Alternative 10, the groundwater model predicted that the benzo(a)pyrene MCL would be achieved when construction is complete; however, as a simplifying assumption for modeling purposes, it was assumed that 100 percent of the PMTs were removed with no residuals remaining because the quantity of residuals is difficult to estimate. However, some amount of residual soil contamination associated with incomplete removal is likely due to the complexity of subsurface conditions. A sensitivity analysis was performed in which it was assumed that a 2-inch-thick layer of soil containing 10 milligrams per kilogram benzo(a)pyrene remained in the excavation as residual. Under this scenario, the model results indicated that benzo(a)pyrene would exceed its MCL for more than 100 years. The presence of residuals following removal is considered the more likely scenario.
- Arsenic was predicted to exceed its MCL in groundwater 100 years following implementation of all alternatives.

Alternatives 1 and 2 slightly reduce the estimated volume of groundwater exceeding MCLs after 100 years. Alternative 1 (No Action) is used as a baseline against which the plume reductions achieved by the other alternatives are compared. The volume of groundwater exceeding MCLs after 100 years would be moderately reduced by implementing Alternatives 3 through 6 and more significantly reduced by implementing Alternatives 7 through 10. Additional comparisons of the long-term aquifer restoration achieved by the remedial alternatives are presented in Section 8.3, as part of the long-term effectiveness and permanence criterion.

In summary, none of the alternatives would achieve compliance with all ARARs because none of the alternatives would achieve compliance with the SDWA (based on modeling of groundwater concentrations 100 years following implementation). However, each alternative, with the exception of the No Action alternative (Alternative 1), would comply with the remaining ARARs identified in Section 4.1. Because all ARARs must be met or waived per CERCLA upon completion of remedial actions, all alternatives may require a waiver.

8.3 Long-Term Effectiveness and Permanence

This NCP balancing criterion evaluates each alternative's long-term effectiveness and permanence by assessing the magnitude of residual risk remaining after implementation and the adequacy and reliability of engineering and institutional control measures to manage those potential residual risks. The magnitude of residual risk was evaluated in the context of achieving RAOs. The adequacy and reliability of controls were evaluated based on the likelihood for re-exposure of contained materials based on their location and the specific controls used. The comparison of alternatives on these general criteria is described below.

8.3.1 *Magnitude of Residual Risk*

As discussed in Section 8.1, all alternatives, except Alternative 1 (No Action), would achieve human health and environmental protection RAOs at potential points of exposure through the use of varying levels of removal, treatment, caps and covers (including

dredging residual covers and ENR), and institutional controls. Alternatives vary more significantly with respect to the magnitude of residual risk associated with contamination left at the Site, depending on the removal/treatment technologies employed, the extent of removal/treatment, and the future exposure risk of contamination left in place. These parameters are discussed below.

Removal/Treatment Technologies Employed. The magnitude of residual risk following removal/treatment of PTMs varies based on the technologies employed. *In situ* solidification (employed in Alternatives 3, 5, 6, 7, and 9) would leave contaminated materials on the Site but would greatly reduce the mobility of the contaminants. Removal and off-site disposal (employed in Alternatives 4 and 6) would permanently remove contaminants from the Site, although excavation or dredging residuals could remain. Removal and on-site treatment/backfill (employed in Alternatives 8, 9, and 10) would reduce the magnitude of residual risk, although residuals with low levels of contaminants above PRGs (that would be subsequently capped or covered) could remain, depending on effectiveness limitations of on-site treatment technologies. For the purposes of this FS, all removal/treatment technologies evaluated would have a high effectiveness for reducing residual risk, but removal with off-site disposal or on-site treatment would have a higher effectiveness than *in situ* solidification because under *in situ* solidification high concentrations of contaminants, although immobilized, would remain on the Site. As described in Section 7, some leaching of contaminants would be likely, and there is uncertainty in the stability of the solidified matrix over the very long term. Bench and pilot testing to optimize solidification amendments could partly address these concerns.

Extent of Removal/Treatment. The magnitude of residual risk following remedy implementation included a comparative evaluation of alternatives based on the respective total volumes of DNAPL removed or treated (Figure 7-2). A secondary factor that was considered is the effectiveness of groundwater treatment among the alternatives based on the predicted reduction in contaminant mass flux in the lakebed sediments 100 years after implementation of the alternative (Figure 7-3). This was considered secondary to the volume of DNAPL removed or treated because the majority of contaminant mass at the Site, and the most toxic materials, are contained in the PTMs.

The primary differences in which the alternatives would remove or treat contaminated materials at the Site are summarized as follows:

- Alternatives 1 and 2 would not substantially remove or treat contaminated materials[54]. The reactive caps used in Alternative 2 would reduce the mobility of DNAPL in shallow sediments; however, the mobility of DNAPL in these materials is already considered very low.

[54] As noted in Section 7, the groundwater model predicted some decline in the groundwater plume volume and contaminant mass flux for Alternative 2, due to the assumption of an impermeable cap. However, this component is an assumed future condition that is not part of the remedial alternative; therefore, the improvement reduction in groundwater quality contaminant mass flux is not considered an effect of the alternative.

- Alternative 3 would remove or treat 12 percent of the DNAPL volume. This alternative would reduce mass flux of COCs (except arsenic) in groundwater by an estimated 57 percent by treating groundwater near the shoreline using a PRB.
- Alternative 4 would remove or treat 22 percent of DNAPL volume, including 88 percent of the sediment DNAPL volume. This alternative would provide greater reduction in groundwater contaminant mass flux compared to Alternative 3 through use of the groundwater PRB and removal of PTMs in the QP-U DNAPL Area.
- Alternatives 5 and 6 would remove or treat progressively greater volumes of DNAPL (62 percent and 91 percent, respectively) by treating the deep upland PTMs targeted in Alternative 3, the shallow PTMs near the lake addressed by Alternative 4, and additional upland areas of PTM occurrences. As with Alternative 4, 88 percent of the sediment DNAPL volume would be removed. These alternatives would provide a substantially greater reduction in groundwater contaminant mass flux compared to Alternative 3.
- Alternatives 7 through 10 would remove or treat all DNAPL and significantly reduce the mass flux of contaminated groundwater. Alternatives 9 and 10 also would treat a substantial volume of contaminated soil and sediment.

Future Exposure Risk of Contamination Left in Place. The future exposure risk associated with contaminants left in place varies by the location, potential mobility, and toxicity of the contaminated materials. Near-surface and potentially mobile PTMs generally represent a greater residual risk, particularly in sediments, since future disturbance or migration to an exposure point is more likely. Alternatives that would treat or remove PTMs in the QP-U, QP-S, and TD DNAPL Areas (Alternatives 4 through 10) would reduce the magnitude of residual risk to a greater degree than alternatives that would leave these materials in place (Alternatives 1 through 3). Alternatives 7 through 10 would treat all PTMs, including all PTMs in shallow sediments and near the shoreline.

8.3.2 *Adequacy and Reliability of Controls*

This factor assesses the reliability of controls used to manage contaminated materials that would remain at the Site after remedy implementation. Controls would include engineered controls such as caps, institutional controls such as restrictive covenants or fish advisories, and long-term monitoring. A summary of institutional controls and monitoring activities under each alternative is provided in Table 7-3. Differences in the reliability of controls include the following:

- Controls in upland areas are generally considered more reliable than controls in aquatic areas because access and use of upland areas could be more easily controlled and enforced, and would be easier to access for monitoring and maintenance. For the purposes of this FS, alternatives have been designed to facilitate such access (e.g., not placing treatment-oriented controls in the shoreline habitat area), and it is assumed that institutional controls would include provisions that prevent future developments from impacting the remedy (e.g., building structures in areas that would prevent access to remedy components requiring maintenance).

- Controls that rely on treatment (e.g., groundwater PRB, reactive sediment caps) to be effective are considered to have a greater risk of failure than controls that rely on providing a physical barrier, since treatment media can lose effectiveness over time (e.g., by becoming saturated with contaminants). These measures typically require more frequent monitoring to evaluate effectiveness and allow for maintenance as needed, and must either be designed conservatively or planned for periodic replacement.

Alternative 1 would not provide any control measures. Alternatives 2 through 10 would include similar types of institutional controls and monitoring (see Table 7-3), except restrictions on construction activities that would potentially mobilize DNAPL would not be needed for Alternatives 7 through 10.

Alternatives 2 through 10 would include similar types of engineering controls. These engineering controls would include an upland cap, an engineered sand cap, and ENR placed over generally similar areas, although the engineered sand cap area would be significantly less for Alternatives 9 and 10 due to greater dredging of contaminated sediments. In dredging areas, the engineered sand cap would be eliminated in favor of dredging; however, a residuals cover would be placed following dredging.

Alternatives 2 through 6 would include reactive capping of sediment DNAPL areas that are not dredged. RCM caps would be used exclusively in Alternatives 3 through 6. They would also be used in Alternative 2 in all sediment DNAPL areas except the QP-S DNAPL Area, where an amended sand cap would be installed instead. Both types of reactive sediment caps are considered innovative and, even though their use is increasing, they are generally considered less reliable (due to the lack of long-term performance data) than dredging with a dredging residuals cover. The amended sand cap, due to its greater thickness and longer design life, would be expected to provide greater reliability with respect to physical isolation. However, it would be heavier than the RCM cap, and consolidation-induced DNAPL migration would need to be addressed during remedy design. The amended sand cap in Alternative 2 would also alter the existing shoreline due to thickness and because its placement would not be preceeded by dredging.

Alternatives 3 and 4 would include DNAPL collection trenches to control DNAPL migration from the upland to the lake. These alternatives would more reliably control DNAPL migration than Alternative 2, which would rely on sediment capping to control migration. DNAPL migration would be more reliably controlled by removal or solidification of potentially mobile DNAPL under Alternatives 5 and 6, and most reliably controlled by complete removal or solidification of DNAPL under Alternatives 7 through 10.

8.3.3 *Overall Long-Term Effectiveness and Permanence Ranking*

The long-term effectiveness and permanence rating is based on consideration of both the magnitude of residual risk associated with any contamination remaining at the Site following implementation of the remedy and the reliability of controls. Even though most alternatives would include similar institutional controls, the institutional controls would be more effective for alternatives where the remedy would reduce the quantity of contamination remaining, particularly in areas of the Site most susceptible for future

disturbance and potential release in the event of remedy failure. For instance, there is less risk in the event of technology failure (e.g., cap disturbance during a seismic event or violation of restrictive covenants) if there is less residual contamination and a lower potential level of exposure. In the event that a control measure fails, all alternatives would have monitoring to identify the failure and to repair the measures. The reduced effectiveness of controls would be due to the potential for short-term exposures until the failure could be corrected.

Long-term effectiveness and permanence could vary based on the location and characteristics of residual contamination; for instance, shallow contaminants are generally more accessible than deep contaminants; therefore, controls on deep contaminants are considered more effective than for shallow contaminants. Areas of the Site representing the greatest future exposure risk include the QP-U, QP-S, and TD DNAPL Areas.

The differences in long-term effectiveness and permanence among the alternatives are summarized as follows:

- Alternative 1 would not provide any removal, treatment, or control measures and would not meet PRGs; therefore, this alternative is rated low for this criterion.
- Alternative 2 would meet PRGs but would not significantly reduce the volume of contaminated materials. In particular, this alternative would rely on passive controls with a risk of failure to address highly toxic and potentially mobile PTMs along the shoreline area (i.e., in the QP-U DNAPL Area.). Therefore, this alternative is rated low for this criterion.
- Alternative 3 would achieve modest reductions in the volume of contamination, primarily through treatment of PTMs. This alternative would improve reliability of control for potentially mobile DNAPL near the lake through the use of DNAPL collection trenches; however, due to the potential future shoreline habitat area, these trenches are assumed to be located 100 feet away from the shoreline and therefore do not address potentially mobile DNAPL closest to the lake in the QP-U DNAPL Area. Therefore, this alternative is rated low for this criterion.
- Alternative 4 would achieve a significantly larger reduction in the volume of contamination compared to Alternative 3, and would also improve effectiveness by removing contamination with the greatest future exposure risk (i.e., PTMs in the QP-U, QP-S, and TD DNAPL Areas.). Therefore, this alternative is rated moderate for this criterion.
- Alternatives 5 and 6 would provide more substantial reductions in the volume of contamination compared to Alternative 4, and similarly address contamination with the greatest future exposure risk. However, a significant volume of PTMs and contaminated groundwater would remain on site. These alternatives are rated moderate for this criterion.
- Alternatives 7 through 10 would greatly reduce the magnitude of residual risk through removal or treatment of all PTMs and substantial reductions in the

volume of contaminated groundwater. These alternatives are rated high for this criterion.

8.4 Reduction of Toxicity, Mobility, or Volume through Treatment

This criterion evaluates the degree to which each remedial alternative reduces toxicity, mobility, or volume through treatment. This evaluation is similar to the evaluation conducted for long-term effectiveness in Section 8.3, except that off-site disposal is not considered for this criterion because the criterion is based on the statutory preference for treatment.

The comparative rating of alternatives for this criterion, presented in Table 8-1, was based primarily on the expected toxicity, mobility, or volume reduction through treatment of PTMs, using the estimated total volume of DNAPL treated as a metric. Figure 7-2 shows approximate DNAPL volumes treated under each alternative. (Off-site disposal volumes, also shown on the figure, are not considered for this criterion.)

As a secondary factor for evaluating this criterion, the alternatives were differentiated based on the expected reduction in volume and mobility of contaminated groundwater resulting from treatment, based on groundwater modeling results (see Figures 7-1 and 7-3, respectively). Groundwater treatment metrics were considered secondary to the PTM treatment metric because the majority of contaminant mass at the Site, and the most toxic materials, are contained in the PTMs.

Alternatives 2 through 6 would include PTM treatment associated with reactive sediment capping to reduce mobility of DNAPL, should DNAPL migrate due to a seismic or other exteme event. Alternatives 3 through 10 would employ several additional treatment methods:

- Off-site incineration of mobile DNAPL accumulating in collection trenches (Alternatives 3 and 4);
- *In situ* solidification of upland PTMs (Alternatives 3, 5, 6, 7, and 9); and
- On-site thermal desorption of PTMs (Alternatives 8, 9, and 10).

The volume of mobile DNAPL that would accumulate in the collection trenches is estimated to be relatively small; therefore, most PTM treatment would be accomplished via *in situ* solidification or on-site thermal desorption. For the purposes of this FS, treatment by thermal destruction technologies (incineration and thermal desorption) was rated higher than *in situ* solidification, because preference was given to technologies that permanently destroy the COCs (thus reducing toxicity, mobility, and volume) over technologies that permanently isolate COCs, and because *in situ* solidification would slightly increase the total volume of contaminated materials.

Groundwater treatment would be achieved through treatment of PTMs and surrounding contaminated soil or sediment as described above. In addition, two groundwater treatment technologies were included in the range of alternatives:

- PRBs to treat Site groundwater in the Shallow Alluvium along the shoreline prior to migration below Lake Washington (Alternatives 3 through 6); and

- Groundwater pump and treatment systems to treat Site groundwater along the shoreline (Alternative 10).

The remedial alternatives were rated with respect to this criterion as follows:

- Alternatives 1 and 2 include no treatment of PTMs or groundwater. Both alternatives are rated low.
- Alternative 3 would treat 9 percent of PTMs via *in situ* solidification. By targeting deep PTMs for treatment and by using a PRB to treat groundwater near the shoreline, this alternative would achieve modest reductions in groundwater volume and mass flux. This alternative is rated low because the majority of PTMs would not be addressed by treatment.
- Alternative 4 includes no treatment of PTMs. This alternative would achieve modest reductions in groundwater volume and mass flux by removing PTMs in the QP-U DNAPL Area and installing a PRB. This alternative is rated low.
- Alternatives 5 and 6 would treat approximately 46 and 68 percent of PTMs, respectively. These alternatives would achieve similarly modest reductions in groundwater volume and flux as Alternative 3 by treating deep PTMs and installing a PRB. These alternatives are rated moderate.
- Alternatives 7 and 8 would treat all PTMs and greatly reduce the volume and mass flux of contaminated groundwater. Alternative 7 would achieve treatment through *in situ* solidification, while Alternative 8 would achieve treatment through on-site thermal desorption. Both alternatives are rated high for this criterion. Alternative 8 satisfies this criterion to a slightly higher degree than Alternative 7 due to the more permanent nature of treatment and reduction in contaminant volume.
- Alternatives 9 and 10 would treat all PTMs and also would treat a substantial volume of contaminated soil and sediment. Alternative 9 would use a combination of *in situ* solidification and on-site desorption, while Alternative 10 would use on-site desorption. Alternative 10 also would achieve the greatest reduction in groundwater plume volume. These alternatives are rated high for this criterion.

8.5 Short-Term Effectiveness

This criterion is used to evaluate the effects and potential risks associated with remedial alternative implementation, considering the protection of workers, protection of the community, and potential impacts to the environment. This criterion also considers the effectiveness of mitigative measures (i.e., measures such as BMPs that would reduce the short-term impacts of the alternatives) and the time until RAOs would be achieved.

In general, short-term impacts increase with construction duration and the quantities of contaminated materials removed or handled. Although many impacts can be adequately managed through standard construction practices such as health and safety programs and BMPs, the potential for worker injuries, exposures, or releases to the environment would increase with longer construction periods and greater volumes of contaminated materials

handled. In addition, several impacts would be difficult to control, including the following:

- Vapor emissions, from disturbance of contaminated materials during excavation, dredging, and (to a lesser degree) *in situ* solidification. These could result in noxious odors and exposure of the community to volatile compounds. Alternatives involving on-site thermal treatment of contaminated materials (Alternatives 8, 9, and 10) also would have the potential for vapor emissions from on-site handling and processing; however, these emissions would be more easily controlled by available process technologies employed in the treatment train.
- Impacts to the community from construction noise, traffic, aesthetics, and affected recreation.
- Water quality impacts from dredging. Water quality impacts would be reduced as much as possible by implementing hydraulic dredging with silt curtain/oil boom controls in the aquatic area and providing barrier containment with sheet piles around mechanical dredge areas in the nearshore. However, some level of water quality impacts may occur during sheet pile installation or sediment removal (see Section 7.5.5.3).

As discussed in EPA's Contaminated Sediment Remediation Guidance for Hazardous Waste Sites (EPA 2005), the NCP evaluation of short-term effectiveness addresses the following general attributes of remedial technologies:

- **Capping.** Typically, this technology is associated with the shortest time to achieve protection, and complete biota recovery could take several years. Generally, there is a low potential for health impacts to the community and workers from contaminant releases during cap placement.
- **Dredging.** The time to achieve protection varies depending on the size (volume and duration) and complexity of the project and is generally more uncertain than capping due to the difficulty of accurately predicting target sediment volumes and residual contamination. Environmental impacts may occur from resuspension and releases to the environment during dredging and there is a low to moderate potential for health impacts to the community and workers from contaminant releases during dredging.

The estimated design and construction duration for each alternative is shown on Figure 7-5. The combined duration of design and construction is also the approximate time required to achieve RAOs, except for the groundwater restoration RAO. Restoration of groundwater to achieve MCLs would not be met for any alternative within 100 years (see Section 8.2).

Alternative 1 has no construction activities and, therefore, no construction impacts. However, it does not attain RAOs in the foreseeable future. Therefore, it is rated moderate for short-term effectiveness.

Alternative 2 would have the greatest short-term effectiveness and is rated high for this criterion. Alternative 2 would have the shortest construction period (less than 1 year),

would disturb a minimum of contaminated material, and would present the least amount of risk to workers, the community, and the environment.

Alternative 3 would present a slightly greater short-term risk than Alternative 2 due to additional construction activities, including disturbance of contaminated materials during *in situ* solidification of deep PTMs, and the construction of a PRB and DNAPL collection trenches. These activities would cause some air emissions. However, the total volume of soil disturbed in this alternative would be relatively modest, and the total construction duration would be relatively short (approximately 1.5 years). This alternative is also rated high for short-term effectiveness.

Alternative 4 would have a longer construction duration (approximately 2.5 years) and increased short-term impacts from dredging of PTMs in sediment, which would result in air and water quality impacts. Alternative 4 also would involve excavation of DNAPL-containing soil in the QP-U DNAPL Area, which would generate additional air quality impacts. This alternative is rated moderate for short-term effectiveness.

Alternative 5 would have similar construction duration and potential for water quality impacts through dredging as Alternative 4. Alternative 5 would involve treatment of a greater volume of upland material than Alternative 4, but would employ *in situ* solidification, resulting in fewer short-term impacts than removal. This alternative is rated moderate for short-term effectiveness.

Alternative 6 would have a slightly longer construction duration (3 years) than Alternatives 4 and 5. This alternative would have a similar potential for water quality impacts through dredging, but greater short-term impacts due to more extensive upland construction (i.e., a combination of removal and *in situ* solidification). This alternative is also rated moderate for short-term effectiveness.

Alternatives 7 and 8 would have relatively long construction durations (ranging from 4.5 to 5.5 years) and involve disturbance of very large quantities of PTMs, which would result in significant extended air and water quality impacts. Alternative 7, which would involve *in situ* solidification of upland PTMs, would have lower short-term impacts than Alternative 8 (removal and on-site thermal treatment) because the materials would be treated *in situ*; however, some air emissions still would be expected. Due to the very long durations and high potential for extended emissions, these alternatives are rated low for short-term effectiveness.

Alternatives 9 and 10 would have very long construction durations (10 and 12 years, respectively). These alternatives would have the greatest short-term impacts to workers, the community, and the environment, and therefore are rated low for short-term effectiveness. Alternative 10 would have greater short-term impacts than Alternative 9 due to the much greater volumes of contaminated soil and sediment that would be removed under Alternative 10.

8.6 Implementability

This section evaluates the relative implementability of the alternatives, focusing on their technical feasibility, administrative feasibility; and the availability of services and materials.

In general, implementability decreases with increased complexity of the alternatives. With the exception of the reactive caps, the technologies used by all alternatives are proven technologies that have been implemented at other, similar sites and could be implemented at the Site. While reactive caps are innovative, their use is increasing as reflected in Appendix C, and there are no market or technical limitations preventing their implementation. Differences in complexity include the following:

- Alternatives involving *in situ* solidification (Alternatives 3, 5, 6, 7, and 9) would require bench and/or pilot testing of potential amendment mixtures to determine proper mixes to optimize effectiveness.
- Alternatives involving deep excavations (Alternatives 8 and 10) would have substantially increased complexity due to robust shoring and dewatering systems. The conceptual shoring system for Alternative 10 would include 95-foot-long sheet piles (based on the analysis performed in Section 6), which are not readily available and could result in transportation challenges.
- Alternatives involving on-site thermal treatment of soil or sediment (Alternatives 8, 9, and 10) would require treatability testing. The local availability of vendors and equipment for on-site thermal treatment are limited, which would make bidding and procurement more difficult. On-site thermal treatment also would have more technical and administrative challenges due to air emissions controls and monitoring.
- Alternatives involving dredging of DNAPL-containing sediments (Alternatives 4 through 10) would have greater technical and administrative implementability issues due to the complexity of dredging, materials handling, residuals management, and water monitoring for in-water work. The presence of complex nearshore bathymetry and significant debris would reduce the practicability and/or efficiency of removing sediment from the targeted areas. These limitations would be present for all dredging alternatives, but would be amplified for the large dredging components. For alternatives with relatively large dredge volumes (e.g., Alternatives 7 through 10), federal agencies may potentially impose further restrictions on in-water construction activities (e.g., additional controls to prevent dredging-related COC releases and further minimize habitat disturbances).

All alternatives would require coordination with federal, state, and local agencies and the Muckleshoot Tribe to conduct work and to implement the required institutional controls. Maintenance of caps would require coordination with the DNR and the Muckleshoot Tribe regarding future aquatic land use and Tribal treaty rights. Alternatives with longer construction durations would generally require more administrative coordination and have a greater potential for technical problems and schedule delays.

The implementability of each alternative is compared in Table 8-1 and summarized as follows:

- Alternative 2 would be the easiest alternative to construct. This alternative would present no unusual construction challenges, and necessary engineering and construction services are available. The amended sand cap is commercially

available and readily implemented. This alternative is rated high for implementability.

- Alternative 3 would involve slightly more technical complexity due to additional treatment and containment measures and the need to bench and pilot test *in situ* solidification. However, all components are proven technologies and the construction quantities are modest. The RCM cap is commercially available and readily implemented. This alternative is also rated high for implementability.
- Alternative 4 would have greater technical complexity for aquatic remedial components compared to Alternative 3 (i.e., dredging of DNAPL-containing sediments.) Alternative 4 would include removal and off-site disposal of a similar quantity of material that would be solidified in Alternative 3. This alternative is rated moderate for implementability, primarily because of the complexities of dredging DNAPL.
- Alternatives 5 and 6 are similar to Alternative 4 but would have slightly more complicated upland remedial components and longer construction durations due to more extensive solidification. These alternatives are also rated moderate for implementability.
- Alternative 7 would have a longer construction period compared to Alternative 6 due to more extensive dredging and solidification, but would not include a PRB due to the increased solidification area. The technical feasibility of treating or removing all PTMs at the Site is lower than the feasibility of targeting hot spots under Alternatives 3 through 6. This alternative is rated moderate for implementability.
- Alternatives 8 would involve significantly greater implementability challenges than Alternative 7 due to the complexities of shoring and dewatering extensive excavations and providing on-site thermal treatment of a large volume of material. This alternative is rated low for implementability.
- Alternatives 9 and 10 would involve the largest soil and sediment removal volumes and very extensive in-water and upland construction activities. The scope of these activities would encounter severe technical and administrative challenges. These alternatives are rated low for implementability.

8.7 Cost

Cost estimates were developed for each alternative per EPA guidance (EPA 2000) as described in Section 7.1.2.5 and detailed in Appendix D. To compare alternative costs for this criterion, this section summarizes the cost of each alternative and identifies the primary components that result in significant cost differences between the alternatives. This section also identifies the relative contribution of long-term (OM&M) costs for each alternative. Consistent with Section 7, this section only references NPV costs using a 1.6 percent discount rate. See Appendix D for two versions of the cost estimates for each alternative: one based on NPV and one with no discount rate applied. In general, not adjusting costs to NPV results in estimated long-term costs roughly 40 percent higher.

The estimated present worth cost for each alternative, in 2013 dollars and using a discount factor of 1.6 percent, is listed in Table 8-1. Capital and OM&M costs are also provided in Table 8-1. In general, alternatives involving more extensive treatment of PTMs would have higher capital and lower long-term costs. Among treatment technologies, *in situ* solidification is significantly cheaper on a unit cost basis than removal and off-site disposal or on-site thermal treatment. Alternative costs ranged as follows:

- Alternative 2 would have the lowest capital ($18 million [M]) and total ($26M) costs of the alternatives. Capital costs are fairly evenly split between upland capping and sediment capping/ENR components. Estimated OM&M costs ($7.6M) are largely for the assumed periodic repair of the reactive cap.
- Alternative 3 would have slightly higher capital ($22M) and OM&M ($9.2M) costs than Alternative 2 due to the *in situ* solidification of deep PTMs and installation of the DNAPL collection trenches and a PRB. These measures result in a slightly higher overall cost ($31M).
- Alternative 4 would have much higher capital ($40M) and total ($44M) costs than Alternative 3, primarily due to dredging instead of capping of several DNAPL-impacted areas. Substitution of deep PTM solidification by removal of the QP-S DNAPL Area, although treating a similar volume of material, also increases the costs somewhat because solidification is cheaper on a unit cost basis than removal/off-site disposal. The OM&M costs of this alternative ($4.8M) are slightly lower than Alternative 3 because OM&M costs for dredging residual covers are less than for reactive caps.
- Alternative 5 would have a higher capital cost ($42M) than Alternative 4 due the expanded treatment (via *in situ* solidification) of upland PTMs. The OM&M cost of this alternative ($4.1M) is less than Alternatives 3 and 4 because no DNAPL collection trenches are included, due to the increased volume of PTM being treated. The total cost of this alternative ($47M) is still slightly higher than Alternative 4.
- Alternative 6 would have a much higher capital cost ($57M) and the same OM&M cost ($4.1M) as Alternative 5. The higher capital cost is due to the much more extensive treatment (via *in situ* solidification) of upland PTMs. The total cost of this alternative is $61M.
- Alternative 7 would have much higher capital ($78M) and total ($80M) costs due to treatment of all upland PTMs via *in situ* solidification. The increase in cost is not proportional to the increase in PTM treatment because a large volume of soil would be solidified to fully treat the thin, widely-dispersed layers of DNAPL-impacted soil. The OM&M cost ($2.7M) is less than Alternative 6 because the PRB is not included. The OM&M cost of Alternative 7 is the lowest of the alternatives (other than Alternative 1) because it primarily consists of groundwater monitoring and inspection/maintenance of the upland cap, engineered sand cap, and ENR
- Alternative 8 would have much higher capital ($137M) and total ($140M) costs than Alternative 7 because treatment of the same amount of PTMs would be

accomplished using removal and on-site treatment, which has a much higher unit cost than *in situ* solidification. The OM&M cost ($2.7M) is the same as Alternative 7.

- Alternative 9 would have significantly higher capital ($259M) and total ($262M) costs compared to Alternative 8 because of the much more extensive treatment through *in situ* solidification of deep soil and removal/on-site treatment of contaminated sediments. The OM&M cost ($2.7M) is the same as Alternatives 7 and 8.
- Alternative 10 would have the highest capital ($380M) and total ($409M) costs of the alternatives. These costs are much higher than Alternative 9 because all contaminated soils would be removed and treated on site, which has a greater unit cost than *in situ* solidification. The OM&M cost ($29M) is much higher because of long-term operation of a groundwater pump-and-treat system.

8.8 Comparative Analysis Summary

In this FS, 10 remedial alternatives were developed and evaluated as described above. The alternatives provide a broad range of actions, including various levels of containment, removal, and/or treatment, consistent with EPA guidance (EPA 1988a). The detailed analysis in Section 7 evaluates each alternative against seven NCP criteria: the threshold criteria of overall protection and ARAR compliance, and the balancing criteria of long-term effectiveness and permanence; reduction of toxicity, mobility, or volume through treatment; short-term effectiveness; implementability; and cost. The comparative analysis, described above and summarized in Tables 8-1 and 8-2, identifies the key differentiating factors between alternatives.

All alternatives (except the No Action) meet the threshold requirements for overall protectiveness and ARAR compliance, with one exception: none of the alternatives would fully comply with the SDWA, based on predictions of MCL exceedances in Site groundwater for more than 100 years after remedy implementation.

The comparative analysis illustrates the tradeoffs for different methods and levels of containment, removal, and/or treatment for Alternatives 2 through 10. Alternatives focused on containment with limited removal and/or treatment rate high for short-term effectiveness and implementability, but would rely more on monitoring and maintenance of containment measures to ensure long-term effectiveness. Containment-focused alternatives also would retain greater residual risk of future exposure, except where augmented by removal and/or treatment of PTMs posing the highest risk of future exposure (QP and TD DNAPL Areas). In contrast, alternatives involving more extensive removal and/or treatment would rely less on monitoring and maintenance of containment measures to achieve long-term effectiveness and permanence but because of the greater scale, complexity, and duration of construction, rate lower for short-term effectiveness and implementability. Further, alternatives with extensive removal and/or treatment would have much higher costs associated with the greater volumes involved and the added complexity of addressing PTM at greater depths.

Certain statutory requirements for CERCLA remedial actions (such as cost effectiveness or using permanent solutions to the maximum extent practicable) are not evaluated in the

FS, but are important considerations during selection of a final remedy. EPA will select a preferred remedy and prepare a proposed plan based on the analysis presented in this FS, risk management considerations, and statutory requirements for remedial actions. The preferred alternative may be one of the alternatives described in the FS or a combination of elements from different alternatives, as appropriate. State and community acceptance of the preferred remedy will be evaluated in the ROD once comments on the FS and proposed plan are received.

9 References

Anchor Environmental, LLC, 2006, Final Removal Action Completion Report, Removal Action NW Natural "Gasco" Site, April 2006.

Anchor Environmental, LLC and Aspect Consulting, LLC (Aspect), 2007, Draft Task 3 – Preliminary Conceptual Site Model, Remedial Action Objectives, Remediation Goals, and Data Gaps, Remedial Investigation/Feasibility Study, Quendall Terminals Site (Draft Task 3 Report), Report prepared for U.S. Environmental Protection Agency, Region 10, on behalf of Altino Properties, Inc., and J.H. Baxter & Company, Seattle, WA, November 2007.

Anchor QEA (Anchor) and Aspect, 2009, Final Work Plan, Human Health and Ecological Risk Assessment, Quendall Terminals Site, Renton, Washington (HERA Work Plan), Prepared for U.S. Environmental Protection Agency, Region 10, on behalf of Altino Properties, Inc., and J. H. Baxter & Co., November 2009.

Anchor QEA and Aspect, 2012, Final Remedial Investigation Report, Quendall Terminals Site, Renton, Washington, Prepared for U.S. Environmental Protection Agency, Region 10, on behalf of Altino Properties, Inc and J.H Baxter & Company, September 2012, Incorporates Revisions Provided by EPA Region 10.

Aspect and Anchor, 2011, Evaluation of Groundwater Restoration Potential Technical Memorandum, Quendall Terminals Site, Prepared for U.S. Environmental Protection Agency, Region 10, on behalf of Altino Properties, Inc and J.H Baxter & Company, May 13, 2011 DRAFT.

Aspect Consulting, 2006, Construction Report, Barbee Mill Arsenic Remediation, Prepared for Barbee Mill Company, Inc., June 21, 2006.

Bailey, Marcia, U.S. Environmental Protection Agency (EPA), 2008, Attachment 4, EPA Comments on Task 3 Document, Screening Level Vapor Intrusion Estimates Using EPA J-E Model, February 9, 2008.

Bridges, T.S., K. E. Gustavson, P. Schroeder, S. J. Ells, D. Hayes, S. C. Nadeau, M. R. Palermo, and C. R. Patmont, 2010, Dredging Processes and Remedy Effectiveness: Relationship to the 4 Rs of Environmental Dredging, Integrated Environmental Assessment and Management, October 2010.

Bullock, A. M. 2007, Innovative Uses of Organophilic Clays for Remediation of Soils, Sediments, and Groundwater, In WM Symposia, Waste Management 2007 Symposium: Global Accomplishments in Environmental and Radioactive Waste Management, Tuscon, AZ, February 25 to March 1, 2007, http://www.wmsym.org/archives/2007/pdfs/7032.pdf.

Bullock, A. M., 2009, Innovative Uses of Organophilic Clays for Remediation of Soils, Sediments and Groundwater, WM2009 Conference, March 1-5, Phoenix AZ

California Environmental Protection Agency (CAEPA), May 2009, Technical Support Document for Cancer Potency Factors, Office of Environmental Health Hazard Assessment, Air Toxics and Epidemiology Branch.

Canadian Council of Ministers of the Environment, 1999, Canadian Water Quality Guidelines for The Protection of Aquatic Life: Polycyclic Aromatic Hydrocarbons (PAHs), Canadian Environmental Quality Guidelines, 1999, Canadian Council of Ministers of the Environment, Winnipeg.

CH2M HILL, 1983, Employee interviews with Bob Johnson and Ward Roberts, Hand-written notes dated April 11, 1983.

Domenico, P.A. and F. W. Schwartz, 1990, Physical and Chemical Hydrogeology, Wiley.

Ecology and Environment, Inc. 2004, Hudson River PCBs Superfund Site Quality of Life Performance Standards, May 2004.

Environmental Agency, 2004, Review of scientific literature on the use of stabilisation/solidification for the treatment of contaminated soil, solid waste and sludges, Science Report, SC980003/SR2, Environment Agency, November 2004.

ENVIRON and SPAWAR, 2009, Merritt, K. A., J.M. Conder, V.S Magar, V.J Kirtay, D.B. Chadwick, Enhanced Monitored Natural Recovery (EMNR) Case Studies Review, July 2009.

Environmental Protection Agency (EPA), 1988a, Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA, U. S. Environmental Protection Agency, Office of Emergency and Remedial Response, Washington, DC, PE89-184626, EPA/540/G-89/004, OSWER Directive 9355.3-01, October 1988.

EPA, 1988b, Guidance on Remedial Actions for Contaminated Ground Water at Superfund Site, U. S. Environmental Protection Agency, Office of Emergency and Remedial Response, Washington, DC, PE89-184626, EPA/540/G-88/003, OSWER Directive 9283.1-2, December 1988.

EPA, 1988c, CERCLA Compliance with Other Laws Manual: Interim Final. U. S. Environmental Protection Agency, Office of Emergency and Remedial Response, Washington DC, EPA/540/G-89/006, OSWER Directive 9234.1-01, August 1988.

EPA, 1989, Risk Assessment Guidance for Superfund, Volume 1: Human Health Evaluation Manual (Part A), Interim Final, EPA/540/1-89/002, December 1989.

EPA, 1990, A guide to Selecting Superfund Remedial Actions, OSWER Directive 9355.0-27FS , April 1990.

EPA, 1991a, Risk Assessment Guidance for Superfund, Volume I: Human Health Evaluation Manual, Supplemental Guidance, Standard Default Exposure Factors, OSWER Directive 9285.6-03, March, 1991.

EPA, 1991b, Risk Assessment Guidance for Superfund, Volume I: Human Health Evaluation Manual, Part, Risk Evaluation of Remedial Alternatives, OSWER Directive 9285.7-O1C, October, 1991.

EPA, 1993a, Guidance for Evaluating Technical Impracticability of Ground-Water Restoration, U. S. Environmental Protection Agency, Office of Solid Waste and Emergency Response, OSWER Directive 9234.2-25, September 1993.

EPA, 1993b, Record Of Decision, American Creosote Works, Inc. Site, Winnfield, Louisiana. United States Environmental Protection Agency. Epa/Rod/R06-93/086. 04/28/1993.

EPA, 1995a, Land Use in the CERCLA Remedy Selection Process, U. S. Environmental Protection Agency, Office of Solid Waste and Emergency Response, OSWER Directive 9355.7-04, May 1995.

EPA, 1995b, Consistent Implementation of the FY 1993 Guidance on Technical Impracticability of Ground-Water Restoration at Superfund Sites, U. S. Environmental Protection Agency, Office of Emergency and Remedial Response, OSWER Directive 9200.4-14, January 1995.

EPA, 1995c, Presumptive Remedies for Soils, Sediments, and Sludges at Wood Treater Sites, U. S. Environmental Protection Agency, Office of Emergency and Remedial Response, OSWER Directive 9200.5-162, December 1995.

EPA, 1996a, Final Guidance: Presumptive Response Strategy and *Ex Situ* Treatment Technologies for Contaminated Ground Water at CERCLA Sites. U. S. Environmental Protection Agency, EPA Directive 9283.1-12, 540/R-96/023. October 1996.

EPA, 1996b, The Role of Cost in the Superfund Remedy Selection Process, U. S. Environmental Protection Agency, OSWER Directive Publication 9200.3-23FS, September 1996.

EPA, 1997, Feasibility Study/Record Of Decision Analysis for Wood Treater Sites with Contaminated Soils, Sediments, and Sludges, U. S. Environmental Protection Agency, http://www.epa.gov/superfund/policy/remedy/presump/wood/study.pdf.

EPA, 1999, A Resource for MGP Site Characterization and Remediation. U. S. Environmental Protection Agency, Office of Solid Waste and Emergency Response, 1999.

EPA, 2000, A Guide to Developing and Documenting Cost Estimates During the Feasibility Study, U.S. Environmental Protection Agency, Office of Emergency and Remedial Response, OSWER Directive 9355.0-75, July 2000.

EPA, 2003a, EPA Administrative Order on Consent (AOC) II–Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA)–2003-2012 for the Quendall Terminal Site.

EPA, 2003b, Procedures for the Derivation of Equilibrium Partitioning Sediment Benchmarks (ESBs) for the Protection of Benthic Organisms: PAH Mixtures. EPA/600/R-02/013, November 2003.

EPA, 2004a, Risk Assessment Guidance for Superfund, Volume 1: Human Health Evaluation Manual (Part E, Supplemental Guidance for Dermal Risk Assessment), Final, EPA/540/R/99/005, July 2004.

EPA, 2004b, Strategy to Ensure Institutional Control Implementation at Superfund Sites. OSWER Directive 9355.0-106, September 2004.

EPA, 2005, Contaminated Sediment Remediation Guidance for Hazardous Waste Sites, OSWER Publication 9355.0-85, United States Environmental Protection Agency, Office of Solid Waste and Emergency Response, http://www.epa.gov/superfund/resources/sediment/guidance.htm.

EPA, 2006, Record of Decision: Garland Creosoting Site, LONGVIEW, TX, EPA/ROD/R2006060001492. 09/15/2006.

EPA, 2007, Second Five-Year Review Report for the Wyckoff/Eagle Harbor Superfund Site, Bainbridge Island, Washington, Prepared for U.S. Environmental Protection Agency Region 10 by U.S. Army Corps of Engineers, Seattle District, Seattle, Washington, September 2007.

EPA, 2009, Technology Performance Review: Selecting and Using Solidification/ Stabilization Treatment for Site Remediation, EPA, Office of Research and Development, 2009.

EPA, 2010, List of RAOs Provided by EPA at June 15, 2010 Meeting.

EPA, 2012, Madisonville Creosote Works, St. Tammany Parish, Louisiana, May 1, 2012.

EPA, 2013, Use of Amendments for In Situ Remediation at Superfund Sediment Sites, U. S. Environmental Protection Agency, Office of Superfund Remediation and Technology Innovation. OSWER Directive 9200.2-128FS. April 2013.

EPRI, 2003, Evaluation of the Effectiveness of In-Situ Solidification/Stabilization at the Columbus, Georgia Manufactured Gas Plant Site. Electric Power Research Institute, Palo Alto, CA, Final Report, September 2003.

EPRI, 2009, Evaluation of Technical Impracticability Determinations and Their Applicability to Former Manufactured Gas Plant Sites, Electric Power Research Institute, Palo Alto, CA, Technical Update, December 2009.

Federal Remediation Technologies Roundtable (FRTR), Website, 2012, Remediation Technologies Screening Matrix and Reference Guide, Version 4.0, http://www.frtr.gov/matrix2/section4/4-21.html.

Hart Crowser, 1994, Notes from Meeting with Ward Roberts, November 15, 1994.

Hayes D. F. and C. H. Je, 2000, DREDGE Module User's Guide, Draft, Vicksburg, MS, U.S. Army Engineer Research and Development Center, http://el.erdc.usace.army.mil/models.

Interstate Technology and Regulatory Council (ITRC), 2007, Vapor Intrusion Pathway: A Practical Guideline, The Interstate Technology and Regulatory Council Vapor Intrusion Team, January 2007.

Lampert, D. J. and D. Reible, 2009, An Analytical Modeling Approach for Evaluation of Capping of Contaminated Sediments, Soil and Sediment Contamination: An International Journal, 18:4, 470-488.

Levin, H. M. and P. J. McEwan, 2000, Cost-Effectiveness Analysis: Methods and Applications, Second Edition, Sage Publications.

McCabe, G.T. Jr., S. A. Hinton, and R. L. Emmett, 1998, Benthic invertebrates and sediment characteristics in a shallow navigation channel of the lower Columbia River, Northwest Science, 72, 116-126.

Niederbacher, P., 2000, *In-situ* Groundwater Remediation, Site Adapted Solutions, Remediation 'Brunn a. G.', Austria, ETCA Workshop on the Protection of European Water Resources: Contaminated Sites-Landfills-Sediments, Progress Review, June 21-23, 2000, Venice, Italy, J. Büsing, P. Cortesi, P. Krejsa and P. Maggiorotti, eds., 253-254.

National Research Council (NRC), 2003, Environmental Cleanup at Navy Facilities: Adaptive Site Management Committee on Environmental Remediation at Naval Facilities, National Research Council, Washington, DC.

NRC, 2007, Sediment Dredging at Superfund Megasites: Assessing the Effectiveness Committee on Sediment Dredging at Superfund Megasites, National Research Council. ISBN: 0-309-10974-4, National Academies Press. Washington, D.C.

Palermo, M., S. Maynord, J. Miller, D. and Reible, 1998, Guidance for *In situ* Subaqueous Capping of Contaminated Sediments, EPA 905-B96-004, Great Lakes National Program Office, Chicago, IL. http://www.epa.gov/glnpo /sediment/iscmain/.

Patmont, C.R. and M. R. Palermo, 2007, Case studies of environmental dredging residuals and management implications, In: Proceedings Remediation of Contaminated Sediments—2007, Savannah, GA, Columbus (OH): Battelle.

Pinnacle GeoSciences, 2009, Phase II Studies, Parcel 2934059005, Renton and King County, Washington, Prepared for Port of Seattle.

Retec, 1997, Draft Feasibility Study, Port Quendall Project, Prepared for Port Quendall Company, November 21, 1997.

Retec, 2001, Data Transmittal to Lynn Manolopolous from Brian Stone (ThermoRETEC) regarding Quendall Terminals Investigation Data, May 16, 2001.

RETEC, 2004, Excavation and In Situ Solidification Specifications, J.H. Baxter South Property Site, Renton, Washington, Prepared for Port Quendall Company, February 23, 2004.

Riser Roberts, 1998, Remediation of Petroleum Contaminated Soils, Eve Riser Robers, CRC Press, 1998.

Roberts, 1989, Employee interview with Ward Roberts, July 26, 1989, Memorandum dated October 19, 1989, (CH003).

Schad, H., B. Haist-Gulde, R. Klein, D. Maier, M. Maier, and B. Schulze, 2000, Funnel-and-gate at the former manufactured gas plant site in Karlsruhe: sorption test results, hydraulic and technical design, construction, Contaminated Soil 2000 (Proceedings of the Seventh International FZK/TNO Conference on Contaminated Soil 18-22 September 2000), Leipzig, Germany, 951-959.

State of Washington, 2004, Washington Administrative Code (WAC) Chapters 296-809 Confined Spaces, Effective May 1, 2004.

Stolzenburg, Thomas, Eugene McLinn, and Kent McCord, 2010, *In Situ* Solidification of NAPL-Containing Sediment: Fundamental Concerns of Permanency, RMT, Inc. Manufactured Gas Plant Symposium, January 2010.

Tabor, R.A., H.A. Gearns, C. McCoy III, and S. Camacho, 2006, Nearshore habitat use by juvenile Chinook salmon in lentic systems of the Lake Washington basin, annual report 2003 ad 2004, Prepared by the U.S. Fish and Wildlife Service, Western Washington Fish and Wildlife Office, Fisheries Division, Prepared for Seattle Public Utilities and City of Mercer Island.

Tabor, R. A., K. L. Fresh, R. M. Piaskowski, H. A. Gearns, and D. B. Hayes, 2011, Habitat used by Chinook salmon in the nearshore areas of Lake Washington: Effects of Depth, Lakeshore Development, Substrate, and Vegetation, North American Journal of Fisheries Management, 31:4, 700-713.

U. S. Army Corps of Engineers (USACE), 1998, Guidance for Subaqueous Dredged Material Capping, Technical Report DOER-1, Engineer Research and Development Center, Vicksburg, MS (http://www.el.erdc.usace.army.mil/dots).

USACE, 2008, Technical Guidelines for Environmental Dredging of Contaminated Sediments, ERDC/EL TR-08-29, September 2008.

U.S. Fish and Wildlife Service (USFWS) and National Marine Fisheries Service (NMFS), 1998, Endangered Species Consultation Handbook: Procedures for Conducting Consultation and Conference Activities Under Section 7 of the Endangered Species Act, Final, March 1998.

USFWS, 2012, Environmental Conservation Online System Listed Animals, Website accessed on July 15, 2012: http://ecos.fws.gov/tess_public/pub/listedAnimals.jsp.

Washington State Department of Ecology (Ecology), 1989, Employee interview with Ward Roberts, July 26, 1989, Memorandum dated October 19, 1989.

Washington State Department of Ecology (Ecology), 1994, Natural Background Soil Metals Concentrations in Washington State. Washington State Department of Ecology, Toxics Cleanup Program, Publication #94-115. October 1994.

Wilk, Charle M., 2003, Principles of Solidification/Stabilization and Examples of the Technology's Use at Brownfield Sites, Portland Cement Association, 2003.

Table 3-1 Chemicals of Concern by Medium

Quendall Terminals
Renton, Washington

Chemical of Concern[a]	Medium												
	Soil		Groundwater	Indoor Air	Trench Vapor	Surface Water/ Porewater		Nearshore Sediment		Site-Wide Sediment		Fish/ Shellfish[b]	Food/Prey Item
	HHRA[c]	ERA[d]	HHRA	HHRA	HHRA	HHRA	ERA	HHRA	ERA	HHRA	ERA	HHRA	ERA
2-Methylnaphthalene	X		X				X					X	
Acenaphthene			X				X				via LPAH		via LPAH
Anthracene							X				via LPAH		via LPAH
Arsenic	X		X										
Benzene			X	X	X	X							
Benzo(a)anthracene[e]	X	via HPAH	X				X		via HPAH		via HPAH	X	via HPAH
Benzo(a)pyrene[e]	X	X	X				X	X	X	X	X	X	X
Benzo(b)fluoranthene[e]	X	via HPAH	X						via HPAH		via HPAH		via HPAH
Benzo(k)fluoranthene[e]	X	via HPAH	X						via HPAH		via HPAH		via HPAH
Chromium		X											
Chrysene[e]			X										
Dibenz(a,h)anthracene[e]	X	via HPAH	X					X	via HPAH	X	via HPAH	X	via HPAH
Dibenzofuran			X										
Ethylbenzene	X		X	X	X								
Fluoranthene		via HPAH	X				X		via HPAH		via HPAH		via HPAH
Fluorene		X	X				X		X		via LPAH		via LPAH
Indeno(1,2,3-cd)pyrene[e]	X	via HPAH	X						via HPAH		via HPAH		via HPAH
Lead		X											X
Naphthalene	X	X	X	X	X		X				via LPAH		via LPAH
PAH ESBQ TU							X						
Pentachlorophenol		X											X
Phenanthrene		X					X				via LPAH		via LPAH
Pyrene		via HPAH	X				X		via HPAH		via HPAH		via HPAH
Toluene							X						
Total 10 of 16 HPAHs (U = 1/2)		X							X		X		X
Total 16 PAHs (U = 1/2)									X		X		X
Total 6 of 16 LPAHs (U = 1/2)		X									X		X
Total Xylenes			X	X	X								

Notes:

[a] Chemicals of concern identified as those associated with a hazard quotient (HQ) exceeding 1 or an excess lifetime cancer risk exceeding 1 x 10^{-6}.

[b] Based on modeled tissue concentrations from sediment, using biota-sediment accumulation factors.

[c] For the HHRA, soil from 0 to 15 feet below ground surface was evaluated.

[d] For the ERA, soil from 0 to 5 feet below ground surface was evaluated.

[e] Carcinogenic polycyclic aromatic hydrocarbon (cPAH).

ERA Ecological Risk Assessment
ESBQ Equilibrium-partitioning sediment benchmark quotient
HHRA Human Health Risk Assessment
TU Toxic unit
U=1/2 - Undetected chemicals were included as one-half the detection limit

via LPAH - Denotes that the chemical was evaluated for sediment as part of the low-molecular-weight polycyclic aromatic hydrocarbon (LPAH) group.
via HPAH - Denotes that the chemical was evaluated for sediment as part of the high-molecular-weight polycyclic aromatic hydrocarbon (HPAH) group.

Table 4-1 Chemical-Specific ARARs for Remedial Action at the Quendall Terminals Site

DRAFT FINAL

Quendall Terminals
Renton, Washington

Act/Authority	Criteria/Issue	Citation	Brief Description	Applicability/Appropriateness
Safe Drinking Water Act	Federal Primary Drinking Water Standards - Maximum Contaminant Levels (MCLs) and MCL Goals (MCLGs)	42 USC 300f, 40 CFR Part 141, Subpart O	Establishes drinking water standards for public water systems to protect human health. Includes standards for the following Site COCs: arsenic, benzene, and benzo[a]pyrene (B[a]P). The NCP states that MCLs, not MCLGs, are ARARs for usable aquifers.	ARARs for groundwater that could potentially be used for drinking water, where the water will be provided directly to 25 or more people or will be supplied to 15 or more service connections.
Safe Drinking Water Act	Federal Secondary Drinking Water Standards - Secondary MCLs	42 USC 300f, 40 CFR Part 143	Establishes drinking water standards for public water systems to achieve the aesthetic qualities of drinking water (secondary MCLs).	To Be Considered (TBC) for groundwater that could potentially be a drinking water source (i.e., achieved as practicable).
Clean Water Act	Federal Ambient Water Quality Criteria	33 USC 1311 -1317; 40 CFR Part 131	Under Clean Water Act Section 304(a), minimum criteria are developed for water quality programs established by states. Two kinds of water quality criteria are developed: one for protection of human health, and one for protection of aquatic life. The federal recommended water quality criteria are published on EPA's website: http://water.epa.gov/scitech/swguidance/standards/current/index.cfm	ARARs for surface water if more stringent than promulgated state criteria.
Surface Water Quality Standards	State Ambient Water Quality Criteria	Chapter 90.48 RCW; Chapter 173-201A WAC	Establishes Water Quality Standards for protection of human health and for protection of aquatic life (for both acute and chronic exposure durations).	ARARs for surface water where Washington State has adopted, and EPA has approved, Water Quality Standards.
Model Toxics Control Act	State Soil, Air, Groundwater, and Surface Water Cleanup Standards	Chapter 70.105D RCW; Chapter 173-340 WAC	Establishes cleanup levels for Site groundwater, surface water, soil, and air, including rules for evaluating cross-media protectiveness. MTCA cleanup levels cannot be set at concentrations below natural background.	Promulgated numeric cleanup levels are ARARs for soil, air, groundwater, and surface water. Equations to develop cleanup levels are not ARARs.
Model Toxics Control Act	Protection of Terrestrial Plants and Animals	"Terrestrial Ecological Evaluation Procedures" (WAC 173-340-7490) Site-Specific Terrestrial Ecological Evaluation Procedures" (WAC 173-340-7493) Priority Contaminants of Ecological Concern (WAC 173-340-7494)	Establishes Site-specific cleanup standards for the protection of terrestrial plants and animals	ARARs for developing and evaluating cleanup action alternatives and in selecting a cleanup action under WAC 173-340-350 through 173-340-390.

Table 4-1 Chemical-Specific ARARs for Remedial Action at the Quendall Terminals Site

Quendall Terminals
Renton, Washington

Act/Authority	Criteria/Issue	Citation	Brief Description	Applicability/Appropriateness
EPA Guidance	Protection of Terrestrial Plants and Animals	Guidance for Developing Ecological Soil Screening Levels (OSWER Directive 9285.7-55)	Describes the process used to derive a set of risk-based ecological soil screening levels (Eco-SSLs) for many of the soil contaminants that are frequently of ecological concern for plants and animals at hazardous waste sites, and provides guidance for their use.	To Be Considered (TBC) guidance. The Eco-SSLs are not designed to be used as cleanup levels, and EPA emphasizes that it is inappropriate to adopt or modify the Eco-SSLs as cleanup standards.
Sediment Management Standards	State Sediment Quality Criteria	Chapters 90.48 & 70.105D RCW; Chapter 173-204 WAC	Establishes numerical standards for the protection of benthic invertebrates in marine sediments. Washington State is working to promulgate freshwater sediment quality values (SQVs) consistent with the northwest regional sediment evaluation team framework (RSET; including EPA and other agency representatives). The proposed standards include chemical criteria and provisions for overriding the chemical criteria using bioassay tests.	Until the SQVs are promulgated, the proposed SQVs (Michelsen 2011) and bioassay interpretation endpoints are TBC performance standards for freshwater surface sediments (i.e., achieved as practicable); however, if and when the SQVs are promulgated, they would be ARARs for sediment.

Table 4-2 Action-Specific ARARs for Remedial Action at the Quendall Terminals Site

Quendall Terminals
Renton, Washington

Remedial Activity	Act/Authority	Criteria/Issue	Citation	Brief Description	Applicability/Appropriateness
Soil Excavation and Upland Filling	Solid Waste Disposal Act	Management and disposal of solid waste	42 USC 6901-6917; 40 CFR 257-258	Establishes requirements for the management and disposal of solid waste.	ARAR for remedial actions that result in upland disposal of excavated or dredged material.
	Resource Conservation and Recovery Act (RCRA); Washington Hazardous Waste Management Act and Dangerous Waste Regulations	Generation and Management (Transportation, Treatment, Storage and Disposal) of Hazardous Waste; Off-Site Land Disposal Considerations	42 USC 6921-22; 40 CFR Parts 260, 261 & 268; Chapter 70.105 RCW; Chapter 173-303 WAC (Chapter 173-307 WAC Pollution Prevention Plans is a TBC)	Defines solid wastes subject to regulation as hazardous wastes. Requires management of hazardous waste from "cradle to grave" unless exemption applies.	Potential ARAR for DNAPL and soils/ sediments excavated from the Site for off-site disposal, and a TBC for on-site stabilization actions. Recovered DNAPL that designates as hazardous waste would require additional management during handling (e.g., secondary containment), and may also be subject to land disposal requirements (e.g., pre-treatment prior to disposal). EPA determined that soils excavated above the water table in the former footprint of the North and South Sumps may designate as K035 waste (see EPA 2012) DNAPL, soil and/or sediment excavated and removed from the Site may also be a characteristic hazardous waste if it exhibits one of the characteristics defined in 40 CFR Part 261 Subpart C or in State Dangerous Waste Regulations. Excavated soils and/or sediment that exceed toxicity characteristic leaching procedure (TCLP) criteria must be managed as a hazardous waste and must meet the land disposal restriction treatment standards for contaminated soil (40 CFR 268.49). The treatment standard is the higher of a 90% concentration reduction or 10 times the universal treatment standard.
	Hazardous Materials Transportation Act	Transport of Hazardous Materials	49 USC 5101 et seq.; 49 CFR Parts 171-177	Establishes requirements for transport of hazardous materials.	ARAR for those hazardous materials (e.g., DNAPL) transported off site.
	Off-Site Rule	Disposal of CERCLA Wastes	40 CFR 300.440	Requires disposal of CERCLA wastes at a facility operating in compliance with RCRA.	ARAR for remediation wastes transported off site.

Table 4-2 Action-Specific ARARs for Remedial Action at the Quendall Terminals Site

Quendall Terminals
Renton, Washington

Remedial Activity	Act/Authority	Criteria/Issue	Citation	Brief Description	Applicability/Appropriateness
	Washington Hydraulics Code	Filling of Wetlands	Chapters 75.20 & 77.55 RCW; Chapter 220-110 WAC	Establishes requirements for performing work that would alter existing jurisdictional wetlands.	ARAR if remedial actions such as excavation or capping impact existing jurisdictional wetlands. Remedial actions must result in no net loss of aquatic habitat and function after sequential consideration of avoidance and mitigation, allowing for site-specific evaluations of existing wetland functions.
	National Environmental Policy Act (NEPA) and State Environmental Policy Act (SEPA)	Construction Activities, Including Grading and Filling	40 CFR 1500-1508; Chapter 43.21C RCW; Chapter 197-11 WAC	Requires agencies to consider environmental impacts of a proposal.	ARAR for remedial activities that include excavation or filling.
	City of Renton Shoreline Master Program (SMP)	Wetland Buffer and Setback Requirements	Chapter 90.58 RCW; Chapter 173-14 WAC; City of Renton Ordinance #5633 (effective November 24, 2011); Critical Area Regulations (RMC 4-3-050) are incorporated into the SMP by reference	Establishes replacement requirements for wetlands affected by remedial actions to ensure no net loss of existing wetland acreage and functions; also establishes requirements for buffers and setbacks from shorelines and wetlands, including replacement wetlands.	ARAR if remedial actions such as excavation or capping impact existing jurisdictional wetlands. Remedial actions must result in no net loss of aquatic habitat and function after sequential consideration of avoidance and mitigation, allowing for site-specific evaluations of existing wetland functions. Washington's vested rights rule governs which SMP requirements apply in a given circumstance. Substantive requirements of the SMP that were in effect when redevelopment project applications were filed may be ARARs for future redevelopment actions at the Site.
Dredging, Capping, and/or Discharge to Lake Washington	Clean Water Act	Federal Ambient Water Quality Criteria	33 USC 1311 -1317; 40 CFR Part 131	See Table 4-1. Regulates activities which may result in discharges into navigable waters.	ARAR for control of short-term impacts to surface water from implementation of remedial actions that include dredging, capping, and discharge of treated water into Lake Washington. Incorporates the substantive provisions of relevant and appropriate Joint Aquatic Resources Permit Application (JARPA), Nationwide Permit, and stormwater regulation requirements.

Table 4-2 Action-Specific ARARs for Remedial Action at the Quendall Terminals Site

Quendall Terminals
Renton, Washington

Remedial Activity	Act/Authority	Criteria/Issue	Citation	Brief Description	Applicability/Appropriateness
	Surface Water Quality Standards	State Ambient Water Quality Criteria	Chapter 90.48 RCW; Chapter 173-201A WAC	See Table 4-1. Regulates activities which may result in discharges into navigable waters.	ARAR for control of short-term impacts to surface water from implementation of remedial actions that include dredging, capping, and discharge of treated water into Lake Washington. Incorporates the substantive provisions of relevant and appropriate requirements, where Washington State has adopted and EPA has approved Water Quality Standards.
	National Pollutant Discharge Elimination System	Discharge of Pollutants into Lake Washington	40 CFR Part 122; Chapter 90.48 RCW; Chapter 173-226 WAC	Permitting system for discharging pollutants into waters of the United States.	ARAR for discharge of treated water to Lake Washington.
	Clean Water Act	Discharge of Materials into Lake Washington	33 USC 1344; 40 CFR Part 230	Regulates discharge of dredged and fill material into navigable waters of the United States.	ARAR for dredging and capping activities in Lake Washington.
	Fish and Wildlife Coordination Act	Discharge of Materials, Impoundment or Diversion of Waters in Lake Washington	16 USC 662 & 663; 40 CFR 6.302(g)	Requires federal agencies to consider effects on fish and wildlife from projects that may alter a body of water and mitigate or compensate for project-related losses, which includes discharges of pollutants to water bodies.	ARAR for in-water remedial actions or if treated water is discharged into Lake Washington.
	River and Harbors Act	Placement of Structures in Lake Washington	33 USC 401 et seq.; 33 CFR 320-330	Prohibits the unauthorized obstruction or alteration of any navigable water. Establishes requirements for structures or work in, above, or under navigable waters.	ARAR for remedial actions in Lake Washington.

Table 4-2 Action-Specific ARARs for Remedial Action at the Quendall Terminals Site

Quendall Terminals
Renton, Washington

Remedial Activity	Act/Authority	Criteria/Issue	Citation	Brief Description	Applicability/Appropriateness
	Washington Hydraulics Code	Filling in Lake Washington	Chapter 75.20 & 77.55 RCW; Chapter 220-110 WAC	Establishes requirements for performing work that would use, divert, obstruct, or change the natural flow or bed of Lake Washington.	ARAR for shoreline excavation, dredging, and/or capping actions. Remedial actions must result in no net loss of aquatic habitat or function after sequential consideration of avoidance and mitigation.
Well-Related Activities	Washington Water Well Construction Act	Monitoring Wells	"Water Well Construction Act of 1971" (Chapter 18.104 RCW, as amended); "Minimum Standards for Construction and Maintenance of Wells" (Chapter 173-160 WAC)	Establishes minimum standards for construction and maintenance of wells.	ARAR for monitoring well design, construction, development, and abandonment. Also provides technical standards by which well cuttings and development water are handled.
	Washington Water Pollution Control Act	Injection Wells	"UIC Well Classification Including Allowed and Prohibited Wells" (WAC 173-218-040)	Regulates the discharge of fluids into Underground Injection Control (UIC) wells.	ARAR for reinjecting treated groundwater and for injecting fluids intended to clean up, treat, or prevent subsurface contamination.
Other Remedial Activities	Federal Clean Air Act; Washington Clean Air Act; Puget Sound Clean Air Agency (PSCAA) Regulations	Air Emission Discharges	42 USC §7401 et seq.; Chapter 70.94 RCW; Chapter 173-400 WAC; WAC 173-460 Controls for New Sources of Toxic Air Pollutants; WAC 173-470 Ambient Air Quality Standards for Particulate Matter; PSAPCA Regulation III	Regulates air emission discharges.	ARAR for remedial activities that generate fugitive dust or other air emissions, including treatment operations.
	Occupational Safety and Health Act (OSHA); Washington Industrial Safety and Health Act	Occupational Safety	29 USC 653, 655, 657; 29 CFR 1910; Chapter 49.12 RCW; Chapter 296-62 WAC	Provides safety and health rules to protect employees from workplace hazards	ARAR for remedial activities that include hazardous working conditions, including potential exposure to pollutants or construction hazards
	City of Renton Municipal Code (RMC)	Building Requirements and Noise Regulations	Title 4 and Title 8 RMC	Regulates activities within city limits including grading, building and utility construction, and noise	ARAR for remedial activities involving on-site construction activities.

Table 4-2 Action-Specific ARARs for Remedial Action at the Quendall Terminals Site

Quendall Terminals
Renton, Washington

Remedial Activity	Act/Authority	Criteria/Issue	Citation	Brief Description	Applicability/Appropriateness
	Historic Preservation Act; Washington Historical Activities Act	Alteration of Historic Properties	16 USC 470 et seq.; 36 CFR Part 800; Chapter 27 RCW	Requires the identification of historic properties potentially affected by remedial actions, and ways to avoid, minimize, or mitigate such effects. Historic property is any district, site, building, structure, or object included in or eligible for the National Register of Historic Places, including artifacts, records, and material remains related to such a property.	ARAR if historic properties are affected by remedial activities. No historic properties have been identified at the Site to date, but could potentially be identified during remedial design.
	Archeological and Historic Preservation Act	Alteration of Historic and Archaeological Properties	16 USC 469a-1	Provides for the preservation of historical and archeological data that may be irreparably lost as a result of a federally approved project and mandates only preservation of the data.	ARAR if historical and archeological resources may be irreparably lost by implementation of remedial activities.

Remedial Activity	Act/Authority	Criteria/Issue	Citation	Brief Description	Applicability/Appropriateness
	Native American Graves Protection and Reparation Act	Alteration of American Graves	25 USC 3001-3013; 43 CFR Part 10	Requires federal agencies and museums which have possession of or control over Native American cultural items (including human remains, associated and unassociated funerary items, sacred objects and objects of cultural patrimony) to compile an inventory of such items. Prescribes when such federal agencies and museums must return Native American cultural items. “Museums” are defined as any institution or state or local government agency that receives federal funds and has possession of, or control over, Native American cultural items.	ARAR if Native American cultural items are present in an excavation or dredging area.

Table 4-3 Location-Specific ARARs for Remedial Action at the Quendall Terminals Site

DRAFT FINAL

Quendall Terminals
Renton, Washington

Act/Authority	Criteria/Issue	Citation	Brief Description	Applicability/Appropriateness
Endangered Species Act	Effects on Endangered Species	16 USC 1531 et seq.; 50 CFR Part 17	Actions authorized, funded, or carried out by federal agencies may not jeopardize the continued existence of endangered or threatened species or adversely modify or destroy their critical habitats, or must take appropriate mitigation steps.	ARAR for remedial actions that may adversely impact endangered or threatened species or critical habitat present at the Site.
Migratory Bird Treaty Act	Effects on Migratory Birds	16 USC 703-712	Regulates taking or killing migratory birds, including feathers and nests.	ARAR for remedial actions that might harm migratory birds or remove or relocate nests.
Safe Drinking Water Act	Underground Injection Control, Sole Source Aquifer Program, and Wellhead Protection Program	42 USC 300h – 300h-8, 40 CFR Part 300.400(g)(4), Chapter 173-160 WAC; Section 246-290-135 WAC	Resource planning programs designed to prevent contamination of underground sources of drinking water	The requirements of the City of Renton wellhead protection program are TBC as a performance standard for groundwater that is a potential drinking water source (i.e., achieved as practicable) (Note that there are no water supply wells near the Quendall Terminals Site that are currently regulated by Renton's program).
Fish and Wildlife Conservation Act of 1980, "Nongame Act"	Effects on Fish and Wildlife and Their Habitats	Public Law 96-366, as Amended; 16 U.S.C. 2901-2911	Preserves and promotes conservation of non-game fish and wildlife and their habitats.	ARAR if the remedial action may adversely impact non-game fish and wildlife or their habitats.
Magnuson-Stevens Fishery Conservation and Management Act	Habitat Impacts	16 USC 1855(b), 50 CFR Part 600.920	Requires evaluation of impacts to Essential Fish Habitat (EFH) if activities may adversely affect EFH.	ARAR if the remedial action may adversely affect EFH.
Executive Order for Wetlands Protection	Wetlands Impacts	Executive Order 11990 (1977), 40 CFR Part 6.302(a), 40 CFR Part 6, App. A	Requires measures to avoid adversely impacting wetlands whenever possible, to minimize wetland destruction, and to preserve the value of wetlands.	ARAR for assessing impacts to wetlands, if any, from the remedial action and for developing appropriate compensatory mitigation.
Bald Eagle Protection Act	Effects on Bald Eagles	Chapter 77.12.655 RCW, "Habitat Buffer Zone for Bald Eagles – Rules"; "Bald Eagle Protection Rules" (Chapter 232-12-29 WAC)	Requires buffer zones to be defined around bald eagle nests and roost sites.	ARAR for remedial actions that might be conducted near bald eagle nests or roost sites.

Table 4-4 Development of PRGs for Soil

Quendall Terminals
Renton, Washington

Chemical of Concern	Potential PRG (mg/kg)								Background Concentration	Notes
	Risk-Based Concentration (RBC)									
	Carcinogenic						Non-Carcinogenic		Ecological	
	MTCA (1X10^{-4})	MTCA (1X10^{-5})	MTCA (1X10^{-6})	EPA RSL (1x10^{-4})	EPA RSL (1x10^{-5})	EPA RSL (10^{-6})	MTCA (HQ=1)	EPA RSL (HQ=1)		
2-Methylnaphthalene							320	310		
Arsenic	67	6.7	0.67	39	3.9	0.39	24	22	7.3	
Benzo(a)anthracene[2]	140	14	1.4	15	1.5	0.15	--	--	via HPAH	
Benzo(a)pyrene[2]	14	1.4	0.14	1.5	0.15	0.015	--	--	4.2	Robin highest HQ. Potential PRG back calculated from RI Report Table 7.2-9.
Benzo(b)fluoranthene[2]	140	14	1.4	15	1.5	0.15	--	--	via HPAH	
Benzo(k)fluoranthene[2]	140	14	1.4	15	1.5	0.15	--	--	via HPAH	
Chromium	--	--	--	--	--	--	--	--	51	Chromium not a human health risk driver for soil. Hawk highest HQ. Potential PRG back calculated from RI Report Table 7.2-11.
Chrysene[2]	1,400	140	14	150	15	1.5	--	--		
Dibenz(a,h)anthracene[2]	140	14	1.4	15	1.5	0.15	--	--	via HPAH	
Ethylbenzene	--	--	--	540	54	5.4	8,000	3,500		
Fluoranthene	--	--	--	--	--	--	--	--	via HPAH	
Indeno(1,2,3-cd)pyrene[2]	--	--	--	15	1.5	0.15	--	--	via HPAH	
Lead	--	--	--	--	--	--	--	--	37	16 Hawk highest HQ. Potential PRG back calculated from RI Report Table 7.2-11.
Naphthalene	--	--	--	360	36	3.6	1,600	140		
Pentachlorophenol	--	--	--	--	--	--	--	--	16	Rabbit highest HQ. Potential PRG back calculated from RI Report Table 7.2-13.
Pyrene	--	--	--	--	--	--	--	--	via HPAH	
Total 10 of 16 HPAH (U = 1/2)	--	--	--	--	--	--	--	--	3.7	Raccoon highest HQ. Potential PRG back calculated from RI Report Table 7.2-19.
Total 6 of 16 LPAH (U = 1/2)	--	--	--	--	--	--	--	--	65	Robin highest HQ. Potential PRG back calculated from RI Report Table 7.2-9.

Yellow highlight = Indicates preliminary remediation goal (PRG) selected for purpose of defining areas requiring remediation in the FS, according to the following hierarchy:

- If one or more applicable or relevant and appropriate requirements (ARARs) has been established for a particular chemical of concern (COC), the lowest value was selected as the PRG.
- If an ARAR has not been established for a COC, the lowest RBC based on either carcinogenic effects, at a 1 x 10^{-5} excess cancer risk, or non-carcinogenic effects based on an HQ = 1, was selected as the PRG.
- If an ARAR or RBC is lower than either the background concentration or practical quantitation limit (PQL) for a particular COC, the higher of the background concentration or PQL was selected as the PRG.

Notes:
1) See Section 4.1 for identification of ARARs.
2) Carcinogenic polycyclic aromatic hydrocarbon (cPAH). Total cPAH values based on B[a]P equivalents from Quendall HHRA.
3) MTCA (1X10^{-4}) = the MTCA RBC at a excess cancer risk of 1X10^{-4}.
4) MTCA (HQ=1) = the MTCA RBC at a hazard quotient equal to 1.
5) RBC = Risk-Based Concentration
6) HQ = Hazard Quotient
7) U = 1/2 - undetected chemicals were included as one-half the detection limit.

via HPAH - Denotes that the chemical was evaluated for sediment as part of the high-molecular-weight polycyclic aromatic hydrocarbon (HPAH) group.

MCL = Maximum contaminant level
RSL = Regional screening level, May 2012

Table 4-5 Development of PRGs for Groundwater

Quendall Terminals
Renton, Washington

Chemical of Concern	Potential PRG (µg/L)								
	ARARs	Risk-Based Concentration (RBC)							
		Carcinogenic						Non-Carcinogenic	
	Federal MCL	MTCA ($1X10^{-4}$)	MTCA ($1X10^{-5}$)	MTCA ($1X10^{-6}$)	EPA RSL ($1x10^{-4}$)	EPA RSL ($1x10^{-5}$)	EPA RSL (10^{-6})	MTCA (HQ=1)	EPA RSL (HQ=1)
2-Methylnaphthalene	--							32	27
Acenaphthene	--							960	400
Arsenic	10	5.8	0.58	0.058	4.5	0.45	0.045	4.8	4.7
Benzene	5	79.5	7.95	0.795	39	3.9	0.39	32	29
Benzo(a)anthracene[2]	--	12	1.2	0.12	2.9	0.29	0.029	--	--
Benzo(a)pyrene[2]	0.2	1.2	0.12	0.012	0.29	0.029	0.0029	--	--
Benzo(b)fluoranthene[2]	--	12	1.2	0.12	2.9	0.29	0.029	--	--
Benzo(k)fluoranthene[2]	--	12	1.2	0.12	2.9	0.29	0.029	--	--
Chrysene[2]	--	120	12	1.2	29	2.9	0.29	--	--
Dibenz(a,h)anthracene[2]	--	12	1.2	0.12	2.9	0.29	0.029	--	--
Dibenzofuran	--	--	--	--	--	--	--	16	5.8
Ethylbenzene	700	--	--	--	130	13	1.3	800	670
Fluoranthene	--	--	--	--	--	--	--	640	630
Fluorene	--	--	--	--	--	--	--	640	220
Indeno(1,2,3-cd)pyrene[2]	--	12	1.2	0.12	2.9	0.29	0.029	--	--
Naphthalene	--	--	--	--	14	1.4	0.14	160	6.1
Total Xylenes	10,000	--	--	--	--	--	--	1600	190

Yellow highlight = Indicates preliminary remediation goal (PRG) selected for purpose of defining areas requiring remediation in the FS, according to the following hierarchy:

- If one or more applicable or relevant and appropriate requirements (ARARs) has been established for a particular chemical of concern (COC), the lowest value was selected as the PRG.
- If an ARAR has not been established for a COC, the lowest RBC based on either carcinogenic effects, at a 1 x 10^{-5} excess cancer risk, or non-carcinogenic effects based on an HQ = 1, was selected as the PRG.
- If an ARAR or RBC is lower than either the background concentration or practical quantitation limit (PQL) for a particular COC, the higher of the background concentration or PQL was selected as the PRG.

Notes:
1) See Section 4.1 for identification of ARARs.
2) Carcinogenic polycyclic aromatic hydrocarbon (cPAH). Total cPAH values based on B[a]P equivalents from Quendall HHRA.
3) MTCA ($1X10^{-4}$) = the MTCA RBC at a excess cancer risk of $1X10^{-4}$.
4) MTCA (HQ=1) = the MTCA RBC at a hazard quotient equal to 1.
5) RBC = Risk-Based Concentration
6) HQ = Hazard Quotient
7) U = 1/2 - undetected chemicals were included as one-half the detection limit.

MCL = Maximum Contaminant Level
RSL = Regional screening level, May 2012

Table 4-6 Development of PRGs for Surface Water/Porewater

Quendall Terminals
Renton, Washington

Chemical of Concern	Potential PRG (µg/L)			
	ARARs National Water Quality Criteria		Risk-Based Concentration (RBC) Ecological	
	Aquatic Life	Human Health	EPA Region 3[2]	PAH ESBQ
2-Methylnaphthalene	--		4.7	--
Acenaphthene	--	--	5.8	--
Anthracene	--	--	0.012	--
Benzene	--	22[3]		--
Benzo(a)anthracene	--	--	0.018	--
Benzo(a)pyrene	--	--	0.015	--
Fluoranthene	--	--	0.04	--
Fluorene	--	--	3	--
Naphthalene	--	--	1.1	--
PAH ESBQ TU	--	--	--	1 TU
Phenanthrene	--	--	0.4	--
Pyrene	--	--	0.025	--
Toluene	--	--	2	--

Yellow highlight = Indicates preliminary remediation goal (PRG) selected for purpose of defining areas requiring remediation in the FS, according to the following hierarchy:

- If one or more applicable or relevant and appropriate requirements (ARARs) has been established for a particular chemical of concern (COC), the lowest value was selected as the PRG.
- If an ARAR has not been established for a COC, the lowest RBC based on either carcinogenic effects, at a 1×10^{-5} excess cancer risk, or non-carcinogenic effects based on an HQ = 1, was selected as the PRG.
- If an ARAR or RBC is lower than either the background concentration or practical quantitation limit (PQL) for a particular COC, the higher of the background concentration or PQL was selected as the PRG.

Notes:
1) See Section 4.1 for identification of ARARs.
2) EPA Region 3 Biological Technical Assistance Group (BTAG) Ecological Screening Level for Surface Water
3) Potential PRG for benzene based on carcinogenic effects, at a 1×10^{-5} excess cancer risk.

PAH ESQB = Polycyclic aromatic hydrocarbon equilibrium-partitioning sediment benchmark quotient
TU - Toxic Unit

Table 4-7 Development of PRGs for Sediment

Quendall Terminals
Renton, Washington

Chemical of Concern	Potential PRG (mg/kg)											Notes
	Risk-Based Concentration (RBC)										Background Concentration	
	Human Health									Ecological		
	Nearshore[2]			Site-Wide Sediment[3]			Fish/Shellfish Ingestion - Site Sediment[5]					
	Site RA 1X10^{-4}	Site RA 1X10^{-5}	Site RA 1X10^{-6}	Site RA 1x10^{-4}	Site RA 1x10^{-5}	Site RA 1x10^{-6}	Site RA 1x10^{-4}	Site RA 1x10^{-5}	Site RA 1x10^{-6}	Nearshore	Site-wide	
Benzo(a)anthracene[4]	55	5.5	0.55	1,200	120	12				via HPAH	via TPAH	Background is 90% UCL of background data set. OC normalized is 90% UCL on the mean of the background data set.
Benzo(a)pyrene[4]	5.5	0.55	0.055	120	12	1.2	62	6.2	0.62	260[6]	3.5[7]	0.15 mg/kg 6.2 mg/kg OC
Benzo(b)fluoranthene[4]	55	5.5	0.55	1,200	120	12				via HPAH	via TPAH	
Benzo(k)fluoranthene[4]	55	5.5	0.55	1,200	120	12				via HPAH	via TPAH	
Chrysene[4]	550	55	5.5	12,000	1,200	120				via HPAH	via TPAH	
Dibenz(a,h)anthracene[4]	55	5.5	0.55	1,200	120	12				via HPAH	via TPAH	
Fluoranthene	--	--	--	--	--	--				via HPAH	via TPAH	
Fluorene												
Indeno(1,2,3-cd)pyrene[4]	55	5.5	0.55	1,200	120	12				via HPAH	via TPAH	
Total 10 of 16 HPAH (U = 1/2)	--	--	--	--	--	--				29[6]	--	
Total 16 PAH (U = 1/2)	--	--	--	--	--	--				25[6]	99[7]	

Yellow highlight Indicates preliminary remediation goal (PRG) selected for purpose of defining areas requiring remediation in the FS, according to the following hierarchy:

- If one or more applicable or relevant and appropriate requirements (ARARs) has been established for a particular chemical of concern (COC), the lowest value was selected as the PRG.
- If an ARAR has not been established for a COC, the lowest RBC based on either carcinogenic effects, at a 1x10^{-5} excess cancer risk, or non-carcinogenic effects based on an HQ=1, was selected as the PRG.
- If an ARAR or RBC is lower than either the background concentration or PQL for a particular COC, the higher of the background concentration or practical quantitation limit (PQL) was selected as the PRG.

Notes:
1) See Section 4.1 for identification of ARARs.
2) Nearshore sediment human health potential PRG back calculated from RI Report Table J-7-65. Potential routes of exposure to nearshore surface sediment (0 to 4 inches below mudline) include incidental ingestion and dermal contact.
3) Site-wide sediment human health potential PRG back calculated from RI Report Table J-7-68.
4) Carcinogenic polycyclic aromatic hydrocarbon (cPAH). Total cPAH values based on B[a]P equivalents from Quendall HHRA.
5) For fish/shellfish HHRA, soil from 0 to 15 feet below ground surface was evaluated.
6) Otter highest HQ. Potential PRG back calculated from RI Report Table 7.2-38.
7) Sandpiper highest HQ. Potential PRG back calculated from RI Report Table 7.2-40.
8) Site RA 1X10^{-4} = the Site-specific RBC at an excess cancer risk of 1X10^{-4}.
9) RBC = Risk-Based Concentration
10) HQ = Hazard Quotient
11) U = 1/2 - undetected chemicals were included as one-half the detection limit.
12) Background values were calculated based on Benzo[a]pyrene equivalents.
13) The background threshold value (BTV) is calculated as 17.5 mg/kgOC based on the gamma 95% upper tolerance limit (UTL) with 95% coverage of the background data set.
14) Sediment cPAH concentrations are reported as a dry weight in the units of micrograms per kilogram (µg/kg). The total organic carbon (TOC) is reported as a percentage which represents a mass of organic carbon (kg-OC) per 100 kg of solid. The OC (organic carbon) normalized cPAH concentration is determined by dividing the PAH concentration by the fraction of TOC as follows:

$$cPAH\ \left(\frac{\mu g}{kg\text{-OC}}\right) = \frac{cPAH\left(\frac{\mu g}{kg}\right)}{\frac{TOC\%}{100}\left(\frac{kg\text{-OC}}{kg}\right)}$$

via HPAH - Denotes that the chemical was evaluated for sediment as part of the high-molecular-weight polycyclic aromatic hydrocarbon (HPAH) group
via TPAH - Denotes that the chemical is evaluated for sediment as part of the total polycyclic aromatic hydrocarbon (TPAH) group.

Table 4-8 - Summary of PRGs

Quendall Terminals
Renton, Washington

Chemical of Concern[a]	Medium												
	Soil in mg/kg		Groundwater in µg/L	Indoor Air in µg/m^3	Trench Vapor in µg/m^3	Surface Water/ Porewater in µg/L		Nearshore Sediment in mg/kg		Site-Wide Sediment in mg/kg		Fish/ Shellfish in mg/kg-OC[b]	Food/Prey Item in mg/kg-OC [b]
	HHRA[c]	ERA[d]	HHRA	HHRA	HHRA	HHRA	ERA	HHRA	ERA	HHRA	ERA	HHRA	ERA
2-Methylnaphthalene	310		27				4.7						
Acenaphthene			400				5.8						
Anthracene							0.012						
Arsenic	7.3 (b)		10 (MCL)										
Benzene			5 (MCL)	3.1 (c)	16 (c)	22 (c)							
Benzo(a)anthracene[e]	1.5 (c)	via HPAH	0.29 (c)				0.018	5.5 (c)	via HPAH	120 (c)	via TPAH		
Benzo(a)pyrene[e]	0.15 (c)	4.2	0.2 (MCL)				0.015	0.55 (c)	260	12 (c)	3.5	6.2 (c)	6.2 (c)
Benzo(b)fluoranthene[e]	1.5 (c)	via HPAH	0.29 (c)					5.5 (c)	via HPAH		via TPAH		
Benzo(k)fluoranthene[e]	1.5 (c)	via HPAH	0.29 (c)					5.5 (c)	via HPAH		via TPAH		
Chromium		51											
Chrysene[e]	15 (c)		2.9 (c)					55 (c)		1,200 (c)			
Dibenz(a,h)anthracene[e]	1.5 (c)	via HPAH	0.29 (c)					5.5 (c)	via HPAH	120 (c)	via TPAH		
Dibenzofuran			5.8										
Ethylbenzene	54 (c)		700 (MCL)	9.7 (c)	49 (c)								
Fluoranthene		via HPAH	630				0.04		via HPAH		via TPAH		
Fluorene			220				3						
Indeno(1,2,3-cd)pyrene[e]	1.5 (c)	via HPAH	0.29 (c)					5.5 (c)	via HPAH	120 (c)	via TPAH		
Lead		16 (b)											
Naphthalene	36 (c)		1.4 (c)	0.72 (c)	3.6 (c)		1.1						
PAH ESBQ TU							1 TU		1 TU		1 TU		
Pentachlorophenol		16											
Phenanthrene							0.4						
Pyrene		via HPAH	87				0.025		via HPAH		via TPAH		
Toluene							2						
Total 10 of 16 HPAH (U = 1/2)		3.7							29				
Total 16 PAH (U = 1/2)									25		99		
Total 6 of 16 LPAH (U = 1/2)		65											
Total Xylenes			10,000 (MCL)	1,000 (c)	4,400 (c)								

Notes:

[a] Chemicals of concern identified as those associated with hazard quotients (HQs) exceeding 1 or excess lifetime cancer risk (ELCR) exceeding 1 x 10^{-6}.

[b] Based on modeled tissue concentrations from sediment, using biota-sediment accumulation factors.

[c] For the HHRA, soil from 0 to 15 feet below ground surface was evaluated.

[d] For the ERA, soil from 0 to 5 feet below ground surface was evaluated.

[e] Carcinogenic polycyclic aromatic hydrocarbon (cPAH)

(b) - background concentration.

(c) - carcinogenic chemical. Total cPAH values based on B[a]P equivalents from Quendall HHRA. PRG value presented is for 1 x 10^{-5} excess lifetime cancer risk (ELCR).

HHRA - Human Health Risk Assessment

ERA - Ecological Risk Assessment

U=1/2 - Undetected chemicals were included as one-half the detection limit

ESBQ - Equilibrium-partitioning sediment benchmark quotient

TU - Toxic Unit

via LPAH - Denotes that the chemical is evaluated for sediment as part of the low-molecular-weight polycyclic aromatic hydrocarbon (LPAH) group.

via HPAH - Denotes that the chemical is evaluated for sediment as part of the high-molecular-weight polycyclic aromatic hydrocarbon (HPAH) group.

via TPAH - Denotes that the chemical is evaluated for sediment as part of the total polycyclic aromatic hydrocarbon (TPAH) group.

HHRA
Residental Soil Regional Screening Level (RSL) May 2012
Residential Tapwater RLS May 2012
Residental Air RSL May 2012
Industrial Air RSL May 2012
National Water Quality Criteria (Organism +Water)
Nearshore sediment human health PRG back calculated from RI Report Table J-7-65
Site-wide sediment human health PRG back calculated from RI Report Table J-7-68

ERA
Robin highest HQ. PRG back calculated from RI Report Table 7.2-9
Hawk highest HQ. PRG back calculated from RI Report Table 7.2-11
Rabbit highest HQ. PRG back calculated from RI Report Table 7.2-13
Raccoon highest HQ. PRG back calculated from RI Report Table 7.2-19
EPA Region 3 Biological Technical Assistance Group (BTAG) Ecological Screening Level for Surface Water
Otter highest HQ. PRG back calculated from RI Report Table 7.2-38
Sandpiper highest HQ. PRG back calculated from RI Report Table 7.2-40

Table 5-1 Initial Screening of DNAPL Technologies and Process Options

Quendall Terminals
Renton, Washington

DNAPL General Response Actions	Remedial Technology	Process Options	Description	Screening Comments
Institutional Controls	Access Restrictions	Fences and warning signs to control Site access	Signs, fences, or other measures to prevent access to the Site.	Potentially applicable
	Use Restrictions	Use restrictions and monitoring to prevent disturbance of engineered controls	Covenant placed on property that limits or prohibits activities that may interfere with a cleanup action or result in exposure to hazardous substances. Use and deed restrictions are often used in conjunction with other technology approaches.	
		Deed restrictions addressing soil disturbance and/or groundwater wells		
In Situ Containment	Vertical Barriers	Slurry Wall	Control lateral movement of DNAPL by excavating a trench and backfilling with a low-permeability material (e.g., bentonite slurry), or *in situ* mixing of bentonite with native soils.	Potentially applicable
		Sheet Pile Wall	Control lateral movement of DNAPL by installing (driving or vibrating) steel or plastic sheet piling.	Potentially applicable
		Grout Curtain	Control lateral movement of DNAPL by injecting, using jetting tools, bentonite or cement grout.	Potentially applicable
In Situ Treatment	Low-Temperature Thermal Treatment	Hot Water Injection	A variety of heating methods, heating to temperatures less the boiling point of water, increasing the mobility and solubility of DNAPL. Contaminated liquids, including DNAPL, are removed by pumping from wells, and contaminants are treated. Heating can be performed by injecting hot water in vertical wells, thermal conduction from vertical heated wells, or by electrical resistance when voltage is applied between subsurface electrodes.	Potentially applicable
		Electrical Resistance Heating		
		Thermal Conductive Heating		
	Mid-Temperature Thermal Treatment	Steam Injection	The subsurface is heated to temperatures near the boiling point of water, volatilizing or destroying (by pyrolysis) volatile organic compounds. Contaminated vapors are collected using soil vapor extraction, contaminated liquids are removed by pumping from wells, and contaminants are treated. Heating can be performed by injecting steam in vertical wells, thermal conduction from vertical heated wells, or by electrical resistance when voltage is applied between subsurface electrodes.	Potentially applicable
		Electrical Resistance Heating		
		Thermal Conductive Heating		
	High-Temperature Thermal Treatment	Thermal Conductive Heating	The subsurface is heated to temperatures above the boiling point of water, volatilizing or destroying (by pyrolysis) volatile and semi-volatile organic compounds. Contaminated vapors are collected using soil vapor extraction, contaminated liquids are removed by pumping from wells, and contaminants are treated. Heating can be performed by thermal conduction from vertical heated wells, or by electrical resistance when voltage is applied between subsurface electrodes.	Potentially applicable
	Stabilization	Solidification/ Stabilization	In this technology, soil containing DNAPL is stabilized by adding amendments to immobilize contaminants. Potential amendments include polymers, pozzolans, and cement. Amendments can be mixed with soil *in situ* using large-diameter augers, soil mixers, or similar equipment.	Potentially applicable
	Chemical Treatment	Chemical oxidation	In this technology, chemical oxidants are injected into the subsurface in solution form to react with and destroy organic contaminants. Common oxidants include hydrogen peroxide, potassium permanganate, ozone, and sodium persulfate.	Potentially applicable
Removal	DNAPL Pumping	Pumping of DNAPL from Vertical Wells	Pumping to remove DNAPL accumulating in a sump constructed in a well or trench.	Potentially applicable
		Pumping of DNAPL from Horizontal or Angled Wells	Pumping to remove DNAPL accumulating in a well installed using horizontal drilling techniques.	Potentially applicable
		Pumping of DNAPL from Trenches	Pumping to remove DNAPL accumulating in a sump constructed in a well or trench.	Potentially applicable
	Excavation	Excavation	DNAPL is removed by excavating soil or dredging sediment containing DNAPL.	Potentially applicable
Ex Situ Treatment[1]	Thermal	Incineration	When soil or sediment containing DNAPL is heated to temperatures above 1,400°F, contaminants are directly oxidized.	Potentially applicable
Disposal	Off-Site Management	Recycling of recovered DNAPL	Reuse of recovered product.	Potentially applicable
		Disposal of recovered DNAPL via incineration	Treatment of DNAPL via incineration at a hazardous waste treatment facility.	Potentially applicable

Note: This table represents the intial screening process described in Section 5.2.
1. See Soil (5-2) and Sediment (5-3) Tables for other *ex situ* treatment options.

Table 5-2 Initial Screening of Soil Technologies and Process Options

DRAFT FINAL

Quendall Terminals
Renton, Washington

Soil General Response	Remedial Technology	Process Options	Description	Screening Comments
Institutional Controls	Access Restrictions	Fences and warning signs to control Site access	Signs, fences, or other measures to prevent access to the property.	Potentially applicable
	Use Restrictions	Use restrictions and monitoring to prevent disturbance of engineered controls	Covenant placed on the property that limits or prohibits activities that may interfere with a cleanup action or result in exposure to hazardous substances.	Potentially applicable
		Deed restrictions addressing soil disturbance		Potentially applicable
In Situ Containment	Capping	Permeable soil cover	Placing clean soil on the surface provides a barrier that prevents exposure to underlying soil but allows storm water to infiltrate.	Potentially applicable
		Low-permeability cap	Low-permeability caps may be constructed of low-permeability soil such as clay or an engineered material such as asphalt or concrete. This cap would not only prevent exposure to underlying soils, but would also minimize storm water infiltration through potentially contaminated materials, thereby reducing mobility of contaminants located in the unsaturated soil zone. Engineered materials could also be used in areas requiring a durable surface, such as high-traffic areas.	Potentially applicable
		Impervious cap	Impervious caps may be constructed of low-permeability soil such as clay or an engineered material such as asphalt or concrete, overlain by an additional impermeable layer. This cap would not only prevent exposure to underlying soils, but would also prevent storm water from infiltrating potentially contaminated soils beneath the cap, thereby reducing mobility of contaminants located in the unsaturated soil zone. Often combined with barrier wall technology to fully encapsulate soils.	Potentially applicable
In Situ Treatment	Physical Removal and Treatment	Passive venting of soil vapors	Passive soil venting is a less aggressive version of soil vapor extraction that is usually applied to prevent contaminated soil vapors from migrating into buildings or crawl spaces. In passive venting, soil vapors beneath a building foundation are vented to the atmosphere either through atmospheric pressure changes or by applying a low vacuum with a ventilation fan. Vented vapors can be passed through activated carbon for treatment if necessary.	Potentially applicable
		Soil vapor extraction	In soil vapor extraction, a vacuum is applied to subsurface soil to remove soil vapor. Volatile contaminants in soil are removed in the vapor stream and are treated above ground.	Potentially applicable
		Soil flushing	Soil flushing is an enhancement to groundwater extraction and treatment in which a solution that enhances the solubility of organic contaminants is injected into groundwater, passed through contaminated soil to remove contaminants, and then extracted for treatment.	Potentially applicable
	Low-Temperature Thermal Treatment	Hot Water Injection	The subsurface is heated to temperatures less the boiling point of water, increasing the mobility and solubility of DNAPL and DNAPL constituents. Contaminated liquids are removed by pumping from wells, and contaminants are treated. Heating can be performed by injecting steam in vertical wells, thermal conduction from vertical heated wells, or by electrical resistance when voltage is applied between subsurface electrodes.	Potentially applicable
		Electrical Resistance Heating		Potentially applicable
		Thermal Conductive Heating		Potentially applicable
	Mid-Temperature Thermal Treatment	Steam Injection	The subsurface is heated to temperatures near the boiling point of water, volatilizing or destroying (by pyrolysis) volatile organic compounds. Contaminated vapors are collected using soil vapor extraction, contaminated liquids are removed by pumping from wells, and contaminants are treated. Heating can be performed by injecting steam in vertical wells, thermal conduction from vertical heated wells, or by electrical resistance when voltage is applied between subsurface electrodes.	Potentially applicable
		Electrical Resistance Heating		Potentially applicable
		Thermal Conductive Heating		Potentially applicable
	High-Temperature Thermal Treatment	Thermal Conductive Heating	The subsurface is heated to temperatures above the boiling point of water, volatilizing or destroying (by pyrolysis) volatile and semi-volatile organic compounds. Contaminated vapors are collected using soil vapor extraction, contaminated liquids are removed by pumping from wells, and contaminants are treated. Heating can be performed by thermal conduction from vertical heated wells, or by electrical resistance when voltage is applied between subsurface electrodes.	Potentially applicable
		Vitrification	Soil is heated via electrical current to temperatures greater than 2,400°F, destroying contaminants and fusing soil into a glassy matrix.	Potentially applicable
	Stabilization	Solidification/ Stabilization	In this technology, soil or sediment is stabilized by adding amendments to immobilize contaminants. Potential amendments include polymers, pozzolans, and cement. Amendments can be mixed with soil *in situ* using large-diameter augers, soil mixers, or similar equipment.	Potentially applicable

Table 5-2 Initial Screening of Soil Technologies and Process Options

DRAFT FINAL

Quendall Terminals
Renton, Washington

Soil General Response	Remedial Technology	Process Options	Description	Screening Comments
In Situ Treatment	Chemical Treatment	Chemical oxidation	In this technology, chemical oxidants are injected into the subsurface in solution form to react with and destroy organic contaminants. Common oxidants include hydrogen peroxide, potassium permanganate, ozone, and sodium persulfate, which have been shown to destroy a wide range of contaminants in soil.	Potentially applicable
		Electrochemical remediation technology	ECRT is an innovative technology for destroying organic contaminants *in situ* by applying an alternating current across electrodes placed in the subsurface. In theory, the applied voltage creates redox reactions that destroy contaminants through oxidation-reduction mechanisms.	Potentially applicable
	Bioremediation	Amendment injection	Biodegradation of contaminants by indigenous soil microbes can be enhanced by amending soil with nutrients, moisture, and oxygen (typically provided by injecting air or solutions into wells or trenches).	Potentially applicable
		Bioventing	Bioventing, which is applied similarly to soil vapor extraction, supplies oxygen to the unsaturated zone to increase the rate of biodegradation.	Potentially applicable
Removal	Excavation	Excavation	Excavators, backhoes, and other conventional earth moving equipment are the most common equipment used to remove contaminated soil from upland areas.	Potentially applicable
Ex Situ Treatment	Physical	Physical Separation	This technology involves reducing contaminated soil volume by separating large soil particles (large gravel, cobbles, or debris) by screening.	Not Technically Implementable: Most contaminated soil at the Site are fine- to medium-grained that would not easily be separated or have significant differences in contamination concentrations. Therefore, this process would not significantly reduce the volume of contaminated soil at the Site.
		Solidification/ Stabilization	This technology involves adding amendments to excavated soil or sediment that immobilize and/or bind contaminants within the stabilized product. Depending on the proportion of amending agents, the end product may take on the form of a quasi-soil/concrete material that could later be used as bulk fill or a solid mass that could be used as building blocks or tiles.	Potentially applicable
	Thermal	Thermal desorption	Low-temperature thermal desorption involves heating soils or sediments to temperatures between 200°F and 600°F until volatile and semivolatile COCs such as benzene and naphthalene evaporate. Exhaust gases produced by the process are typically combusted.	Potentially applicable
		Vitrification	Vitrification is a process in which high temperatures (2,500°F to 3,000°F) are used to destroy organic chemicals by melting the contaminated soil into a glass aggregate product.	Potentially applicable
		Incineration	When soil is heated to temperatures above 1,400°F, contaminants are directly oxidized.	Potentially applicable
	Chemical/ Physical	Particle washing	In particle washing, soil is put in contact with an aqueous solution to remove contaminants from the soil particles. The suspension is often also used to separate fine particles from coarser particles, allowing beneficial use of the coarser fraction (if sufficiently clean) at the Site.	Potentially applicable
		Solvent extraction	Solvent extraction is a variant of soil washing in which an organic solvent (rather than an aqueous solution) is put in contact with the soil to remove contaminants.	Potentially applicable
	Biological	Biotreatment	Biodegradation of contaminants by indigenous soil microbes can be enhanced by amending excavated soil with nutrients, moisture, and oxygen (typically provided by mixing).	Potentially applicable
Disposal	On-Site Beneficial Use	Sand/Aggregate Reclamation	Excavated soil with high sand content that undergo particle separation may be available for use as concrete aggregate or general upland fill. Contaminated soils would require treatment to achieve cleanup standards.	Potentially applicable
		Topsoil Feedstock	Excavated soil may be used as non-organic feedstock for topsoil (i.e., material would be blended with organics). Contaminated soils would require treatment to achieve cleanup standards.	Potentially applicable
	Confined On-Site Disposal	Confined On-site disposal	Excavated soils exceeding applicable cleanup standards could potentially be placed on Site in a specially designed upland CDF. Depending on the leachability of confined materials, the CDF could potentially include a liner and a liquid collection system to prevent leachate from contaminating groundwater.	Potentially applicable
	Off-Site Landfill Disposal	Subtitle D (Solid Waste)	Contaminated soils from the Site may be transported to an off-Site, permitted disposal facility. This disposal method provides for secure, long-term containment of hazardous and non-hazardous solid wastes.	Potentially applicable
		Subtitle C (Hazardous Waste)		Potentially applicable

Note: This table represents the intial screening process described in Section 5.2.

Table 5-3 Initial Screening of Groundwater Technologies and Process Options

Quendall Terminals
Renton, Washington

Groundwater General Response Actions	Remedial Technology	Process Options	Description	Screening Comments
Institutional Controls	Deed Restrictions	Deed restrictions to preclude drinking water use	Covenant placed on property that limits or prohibits activities that may interfere with a cleanup action or result in exposure to hazardous substances.	Potentially applicable
		Deed restrictions addressing groundwater wells		Potentially applicable
Monitored Natural Attenuation	Monitored Natural Attenuation	Groundwater Monitoring	Provides monitoring to document the presence and effectiveness of natural processes in removing or containing Site COCs.	Potentially applicable
In Situ Containment	Vertical Barriers	Slurry Wall	Control lateral movement of contaminated groundwater by installing impermeable vertical barriers. Vertical barriers can be constructed of a variety of materials and installation techniques, including driving or vibrating steel sheet piling, excavation of a trench and backfilling with a low-permeability material (e.g., bentonite slurry), or *in situ* mixing of bentonite with native soils.	Potentially applicable
		Sheet Pile Wall		Potentially applicable
		Grout Curtain		Potentially applicable
	Pumping	Pumping from vertical wells or trenches	Migration of contaminants dissolved in groundwater can be controlled by pumping groundwater from vertical wells or trenches, creating a capture zone within which groundwater flows toward the capture point.	Potentially applicable
	Stormwater Controls	Targeted Infiltration	A hydraulic barrier can be created by collecting and infiltrating stormwater and forming a local groundwater 'mound.'	Potentially applicable
		Reduced Infiltration	Hydraulic controls can reduce localized infiltration and seepage of stormwater in impacted areas along the shoreline.	Potentially applicable
In Situ Treatment	Permeable Reactive Barrier	Sorptive/Reactive Wall	A trench may be excavated in the uplands and filled with a permeable material that sorbs dissolved-phase contaminants, facilitating further biodegradation and limiting migration into offshore groundwater and sediments.	Potentially applicable
	Chemical Treatment	Chemical Oxidation	In this technology, chemical oxidants are injected into the subsurface in solution form to react with and destroy organic contaminants. Common oxidants include hydrogen peroxide, potassium permanganate, ozone, and sodium persulfate.	Potentially applicable
	Bioremediation	Amendment Injection	Injecting compounds, such as peroxides or nutrients, that enhance degradation of contaminants.	Potentially applicable
		Biosparging	Biosparging is the addition of oxygen to groundwater by injecting air.	Potentially applicable
Removal	Groundwater Extraction	Pumping from vertical wells or trenches	Groundwater can be removed from the subsurface by pumping fluids from wells or trenches.	Potentially applicable
Ex Situ Treatment	Physical/ Chemical	Adsorption	The most widely used in water treatment technologies. In this technology, contaminated groundwater is passed through a bed of granulated activated carbon, and hydrophobic organic compounds in solution adsorb onto the carbon until the carbon becomes saturated.	Potentially applicable
		Air stripping	Contaminated groundwater and air are typically passed counter-currently through a tower, and volatile contaminants (such as benzene and, to a lesser extent, naphthalene) transfer from the water to the air. The contaminant-laden air is usually treated by activated carbon and then discharged to the atmosphere.	Potentially applicable
		Advanced oxidation processes	Involves adding chemicals that directly oxidize organic contaminants in water. Process options include ozonation, hydrogen peroxide (with or without catalysts such as Fenton's Reagent or ultraviolet light), and permanganate.	Potentially applicable
	Biological	Biotreatment	Contaminated groundwater is passed through a biological reactor in which a contaminant-degrading microbial culture is maintained, generally by adding nutrients and oxygen and controlling temperature, pH, and other parameters. Process options include bioslurry reactors, fixed-film bioreactors, and constructed wetlands.	Potentially applicable
Disposal	Off-Site Management	Discharge to sanitary sewer	In this disposal option, groundwater is discharged to the local sanitary sewer system. Pre-treatment of groundwater may not be required if concentrations of COCs meet discharge criteria. Water containing high concentrations of solids (e.g., from construction dewatering) would likely need to be passed through a settling tank or filter to meet discharge requirements.	Potentially applicable
Disposal	Off-Site Management	Discharge to surface water	Extracted groundwater may also be discharged to surface water, although this discharge option would likely require a NPDES permit. Water discharged to surface water would have to meet strict water quality requirements and would likely require treatment before discharge.	Potentially applicable
	On-Site Management	Reintroduction to groundwater	Extracted groundwater may also be discharged on Site to groundwater via infiltration galleries or injection wells. Contaminated groundwater would likely require treatment before discharge via this method.	Potentially applicable

Note: This table represents the intial screening process described in Section 5.2.

Table 5-4 Initial Screening of Sediment Technologies and Process Options

Quendall Terminals
Renton, Washington

Sediment General Response Actions	Remedial Technology	Process Options	Description	Screening Comments
Institutional Controls	Use Restrictions	Governmental advisories and public outreach on fish/shellfish consumption	Institutional controls are measures undertaken to limit or prohibit activities that may interfere with a cleanup action or result in exposure to hazardous substances.	Potentially applicable
		Easements or restrictive covenants to limit activities which may damage the remedy or increase the potential for exposure		Potentially applicable
		Monitoring and notification of waterway users to restrict specific activities to protect the remedy		Potentially applicable
Monitored Natural Recovery	Monitored Natural Recovery	Monitored Natural Recovery	A passive remedial approach which relies on monitoring of ongoing, natural processes (physical, biological, and/or chemical mechanisms) that act together to reduce the risk (bioavailability and/or toxicity) of the Site COCs. Monitoring is required to evaluate the effectiveness and frequently includes multiple lines of evidence.	Potentially applicable
	Enhanced Natural Recovery	Thin-Layer Sand Placement	Thin-layer placement normally accelerates natural recovery by adding a layer of clean sediment over contaminated sediment. The acceleration can occur through several processes, including increased dilution through bioturbation of clean sediment mixed with underlying contaminants. Thin-layer placement is typically different than the in situ isolation caps, because it is not designed to provide long-term isolation of contaminants from benthic organisms.	Potentially applicable
In Situ Containment	Capping (Non-reactive)	Engineered Sand Cap	An engineered sand cap consists of a layer of granular material placed over contaminated sediments to contain and isolate them from the biologically active surface zone. Engineered caps may also include erosion protection or stability layers such as geosynthetics or armoring materials.	Potentially applicable
		Post-Dredge Residuals Management Layer	Similar to cap placement methods described above, with the exception that granular material is applied after dredging to manage residual contamination resulting from dredging. In some cases, a reactive media may be included in the residuals/backfill layer.	Potentially applicable
In Situ Treatment	Physical/ Chemical	Permeable Reactive Cap	A permeable reactive cap includes a reactive material (such as organoclay, coke, coal, or activated carbon) and similar to a sand cap is placed over contaminated sediments to isolate and contain the contaminated sediments. The reactive material also provides treatment by sorping or binding COCs (dissolved and/or NAPL) and further limiting migration into overlying sediment porewater and surface water.	Potentially applicable
		Stabilization	This technology involves adding amendments to in situ sediment that immobilize and/or bind contaminants within the stabilized media.	Effectiveness is limited by high COC concentrations and heterogeneity of grain size
		ElectroChemical Remediation Technology (ECRT)	ECRT is an innovative technology for destroying organic contaminants *in situ* by applying an alternating current across electrodes placed in the subsurface. In theory, the applied voltage creates redox reactions that destroy contaminants through oxidation-reduction mechanisms.	Not Technically Implementable: Not proven effective in aquatic environment.
	Bioremediation	Amendment Injection	Biodegradation of contaminants by indigenous soil microbes can be enhanced by amending soil with nutrients, moisture, and oxygen (typically provided by injecting into wells or trenches).	Applicable to VOCs, but very slow for high molecular weight PAHs.

Table 5-4 Initial Screening of Sediment Technologies and Process Options

Quendall Terminals
Renton, Washington

Sediment General Response Actions	Remedial Technology	Process Options	Description	Screening Comments
Removal	Excavation	Upland-based Excavation	Wet excavation of near-shore sediments using excavators, backhoes, and other conventional earth moving equipment.	Potentially applicable
		Cofferdam Containment	Sheet pile cofferdams are constructed to contain the dredge area and dewatering is used to allow the excavation to occur "in the dry" using conventional earth moving equipment.	Potentially applicable
	Dredging	Hydraulic	Dredging is the removal of sediment in the wet and is primarily accomplished with hydraulic or mechanical equipment. Hydraulic dredging removes and transports sediment with entrained water in a slurry. Mechanical dredging uses mechanical equipment/force to dislodge and excavate sediment in the wet. Dredging effectiveness may be limited by resuspension, release of COCs (i.e., dissolved, particles, and sheens) to water and volatilization to air during dredging, and residual COCs remaining after dredging (USACE 2008). These effects may be reduced by use of containment (e.g., sheet pile, silt curtains) and best management practices.	Potentially applicable
		Mechanical		Potentially applicable
Ex Situ Treatment	Physical	Physical Separation	The volume of excavated or dredged contaminated materials may be reduced by physically separating the materials into two or more fractions that can be handled separately.	Potentially applicable
		Stabilization	This technology involves adding amendments to excavated sediment that immobilize and/or bind contaminants within the stabilized media.	Potentially applicable
	Thermal	Thermal Desorption	Low-temperature thermal desorption involves heating soils or sediments to temperatures between 200°F and 600°F until volatile and semivolatile COCs such as benzene and naphthalene evaporate. Exhaust gases produced by the process are typically combusted.	Potentially applicable
		Vitrification	Vitrification is a process in which high temperatures (2,500°F to 3,000°F) are used to destroy organic chemicals by melting the contaminated sediments into a glass aggregate product.	Potentially applicable
		Incineration	When sediment is heated to temperatures above 1,400°F, contaminants are directly oxidized.	Potentially applicable
	Chemical/ Physical	Dehalogenation	Dehalogenation is the process of removing the halogen molecules (e.g., chlorine, bromine) from a contaminant in the sediment.	Not Technically Implementable: Not effective for Site COCs.
		Particle Washing	In particle washing, sediment is put in contact with an aqueous solution to remove contaminants from the soil particles. The suspension is often also used to separate fine particles from coarser particles, allowing beneficial use of the coarser fraction (if sufficiently clean) at the Site.	Not Technically Implementable: Applicable to sediment with lower concentrations of contamination and minimal free product present; less effective with high fines content.
		Solvent Extraction	Solvent extraction is a variant of soil washing in which an organic solvent (rather than an aqueous solution) is put in contact with the soil to remove contaminants.	Applicable to sediment with lower concentrations of contamination and minimal free product present; less effective with high fines content.
	Biological	Biotreatment	Enhanced biodegradation of contaminants by indigenous soil microbes can be enhanced by amending excavated sediment with nutrients, moisture, and oxygen (typically provided by mixing).	Potentially applicable
Disposal	On-Site Beneficial Use	Sand/Aggregate Reclamation	Dredged material with high sand contents that undergo particle separation may be available for use as concrete aggregate or general upland fill.	Potentially applicable
		Topsoil Feedstock	Dredged material may be used as non-organic feedstock for topsoil (i.e., material would be blended with organics).	Potentially applicable
	Confined On-Site Disposal	Confined On-site Disposal	Removed sediments exceeding applicable cleanup standards could potentially be placed on Site in a specially designed upland CDF. Depending on the leachability of confined materials, the CDF could potentially include a liner and a liquid collection system to prevent leachate from contaminating groundwater.	Potentially applicable
		Near-shore Confined Disposal Facility (CDF)	Removed sediments exceeding applicable cleanup standards could potentially be placed on Site in a specially designed CDF built along the shoreline. Construction would require significant filling and conversion of aquatic lands.	Potentially applicable
		Contained Aquatic Disposal (CAD)	Dredged sediments may be consolidated and disposed of in a deep aquatic excavation adjacent to the Site and capped with clean material.	Not Technically Implementable: Not implementable at Site.
	Off-Site Landfill Disposal	Subtitle D (Solid Waste)	Contaminated sediments from the Site may be transported to an off-Site, permitted disposal facility. This disposal method provides for secure, long-term containment of hazardous and non-hazardous solid wastes.	Potentially applicable
		Subtitle C (Hazardous Waste)		Potentially applicable

Note: This table represents the initial screening process described in Section 5.2.

Table 5-5 DNAPL Process Options Evaluation

Quendall Terminals
Renton, Washington

DNAPL General Response Actions	Remedial Technology	Process Options	Effectiveness	Implementability	Cost (Capital/O&M)	Secondary Screening for Alternative Development	
						Comment	Consider Process Option for Alternatives
Institutional Controls	Access Restrictions	Fences and warning signs to control Site access	Highly effective	Implementable	Low/Low	Currently implemented. Does not meet RAOs when implemented alone; may be applicable in conjunction with other technologies.	**Yes***
	Use Restrictions	Use restrictions and monitoring to prevent disturbance of engineered controls	Highly effective	Implementable	Low/Low	Does not meet RAOs when implemented alone; may be applicable in conjunction with other technologies.	**Yes***
		Deed restrictions addressing soil disturbance and/or groundwater wells	Highly effective	Implementable	Low/Low		**Yes***
In Situ Containment	Vertical Barriers	Slurry Wall	Highly effective at preventing horizontal migration	Implementable	Low/Low	Retained on basis of cost relative to other process options. Trench excavation and one pass continuous trencher slurry wall installation methods have similar costs, but the conventional trench excavation method has been more commonly used and could more readily cope with subsurface debris, which is expected to be present in some Site locations.	**Yes**
		Sheet Pile Wall	Highly effective at preventing horizontal migration	Implementable	Medium/Low	Higher cost and no more effective than slurry wall.	No
		Grout Curtain	Highly effective at preventing horizontal migration; less reliable to construct wall of consistent thickness	Implementable	High/Low	Higher cost and less effective than slurry wall. The greater depths obtainable with grout curtains are not necessary for the Site as DNAPL is present at a maximum depth of 34 feet.	No
In Situ Treatment	Low-Temperature Thermal Treatment	Hot Water Injection	Low to moderate effectiveness. Can enhance DNAPL removal, but will leave residual DNAPL behind. Heterogeneous soils make injection/recovery difficult. Developing technology.	Implementable	Medium/Low	May have limited effectiveness based on the heterogeneous Shallow Alluvium soils where DNAPL is located. Potential for mobilization of NAPL exists. Residual DNAPL more effectively addressed by other *in situ* treatment methods.	No
		Electrical Resistance Heating		Implementable	Medium/ Medium		No
		Thermal Conductive Heating		Implementable	Medium/ Medium		No
	Mid-Temperature Thermal Treatment	Steam Injection	Moderately effective. Low-permeability, heterogeneous soils that exist at the site limit effective steam heating resulting in pockets of untreated and unheated soil. Developing technology, demonstrated at a few coal tar/creosote sites.	Implementable	High/High	May have limited effectiveness based on the heterogeneous Shallow Alluvium soils where DNAPL is located. More cost-effective *in situ* treatment of DNAPL is available.	No
		Electrical Resistance Heating		Implementable	High/High		No
		Thermal Conductive Heating		Implementable	High/High		No
	High-Temperature Thermal Treatment	Thermal Conductive Heating	Potentially high effectiveness, but achieving temperatures greater than boiling point of water would require significant dewatering. Not widely demonstrated.	Dewatering requirements may not be achievable	High/High	Has not been demonstrated at similar sites. More cost-effective *in situ* treatment of DNAPL is available.	No
	Stabilization	Solidification/ Stabilization	High effectiveness for all COCs. Demonstrated at a number of coal tar and creosote sites, including adjacent Seahawks property.	Technically implementable.	Medium/NA	Can reduce the mobility of organic and inorganic contaminants and provides a decreased exposed surface area across which contaminant loss may occur.	**Yes***
	Chemical Treatment	Chemical oxidation	Moderately effective.	Implementable	Medium/ Medium	This technology may be capable of reducing the quantity of free-phase NAPL at the Site; however, the quantity of reagent required to oxidize free-phase NAPL *in situ* across a large portion of the upland could be difficult and costly to inject. Multiple injections may be required to achieve remediation goals. More cost-effective *in situ* treatment of DNAPL is available.	No

Table 5-5 DNAPL Process Options Evaluation

Quendall Terminals
Renton, Washington

DNAPL General Response Actions	Remedial Technology	Process Options	Effectiveness	Implementability	Cost (Capital/O&M)	Secondary Screening for Alternative Development	
						Comment	Consider Process Option for Alternatives
Removal	DNAPL Pumping	Pumping of DNAPL from Vertical Wells	Pilot testing has shown DNAPL recovery is effective at collecting free-phase DNAPL in some site areas.	Implementable	Medium/ Medium	Demonstrated at Site wells.	**Yes**
		Pumping of DNAPL from Horizontal or Angled Wells		Implementable	High/High	Angled wells targeted to relatively shallow contamination, as observed in the near shore Quendall Pond area, would provide for only minimal additional lateral DNAPL capture compared to vertical wells. Vertical wells and trenches better suited to site conditions.	No
		Pumping of DNAPL from Trenches		Implementable	Low/Low	Potentially more effective than wells, but depends on specific geology. Could increase DNAPL vertical mobility in areas of stratified DNAPL occurrences. Constructing DNAPL collection trenches adjacent to the lake may require significant dewatering.	**Yes***
	Excavation	Excavation	Highly effective	Implementable	Medium/NA	May be applicable in conjunction with other technologies. Cost does not include treatment (see below).	**Yes***
Ex Situ Treatment	Thermal	Incineration	High for VOCs and SVOCs. Not effective for arsenic. EPA presumptive technology.	Technically implementable. Permitting/public support can be difficult.	High/NA	Typically expensive, but the high energy content of DNAPL may reduce the cost somewhat. May be necessary if DNAPL is classified as a hazardous waste.	**Yes***
Disposal	Off-site Management	Recycling of recovered DNAPL	Highly effective	Not evaluated	Low/NA	Preferred to incineration, but ability to recycle Site products has not been evaluated.	**Yes***
		Disposal of recovered DNAPL via incineration	Highly effective	Implementable	High/NA	May be applicable in conjunction with other technologies.	**Yes***

Note: This table represents the secondary screening process described in Section 5.3.1.
* - Process Option was selected for inclusion in a Remedial Alternative developed in Section 6.

Table 5-6 Soil Process Options Evaluation

Quendall Terminals
Renton, Washington

Soil General Response Actions	Remedial Technology	Process Options	Effectiveness	Implementability	Cost (Capital/ O&M)	Secondary Screening for Alternative Development	
						Comment	Consider Process Option for Alternatives
Institutional Controls	Access Restrictions	Warning signs and/or fences to control access	High for all COCs	Implementable	Low/ Low	Currently implemented. Does not meet RAOs when implemented alone; may be applicable in conjunction with other technologies.	**Yes***
	Use Restrictions	Use restrictions and monitoring to prevent disturbance of engineered controls	High for all COCs	Implementable	Low/ Low	Would be compatible with current and potential future site uses. Does not meet RAOs when implemented alone; may be applicable in conjunction with other technologies.	**Yes***
		Deed restrictions addressing soil disturbance	High for all COCs	Implementable	Low/ Low		**Yes***
In Situ Containment	Capping	Permeable soil cover	High for all COCs.	Implementable	Medium/ Low	Effective barrier to prevent direct contact with soil. Does not meet RAOs when implemented alone; may be applicable in conjunction with other technologies.	**Yes***
		Low-permeability cap	High for all COCs	Implementable	High/ Medium	Higher cost than permeable cap, but may be appropriate in portions of the Site for some future Site uses. Provides further groundwater mobility controls than permeable soil cover.	**Yes***
		Impervious cap	High for all COCs	Implementable	High/ Medium	Higher cost than permeable and low-permeability caps, but may be appropriate in portions of the Site for some future Site uses. Would provide the greatest groundwater mobility controls.	**Yes***
In Situ Treatment	Physical Removal and Treatment	Passive venting of soil vapors	High for VOCs. SVOCs and arsenic generally do not require vapor controls.	Implementable	Low/ Low	Not retained for alternatives because no occupied structures on Site. However, could be required for future development under institutional controls.	**Yes***
		Soil vapor extraction	Moderate for VOCs in unsaturated soils, not effective for SVOCs or arsenic. Limited by shallow unsaturated zone.	Implementable	Low/ Low	Dewatering may be required to install an effective SVE system at the Site as a result of the high water table. This technology may not be effective for SVOCs and would not be effective for metals.	No
		Soil flushing	Low to moderate for all COCs. Not widely implemented. Preferential flow paths in heterogeneous, low-permeability soils limit distribution of solution and removal of contaminants.	Implementable	High/ Medium	Developing technology that would require bench and field testing prior to design and implementation. Significantly more expensive than other *in situ* treatment options. Not retained because of geologic limitations, high cost, and unproven nature of technology.	No
	Low-Temperature Thermal Treatment	Hot Water Injection	Moderate for VOCs, Low for SVOCs. Not effective for arsenic. Not widely demonstrated.	Implementable	Medium/ Low	May have limited effectiveness based on heterogeneous shallow alluvium soils. Potential for mobilization of NAPL exists. More effective *in situ* treatment of soil COCs is available.	No
		Electrical Resistance Heating		Implementable	Medium/ Medium		No
		Thermal Conductive Heating		Implementable	Medium/ Medium		No

Table 5-6 Soil Process Options Evaluation

Quendall Terminals
Renton, Washington

Soil General Response Actions	Remedial Technology	Process Options	Effectiveness	Implementability	Cost (Capital/ O&M)	Secondary Screening for Alternative Development	
						Comment	Consider Process Option for Alternatives
In Situ Treatment	Mid-Temperature Thermal Treatment	Steam Injection	Moderate to high for VOCs, moderate for SVOCs. Not effective for arsenic.	Implementable. Steam injection difficult to achieve even heating in low-permeability, heterogeneous soils. Demonstrated at a number of sites, including several coal tar and creosote sites.	High/ High	May have limited effectiveness based on heterogeneous Shallow Alluvium soils where majority of contaminated soil is located. More cost-effective *in situ* treatment of soil is available.	No
		Electrical Resistance Heating		Implementable. Demonstrated at a number of sites, including several coal tar and creosote sites.	High/ High		No
		Thermal Conductive Heating		Implementable. Demonstrated at a number of sites, including several coal tar and creosote sites.	High/ High		No
	High-Temperature Thermal Treatment	Thermal Conductive Heating	Potentially high effectiveness for VOCs and SVOCs, but achieving temperatures greater than boiling point of water would require significant dewatering. Not effective for arsenic. Not widely demonstrated.	Dewatering requirements may not be achievable.	High/ High	Has not been demonstrated at similar sites. More cost-effective *in situ* treatment of soil is available	No
		Vitrification	Potentially high effectiveness, but very high energy requirements to vitrify saturated soils. Demonstrated, though at few sites.	Implementable	High/ NA	Very high cost for implementation. Equally effective process options exist that can be implemented at a lower cost.	No
	Stabilization	Solidification/ Stabilization	High effectiveness for all COCs. Demonstrated at a number of coal tar and creosote sites, including adjacent Seahawks property.	Implementable	Medium/ Medium	Can reduce the mobility of organic and inorganic contaminants and provides a decreased exposed surface area across which contaminant loss may occur.	**Yes***
	Chemical Treatment	Chemical oxidation	Moderate effectiveness for VOCs and SVOCs. Not effective for arsenic. Distribution of oxidants in subsurface limited by low-permeability, heterogeneous soils. High natural organic content of site soils will consume oxidants and make this technology inefficient.	Implementable	Medium to High/ Medium	High natural oxidant demand and heterogeneous soils at the Site creates inefficiencies. Equally effective and less expensive *in situ* treatment options exist.	No
		Electrochemical remediation technology	Low effectiveness in soils of high organic content, as are found at the site. Few field demonstrations. Inconclusive results.	Implementable	Medium/ Medium	Treatment is less effective in soils with high organic carbon content. This treatment has produced mixed results at the field level. Not retained because of lack of demonstrated effectiveness.	No
	Bioremediation	Amendment injection	Moderate for VOCs, low to moderate for SVOCs. Not effective for arsenic. Not effective for very high concentrations of contaminants.	Implementable	Low to Medium/ Medium	May not meet RAOs when implemented alone; may be applicable in conjunction with other technologies. Retained as potential polishing technology.	**Yes**
		Bioventing	Moderate for VOCs, low for SVOCs. Not effective for arsenic. Not effective in saturated zone.	Implementable	Low/Low	Dewatering may be required to install an effective venting system at the Site as a result of the high water table. This technology may not be effective for SVOCs, and would not be effective for metals.	No

Table 5-6 Soil Process Options Evaluation

Quendall Terminals
Renton, Washington

Soil General Response Actions	Remedial Technology	Process Options	Effectiveness	Implementability	Cost (Capital/ O&M)	Secondary Screening for Alternative Development	
						Comment	Consider Process Option for Alternatives
Removal	Excavation	Excavation	High for all COCs	Implementable	Medium/ NA	Proven technology potentially applicable to a range of Site conditions. May be applicable in conjunction with other technologies. Cost does not include treatment; see treatment options below.	**Yes***
Ex Situ Treatment	Physical	Solidification/ Stabilization	High for all COCs	Implementable	Medium/ NA	Higher cost than equally effective *in situ* stabilization	No
	Thermal	Thermal desorption	High for VOCs and SVOCs. Not effective for arsenic. EPA presumptive technology.	Implementable	Medium/ NA	Proven technology potentially applicable to a range of Site conditions. May be accomplished on Site with a mobile treatment unit or off Site at a permanent treatment facility. Compared to off Site landfill disposal, thermal desorption is typically more expensive, but has the advantage of providing contaminant treatment and destruction rather than containment.	**Yes***
		Vitrification	Well demonstrated for VOCs and SVOCs.	Implementable. Permitting/public support can be difficult.	High/NA	Not retained for further consideration at this time; equally effective process option thermal desorption can be implemented at a lower cost.	No
		Incineration	High for VOCs and SVOCs. Not effective for arsenic. EPA presumptive technology.	Implementable. Permitting/public support can be difficult.	High/NA	Not retained for further consideration at this time as a stand-alone treatment option; equally effective process option thermal desorption can be implemented at a lower cost. Incineration required by landfill facilities to meet Landfill Disposal Restrictions is a design-level consideration.	No
	Chemical/ Physical	Particle washing	Low to Moderate for all Site COCs. Poor removal of hydrophobic compounds, especially SVOCs. Fines content of Site soils would lower effectiveness.	Implementable	Medium/ NA	A high coarse- to fine-grained material ratio is required to make washing cost-effective. The principal idea that contaminants are preferentially present with finer grain material allowing for particle size separation to remove most of the contaminated media would not be effective at the Site. Other *ex situ* options (e.g., thermal desorption) are less affected by fines content and are likely more effective for less cost. Inclusion of option in a treatment train would not increase effectiveness of an assembled alternative.	No
		Solvent extraction	Moderate for all Site COCs. Fines content of Site soils would lower effectiveness.	Implementable	Medium to High/NA	Similar to soil washing, a high coarse- to fine-grained material ratio is required to make soil washing cost-effective. Other *ex situ* options (e.g., thermal desorption) are less affected by fines content and are likely more effective for less cost.	No
	Biological	Biotreatment	Moderate to high for VOCs and some SVOCs, but very slow for high molecular weight PAHs. Not effective for arsenic.	Implementable. Large staging areas are required for long periods of time.	Medium/ NA	Difficult to achieve low concentrations of some PAHs with biotreatment. Would require long treatment times to achieve cleanup levels. Not retained because of lack of effectiveness on recalcitrance of high-molecular weight PAHs.	No

Table 5-6 Soil Process Options Evaluation

Quendall Terminals
Renton, Washington

Soil General Response Actions	Remedial Technology	Process Options	Effectiveness	Implementability	Cost (Capital/ O&M)	Secondary Screening for Alternative Development	
						Comment	Consider Process Option for Alternatives
Disposal	On-Site Beneficial Use	Sand/Aggregate Reclamation	Well demonstrated for all COCs with high sand content matrices.	Implementable. Depends on state regulatory approvals and compatible beneficial use project.	Low/NA	Can potentially serve as an offset cost to disposal.	**Yes***
		Topsoil Feedstock	Demonstrated	Implementable. Depends on state regulatory approvals and compatible beneficial use project.	Low/NA	Can potentially serve as an offset cost to disposal.	**Yes**
	Confined On-Site Disposal	Confined on-Site disposal	High for all COCs	Implementable	Low to Medium/ NA	On-Site confined disposal can be less expensive then off-Site confined disposal, but requires long-term management of contaminated materials. May not be compatible with future Site uses.	**Yes**
	Off-Site Landfill Disposal	Subtitle D (Solid Waste)	High for all COCs	Implementable	Low/NA	Proven technology potentially applicable to a range of Site conditions. This disposal option may be included in alternatives involving excavation and/or treatment of contaminated soil.	**Yes***
		Subtitle C (Hazardous Waste)	High for all COCs	Implementable	High/NA	Proven technology potentially applicable to a range of Site conditions. This disposal option may be included in alternatives involving excavation and/or treatment of contaminated soil.	**Yes***

Note: This table represents the secondary screening process described in Section 5.3.2.
* - Process Option was selected for inclusion in a Remedial Alternative developed in Section 6.

Table 5-7 Groundwater Process Options Evaluation

Quendall Terminals
Renton, Washington

Groundwater General Response Actions	Remedial Technology	Process Options	Effectiveness	Implementability	Cost (Capital/O&M)	Secondary Screening for Alternative Development	
						Comment	Consider Process Option for Alternatives
Institutional Controls	Deed Restrictions	Deed restrictions to preclude drinking water use	High for all COCs	Implementable	Low/Low	Currently implemented.	**Yes***
		Deed restrictions addressing groundwater wells	High for all COCs	Implementable	Low/Low	Would be compatible with current and potential future Site uses. Does not meet RAOs when implemented alone; may be applicable in conjunction with other technologies.	**Yes***
Monitored Natural Attenuation	Monitored Natural Attenuation	Groundwater Monitoring	Moderate for all COCs	Implementable	NA/Low	Attenuation processes are ongoing at the Site. May not meet RAOs when implemented alone; may be applicable in conjunction with other technologies. May be capable of reducing residual organic contaminant concentrations and thereby economically reducing risk after source zone treatment/removal.	**Yes***
In Situ Containment	Vertical Barriers	Slurry Wall	High, but would require implementation with other methods to prevent flow around barrier	Implementable	Low/Low	Retained on basis of cost relative to other process options. Trench excavation and one pass continuous trencher slurry wall installation methods have similar costs, but the conventional trench excavation method has been more commonly used and could more readily cope with subsurface debris, which is expected to be present in some Site locations.	**Yes**
		Sheet Pile Wall		Implementable	Medium/Low	Higher cost and no more effective than slurry wall.	No
		Grout Curtain		Implementable	High/Low		No
	Pumping	Pumping from vertical wells or trenches	Moderately effective. Heterogeneous soils reduce capture effectiveness.	Implementable	Medium/ Medium	Based on heterogeneous soil conditions and close proximity to Lake Washington, would likely need to implemented with vertical barriers to achieve containment. Short-term pumping may be a component of another technology such as dewatering to support soil excavation.	**Yes***
	Stormwater Controls	Targeted Infiltration	Low effectiveness. Could only be implemented seasonally, since precipitation rates are low in summer. Infiltration is well demonstrated, but use as a containment mechanism not widely demonstrated.	Implementable	Low/Low	Not retained because seasonal variability of Site groundwater limits ability to implement option.	No
		Reduced Infiltration	Moderately effective	Implementable	Medium/Low	Future Site development will include storm water control structures. Reducing localized infiltration and seepage in impacted areas along the shoreline may address the petroleum sheen caused by surface water accumulation previously observed along shoreline adjacent to Quendall Pond.	**Yes**
In Situ Treatment	Permeable Reactive Barrier	Sorptive/Reactive Wall	High for all COCs	Implementable	Medium to High/Low	May be effective at preventing upland groundwater contamination from discharging to Lake Washington; may be effective at addressing both organic and inorganic COCs depending on the amendments used. Deep walls have significantly higher cost	**Yes***
	Chemical Treatment	Chemical Oxidation	Moderate effectiveness for VOCs and SVOCs. Not effective for arsenic. Distribution of oxidants in subsurface limited by low-permeability, heterogeneous soils. High natural organic content of site soils will consume oxidants and make this technology inefficient.	Implementable	Medium to High/Medium	Generally not effective for metals. High natural oxidant demand and heterogeneous soils at the site creates inefficiencies and higher cost compared to bioremediation.	No

Table 5-7 Groundwater Process Options Evaluation

Quendall Terminals
Renton, Washington

Groundwater General Response Actions	Remedial Technology	Process Options	Effectiveness	Implementability	Cost (Capital/O&M)	Secondary Screening for Alternative Development	
						Comment	Consider Process Option for Alternatives
In Situ Treatment	Bioremediation	Amendment Injection	Moderate for VOCs, low for SVOCs.	Implementable	Medium/ Medium	This technology may not be effective for high molecular weight SVOCs and would not be directly effective for metals. Retained as a potential polishing technology.	**Yes**
		Biosparging	Moderate for VOCs, low for SVOCs.	Implementable	Medium/ Medium	This technology may not be effective for high molecular weight SVOCs and would not be directly effective for arsenic. Retained as a potential polishing technology.	**Yes**
Removal	Groundwater Extraction	Pumping from vertical wells or trenches	Yes	Implementable	Medium/ Medium	May not meet RAOs when implemented alone; may be applicable when implemented as a polishing technology combined with other technologies. Cost does not include treatment (see treatment options below).	**Yes***
Ex Situ Treatment	Physical/ Chemical	Adsorption	High for all COCs	Implementable	Medium/ Medium	One of the most widely used water treatment technologies, typically the most cost-effective means of treatment for VOCs, SVOCs, and metals. Different media may be needed for arsenic and organic compounds.	**Yes**
		Air stripping	High for VOCs, low for SVOCs. Not effective for arsenic.	Implementable	Medium/Low	Can be cost-effective for VOCs; typically not effective for SVOCs or metals, but could be part of a treatment train.	**Yes***
		Advanced oxidation processes	High for VOCs and SVOCs. Not effective for arsenic.	Implementable	High/High	Capital and O&M costs are significant higher than treatment by GAC or air stripping. Not effective for treatment metals.	No
	Biological	Biotreatment	High for VOCs, moderate for SVOCs	Implementable	Medium to High/Medium	Highly effective for treating VOCs; treatability of SVOCs would have to be demonstrated in bench-scale and/or pilot tests. Retained, though likely only cost-effective for very large treatment system	**Yes**
Disposal	Off-Site Management	Discharge to sanitary sewer	High for all COCs	Implementable	Low/Medium	Volume restrictions may limit allowable discharge. Groundwater pre-treatment may be required.	**Yes***
		Discharge to surface water	High for all COCs	Implementable. Would likely require NDPES Permit	Low/Low	Regulatory and community acceptable of this process option may be difficult to obtain. Groundwater pre-treatment may be required.	**Yes**
	On-Site Management	Reintroduction to groundwater	High for all COCs	Implementable	Low/Low	Groundwater pre-treatment may be required.	**Yes**

Note: This table represents the secondary screening process described in Section 5.3.3.
* - Process Option was selected for inclusion in a Remedial Alternative developed in Section 6.

Table 5-8 Sediment Process Options Evaluation

DRAFT FINAL

Quendall Terminals
Renton, Washington

Sediment General Response Actions	Remedial Technology	Process Options	Effectiveness	Implementability	Cost (Capital/O&M)	Secondary Screening for Alternative Development	
						Comment	Consider Process Option for Alternatives
Institutional Controls	Use Restrictions	Governmental advisories and public outreach on fish/shellfish consumption	Yes	Implementable	Low/Low	Applicable to a range of Site conditions. Does not meet RAOs when implemented alone; may be applicable in conjunction with other technologies.	**Yes***
		Easements or restrictive covenants to limit activities which may damage the remedy or increase the potential for exposure	Yes	Implementable	Low/Low		**Yes***
		Monitoring and notification of waterway users to restrict specific activities to protect the remedy	Yes	Implementable; site is not adjacent to major navigation lanes.	Low/Low		**Yes***
Monitored Natural Recovery	Monitored Natural Recovery	Monitoring of Natural Processes	Documented within some areas of the Site.	Recontamination potential must be considered.	Low/Medium	Proven technology potentially applicable to a range of site conditions and contaminants. May not meet RAOs when implemented alone; may be applicable in conjunction with other technologies. May be capable of reducing residual organic contaminant concentrations and thereby economically reduce risk after source zone treatment/removal.	**Yes**
	Enhanced Natural Recovery	Thin Layer Placement	Demonstrated. Recontamination potential must be considered for long-term effectiveness.	Recontamination potential must be considered.	Low/Medium	Proven technology, successfully implemented as part of a remedy at other similar Sites. Can enhance natural recovery. Potentially applicable to a range of Site conditions. May not meet RAOs when implemented alone; may be applicable in conjunction with other technologies; may be appropriate in portions of the Site.	**Yes***
In Situ Containment	Capping (Non-Reactive)	Engineered Sand Cap	Well demonstrated.	Armored caps (e.g., with a gravel surface) may potentially be appropriate for consideration in sediment areas with high potential for disturbance (e.g., areas likely to experience propeller wash). Well demonstrated.	Low/Medium	Effective prevent exposure to contaminated sediments, potentially applicable to a range of Site conditions. May not meet RAOs when implemented alone; may be applicable in conjunction with other technologies; may be appropriate in portions of the Site. However, caps in shallow near-shore areas could eliminate significant areas of aquatic habitat, requiring compensatory mitigation or potentially requiring excavation to offset elevation changes.	**Yes***
		Post-Dredging Residuals Management Layer	Well demonstrated. Recontamination potential must be considered for long-term effectiveness.	Implementable	Low/Low	Proven technology potentially applicable to a range of Site conditions. May not meet RAOs when implemented alone; may be applicable in conjunction with other technologies; may be appropriate in portions of the Site.	**Yes***
In Situ Treatment	Physical / Chemical	Permeable Reactive Cap	At least ten full-scale reactive cap remedies implemented. Effective for VOCs, SVOCs, and NAPL, depending on reactive media.	Implementable	Medium/ Medium	Enhancement to traditional caps by providing chemical isolation as well as physical isolation of contaminants. A reactive cap that incorporates organoclay for treatment of NAPL is retained. GAC retained as potential polishing technology for future consideration.	**Yes***
	Bioremediation	Amendment Injection	Moderate for VOCs, low to moderate for SVOCs. Not effective for very high concentrations of contaminants or NAPL.	Implementable	Low to Medium/ Medium	Biodegradation of Site COCs in ongoing and has been widely demonstrated in upland applications, but not in sediment. Does not meet RAOs when implemented alone; may be applied in conjunction with other technologies. Retained as potential polishing technology for future consideration.	**Yes**
Removal	Excavation	Upland-based Excavation	Well demonstrated.	Implementable	Low/NA	Proven technology potentially applicable to nearshore removal areas. Cost does not include treatment; see treatment options below.	**Yes**
		Cofferdam Containment	Well demonstrated in shallow water on small scale projects.	May not be implementable. Would require low permeability foundation layer. Dewatering may spread groundwater contamination.	High/NA	Lowering of the groundwater table to facility cofferdam excavation and subsequent treatment or disposal of dewatered fluids is more costly than equally effective options. The technical feasibility and implementability of dewatering and dry excavation declines rapidly with increasing surface water and excavation depth. Cost does not include treatment; see treatment options below.	No
	Dredging	Hydraulic	Well demonstrated.	Implementable. Will require more staging areas for dewatering than mechanical methods; may not be effective for areas with significant debris.	Medium/NA	Produces dredged material slurry, requiring significant dewatering prior to off Site disposal. Generates significantly greater volumes of water vs. mechanical dredging. Cost does not include treatment; see treatment options below.	**Yes***
		Mechanical	Well demonstrated.	Implementable	Medium/NA	Proven technology potentially applicable to a range of Site conditions. Generates significantly less water requiring treatment and less dewatering of sediment required than for hydraulic. Cost does not include treatment; see treatment options below.	**Yes***

Table 5-8 Sediment Process Options Evaluation

Quendall Terminals
Renton, Washington

Sediment General Response Actions	Remedial Technology	Process Options	Effectiveness	Implementability	Cost (Capital/O&M)	Secondary Screening for Alternative Development	
						Comment	Consider Process Option for Alternatives
Ex Situ Treatment	Physical	Physical Separation	Well demonstrated.	Implementable. Contingent upon the characteristics of sediment and COCs. May be used as pre-treatment to reduce disposal volumes.	High/NA	Proven technology potentially applicable to a range of Site conditions. May reduce overall treatment/disposal costs by reducing contaminant volume.	**Yes**
		Stabilization	Applicable to sediment with lower levels of contamination and minimal free product.	Implementable. Could also be used as a dewatering technique.	Low/NA	Proven technology potentially applicable to a range of Site conditions. Relatively low cost and effective dewatering method for treating sediments for off-Site disposal and/or treatment. May increase disposal quantities.	**Yes***
	Thermal	Thermal Desorption	High for VOCs and SVOCs. EPA presumptive technology.	Implementable. Could be performed in combination with upland soil treatment to improve efficiency.	Medium/NA	Proven technology potentially applicable to a range of Site conditions. May be accomplished on Site with a mobile treatment unit or off Site at a permanent treatment facility. Compared to off-Site landfill disposal, thermal desorption is typically more expensive, but has the advantage of providing contaminant treatment and destruction rather than containment.	**Yes***
		Vitrification	Well demonstrated for VOCs and SVOCs.	Implementable. Permitting/public support can be difficult to perform on-site.	High/NA	Not retained for further consideration at this time; equally effective process option thermal desorption can be implemented at a lower cost.	No
		Incineration	Well demonstrated for VOCs and SVOCs.	Implementable. Permitting/public support can be difficult to perform on-site.	High/NA	Not retained for further consideration at this time as a stand-alone treatment option; equally effective process option thermal desorption can be implemented at a lower cost. Incineration required by landfill facilities to meet LDRs is a design-level consideration.	No
	Biological	Biotreatment	Moderate to high for VOCs and some SVOCs, but very slow for high molecular weight PAHs.	Implementable. Large staging areas are required for long periods of time.	Medium/NA	Difficult to achieve low levels of some PAHs with biotreatment. Would require long treatment times to achieve cleanup levels. Not retained because of lack of effectiveness on recalcitrance of high-molecular weight PAHs.	No
Disposal	On-Site Beneficial Use	Sand/Aggregate Reclamation	Well demonstrated for some COCs at sites with high sand content matrices.	Implementable. Depends on state regulatory approvals and compatible beneficial use project.	Low/NA	Can potentially serve as an offset cost to disposal.	**Yes**
		Topsoil Feedstock	Demonstrated	Implementable. Depends on state regulatory approvals and compatible beneficial use project.	Low/NA	Can potentially serve as an offset cost to disposal.	**Yes**
	Confined On-Site Disposal	Confined On-Site Disposal	Yes	Implementable	Low/Low	On-Site confined disposal can be less expensive than off-Site confined disposal, but requires long-term management of contaminated materials. May not be compatible with future site uses.	**Yes**
		Nearshore Confined Disposal Facility (CDF)	Yes	Implementable. Permitting/public support can be difficult.	Medium/Low	May be suitable for low concentrations of COCs in sediment. Can be less expensive than off-Site confined disposal, but requires long-term management of contaminated materials. Limited administrative implementability, significant filling and loss of aquatic lands within Lake Washington to construct nearshore CDF may be difficult to permit.	No
	Off-Site Landfill Disposal	Subtitle D (Solid Waste)	Well demonstrated for all COCs.	Implementable. Material must be dewatered prior to off-Site disposal.	Medium/NA	Proven technology potentially applicable to a range of Site conditions. This disposal option may be included in alternatives involving removal and/or treatment of contaminated sediment.	**Yes***
		Subtitle C (Hazardous Waste)	Well demonstrated for all COCs.	Implementable. Material must be dewatered prior to off-Site disposal.	High/NA	Proven technology potentially applicable to a range of Site conditions. This disposal option may be included in alternatives involving removal and/or treatment of contaminated sediment.	**Yes***

Note: This table represents the secondary screening process described in Section 5.3.4.
* - Process Option was selected for inclusion in a Remedial Alternative developed in Section 6.

Table 6-1 - Assembly of Alternatives - Anticipated Relationship to Remedial Action Objectives (RAOs)

Quendall Terminals
Renton, Washington

			Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5	Alternative 6	Alternative 7	Alternative 8	Alternative 9	Alternative 10
		Alternative Focus	**No Action**	**Containment**	**Containment with Targeted PTM Solidification (RR and MC DNAPL Areas)**	**Containment with Targeted PTM Removal (TD, QP-S, and QP-U DNAPL Areas)**	**Containment with Targeted PTM Solidification (RR, MC, and QP-U DNAPL Areas and ≥ 4-Foot-Thickness) and Removal (TD and QP-S DNAPL Areas)**	**Containment with Targeted PTM Solidification (RR and MC DNAPL Areas and ≥ 2-Foot-Thickness) and Removal (TD, QP-S, and QP-U DNAPL Areas)**	**Containment with PTM Solidification (Upland) and Removal (Sediment)**	**Containment with PTM Removal (Upland and Sediment)**	**Containment with Solidification and Removal of Contaminated Soil and Removal of Contaminated Sediment**	**Containment with Removal of Contaminated Soil and Sediment**
		Prevent Exposure to Contaminated Media		X	X	X	X	X	X	X	X	X
		Reduce Contaminant Migration		X	X	X	X	X	X	X	X	X
		Treat or Remove Principal Threat Materials to Reduce Contaminated Groundwater Plume			X		X	X	X	X	X	X
		Treat or Remove Principal Threat Materials adjacent to Lake Washington with Greatest Toxicity or Potential Mobility				X	X	X	X	X	X	X
		Treat or Remove Other Principal Threat Materials					X	X	X	X	X	X
		Reduce Groundwater Restoration Time Frame								X		X
	RAO	**Description**										
Source Control RAOs	SC1: Source Material as Principal Threat	Treat or remove DNAPL in subsurface soils and groundwater to prevent contamination of groundwater above COC MCLs to the extent practicable	--	--	X	X	X	X	X	X	X	X
	SC2: Source Material	Contain DNAPL in subsurface soils and groundwater where treatment or removal is not practicable	--	X	X	X	X	X	X	X	X	X
	SC3: Source Material: Soil	Reduce migration of COCs to groundwater from soils that exceed remediation goals for the protection of groundwater	--	--	T	T	T	T	T	T	T	T
	SC4: Source Material: Sediment	Reduce migration of COCs to surface water from sediments that exceed remediation goals for the protection of surface water	--	T	T	T	T	T	T	T	T	T
Human Health Protection RAOs	HH1: Groundwater	Restore groundwater to its highest beneficial use (drinking water) by meeting COC MCLs in the Site Shallow Alluvium and Deeper Alluvium Aquifers within a reasonable period of time	--	--	T	T	T	T	T	T	T	T
	HH2: Sediment	Reduce to acceptable levels the risk to adults and children who ingest resident fish and shellfish taken from the Site for subsistence	--	C	C	T	T	T	T	T	T	T
	HH3: Sediment	Reduce to acceptable levels the human health risk from playing, wading, or swimming resulting in incidental ingestion and/or dermal exposure to contaminated sediments that exceed remediation goals	--	C	C	T	T	T	T	T	T	T
	HH4:Surface Water	Reduce to acceptable levels the human health risk from direct contact or incidental ingestion of surface water contaminated with COCs exceeding remediation goals (water quality standards or MCLs)	--	T	T	T	T	T	T	T	T	T
	HH5: Vapor	Reduce to acceptable levels the human health risk from inhalation of vapors from groundwater and/or soils contaminated with COCs exceeding soil or groundwater remediation goals	--	C	C	C	T	T	T	T	T	T
	HH6: Soils (Surface and Subsurface)	Reduce to acceptable levels the human health risk from direct contact or incidental ingestion of COCs in soil exceeding soil remediation goals	--	C	C	C	T	T	T	T	T	T
Environmental Protection RAOs	EP1: Surface Water	Reduce to acceptable levels the risk to aquatic-dependent organisms when direct contact with surface water or incidental ingestion of COCs in surface water exceeds remediation goals (water quality standards)	--	T	T	T	T	T	T	T	T	T
	EP2: Upland Soil	Reduce to acceptable levels the risk to terrestrial wildlife when direct contact and incidental ingestion or consumption of soil invertebrates results in exposures to COCs that exceed remediation goals	--	C	C	C	C	C	T	T	T	T
	EP3: Sediment	Reduce to acceptable levels the risk to aquatic-dependent wildlife (sediment probing birds and piscivorous mammals) where surface sediments containing COCs exceed remediation goals	--	C	C	T	T	T	T	T	T	T
	EP4: Sediment	Reduce to acceptable levels the risk to benthos where surface sediments containing COCs exceed remediation goals	--	C	C	T	T	T	T	T	T	T

Notes:
X indicates this Alternative Focus or RAO is addressed by this alternative

C indicates this RAO is addressed primarily through containment

T indicates this RAO is addressed primarily through treatment

Acronyms and Abbreviations:

-- Dashes indicate no actions taken to address this RAO.

COC = chemical of concern

DNAPL = dense non-aqueous phase liquid
MCL = maximum contaminant level
NA = not applicable; all DNAPL treated or removed
PTM = Principle Threat Materials
RAO = Remedial Action Objective

Table 6-2 - Assembly of Technologies and Process Options into Remedial Alternatives

DRAFT FINAL

Quendall Terminals
Renton, Washington

Technology General Response Actions	Remedial Technologies/ Process Options	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5	Alternative 6	Alternative 7	Alternative 8	Alternative 9	Alternative 10
		No Action	**Containment**	**Containment with Targeted PTM Solidification (RR and MC DNAPL Areas)**	**Containment with Targeted PTM Removal (TD, QP-S, and QP-U DNAPL Areas)**	**Containment with Targeted PTM Solidification (RR, MC, and QP-U DNAPL Areas and ≥ 4-Foot-Thickness) and Removal (TD and QP-S DNAPL Areas)**	**Containment with Targeted PTM Solidification (RR and MC DNAPL Areas and ≥ 2-Foot-Thickness) and Removal (TD, QP-S, and QP-U DNAPL Areas)**	**Containment with PTM Solidification (Upland) and Removal (Sediment)**	**Containment with PTM Removal (Upland and Sediment)**	**Containment with Solidification and Removal of Contaminated Soil and Removal of Contaminated Sediment**	**Containment with Removal of Contaminated Soil and Sediment**
Upland DNAPL/Soil											
Institutional Controls	Deed and Access Restrictions	--	X	X	X	X	X	X	X	X	X
In Situ Containment	Cover or Cap	--	X	X	X	X	X	X	X	X	X
In Situ Treatment	Solidification	--	--	Deep PTMs[2]	--	QP-U DNAPL Area plus shallow PTMs >4-foot cumulative thickness[1] and deep PTMs[2]	ShallowPTMs >2-foot cumulative thickness[1] and deep PTMs[2]	All PTMs	--	All deep contaminated soil (below approx. 15 feet bgs)	--
Removal	DNAPL Collection Trenches	--	--	At former May Creek and Quendall Pond shoreline	At former May Creek and Quendall Pond shoreline	--	--	--	--	--	--
	Excavation	--	--	--	QP-U DNAPL Area	--	QP-U DNAPL Area	--	All PTMs	All shallow contaminated soil (above approx. 15 feet bgs)	All contaminated soil
Ex Situ Treatment	On-site Thermal Desorption	--	--	--	--	--	--	--			
Disposal	Off-site Landfill	--	--	--	QP-U DNAPL Area	--	QP-U DNAPL Area	--	--	--	--
Aquatic DNAPL/Sediment											
Institutional Controls	Deed Restrictions	--	X	X	X	X	X	X	X	X	X
Monitoring	Biological/Physical Recovery	--	X	X	X	X	X	X	X	X	X
Enhanced Natural Recovery (ENR)	Thin-layer Placement	--	Offshore sediments outside PTM areas exceeding BTV	Offshore sediments outside PTM areas exceeding BTV	Offshore sediments outside PTM areas exceeding BTV	Offshore sediments outside PTM areas exceeding BTV	Offshore sediments outside PTM areas exceeding BTV	Offshore sediments outside PTM areas exceeding BTV	Offshore sediments outside PTM areas exceeding BTV	Offshore sediments outside PTM areas exceeding BTV	Offshore sediments outside PTM areas exceeding BTV
In Situ Containment	Engineered Sand Cap	--	Nearshore sediments outside PTM areas	Nearshore sediments outside PTM areas	Nearshore sediments outside PTM areas	Nearshore sediments outside PTM areas	Nearshore sediments outside PTM areas	Nearshore sediments outside PTM areas	Nearshore sediments outside PTM areas	Nearshore sediments outside areas of PTMs or MCL exceedances	Nearshore sediments outside areas of PTMs or MCL exceedances
In Situ Treatment	Reactive Sediment Cap	--	All aquatic DNAPL areas[4]	All aquatic DNAPL areas	Aquatic DNAPL areas DA-3, DA-4, DA-5, DA-7, and DA-8	Aquatic DNAPL areas DA-3, DA-4, DA-5, DA-7, and DA-8	Aquatic DNAPL areas DA-3, DA-4, DA-5, DA-7, and DA-8	--	--	--	--
	Reactive Residuals Cover	--	--	--	Removal areas to address residuals	Removal areas to address residuals	Removal areas to address residuals	Removal areas to address residuals	Removal areas to address residuals	Removal areas to address residuals	Removal areas to address residuals
Removal[3]	Mechanical Dredging with Sheet Pile Containment	--	--	--	QP-S DNAPL Area (DA-6)	QP-S DNAPL Area (DA-6)	QP-S DNAPL Area (DA-6)	Aquatic DNAPL areas DA-5, DA-6, DA-7, and DA-8	Aquatic DNAPL areas DA-5, DA-6, DA-7, and DA-8	Nearshore sediments in areas of PTMs or MCL exceedances	Nearshore sediments in areas of PTMs or MCL exceedances
	Hydraulic Dredging with Water Quality Controls	--	--	--	TD DNAPL Area (DA-1 and DA-2)	TD DNAPL Area (DA-1 and DA-2)	TD DNAPL Area (DA-1 and DA-2)	Aquatic DNAPL areas DA-1, DA-2, DA-3, and DA-4	Aquatic DNAPL areas DA-1, DA-2, DA-3, and DA-4	Aquatic DNAPL areas DA-1, DA-2, DA-3, and DA-4	Aquatic DNAPL areas DA-1, DA-2, DA-3, and DA-4
Ex Situ Treatment	On-site Thermal Desorption	--	--	--	--	--	--	--	All removed sediment	All removed sediment	All removed sediment
Disposal	Off-site Landfill	--	--	--	All removed sediment	All removed sediment	All removed sediment	All removed sediment	--	--	--
Groundwater											
Institutional Controls	Deed Restrictions	--	X	X	X	X	X	X	X	X	X
Monitoring	Groundwater Monitoring	--	X	X	X	X	X	X	X	X	X
In Situ Containment	Slurry Wall Barriers	--	--	Funnel and gate system along most of Site shoreline	Funnel and gate system along most of Site shoreline	Funnel and gate system along most of Site shoreline	Funnel and gate system along most of Site shoreline	--	--	--	--
In Situ Treatment	Permeable Reactive Barrier	--	--					--	--	--	--
Removal	Pumping from Vertical Wells	--	--	--	--	--	--	--	--	--	Pump and treat groundwater from below excavated areas
Ex Situ Treatment	On-site Treatment	--	--	--	--	--	--	--	--	--	
Disposal	Undetermined	--	--	--	--	--	--	--	--	--	

Notes:

-- Dashes indicate action not included for that alternative.

[1] Cumulative thickness of DNAPL-impacted soil in the top 20 feet of soil column.

[2] Deep PTMs refers to the RR DNAPL Area and polygon MC-1 (Former May Creek; refer to Figure 4-6).

[3] Process options for dredging are evaluated on a preliminary basis in this FS and will be more fully evaluated during remedial design.

[4] In Alternative 2, the reactive sediment cap configuration in the QP-S DNAPL Area (DA-6) differs from that in the other sediment cap areas. Refer to Section 6.3.2.3.

BTV = background threshold value
DNAPL = dense non-aqueous phase liquid
PTM = principal threat material
QP-U= Quendall Pond-Upland
RR = Railroad

Table 6-3 Remedial Alternative Summary

Quendall Terminals
Renton, Washington

		Upland		Sediment		
	Remedial Alternative	Upland PTMs	Contaminated Soil Outside PTM Areas	Sediment PTMs	Contaminated Sediment Outside PTM Areas	Groundwater
2	**Containment**	Upland DNAPL and contaminated soil would be capped with clean soil to prevent direct contact exposure. Institutional controls would be established to place restrictions on future land use and control future construction and redevelopment activities, including requirements for vapor intrusion assessment or mitigation for future buildings.		Two configurations of a reactive sediment cap (RCM and amended sand cap) would be installed in aquatic DNAPL areas (DA-1 through DA-8). The amended sand cap would be installed in the QP-S DNAPL Area (DA-6), and the RCM cap in all other areas. The objective of the RCM cap is to sequester DNAPL using a relatively thin reactive cap. From the shoreline to approximately 75 feet offshore, sediment would be removed prior to capping to maintain the existing profile of the nearshore area. The objective of the thick amended sand cap is to sequester DNAPL using a relatively thick reactive cap in areas where the amount of DNAPL is greater and could overwhelm a thinner RCM cap during the design life, and where the effect on aquatic habitat due to capping could be mitigated (e.g., along the shoreline). Existing sediment would not be removed prior to installation of amended sand cap.	An engineered sand cap (1.5 feet sand) and ENR (6-inches sand) would be installed outside of the aquatic DNAPL areas. The engineered sand cap would be placed in the nearshore area and where existing surface sediment concentrations are relatively high along the property line. From the shoreline to approximately 75 feet offshore, sediment would be removed prior to capping to maintain the existing profile. ENR would be applied in remaining areas of sediment contamination. It would immediately reduce surface sediment concentrations, providing a clean bioturbation layer and reducing surface sediment porewater concentrations.	Institutional controls would be established to place restrictions on groundwater use.
3	**Containment with Targeted PTM Solidification (RR and MC DNAPL Areas)**	Upland cap as described above. In addition, DNAPL collection trenches would be installed in the former May Creek and Quendall Pond Areas, to prevent DNAPL migration from upland soils to sediments. The gravel-filled trenches would be installed landward of the PRB (see Groundwater column) and habitat area. The trench bottoms would contain perforated piping and would slope to collection sumps. Deep PTMs in the RR and MC DNAPL Areas and overlying contaminated soil would be solidified *in situ* . Roughly 13,000 CY of soil would be mixed with amendments using 4- to 8-foot-diameter augers. Amendments may include cement, bentonite, and/or powdered activated carbon.	Same as above	Same as above except that the QP-S DNAPL Area (DA-6) would receive a RCM cap (similar to the other sediment DNAPL areas) instead of an amended sand cap.	Same as above	A PRB would be installed near the shoreline to reduce contaminant migration. It would extend to the base of the Shallow Alluvium, and would have a funnel and gate configuration. The impermeable funnel sections would consist of bentonite slurry. Granular activated carbon would be used in the gate sections to adsorb contaminants. Institutional controls would be established to place restrictions on groundwater use.
4	**Containment with Targeted PTM Removal (TD, QP-S, and QP-U DNAPL Areas)**	Upland cap and DNAPL collection trenches as described above. In addition, PTM soil in the QP-U DNAPL Area and overlying contaminated soil (roughly 13,000 CY) would be excavated. Sheet piling would be used to shore the excavation, and wells and sumps would be used for construction dewatering. The excavation would be backfilled with clean imported fill. Excavated materials would be segregated to the extent practical, for disposal at hazardous and non-hazardous waste landfills as appropriate.	Same as above	A RCM reactive sediment cap would be installed in aquatic DNAPL areas DA-3, DA-4, DA-5, DA-7, and DA-8 as described in Alternative 2. Areas DA-1, DA-2, and DA-6 would be dredged, a reactive residuals cover would be placed, and then backfilled to existing grade. The nearshore QP-S DNAPL Area (DA-6) would be removed by mechanical dredging inside a temporary sheet pile enclosure. The offshore TD DNAPL Area (DA-1 and DA-2) would be hydraulically dredged. Best management practices such as oil booms and/or silt curtains may be used to reduce resuspension and release of contaminants. Dredged material would be dewatered and transported off site for landfill disposal.	Same as above	Same as above
5	**Containment with Targeted PTM Solidification (RR, MC, and QP-U DNAPL Areas and ≥ 4-Foot-Thickness) and Removal (TD and QP-S DNAPL Areas)**	Upland cap and solidification of deep PTMs as described above for Alternative 3. In addition, the QP-U DNAPL Area and areas of the Site where a minimum 4-foot thickness of PTM soil has been observed in the upper 20 feet of soil column would be solidified *in situ* to 20-foot depth. Roughly 23,000 CY of soil would be solidified using methods and amendments as noted above.	Same as above	Same as above	Same as above	Same as above
6	**Containment with Targeted PTM Solidification (RR and MC DNAPL Areas and ≥ 2-Foot-Thickness) and Removal (TD, QP-S, and QP-U DNAPL Areas)**	Upland cap, solidification of deep PTMs, and excavation in the QP-U DNAPL Area as described above for Alternative 2, 3, and 4, respectively. In addition, areas of the Site where a minimum 2-foot thickness of PTM soil has been observed in the upper 20 feet of soil column would be solidified *in situ* to 20-foot depth. Roughly 23,000 CY of soil would be solidified using methods and amendments as noted above.	Same as above	Same as above	Same as above	Same as above
7	**Containment with PTM Solidification (Upland) and Removal (Sediment)**	PTM soil and overlying contaminated soil and soil to 2 feet below DNAPL (roughly 240,000 CY) would be solidified *in situ* . Solidification methods and amendments would be similar to those described above for Alternative 4.	Same as above	Offshore aquatic DNAPL areas (DA-1 through DA-4) would be hydraulically dredged. Nearshore areas (DA-5 through DA-8) would be removed by mechanical dredging within a sheet pile enclosure. A reactive residuals cover would be placed, and then backfilled to existing grade as described for Alternative 4. Dredged material would be dewatered and transported off site for landfill disposal.	Same as above	Institutional controls would be established to place restrictions on groundwater use.
8	**Containment with PTM Removal (Upland and Sediment)**	PTM soil and overlying contaminated soil (roughly 210,000 CY) would be excavated, treated on site, and backfilled. Sheet piling would be used to construct excavation cells, with cell dewatering via internal wells and sumps. Excavated soils would be treated using thermal desorption. It is assumed that residual concentrations may exceed PRGs; therefore, capping of backfilled areas would be required.	Same as above	Same as above	Same as above	Same as above
9	**Containment with Solidification and Removal of Contaminated Soil and Removal of Contaminated Sediment**	Contaminated soil (roughly 710,000 CY) that could act as a source of groundwater contamination above MCLs beyond a reasonable restoration timeframe would be treated on site. Contaminated soil above approximately 15 feet in depth would be excavated, treated on site using thermal desorption, and backfilled. Sheet piling would be used to construct excavation cells, with cell dewatering via internal wells and sumps. Contaminated soil below 15 feet in depth would be solidified *in situ* using the same methods described above. It is assumed that residual concentrations may exceed PRGs; therefore, capping of backfilled areas would be required. Institutional controls addressing soil vapors would likely not be required because volatile contaminants should be effectively treated.		Offshore PTM areas (DA-1 through DA-4) would be hydraulically dredged to approximately 2 feet below PTMs. Nearshore PTM areas (DA-5 through DA-8) and an additional volume of nearshore sediments (based on estimated MCL exceedances) would be removed by mechanical dredging within a sheet pile enclosure. A reactive residuals cover would be placed, and then the area would be backfilled to existing grade. Dredged material would be dewatered and treated by thermal desorption on site.	An engineered sand cap and ENR would be installed outside of the dredging areas (PTMs and MCL exceedances) as described for Alternative 2 .	Same as above
10	**Containment with Removal of Contaminated Soil and Sediment**	Same as above, except that both shallow and deep contaminated soils would be removed, treated on Site by thermal desorption and backfilled.		Same as above	Same as above	Pump and treat technology would be used to address contamination remaining below the excavated areas. An estimated pumping rate of roughly 90 gpm is needed to achieve containment. Extracted groundwater would be treated on site and potentially discharged to the sanitary sewer, to groundwater on the Site, or to Lake Washington. Institutional controls would be established to place restrictions on groundwater use.

Notes:

[1] Refer to Section 6 for complete descriptions of the remedial alternatives.

CY = cubic yard

DNAPL = dense non-aqueous-phase liquid

ENR = enhanced natural recovery

MCL = maximum contaminant level

PRB = permeable reactive barrier

PRG = preliminary remedial goal

QP-U = Quendall Pond-Upland

RCM = reactive core mat

Table 6-4 Summary of Remedial Alternative Construction Quantities

Quendall Terminals
Renton, Washington

Remedial Component		Alternative 2 Containment	Alternative 3 Containment with Targeted PTM Solidification (RR and MC DNAPL Areas)	Alternative 4 Containment with Targeted PTM Removal (TD, QP-S, and QP-U DNAPL Areas)	Alternative 5 Containment with Targeted PTM Solidification (RR, MC, and QP-U DNAPL Areas and ≥ 4-Foot-Thickness) and Removal (TD and QP-S DNAPL Areas)	Alternative 6 Containment with Targeted PTM Solidification (RR and MC DNAPL Areas and ≥ 2-Foot-Thickness) and Removal (TD, QP-S, and QP-U DNAPL Areas)	Alternative 7 Containment with PTM Solidification (Upland) and Removal (Sediment)	Alternative 8 Containment with PTM Removal (Upland and Sediment)	Alternative 9 Containment with Solidification and Removal of Contaminated Soil and Removal of Contaminated Sediment	Alternative 10 Containment with Removal of Contaminated Soil and Sediment
Upland DNAPL/Soil	Soil Cap (acres)	22	22	22	22	22	22	22	22	22
	DNAPL Collection Trench (lf)	--	500	500	--	--	--	--	--	--
	In Situ Solidification (CY)									
	- DNAPL-impacted soil	--	3,600	--	17,000	25,100	30,500	--	8,400	--
	- Non-DNAPL-impacted soil	--	13,900	--	61,900	117,400	210,800	--	354,500	--
	Excavate and On-Site Thermal Desorption (CY)									
	- DNAPL-impacted soil	--	--	--	--	--	--	30,500	22,000	30,500
	- Non-DNAPL-impacted soil	--	--	--	--	--	--	179,600	320,500	674,900
	Excavate and Landfill Disposal (CY)									
	- DNAPL-impacted soil	--	500	2,800	400	2,700	--	--	--	--
	- Non-DNAPL-impacted soil	--	2,400	12,800	1,700	12,100	--	--	--	--
Aquatic DNAPL/ Sediment[2]	In Situ Remediation in Acres									
	-Enhanced natural recovery	17.6	17.6	17.6	17.6	17.6	17.6	17.6	17.6	17.6
	- Engineered sand cap	6.2	6.2	6.4	6.4	6.4	5.5	5.5	3.9	3.9
	- Reactive cap	4.9	5.7	2.0	2.0	2.0	--	--	--	--
	-Amended sand cap	0.7	--	--	--	--	--	--	--	--
	- Post dredge residuals management cover/backfilling	--	--	3.5	3.5	3.5	6.4	6.4	8.0	8.0
	Dredge and Onsite Thermal Desorption of Sediment in CY	--	--	--	--	--	--	58,300	173,100	173,100
	Dredge and Landfill Disposal of Sediment in CY	2,800	3,200	25,900	25,900	25,900	58,300	--	--	--
	Temporary Sheet Pile Enclosure in lf	--	--	700	700	700	1,260	1,260	1,530	1,530
Groundwater	Funnel and Gate PRB (lf)	--	1,100	1,100	1,100	1,100	--	--	--	--
	Pump and Treat (gpm)	--	--	--	--	--	--	--	--	90

Notes:
-- not applicable
[1] Refer to Section 6 and Table 6-3 for descriptions of the remedial alternatives.
[2] The sediment dredging volumes include dredging to offset for cap placement in the nearshore area.
CY = cubic yards
DNAPL = dense non-aqueous phase liquid
gpm = gallons per minute
lf = linear feet
PRB = permeable reactive barrier
PTM = principal threat material

Table 7-1 - National Contingency Plan Evaluation Criteria for Detailed Analysis of Remedial Alternatives

Quendall Terminals
Renton, Washington

Evaluation Criteria		FS Analysis Factors
Threshold Criteria	1. Overall Protection of Human Health and the Environment	• How alternative provides human health and environmental protection
	2. Compliance with ARARs	• Compliance with chemical-specific, location-specific, and action-specific ARARs • Compliance with other criteria, advisories, and guidance
Balancing Criteria	3. Long-term Effectiveness and Permanence	• Magnitude of residual risks • Adequacy and reliability of controls
	4. Reduction of Toxicity, Mobility, or Volume through Treatment	• Treatment processes used and materials treated • Amount of hazardous materials destroyed or treated • Degree of expected reductions in toxicity, mobility, and volume • Degree to which treatment is irreversible • Type and quantity of residuals remaining after treatment
	5. Short-term Effectiveness	• Protection of community during remedial actions • Protection of workers during remedial actions • Environmental impacts • Time until remedial action objectives are achieved

	6. Implementability	• Technical feasibility
		  • Ability to construct and operate the technology
		  • Reliability of the technology
		  • Ease of undertaking additional remedial actions, if necessary
		  • Ability to monitor effectiveness of remedy
		• Administrative feasibility
		  • Ability to obtain approvals from other agencies
		  • Coordination with other agencies
		• Availability of services and materials
		  • Availability of offsite treatment, storage, and disposal services and capacity
		  • Availability of necessary equipment and specialists
		  • Availability of prospective technologies

	7. Cost	• Capital costs • Operating and maintenance costs • Present worth cost
Modifying Criteria	8. State (Support Agency) Acceptance[1]	• State (Support Agency) technical and administrative issues and concerns
	9. Community Acceptance[1]	• Public issues and concerns

Notes:
Source: EPA 1988a.
[1]These criteria are assessed following comment on the FS report and the proposed plan.

Abbreviations:
ARAR = applicable or relevant and appropriate requirement
EPA = U.S. Environmental Protection Agency
FS = feasibility study

Table 7-2 Estimated Volumes of DNAPL Treated or Removed Under Alternative Remedial Actions

Quendall Terminals
Renton, Washington

	Alternative 2	Alternative 3	Alternative 4	Alternative 5	Alternative 6	Alternative 7	Alternative 8	Alternative 9	Alternative 10
	Containment	Containment with Targeted PTM Solidification (RR and MC DNAPL Areas)	Containment with Targeted PTM Removal (TD, QP-S, and QP-U DNAPL Areas)	Containment with Targeted PTM Solidification (RR, MC, and QP-U DNAPL Areas and ≥ 4-Foot-Thickness) and Removal (TD and QP-S DNAPL Areas)	Containment with Targeted PTM Solidification (RR and MC DNAPL Areas and ≥ 2-Foot-Thickness) and Removal (TD, QP-S, and QP-U DNAPL Areas)	Containment with PTM Solidification (Upland) and Removal (Sediment)	Containment with PTM Removal (Upland and Sediment)	Containment with Solidification and Removal of Contaminated Soil and Removal of Contaminated Sediment	Containment with Removal of Contaminated Soil and Sediment
Upland DNAPL in Gallons									
Removal via Collection Trench, with Off-site Incineration	--	1,300	1,300	--	--	--	--	--	--
Removal via Excavation, with Off-site Disposal	--	6,600	34,900	4,500	32,900	--	--	--	--
Removal via Excavation, with On-site Thermal Desorption	--	--	--	--	--	--	377,500	273,100	377,500
Total Upland DNAPL Removed	0	7,900	36,200	4,500	32,900	0	377,500	273,100	377,500
Total Upland DNAPLTreated (via *In Situ* Solidification)	0	44,700	0	210,800	311,000	377,500	0	104,400	0
Total Upland DNAPL Treated or Removed									
Gallons	**0**	**52,600**	**36,200**	**215,300**	**343,900**	**377,500**	**377,500**	**377,500**	**377,500**
Percent of Total Upland DNAPL	**0%**	**14%**	**10%**	**57%**	**91%**	**100%[6]**	**100%[6]**	**100%[6]**	**100%[6]**
Sediment DNAPL in Gallons									
Removal via Mechanical Dredge[4], with Off-site Disposal	--	--	25,900	25,900	25,900	32,200	--	--	--
Removal via Mechanical Dredge[4], with On-site Thermal Desorption	--	--	--	--	--	--	32,200	32,200	32,200
Removal via Hydraulic Dredge[5], with Off-site Disposal	--	--	33,700	33,700	33,700	35,400	--	--	--
Removal via Hydraulic Dredge[5], with On-site Thermal Desorption	--	--	--	--	--	--	35,400	35,400	35,400
Total Sediment DNAPL Removed									
Gallons	**0**	**0**	**59,600**	**59,600**	**59,600**	**67,600**	**67,600**	**67,600**	**67,600**
Percent of Total Sediment DNAPL	**0%**	**0%**	**88%**	**88%**	**88%**	**100%[6]**	**100%[6]**	**100%[6]**	**100%[6]**
Total DNAPL Treated or Removed (Site-wide)			(Note 3)	(Note 3)	(Note 3)				
Gallons	**0**	**52,600**	**95,800**	**274,900**	**403,500**	**445,100**	**445,100**	**445,100**	**445,100**
Percent of Total	**0%**	**12%**	**22%**	**62%**	**91%**	**100%[6]**	**100%[6]**	**100%[6]**	**100%[6]**

Notes:

1) -- Dashes indicate not applicable.

2) DNAPL volumes were estimated using the Thiessen polygon areas shown on Figure 4-6. Refer to engineering calculation sheets E-7 through E-15 in Appendix E for detailed calculations.

3) Partial treatment/removal in this alternative includes treatment/removal of DNAPL with the greatest future exposure risk (i.e., the QP-U, QP-S, and TD DNAPL Areas).

4) Mechanical dredge element primarily targets relatively thick, deep (>3 feet) PTM sediment in the nearshore area.

5) Hydraulic dredge element primarily targets relatively thin, shallow (<3 feet) PTM sediment in the offshore area.

6) One hundred percent removal of DNAPL is the goal in Alternatives 7 through 10; however, complete removal of DNAPL is never achieved in practice.

Abbreviations:

DNAPL = dense non-aqueous phase liquid
MC = May Creek
PTM = principal threat materials
QP-S = Quendall Pond-Sediment
QP-U = Quendall Pond-Upland
RR = Railroad
TD = T-Dock

Table 7-3 - Remedial Alternative Institutional Control and Long-Term Monitoring Summary

Quendall Terminals
Renton, Washington

	Remedial Alternative									
	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6	Alt 7	Alt 8	Alt 9	Alt 10
Institutional Controls[1]										
Upland Institutional Controls										
Protection of engineering controls such as soil caps by limiting activities which may damage the control features or increase the potential for exposure.		X	X	X	X	X	X	X	X	X
Evaluation of vapor intrusion potential and/or construction of vapor controls beneath future buildings located above areas containing volatile COCs.		X	X	X	X	X	X	X	X	X
Implementation of a construction management plan specifying monitoring and material management requirements for subsurface activities that would contact potentially contaminated media.		X	X	X	X	X	X	X	X	X
Use of construction techniques that minimize the potential vertical mobilization of DNAPL for future deep-foundation elements potentially penetrating areas of DNAPL.[2]		X	X	X	X	X				
Prohibition on future use of groundwater for drinking purposes and on construction of wells (other than for remediation or monitoring purposes).		X	X	X	X	X	X	X	X	X
Offshore Institutional Controls										
Protection of sediment caps by limiting activities which may damage the caps.		X	X	X	X	X	X	X	X	X
Enforcement and permit tools (i.e., administrative orders, consent decrees)		X	X	X	X	X	X	X	X	X
Informational devices (i.e., seafood consumption advisories, education and public outreach, and site registry for capped areas)		X	X	X	X	X	X	X	X	X
Monitoring and notification of waterway users to restrict specific activities to protect the engineered sand cap and reactive cap.[3]		X	X	X	X	X	X	X	X	X
Long-Term Monitoring Activities[1]										
Upland Monitoring										
Periodic inspection of upland cap integrity.		X	X	X	X	X	X	X	X	X
Periodic groundwater monitoring.		X	X	X	X	X	X	X	X	X
Offshore Monitoring										
Periodic surveys to inspect sediment cap integrity.[4]		X	X	X	X	X	X	X	X	X
Periodic sediment sampling and analysis in sediment cap and ENR areas.		X	X	X	X	X	X	X	X	X

Notes:
[1] In some cases, the areal extent to which institutional controls would apply and the amount of long-term monitoring required would depend on the areal coverage of the various caps and other factors. Refer to Table 6-4 for estimated cap coverage areas.
[2] Such techniques may include use of displacement piles. Specific foundation elements and construction techniques would depend on geotechnical requirements for future structures.
[3] May include restrictions on anchorage within the areas that are capped; restrictions on grounding of small vessels on the shoreline and on vessel draft, horsepower, speed, and time in area; and restrictions on piling placement or removal through cap, or other potential in-water construction/structures.
[4] Cap inspections would also be conducted after a significant natural event, such as a large-magnitude earthquake.

Abbreviations:
COC = chemical of concern
DNAPL = dense non-aqueous phase liquid
ENR = enhanced natural recovery

Table 8-1 - Summary Evaluation of Remedial Alternatives

Quendall Terminals
Renton, Washington

Remedial Alternative		NCP Threshold Criteria		NCP Balancing Criteria				Present Worth Cost ($ Millions)		
		Protective of Human Health and the Environment?	Complies with all ARARs?	Long-Term Effectiveness and Permanence	Reduction of Toxicity, Mobility, or Volume through Treatment	Short-Term Effectiveness	Implementability	Capital	OM&M	Total
1	No Action (Baseline for Comparison)	**No.** No measures to reduce risk or prevent inadvertent exposure/mobilization of contaminants.	Does not comply with ARARs.	**Low.** No measures to reduce risk or prevent inadvertent exposure/mobilization of contaminants.	**Low.** No treatment provided.	**Moderate.** No action implemented. RAOs not achieved in foreseeable future.	**High.** Requires no action.	0	0	0
2	Containment	**Yes.** Reliance on engineering controls, institutional controls, and monitoring to achieve protectiveness.	Complies with all ARARs except groundwater MCLs under the SDWA. Minimal reduction in volume of groundwater exceeding MCLs for benzene, benzo(a)pyrene, and arsenic.	**Low.** Achieves human health and environmental RAOs but relies on containment measures, which have a risk of failure. Requires long-term monitoring to assess remedy performance and maintain controls as needed.	**Low.** No treatment provided.	**High.** Construction actions are of relatively short duration and would result in limited impacts to workers, community, and the environment. Time to achieve RAOs (design and construction duration) estimated to be approximately 2 years.	**High.** No anticipated challenges in coordinating with appropriate agencies, obtaining materials or constructing components.	18	7.6	26
3	Containment with Targeted PTM Solidification (RR and MC DNAPL Areas)	**Yes.** Achieves protectiveness through combination of containment and treatment. Reduces potential migration and improves reliability compared to Alternative 2 through treatment of PTMs and installation of DNAPL collection trenches and groundwater treatment PRB near shoreline.	Complies with all ARARs except groundwater MCLs under the SDWA. Modest reduction in volume of groundwater exceeding MCLs for benzene, benzo(a)pyrene, and arsenic.	**Low.** Similar to Alternative 2, but provides targeted treatment to reduce the extent of groundwater contamination and reduce the potential for DNAPL and contaminated groundwater to migrate from uplands to lake.	**Low.** An estimated 9 percent of DNAPL is treated. Modest reductions in groundwater volume and contaminant flux are achieved through PTM and groundwater treatment.	**High.** Similar to Alternative 2, with slightly greater impacts (including construction traffic, noise, and air emissions) due to *in situ* solidification of deep upland PTMs and DNAPL collection trench/PRB construction. Time to achieve RAOs estimated to be approximately 3 years.	**High.** Similar to Alternative 2, except that *in situ* solidification will require bench and/or pilot testing.	22	9.2	31
4	Containment with Targeted PTM Removal (TD, QP-S, and QP-U DNAPL Areas)	**Yes.** Achieves protectiveness through combination of containment and treatment. Further reduces potential future exposures compared to Alternative 3 through removal of PTMs in shallow sediments and potentially mobile DNAPL near the shoreline.	Complies with all ARARs except groundwater MCLs under the SDWA. Modest reduction in volume of groundwater exceeding MCLs for benzene, benzo(a)pyrene, and arsenic.	**Moderate.** Removes PTMs presenting the most significant risk for re-exposure (shallow sediments and potentially mobile DNAPL near the shoreline).	**Low.** No reduction in PTMs is achieved through treatment (PTMs removed under this alternative are disposed of at an off-site facility). Modest reductions in groundwater volume and contaminant flux are achieved similar to Alternative 3.	**Moderate.** Increased short-term impacts compared to Alternatives 2 and 3 due to air and water quality impacts from dredging DNAPL-impacted sediments and overall longer construction duration. Time to achieve RAOs is estimated to be approximately 4 years.	**Moderate.** Dredging of DNAPL-impacted sediments provides technical and administrative challenges to minimizing contaminant releases.	40	4.8	44
5	Containment with Targeted PTM Solidification (RR, MC, and QP-U DNAPL Areas and ≥ 4-Foot-Thickness) and Removal (TD and QP-S DNAPL Areas)	**Yes.** Achieves protectiveness through combination of containment and treatment similar to Alternative 4 but provides additional treatment of upland PTMs.	Complies with all ARARs except groundwater MCLs under the SDWA. Modest reduction in volume of groundwater exceeding MCLs for benzene, benzo(a)pyrene, and arsenic.	**Moderate.** Similar to Alternative 4, but provides additional treatment of upland PTMs by targeting areas of greater than 4-feet- cumulative DNAPL thickness.	**Moderate.** An estimated 46 percent of PTMs is treated. Modest reductions in groundwater volume and contaminant flux are achieved similar to Alternatives 3 and 4.	**Moderate.** Similar to Alternative 4, but with slightly greater short-term impacts (traffic, noise, and air impacts) due to greater volume of upland soil treated. Time to achieve RAOs is estimated to be approximately 4 years.	**Moderate.** Similar to Alternative 4.	42	4.1	47
6	Containment with Targeted PTM Solidification (RR and MC DNAPL Areas and ≥ 2-Foot-Thickness) and Removal (TD, QP-S, and QP-U DNAPL Areas)	**Yes.** Achieves protectiveness through combination of containment and treatment. Achieves protectiveness similar to Alternatives 4 and 5 but provides additional treatment of upland PTMs.	Complies with all ARARs except groundwater MCLs under the SDWA. Modest reduction in volume of groundwater exceeding MCLs for benzene, benzo(a)pyrene, and arsenic.	**Moderate.** Similar to Alternatives 4 and 5, but provides additional treatment of upland PTMs by also targeting areas of greater than 2-feet-cumulative DNAPL thickness.	**Moderate.** An estimated 68 percent of PTMs are treated. Modest reductions in groundwater volume and contaminant flux are achieved similar to Alternatives 3, 4, and 5.	**Moderate.** Similar to Alternatives 4 and 5, but with greater short-term impacts (traffic, noise, and air impacts) due to greater volume of upland soil treated. Time to achieve RAOs is estimated to be approximately 5 years.	**Moderate.** Similar to Alternatives 4 and 5, but with a slightly longer construction duration.	57	4.1	61
7	Containment with PTM Solidification (Upland) and Removal (Sediment)	**Yes.** Achieves protectiveness through combination of containment and treatment. Greatly reduces potential future exposures through removal of all sediment PTMs and treatment of all upland PTMs.	Complies with all ARARs except groundwater MCLs under the SDWA. Substantial reduction in volume of groundwater exceeding MCLs for benzene, benzo(a)pyrene, and arsenic.	**High.** Permanently treats all PTMs at the Site via *in situ* solidification of upland PTMs and removal of sediment PTMs.	**High.** An estimated 85 percent of PTMs are treated and significant reductions in groundwater volume and contaminant flux are achieved.	**Low.** Greater short-term impacts (traffic, noise, and air impacts) than Alternative 6 due to longer construction duration, greater volume of soil treated, and greater volume of DNAPL-impacted sediment treated. Time to achieve RAOs is estimated to be approximately 6 years.	**Moderate.** Similar implementation challenges as Alternatives 4 through 6, but with a significantly longer construction duration.	78	2.7	80
8	Containment with PTM Removal (Upland and Sediment)	**Yes.** Achieves protectiveness through combination of containment and treatment. Greatly reduces potential future exposures through removal of all PTMs.	Complies with all ARARs except groundwater MCLs under the SDWA. Potentially eliminates groundwater exceeding MCLs for benzene. Substantial reduction in volume of groundwater exceeding MCLs for benzo(a)pyrene and arsenic.	**High.** Permanently treats all PTMs at the Site via removal/on-site thermal desorption.	**High.** All PTMs are treated and significant reductions in groundwater volume and contaminant flux are achieved.	**Low.** Similar to Alternative 7 but greater short-term impacts due to longer construction duration and greater potential for air emissions from excavation, soil handling, and on-site treatment compared to *in situ* solidification. Time to achieve RAOs is estimated to be approximately 7 years.	**Low.** Increased technical challenges compared to Alternative 7 due to complexity of shoring and dewatering for deep excavations and to provide on-site thermal treatment, which is locally uncommon.	137	2.7	140
9	Containment with Solidification and Removal of Contaminated Soil and Removal of Contaminated Sediment	**Yes.** Achieves protectiveness primarily through treatment, although containment of low-level contaminated materials is still required.	Complies with all ARARs except groundwater MCLs under the SDWA. Potentially eliminates groundwater exceeding MCLs for benzene. Substantial reduction in volume of groundwater exceeding MCLs for benzo(a)pyrene and arsenic.	**High.** Permanently treats all PTMs at the Site via *in situ* solidification of shallow upland PTMs and removal/on-site treatment of deep upland PTMs of sediment PTMs. Also treats significant volumes of low-level contaminated soil and sediment.	**High.** All PTMs are treated. Treatment of lower level contaminated soil and sediment provide additional reductions in contaminated groundwater volume and contaminant flux compared to Alternatives 7 and 8.	**Low.** Increased short-term impacts compared to Alternatives 7 and 8 due to very longer construction duration and very large volumes of soil and sediment treated. Time to achieve RAOs is estimated to be approximately 14 years.	**Low.** Technical and administrative challenges for treatment of soils and sediments on this scale are expected to be significant.	259	2.7	262
10	Containment with Removal of Contaminated Soil and Sediment	**Yes.** Achieves protectiveness primarily through treatment, although containment of low-level contaminated materials is still required.	Complies with all ARARs except groundwater MCLs under the SDWA. Potentially eliminates groundwater exceeding MCLs for benzene. Substantial reduction in volume of groundwater exceeding MCLs for benzo(a)pyrene and arsenic.	**High.** Similar to Alternative 9, except all materials treated using removal/on-site thermal desorption, and additional treatment of groundwater provided by long-term pump-and-treat.	**High.** All PTMs are treated. Treatment of materials via on-site thermal desorption rather than a combination of *in situ* solidification and thermal desorption provides additional groundwater restoration, including potential removal of benzene exceeding MCLs, compared to Alternative 9.	**Low.** Similar to Alternative 9 but with even greater short-term impacts due to greater extent of removal/on-site thermal treatment instead of *in situ* solidification. Time to achieve RAOs is estimated to be approximately 15 years.	**Low.** Technical challenges are even greater than for Alternative 9 due to the complexities of shoring and dewatering for very deep excavations.	380	29	409

Notes:

Estimated present worth costs are in 2013 dollars, and were calculated using a discount factor of 1.6 percent. The itemized estimates are provided in Appendix D.

ARAR = applicable or relevant and appropriate requirement
DNAPL = dense non-aqueous phase liquid
MC = May Creek
MCL = maximum contaminant level
OM&M = operation, maintenance, and monitoring
PRB = permeable reactive barrier
PTM = principal threat materials
QP-S = Quendall Pond-Sediment
QP-U = Quendall Pond-Upland
RAO = remedial action objective
RR = Railroad

Table 8-2 - Comparative Rating of Remedial Alternatives

Quendall Terminals
Renton, Washington

		Threshold Criteria		NCP Balancing Criteria				
	Remedial Alternative	Protective of Human Health and the Environment?	Complies with ARARs	Long-Term Effectiveness and Permanence	Reduction of Toxicity, Mobility, or Volume through Treatment	Short-Term Effectiveness	Implementability	Estimated Present Worth Cost [2] ($M)
1	No Action (Baseline for Comparison)	No	No	○	○	◑	●	0
2	Containment	Yes	(Note 1)	○	○	●	●	$26
3	Containment with Targeted PTM Solidification (RR and MC DNAPL Areas)	Yes	(Note 1)	○	○	●	●	$31
4	Containment with Targeted PTM Removal (TD, QP-S, and QP-U DNAPL Areas)	Yes	(Note 1)	◑	○	◑	◑	$44
5	Containment with Targeted PTM Solidification (RR, MC, and QP-U DNAPL Areas and ≥ 4-Foot-Thickness) and Removal (TD and QP-S DNAPL Areas)	Yes	(Note 1)	◑	◑	◑	◑	$47
6	Containment with Targeted PTM Solidification (RR and MC DNAPL Areas and ≥ 2-Foot-Thickness) and Removal (TD, QP-S, and QP-U DNAPL Areas)	Yes	(Note 1)	◑	◑	◑	◑	$61
7	Containment with PTM Solidification (Upland) and Removal (Sediment)	Yes	(Note 1)	●	●	○	◑	$80
8	Containment with PTM Removal (Upland and Sediment)	Yes	(Note 1)	●	●	○	○	$140
9	Containment with Solidification and Removal of Contaminated Soil and Removal of Contaminated Sediment	Yes	(Note 1)	●	●	○	○	$262
10	Containment with Removal of Contaminated Soil and Sediment	Yes	(Note 1)	●	●	○	○	$409

Notes:

[1] Complies with all ARARs except the Safe Drinking Water Act, which requires achievement of groundwater MCLs throughout the Site.

[2] Estimated mid-range present worth costs are in 2013 dollars, and were calculated using a discount factor of 1.6 percent. The itemized estimates are provided in Appendix D.

Legend:

○	The alternative rates low for the criterion.
◑	The alternative rates moderate for the criterion.
●	The alternative rates high for the criterion.



Quendall Terminals Site Location and Vicinity Map

Quendall Terminals Feasibility Study Report
Renton, Washington

Service Layer Credits: Copyright: ©2012 Esri, DeLorme, NAVTEQ Sources: Esri, DeLorme, NAVTEQ, TomTom, Intermap, iPC, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri

Aspect CONSULTING | ARCADIS

FIRM: ASPECT
DRAWN BY: EAH

FIGURE NO. 1-1

GIS Path: T:\projects_8\Quendall\Quendall FS Draft Final\Working\FS_Review_June2013\1-1 Site Location and Vicinity.mxd || Coordinate System: NAD 1983 StatePlane Washington North FIPS 4601 Feet || Date Saved: 6/14/2013 || User: ehealy || Print Date: 6/27/2013

Legend

- Shoreline
- Monitoring Well
- Wellpoint
- Structure
- Property Boundary
- Puget Sound Energy (PSE) Easement Boundary
- City Right-of-Way (R.O.W.) Easement Boundary
- Sewer Easement Boundary
- City Water Line Easement Boundary
- Puget Sound Energy (PSE) Submarine Cable Easement Boundary

Surface Water Features and Stormwater Control Structures

- Detention Pond
- Stormwater Drainage Ditch with Silt Fence and/or Rock Check Dams (Approximate Location)
- Overland Drainage Flow Direction
- Ditch Flow Direction

Notes:

1) Vertical datum is North American Vertical Datum 1988 (NAVD 88).

2) Wellpoints with *'s, WP-19 A/B/C and WP-20 A/B, were confirmed to still exist in September 2002. WP-21C could not be located at that time. Attempts to locate remaining wellpoints have not been made since Retec last sampled them in 2001.

3) "City" refers to City of Renton in easement labels.

4) The southern boundary of the PSE Easement is the northern boundary of the Quendall Property.

N

0 200 400

Feet

King County Sewer Easement
PSE Submarine Cable Easement
King County Sewer Easement
King County Sewer Easement
OUTER HARBOR LINE
INNER HARBOR LINE
INNER HARBOR LINE
Lake Washington
Sand Spit
Football Northwest Property (Former Baxter Site)
PSE Energy Substation
PSE Easement (Note 4)
King County Sewer Easement
Burlington Northern R.O.W.
Hazelwood Lane
Quendall Pond
T-Dock Remnant
Oil Dock
Shallow Interceptor Swale
Shallow Interceptor Swale
City Water Line Easement
City Sewer Easement
Office
Truck Scales
City R.O.W. Easement
City Sewer Easement
South Detention Pond
Lake Washington Blvd
405
On-Ramp
Conner Homes Property (Former Barbee Mill Site)

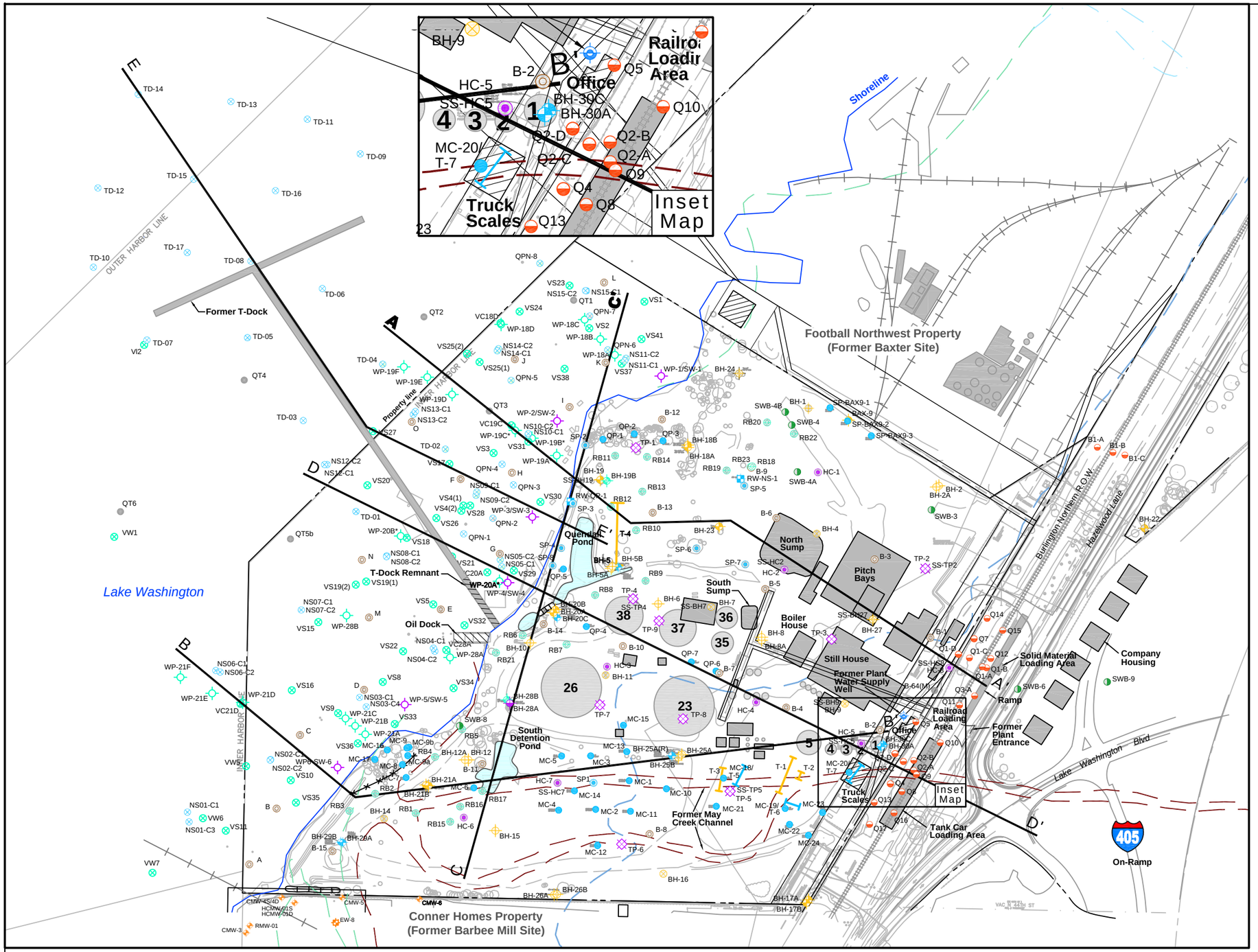
DRAFT FINAL
October 14, 2013

Summary of Current Site Features

Quendall Terminals Feasibility Study Report
Renton, Washington

Aspect Consulting	ARCADIS	FIRM: ASPECT DRAWN BY: JJP/DAH/PMB	FIGURE NO. 2-1

CAD Path: Q:\Quendall\020027 Quendall Terminals\2013-06 FS Draft Final\020027-21.dwg Figure 2-1 (11 x 17) || Coordinate System: NAD 1983 State Plane Washington North FIPS 4601 Feet || Date Saved: Jun 27, 2013 3:17pm || User: scudd



Summary of Explorations by Consultant

Consultant	Year	Exploration Type	Exploration ID	Map Symbol
Anchor QEA	2009	Subsurface Sediment Core	TD-01 through TD-17	
Aspect Consulting	2007	Monitoring Wells	CMW-1 through CMW-6	
	2007	Extraction Wells	EW-1 through EW-8	
	2009	Monitoring Wells	BH-5B, BH-25A(R), BH-29A, BH-29B, BH-30A, BH-30C	
		Soil Borings	QP-1 through QP-7, MC-1 through MC-24 SP-BAX9-1 through SP-BAX9-3	
		Trenches	T-5 through T-7	
	2003	Monitoring Wells	RW-NS-1, RW-QP-1	
		Soil Borings	SP1 through SP8	
		Surface Soil Samples	SS-BH7, SS-BH9, SS-BH19, SS-BH27, SS-TP2, SS-HC2, SS-HC5, SS-HC7, SS-HC8	(a)
Pinnacle Geosciences	2008	Soil Borings	Q1 through Q17, B1-A through B1-C	
Retec	2001	Soil Borings	RB1 through RB23	
	2001	Subsurface Sediment Core	WP-18 through WP-28	
	2000	Monitoring Wells	BH-19B, BH-28B	
	1997	Subsurface Sediment Core	VS-1 through VS-41, VC18 through VC28 VW-1 through VW-7	
Shannon & Wilson	1997	Soil Borings	SWB-3, SWB-4, SWB-4A, SWB-4B, SWB-8	
Hart Crowser	1997	Surface Sediment Samples	WP-1/SW-1 through WP-6/SW-6	
	1996, 1995	Soil Borings	HC-1 through HC-8	
		Monitoring Wells	BH-28A	
		Test Pits	TP-1 through TP-9	
Woodward Clyde	1990	Monitoring Wells	BH-24, BH-25A, BH-25B, BH-26A, BH-26B, BH-27	
Woodward Clyde	1988	Monitoring Wells	BH-17A, BH-17B, BH-18A, BH-18B, BH-19, BH-20A, BH-20B, BH-21A, BH-21B, BH-22, BH-23, BAX-9	
Woodward Clyde	1983	Monitoring Wells	BH-1, BH-2, BH-2A, BH-5, BH-5A, BH-6, BH-8, BH-8A, BH-10, BH-12, BH-12A, BH-15	
		Soil Borings	BH-4, BH-7, BH-9, BH-11, BH-14, BH-16	
		Trenches	T-1 through T-4	
Twelker	1971	Soil Borings	B-1 through B-15, A through M	
Metro	1963	Soil Borings	B-64(M)	

Notes
(a) Surface soil samples co-located with previous explorations.
Exploration ID of the surface soil sample includes the ID of the previous exploration.

Legend

- Detention Pond
- Existing Structure
- 23 — Historical Tank with Tank Number
- Other Historical Feature
- Shoreline (2009)
- Shoreline (1936)
- Shoreline (1916)
- May Creek (1920)
- A A' — Cross Section Location and Designation

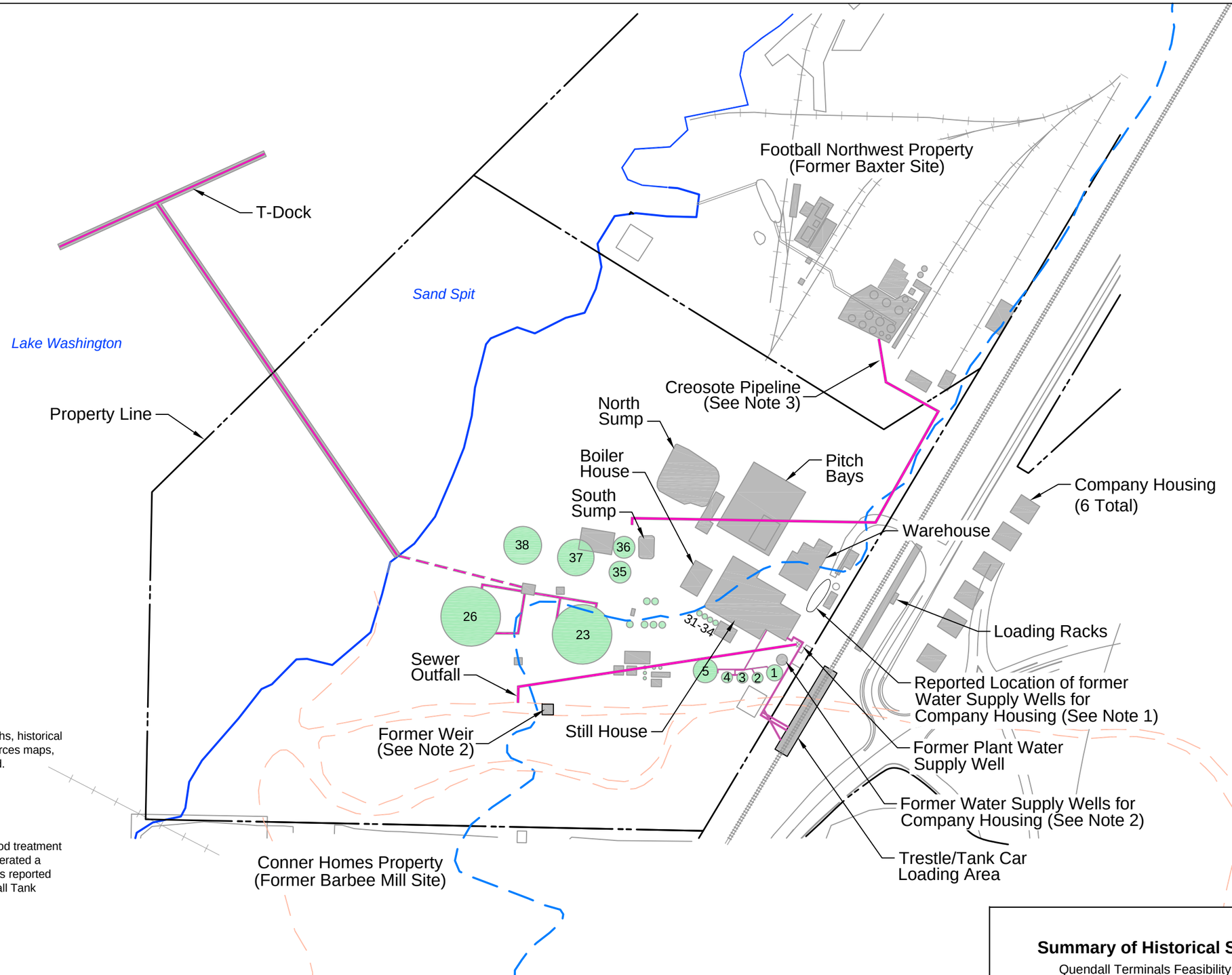
Exploration and Cross Section Location Map

Quendall Terminals Feasibility Study Report
Renton, Washington

DRAFT FINAL
October 14, 2013

FIRM:	FIGURE NO.
ASPECT CONSULTING / ARCADIS	3-1
DRAWN BY: JJP/DAH/SCC	

CAD Path: Q:\Quendall\020027 Quendall Terminals\2013-06 FS Draft Final\020027-31.dwg Figure 3-1 (11 x 17) || Coordinate System: NAD 1983 State Plane Washington North FIPS 4601 Feet || Date Saved: Oct 08, 2013 3:00pm || User: scudd



LEGEND

- 1916 Shoreline
- Former May Creek Channel
- Current Shoreline
- 1 — Tank with Tank Number
- Pipe
- Pipe (Location Inferred)
- Other Historical Structure

Notes:

Site feature locations based on aerial photographs, historical Washington State Department of Natural Resources maps, and 1918 and 1958 Plant Maps, except as noted.

1. Reported by Ward Roberts (Ecology 1989).
2. Based on 1918 Plant Map.
3. Pipeline transported creosote used in the wood treatment process to J.H. Baxter & Company, which operated a wood treatment plant from 1955 until 1982, as reported by Retec (2001). Origin identified as "Quendall Tank Farm"; details of connection not provided.
4. Tank Numbers from 1958 Plant Map.

N

0 200 400

Feet

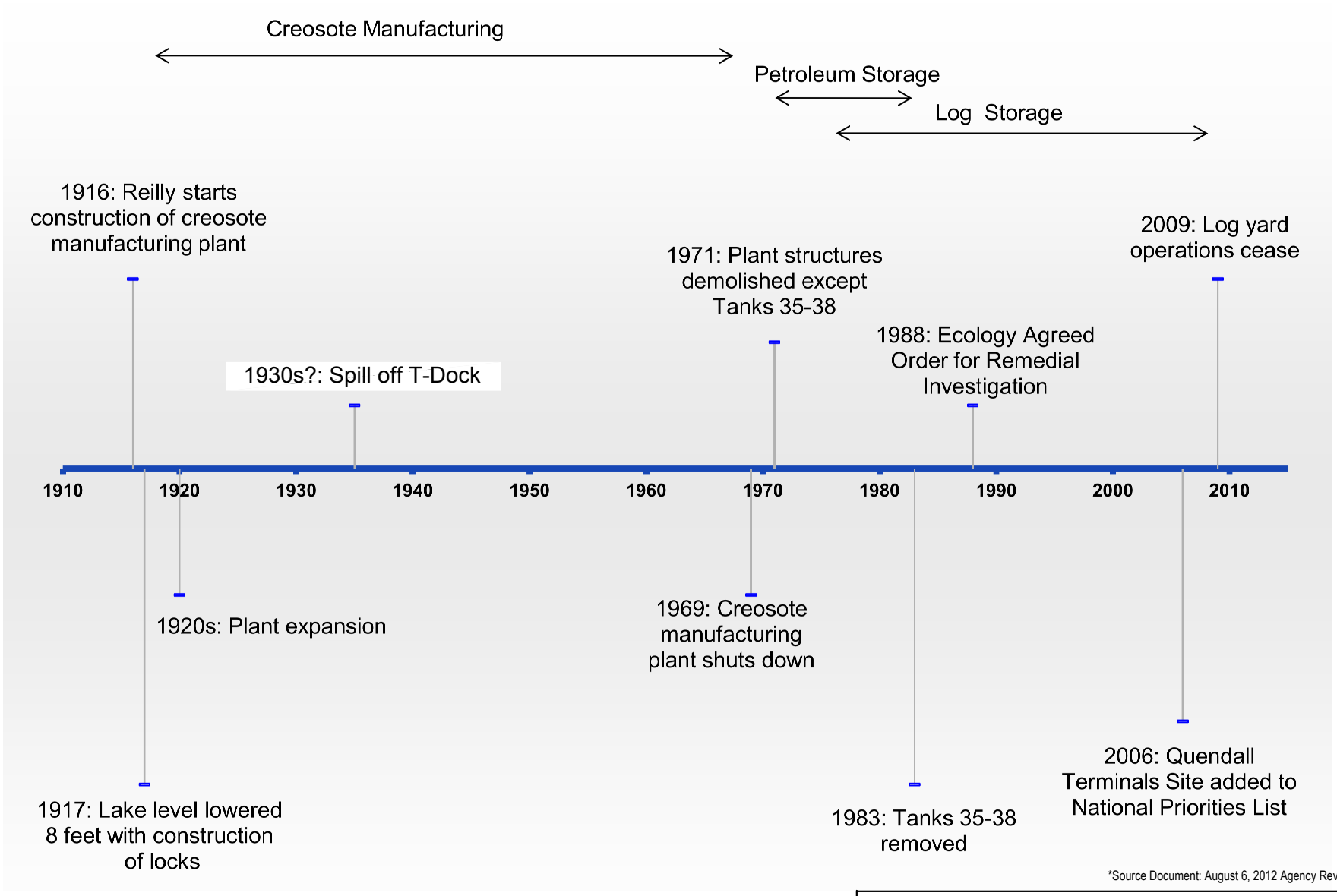
DRAFT FINAL
October 14, 2013

Summary of Historical Site Features

Quendall Terminals Feasibility Study Report
Renton, Washington

Aspect Consulting | ARCADIS | FIRM: ASPECT | DRAWN BY: PMB/SCC | FIGURE NO. 3-2

CAD Path: Q:\Quendall\020027 Quendall Terminals\2013-06 FS Draft Final\020027-32.dwg Figure 3-2 (11x17) || Coordinate System: NAD 1983 State Plane Washington North FIPS 4601 Feet || Date Saved: Jun 14, 2013 10:47am || User: scudd



*Source Document: August 6, 2012 Agency Review Draft FS

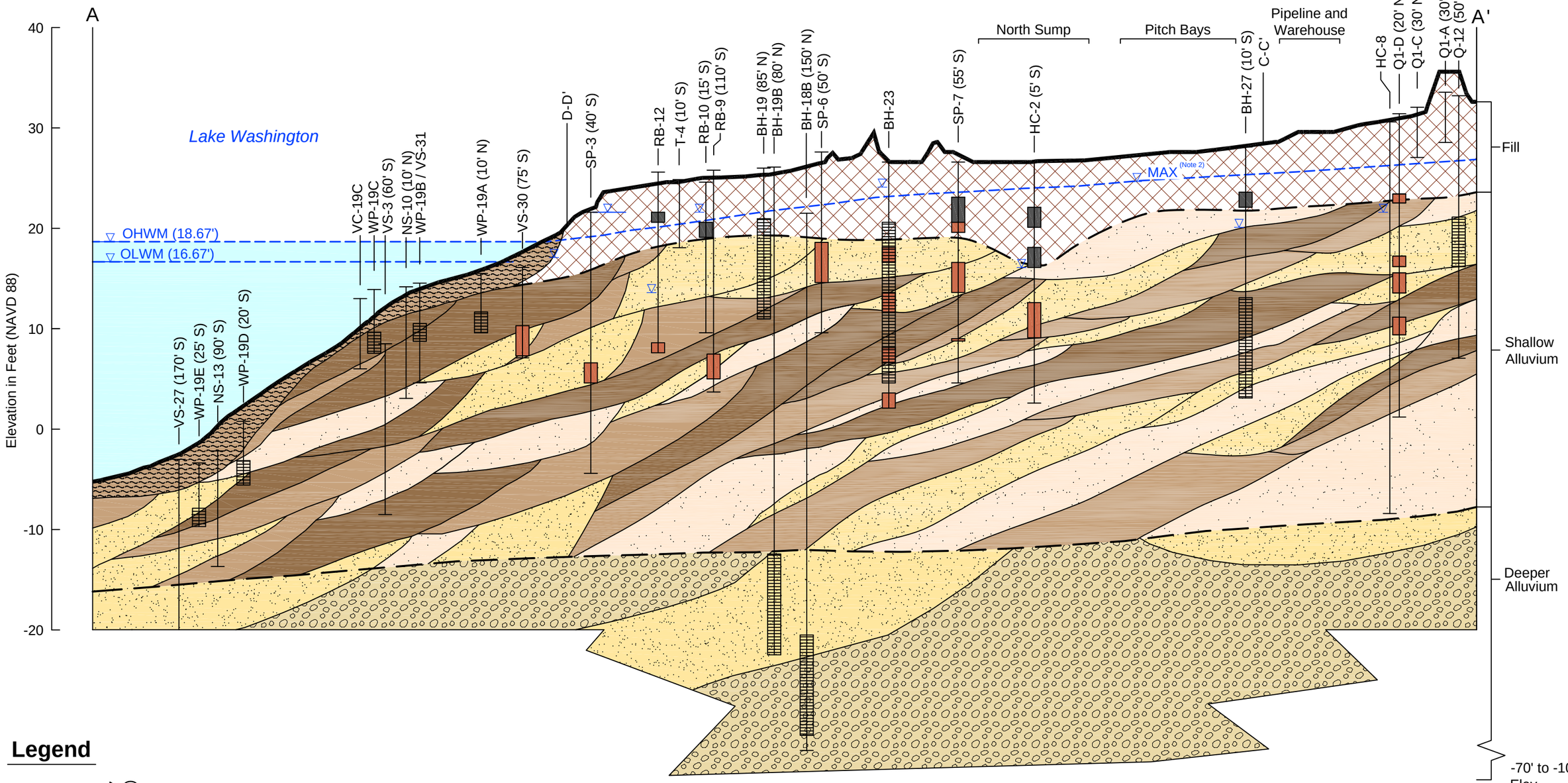
Timeline of Site Operations

Quendall Terminals Feasibility Study Report
Renton, Washington

DRAFT FINAL
October 14, 2013

Aspect CONSULTING	ANCHOR QEA	FIRM: ASPECT DRAWN BY: JJP/SCC	FIGURE NO. 3-3

CAD Path: Q:\Quendall\020027 Quendall Terminals\2013-06 FS Draft Final\020027-33.dwg 11x17 Landscape | | Date Saved: Sep 10, 2013 2:39pm | | User: scudd



Legend

BH-27 (10' S) — Exploration ID and Offset from Cross Section

Water Level Observed at Time of Drilling

- Solidified Tar Products
- Non-Aqueous Phase Liquids
- Well Screen

- Fill
- Organic Sandy Silt (Mud)
- Peat/Organic Silt
- Silt/Clayey Silt
- Sandy Silt/Silty Sand
- Sand
- Gravelly Sand/ Sandy Gravel

Horizontal Scale
0 100 200
Feet

Vertical Scale
0 10 20
Feet

Vertical Exaggeration X10

Notes:
1. Refer to Figure 3-1 for exploration locations.
2. Maximum observed groundwater elevation based on periodic monitoring of shallow aquifer monitoring wells.

DRAFT FINAL
October 14, 2013

Geologic Cross Section A-A'
Quendall Terminals Feasibility Study Report
Renton, Washington

Aspect Consulting | ARCADIS | FIRM: ASPECT | DRAWN BY: JJP/PMB/SCC | FIGURE NO. 3-4

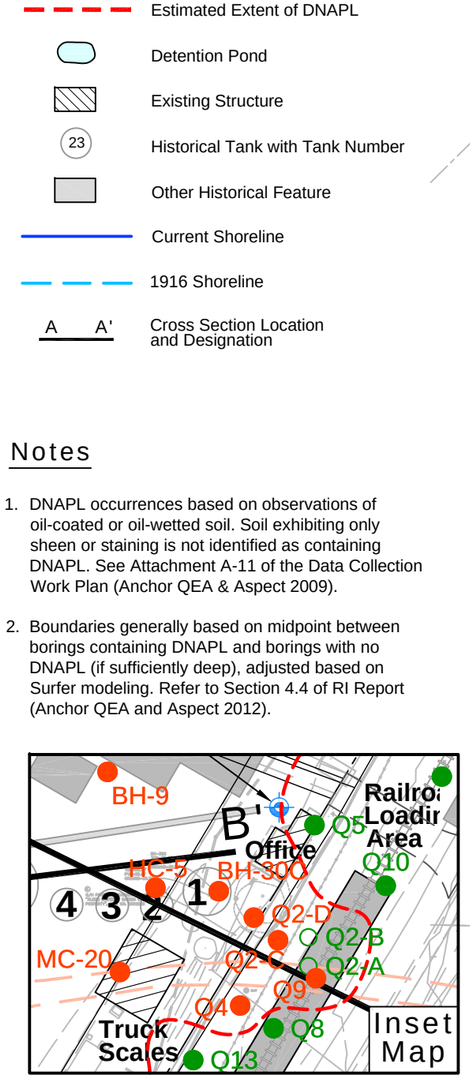
CAD Path: Q:\Quendall\020027 Quendall Terminals\2013-06 FS Draft Final\020027-34.dwg Figure 3-4 (11 x 17) || Coordinate System: NAD 1983 State Plane Washington North FIPS 4601 Feet || Date Saved: Jun 14, 2013 10:56am || User: scudd

Legend

- TD-08 — Boring with DNAPL
- VT-3 — Boring with no DNAPL
- EPA-2 — Boring with no DNAPL but base is above adjacent occurrences, or lack of adequate soil sample descriptions
- Estimated Extent of DNAPL
- Detention Pond
- Existing Structure
- 23 — Historical Tank with Tank Number
- Other Historical Feature
- Current Shoreline
- 1916 Shoreline
- A A' — Cross Section Location and Designation

Notes

1. DNAPL occurrences based on observations of oil-coated or oil-wetted soil. Soil exhibiting only sheen or staining is not identified as containing DNAPL. See Attachment A-11 of the Data Collection Work Plan (Anchor QEA & Aspect 2009).
2. Boundaries generally based on midpoint between borings containing DNAPL and borings with no DNAPL (if sufficiently deep), adjusted based on Surfer modeling. Refer to Section 4.4 of RI Report (Anchor QEA and Aspect 2012).



N
0 100 200
Feet
Inset Map

N
0 200 400
Feet
Site Plan

DRAFT FINAL
October 14, 2013

Site Plan Showing DNAPL Occurrences

Quendall Terminals Feasibility Study Report
Renton, Washington

FIRM:	FIGURE NO.
ASPECT CONSULTING / ARCADIS	3-5
DRAWN BY: PMB/SCC	

CAD Path: Q:\Quendall\020027 Quendall Terminals\2013-06 FS Draft Final\020027 35 Modified.dwg Figure 3-5 (11 x 17) || Coordinate System: NAD 1983 State Plane Washington North FIPS 4601 Feet || Date Saved: Oct 08, 2013 5:01pm || User: scudd

LEGEND

- Subsurface Core Location
- Grab Sample Location
- Well Location

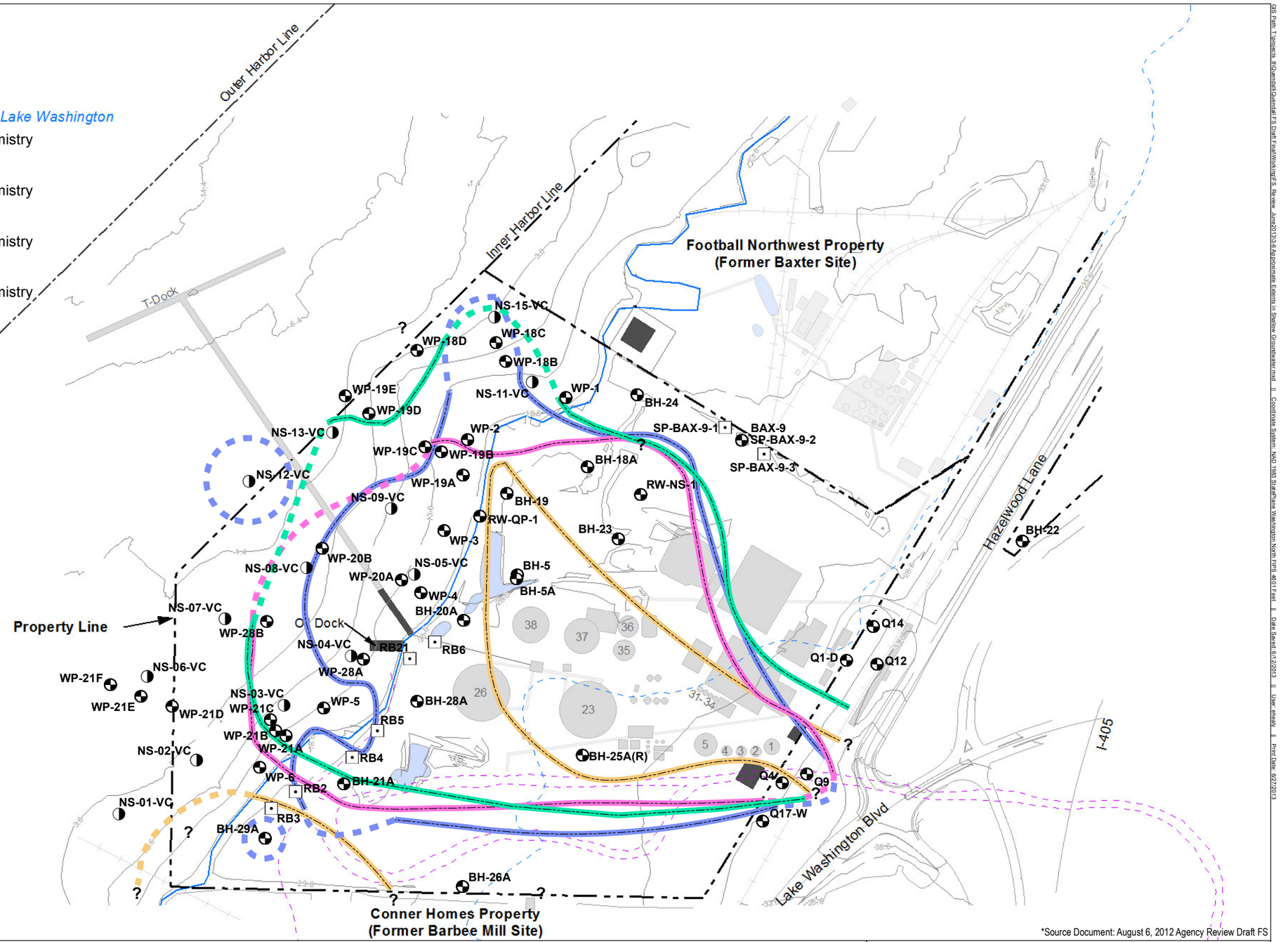
Benzene Detected
- Above MCL (5 µg/L)
- Inferred from Lines of Evidence other than Groundwater Chemistry

Naphthalene Detected
- Above PRG (1.4 µg/L)
- Inferred from Lines of Evidence other than Groundwater Chemistry

cPAHs (Benzo[a]Pyrene Equivalents) Detected
- Above MCL (0.2 µg/L)
- Inferred from Lines of Evidence other than Groundwater Chemistry

Arsenic Detected
- Above MCL (10 µg/L)
- Inferred from Lines of Evidence other than Groundwater Chemistry

- Current Shoreline
- Historical Shoreline (1916)
- Former May Creek Channel
- Property Boundary
- Existing Structure
- Historical Structure
- Detention Pond



*Source Document: August 6, 2012 Agency Review Draft FS

Notes:
1. Contour Intervals are 5 ft, NAVD 88.
2. See Figures 5.2-1, 5.2-8, 5.2-14, and 5.2-16 of the RI Report for basis of approximate extents (Anchor QEA and Aspect 2012). Naphthalene extent has been adjusted from the RI Report based on its lower PRG for the FS. Estimated extents do not consider dispersion.

N

0 200 400
Feet

DRAFT FINAL
October 14, 2013

Approximate Extents of Benzene, Naphthalene, cPAHs, and Arsenic in the Shallow Aquifer

Quendall Terminals Feasibility Study Report
Renton, Washington

Aspect Consulting	ANCHOR QEA	FIRM: ANCHOR QEA DRAWN BY: EBP	FIGURE NO. 3-6

GIS Path: T:\projects_8\Quendall\Quendall FS Draft Final\Working\FS_Review_June2013\5-6 Approximate Extents in Shallow Groundwater.mxd JL Coord Info: System: NAD 1983 StatePlane Washington North FIPS 4601 Feet JL Data Saved: 6/12/2013 JL User: ehsieh JL Print Date: 6/27/2013

LEGEND

- Well Location

Benzene Detected

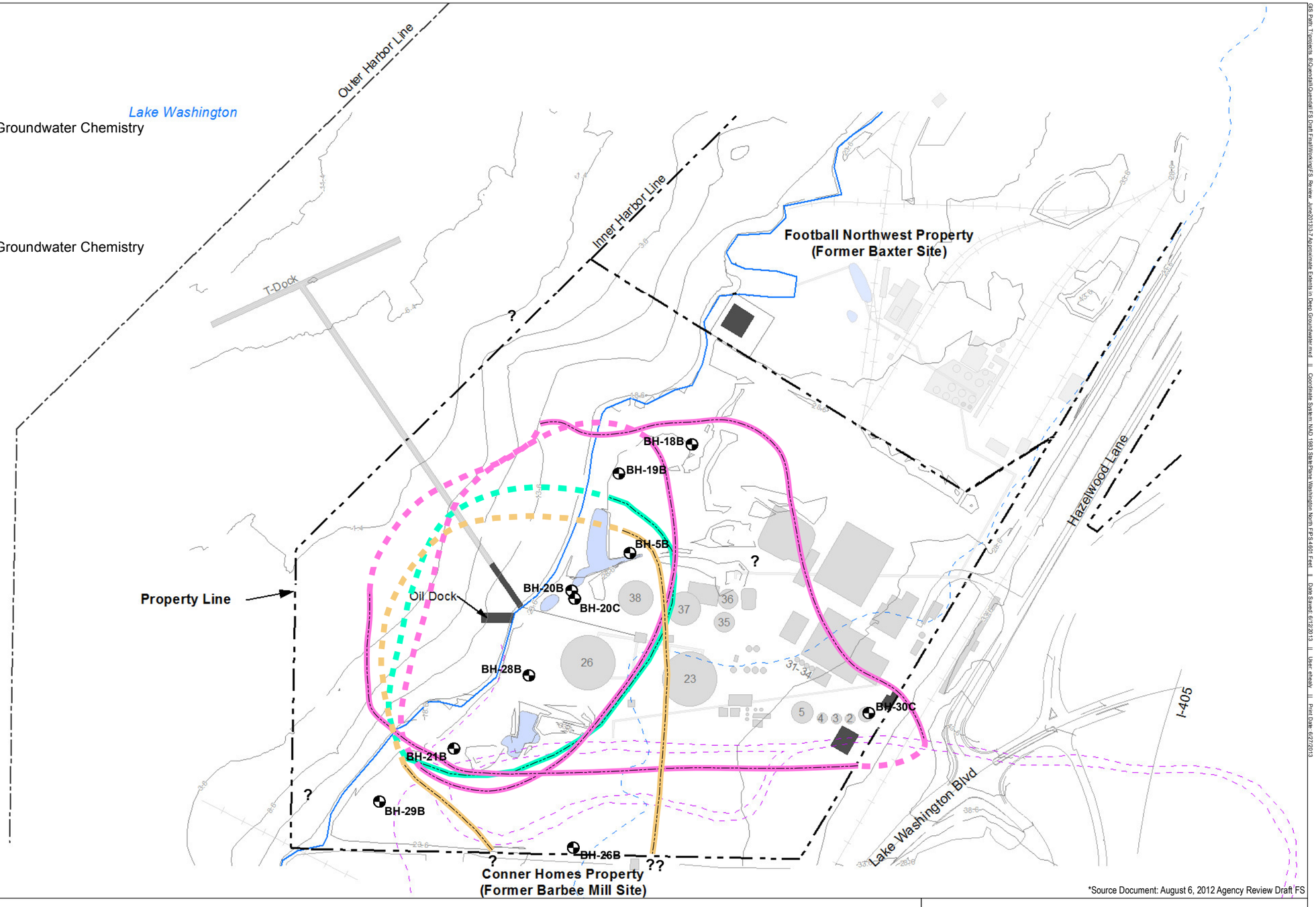
- Above MCL (5 µg/L)
- Inferred from Lines of Evidence other than Groundwater Chemistry

Naphthalene Detected

- Above PRG (1.4 µg/L)

Arsenic Detected

- Above MCL (10 µg/L)
- Inferred from Lines of Evidence other than Groundwater Chemistry
- Current Shoreline
- Historical Shoreline (1916)
- Former May Creek Channel
- Property Boundary
- Existing Structure
- Historical Structure
- Detention Pond



*Source Document: August 6, 2012 Agency Review Draft FS

Notes:

1. Contour intervals are 5 ft, NAVD 88.
2. cPAHs (Benzo[a]pyrene Equivalent) have not been detected above the PRG in wells completed in the Deep Aquifer.
3. See Figures 5.2-2, 5.2-9, 5.2-15, and 5.2-17 of the RI Report for basis of approximate extents (Anchor QEA and Aspect 2012). Naphthalene extent has been adjusted from the RI Report based on its lower PRG for the FS. Estimated extents do not consider dispersion.

N

0 200 400

Feet

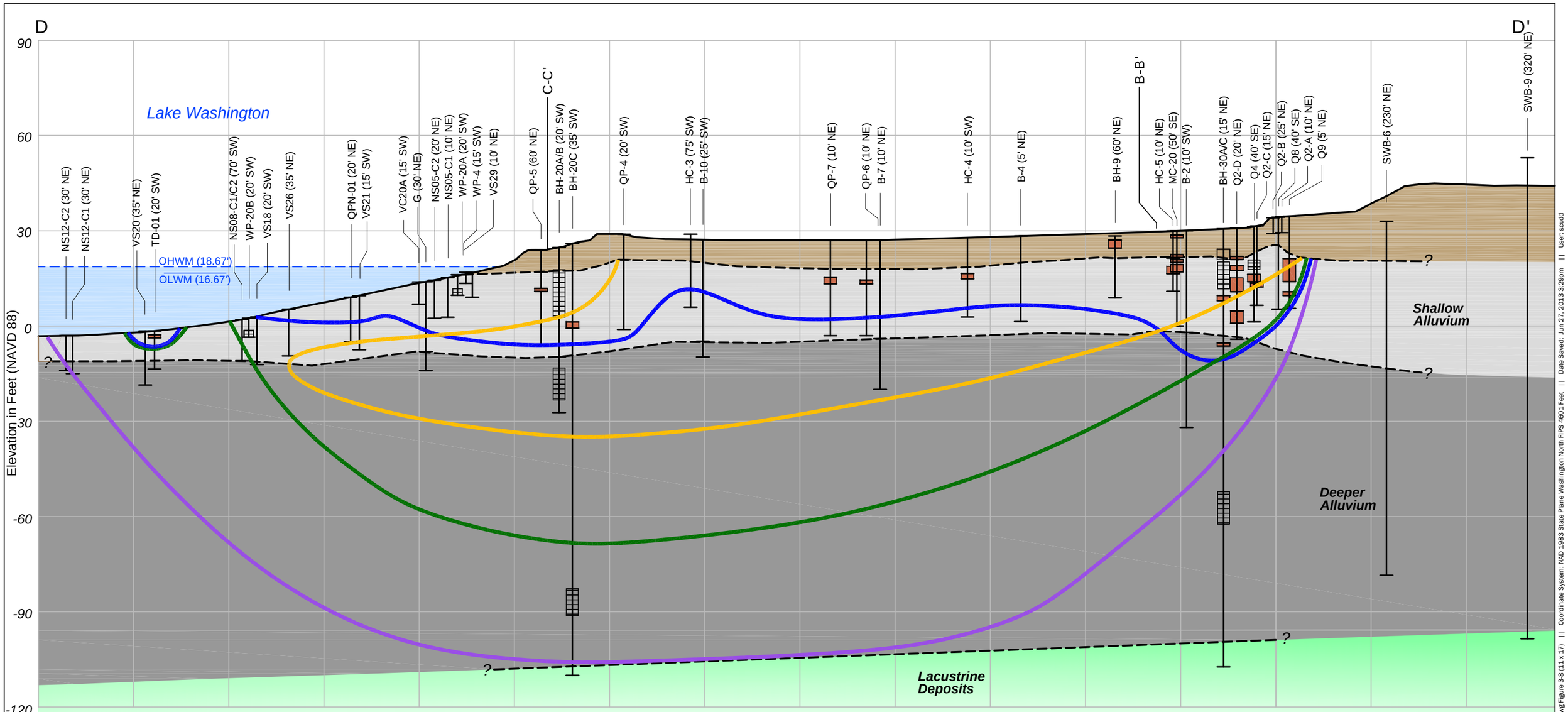
DRAFT FINAL
October 14, 2013

Approximate Extents of Benzene, Naphthalene, and Arsenic in the Deep Aquifer

Quendall Terminals Feasibility Study Report
Renton, Washington

Aspect CONSULTING	ANCHOR QEA	FIRM: ANCHOR QEA DRAWN BY: EBP	FIGURE NO. 3-7

GIS Path: T:\projects_8\Quendall\Quendall FS Draft Final\Working\FS_Review_June2013\3-7 Approximate Extents in Deep Groundwater.mxd JL Coordinate System: NAD 1983 StatePlane Washington North FIPS 4601 Feet JL Date Saved: 6/12/2013 JL User: ehealy JL Print Date: 6/27/2013



Legend

- NS12-C2 (30' NE) — Exploration ID and Offset from Cross Section
- Non-Aqueous Phase Liquid
- Well Screen
- Fill or Surface Sediment: Silt, Sand, Gravel, Wood and Mixed Debris
- Shallow Alluvium: Stratified Organic Silt, Peat, Sand
- Deep Alluvium: Sand and Gravels
- Lacustrine Deposits: Silt and Clay
- Estimated extent of Benzene exceeding PRG in groundwater and porewater (5 ug/L)
- Estimated extent of Naphthalene exceeding PRG in groundwater and porewater (1.4 ug/L)
- Estimated extent of cPAHs (Benzo[a]pyrene Equivalents) exceeding PRG in groundwater and porewater (0.2 ug/L)
- Estimated extent of Arsenic exceeding PRG in groundwater and porewater (10 ug/L)

Notes:

1. Refer to Figure 3-1 for exploration locations.
2. Vertical extents generally based on groundwater data from wells BH-20A, BH-20B, and BH-20C (Figures 5.2-1, 5.2-2, 5.2-8, 5.2-9, 5.2-14, 5.2-15, 5.2-16, and 5.2-17 of the RI Report (Anchor QEA and Aspect 2012)) and groundwater grab samples at BH-20C and BH-30C (Appendix A of the RI Report). Vertical extent of Benzo(a)pyrene approximate based on model predictions (Appendix A of this FS), adjusted to account for empirical data and artifacts from model cell size. Vertical extent of Naphthalene based on base of Deeper Alluvium.
3. Vertical extents of PRG exceedances on this figure consider fate and transport predictions of the RI groundwater model (Anchor QEA and Aspect 2012). Therefore, the estimated boundaries shown do not exactly match the estimated extent of contamination in Deep and Shallow groundwater shown on Figures 3-6 and 3-7.

Horizontal Scale
0 100 200
Feet

Vertical Scale
0 30 60
Feet

Vertical Exaggeration X3.33

Extent of Groundwater and Porewater Exceeding PRGs along Cross Section D-D'

Quendall Terminals Feasibility Study Report
Renton, Washington

DRAFT FINAL
October 14, 2013

Aspect CONSULTING | ARCADIS | FIRM: ASPECT | DRAWN BY: JJP/DAH/SCC | FIGURE NO. 3-8

CAD Path: Q:\Quendall\020027 Quendall Terminals\2013-06 FS Draft Final\020027-38.dwg Figure 3-8 (11 x 17) || Coordinate System: NAD 1983 State Plane Washington North FIPS 4601 Feet || Date Saved: Jun 27, 2013 3:29pm || User: scudd

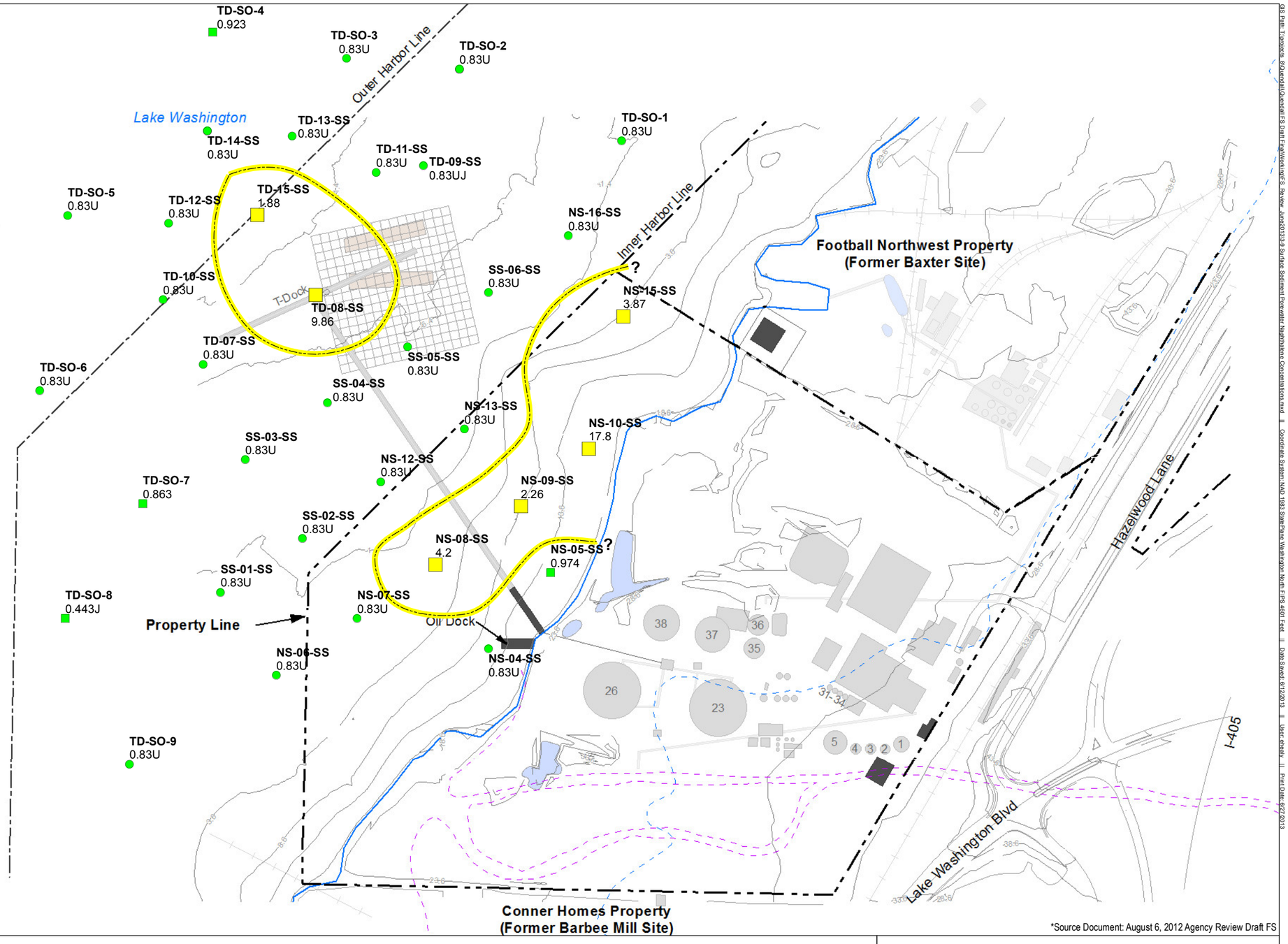
LEGEND

Non-Detected Naphthalene Concentration in µg/L

- <1.1
- ≥1.1 - 160
- ≥160

Detected Naphthalene Concentration in µg/L

- <1.1
- ≥1.1 - 160
- ≥160
- Approximate Extent of Area Exceeding EPA Region 3 BTAG Surface Water Screening Value (1.1 µg/L)
- Current Shoreline
- Historical Shoreline (1916)
- Former May Creek Channel
- Property Boundary
- Existing Structure
- Historical Structure
- Detention Pond
- Sand Placement Grid
- Dry Dock Concrete



*Source Document: August 6, 2012 Agency Review Draft FS

Notes:

1. Contour Intervals are 5 ft, NAVD 88.
2. U = Non-detect
3. J = Estimated value
4. The PRG screening level for naphthalene in sediment porewater is the EPA Region 3 Biological Technical Assistance Group (BTAG) Surface Water Screening Value of 1.1 micrograms per liter (µg/L). Exceedances of this screening level are shown on this figure.

0 200 400
Feet

DRAFT FINAL
October 14, 2013

Surface Sediment Porewater Naphthalene Concentrations

Quendall Terminals Feasibility Study Report
Renton, Washington

Aspect Consulting	ANCHOR QEA	FIRM: ANCHOR QEA DRAWN BY: EBP	FIGURE NO. 3-9

GIS Path: T:\projects_8\Quendall\Quendall FS Draft Final\Working\FS_Review_June2013\3-9 Surface Sediment Porewater Naphthalene Concentrations.mxd JL Coordinate System: NAD 1983 StatePlane Washington North FIPS 4601 Feet JL Date Saved: 6/12/2013 JL User: ehealy JL Print Date: 6/27/2013

LEGEND

Non-Detected Naphthalene Concentration in µg/L

- <1.1
- ≥1.1 - 160
- ≥160

Detected Naphthalene Concentration in µg/L

- <1.1
- ≥1.1 - 160
- ≥160

- Approximate Extent of Naphthalene Concentrations Exceeding EPA Region 3 BTAG Surface Water Screening Value (1.1 µg/L)
- Approximate Extent of Naphthalene Concentrations Exceeding MTCA Method B Drinking Water Criterion (160 µg/L)
- Current Shoreline
- Historical Shoreline (1916)
- Former May Creek Channel
- Property Boundary
- Existing Structure
- Historical Structure
- Detention Pond
- Sand Placement Grid
- Dry Dock Concrete

Location Name NS-012-VC
0 - 4 in – **1.5**
8- 12 in – **0.72J**
20 - 24 in – **0.83U**
36- 40 in – **0.83U**

Lake Washington
Outer Harbor Line
Inner Harbor Line
T-Dock
Property Line
Oil Dock
Football Northwest Property
(Former Baxter Site)
Conner Homes Property
(Former Barbee Mill Site)
Hazelwood Lane
Lake Washington Blvd
I-405

NS-15-VC: 0.83U, **2.02**, **2.64**, **5.03**
NS-14-VC: NA, 0.83U, NA, NA
NS-13-VC: 0.83U, 0.83U, 0.83U, 0.83U
NS-12-VC: **1.5**, 0.72J, 0.83U, 0.83U
NS-11-VC: NA, NA, 0.83U, 0.83U
NS-10-VC: NA, NA, **1150**, NA
NS-09-VC: **2.6**, NA, NA, NA
NS-08-VC: **2.5**, **6.34**, **5.73**, **8.36**
NS-07-VC: 0.83U, 0.83U, 0.83U, 0.83U
NS-06-VC: 0.83U, 0.83U, 0.83U, NA
NS-05-VC: **332J**, **844J**, **17.6**, **7.01**
NS-04-VC: 0.83U, 0.83U, **2.23**, 0.84
NS-03-VC: 0.83U, NA, NA, **52**
NS-02-VC: 0.83U, 0.83U, 0.83U, 0.49J
NS-01-VC: 0.83U, NA, NA, NA

*Source Document: August 6, 2012 Agency Review Draft FS

Notes:
1. Contour Intervals are 5 ft, NAVD 88.
2. U = Non-detect
3. J = Estimated value
4. The PRG screening level for naphthalene in sediment porewater is the EPA Region 3 Biological Technical Assistance Group (BTAG) Surface Water Screening Value of 1.1 micrograms per liter (µg/L). Exceedances of this screening level are shown in bold on this figure. Exceedances of the Washington State Model Toxics Control Act (MTCA) Method B Drinking Water Criterion of 160 µg/L are also shown on this figure.
5. NA = Not Applicable. Sample not collected due to insufficient porewater recovery.
6. Stations with no results due to insufficient recovery have been omitted.

N

0 200 400
Feet

DRAFT FINAL
October 14, 2013

Subsurface Sediment Porewater Naphthalene Concentrations

Quendall Terminals Feasibility Study Report
Renton, Washington

Aspect CONSULTING | ANCHOR QEA

FIRM: ANCHOR QEA
DRAWN BY: EBP

FIGURE NO. 3-10

GIS Path: T:\projects_8\Quendall\Quendall FS Draft Final\Working\FS_Review_June2013\3-10 Subsurface_Sediment Porewater Naphthalene Concentrations.mxd JL Coordinate System: NAD 1983 StatePlane Washington North FIPS 4601 Feet JL Date Saved: 6/12/2013 JL User: ebahl JL Print Date: 6/27/2013

LEGEND

Detected Organic Carbon Normalized cPAH (B[a]P Equivalent) Concentration in mg/kg-OC

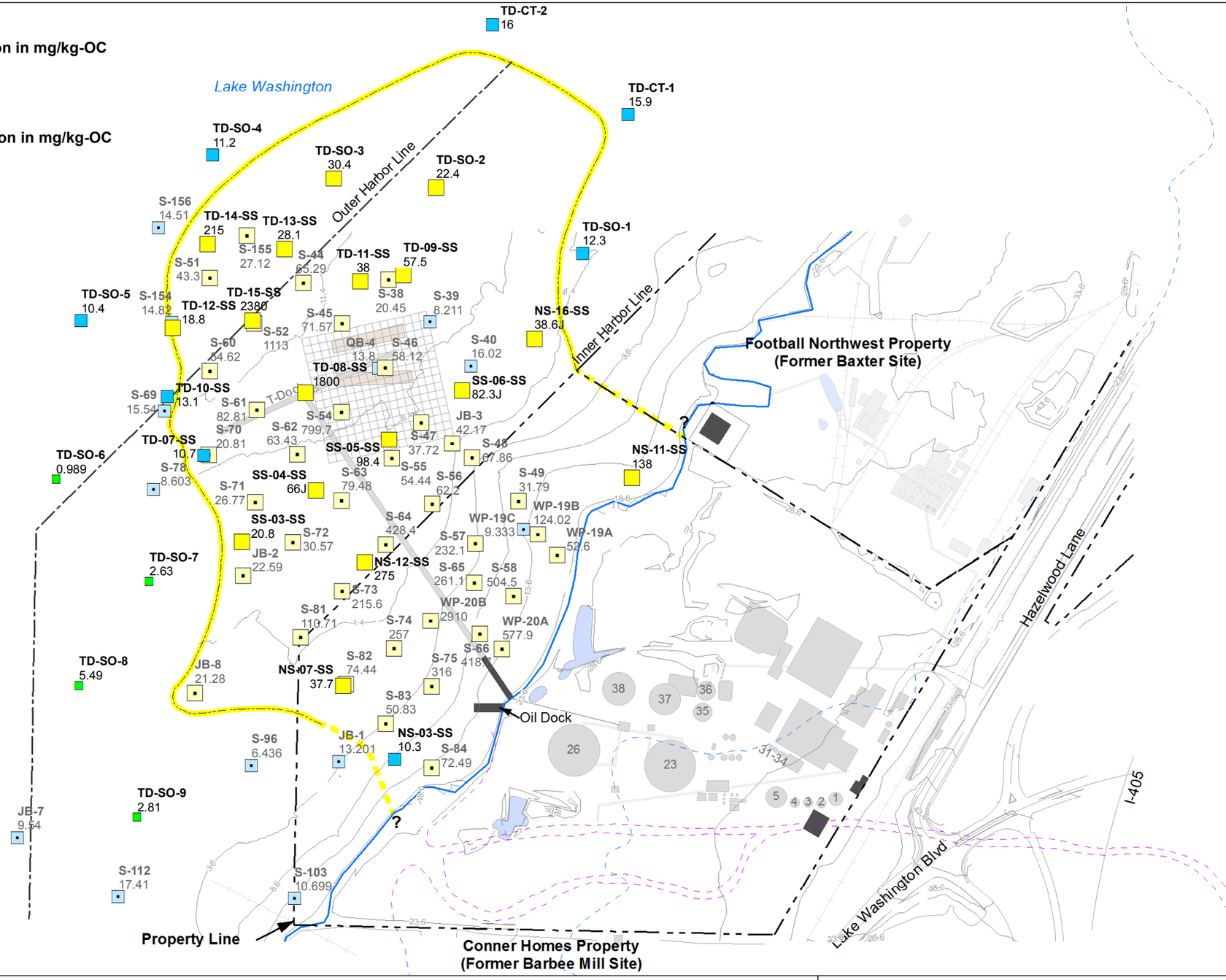
- <6.2
- ≥6.2 - 17.5
- ≥17.5

Historical Organic Carbon Normalized cPAH (B[a]P Equivalent) Concentration in mg/kg-OC

- <6.2
- ≥6.2 - 17.5
- ≥17.5

- Approximate Extent of Detected cPAH Concentrations Exceeding the Background Threshold Value (BTV)
- Inferred from Historical Data
- Current Shoreline
- Historical Shoreline (1916)
- Former May Creek Channel
- Property Boundary
- Existing Structure
- Historical Structure
- Detention Pond
- Sand Placement Grid
- Dry Dock Concrete

Basis of Screening Level Intervals
6.2 90% Upper Confidence Limit
17.5 Background Threshold Value (BTV)



Notes:

1. Contour intervals are 5 ft, NAVD 88.
2. U = Non-Detect
3. J = Estimated Value
4. The organic carbon normalized PRG screening level for cPAHs in surface bulk sediment of 6.2 milligrams per kilogram (mg/kg)-OC is the 90 percent upper confidence limit on the mean of site-specific background samples collected during the 2009 RI field investigation and documented in the RI Report (Anchor QEA and Aspect 2012).
5. The historical stations shown on this figure were sampled by Retec (in 1996 and 1997) and Anchor (in 2002 and 2003).

N

0 200 400

Feet

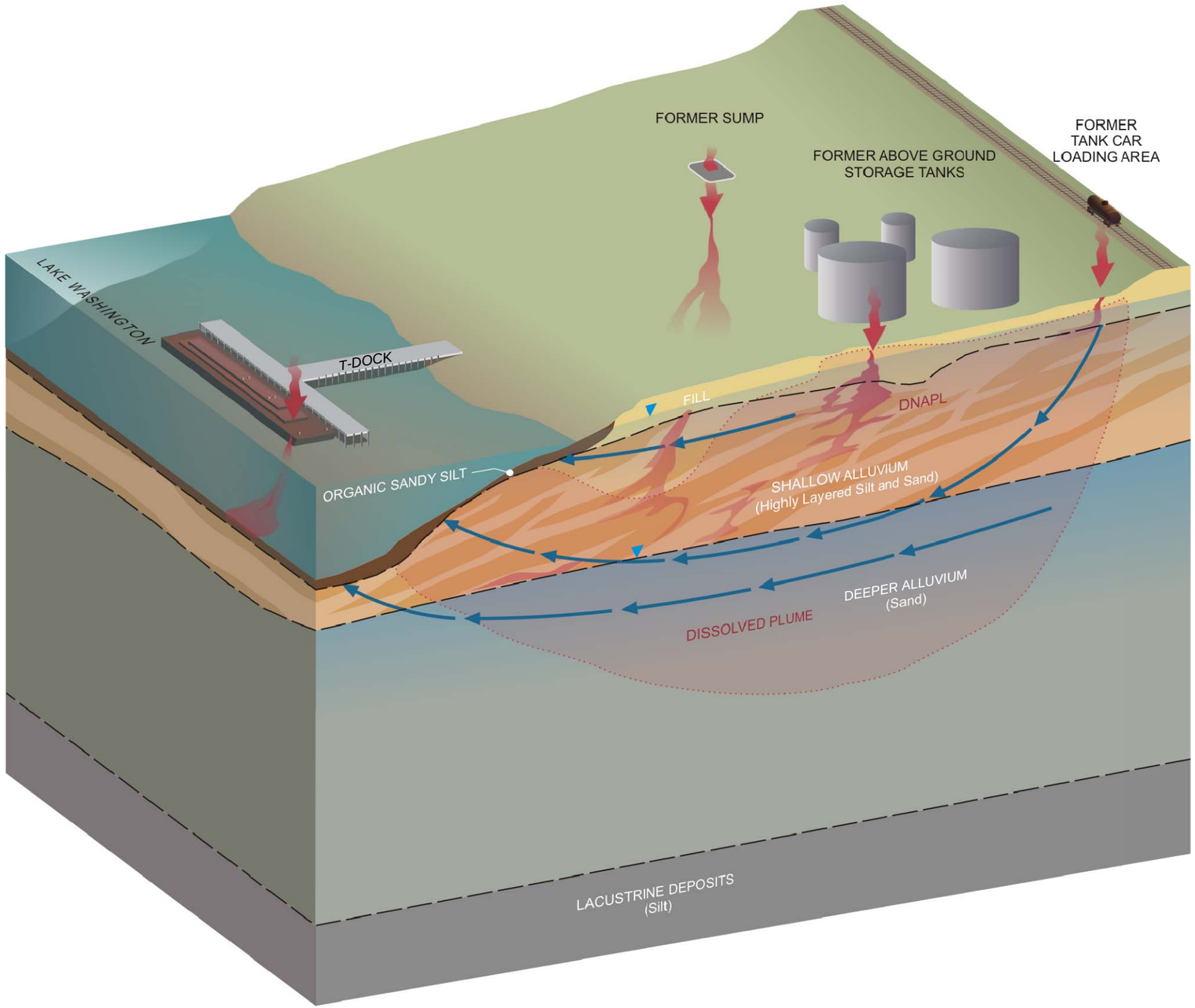
DRAFT FINAL
October 14, 2013

Surface Bulk Sediment Organic Carbon Normalized cPAH (Benzo[a]pyrene Equivalent) Concentrations

Quendall Terminals Feasibility Study Report
Renton, Washington

Aspect CONSULTING | ARCADIS | FIRM: ARCADIS | DRAWN BY: JC | FIGURE NO. 3-11

GIS Path: T:\projects_8\Quendall\Quendall FS Draft Final\3-11 Surface Bulk Sediment OCN cPAH BaP_Revised.mxd JL Coordinate System: NAD 1983 StatePlane Washington North FIPS 4601 Feet JL Date Saved: 6/14/2013 JL User: scudd JL Print Date: 6/14/2013



*Source Document: August 6, 2012 Agency Review Draft FS

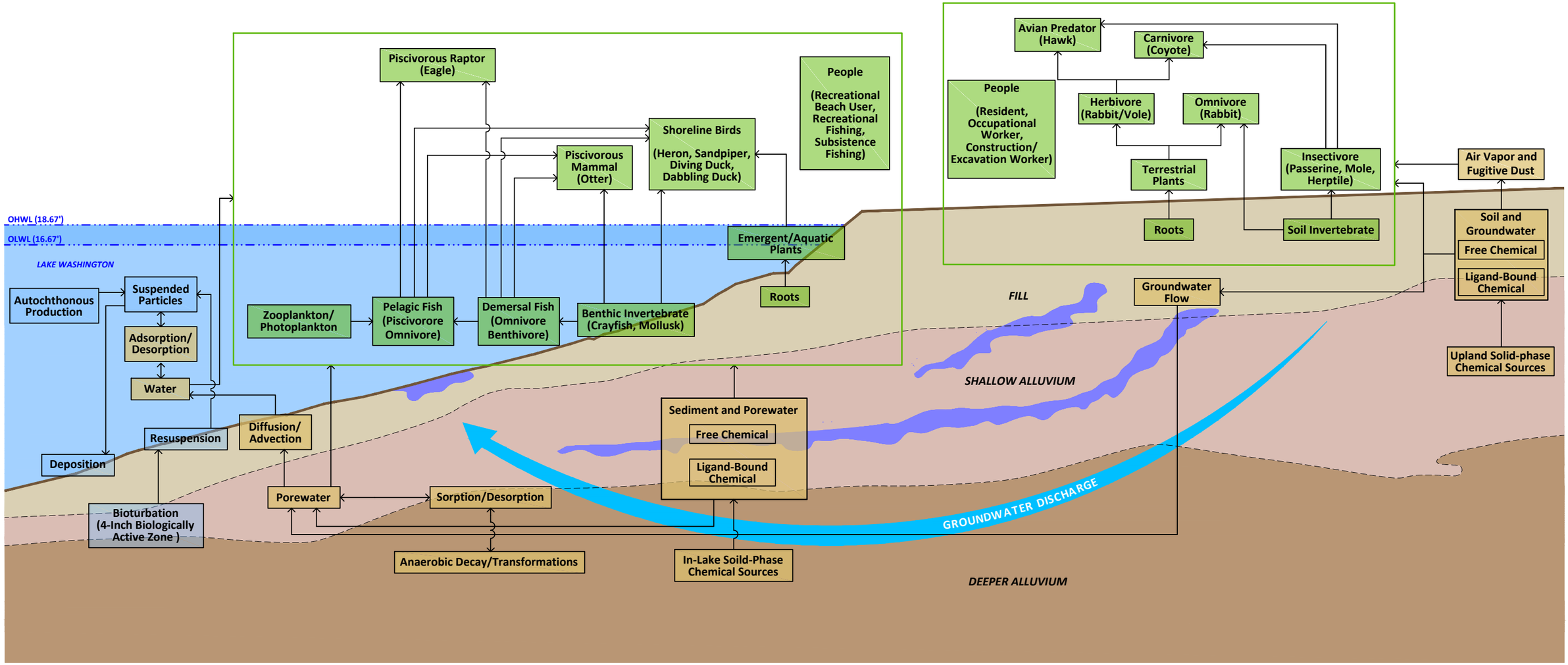
Graphic Illustration of the DNAPL Conceptual Site Model

Quendall Terminals Feasibility Study Report
Renton, Washington

DRAFT FINAL
October 14, 2013

Aspect CONSULTING	ANCHOR QEA	FIRM: ANCHOR QEA DRAWN BY: EBP	FIGURE NO. 3-12

GIS Path: T:\projects_8\Quendall\Quendall FS Draft Final\Working\FS_Review_June2013\3-12 Graphic Illustration of the DNAPL.mxd JL Coordinate System: NAD 1983 StatePlane Washington North FIPS 4601 Feet JL Date Saved: 6/27/2013 JL User: ebaily JL Print Date: 6/27/2013



LEGEND:

- Ground Surface
- Inferred Geologic Contact
- Shallow Alluvium
- Deeper Alluvium
- DNAPL
- Fill
- Hydrodynamics and Sediment Dynamics
- Biological Fate and Transport (Predation/Bioaccumulation/Biomagnification)
- Chemical Fate and Transport

*Source Document: August 6, 2012 Agency Review Draft FS

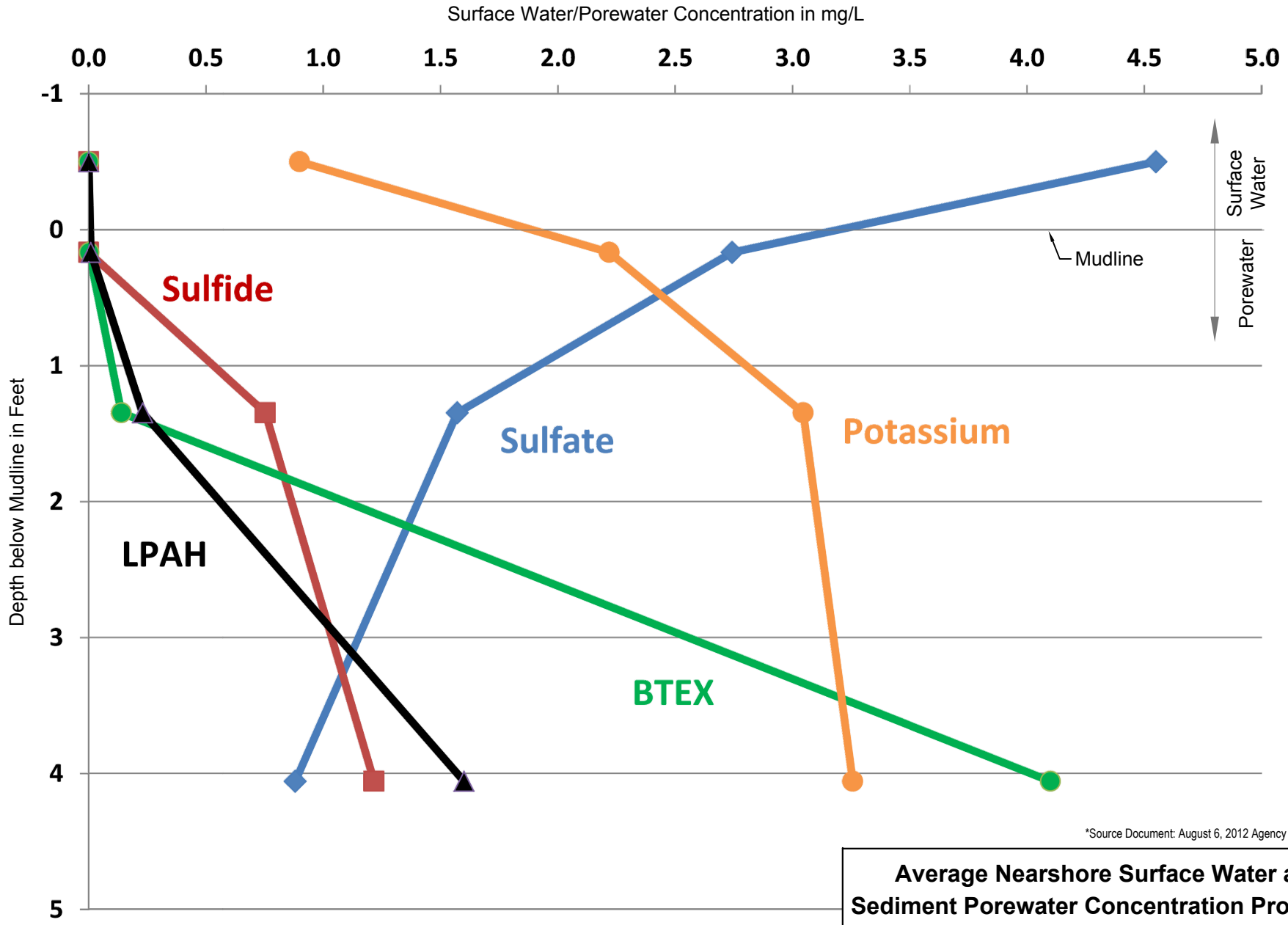
Graphic Illustration of the Contaminant Fate and Transport Conceptual Site Model

Quendall Terminals Feasibility Study Report
Renton, Washington

DRAFT FINAL
October 14, 2013

Aspect CONSULTING	ANCHOR QEA	FIRM: ANCHOR QEA DRAWN BY: EBP	FIGURE NO. 3-13

GIS Path: T:\projects_8\Quendall\Quendall FS Draft Final\Working\FS_Review_June2013\3-13 Graphic Illustration of Fate and Transport.mxd JL Coordinate System: NAD 1983 StatePlane Washington North FIPS 4601 Feet JL Date Saved: 6/27/2013 JL User: dbrady JL Print Date: 6/27/2013



*Source Document: August 6, 2012 Agency Review Draft FS

Average Nearshore Surface Water and Sediment Porewater Concentration Profiles of Key Fate and Transport Constituents

Quendall Terminals Feasibility Study Report

Renton, Washington

DRAFT FINAL
October 14, 2013

Aspect CONSULTING	ANCHOR QEA	FIRM: ANCHOR QEA DRAWN BY: DJH	FIGURE NO. 3-14

CAD Path: Q:\Quendall\020027 Quendall Terminals\2013-06 FS Draft Final\020027-314.dwg 11x17 Landscape | | Date Saved: Sep 10, 2013 3:10pm | | User: scudd

LEGEND:

- DNAPL
- Contaminated Groundwater
- Pitch
- Slag
- Groundwater Flow Direction

NOTE: Not to Scale

Residential Exposure
- Soil/Groundwater Contact
- Incidental Soil/ Groundwater Ingestion
- Drinking Water Ingestion
- Vapor/Dust Inhalation

Occupational Exposure
- Soil Contact
- Incidental Soil Ingestion
- Vapor/Dust Inhalation

Construction/Excavation Worker Exposure
- Soil/Groundwater Contact
- Incidental Soil Ingestion
- Vapor/Dust Inhalation

Recreational Beach User Exposure
- Sediment and Water Contact
- Incidental Sediment and Water Ingestion

Recreational and Subsistence Fishing
- Fish and Shellfish Ingestion
- Sediment Direct Contact
- Incidental Sediment Ingestion

Pelagic Fish

EXISTING SOIL (FILL)

STRATIFIED SILT, SAND, AND PEAT

LAKE WASHINGTON

Fish Exposure
- Sediment
- Surface Water

Leaks/Spills from Dock Transfer Piping

Spill from Freighter Off-Loading

Demersal Fish

Stratified Silt, Sand, and Peat

SAND AND GRAVEL

Benthic Invertebrates

*Source Document: August 6, 2012 Agency Review Draft FS

Graphic Illustration of Human Exposure Conceptual Site Model

Quendall Terminals Feasibility Study Report
Renton, Washington

DRAFT FINAL
October 14, 2013

Aspect CONSULTING	ANCHOR QEA	FIRM: ANCHOR	FIGURE NO. 3-15
		DRAWN BY: HEE	

CAD Path: Q:\Quendall\020027 Quendall Terminals\2013-06 FS Draft Final \020027-315.dwg 11x17 Landscape || Date Saved: Jun 27, 2013 4:27pm || User: scudd

Legend

- Current Shoreline (Ordinary High Water)
- Property Line
- A A' — Cross Section Location and Designation
- Detention Pond
- Existing Structure
- 23 — Historical Tank with Tank Number
- Other Historical Feature
- Estimated Extent of DNAPL
- Estimated Extent of PRG Exceedances in Groundwater (Subsurface Soil and Groundwater Area)
- Former May Creek Channel DNAPL Area
- Quendall Pond Upland DNAPL Area
- Quendall Pond Sediment DNAPL Area
- Former Railroad DNAPL Area
- T-Dock DNAPL Area
- Other Upland DNAPL Areas
- Other Aquatic DNAPL Areas
- Surface Soil Area*
- Surface and Subsurface Sediment Area*

* PRG Exceedance Areas

Notes

1. Refer to Section 4.4 for descriptions of the areas identified in the Legend.
2. Refer to Figure 3-5 for notes regarding delineation of DNAPL.

N

0 200 400

Feet

Areas Targeted for Remedial Action

Quendall Terminals Feasibility Study Report

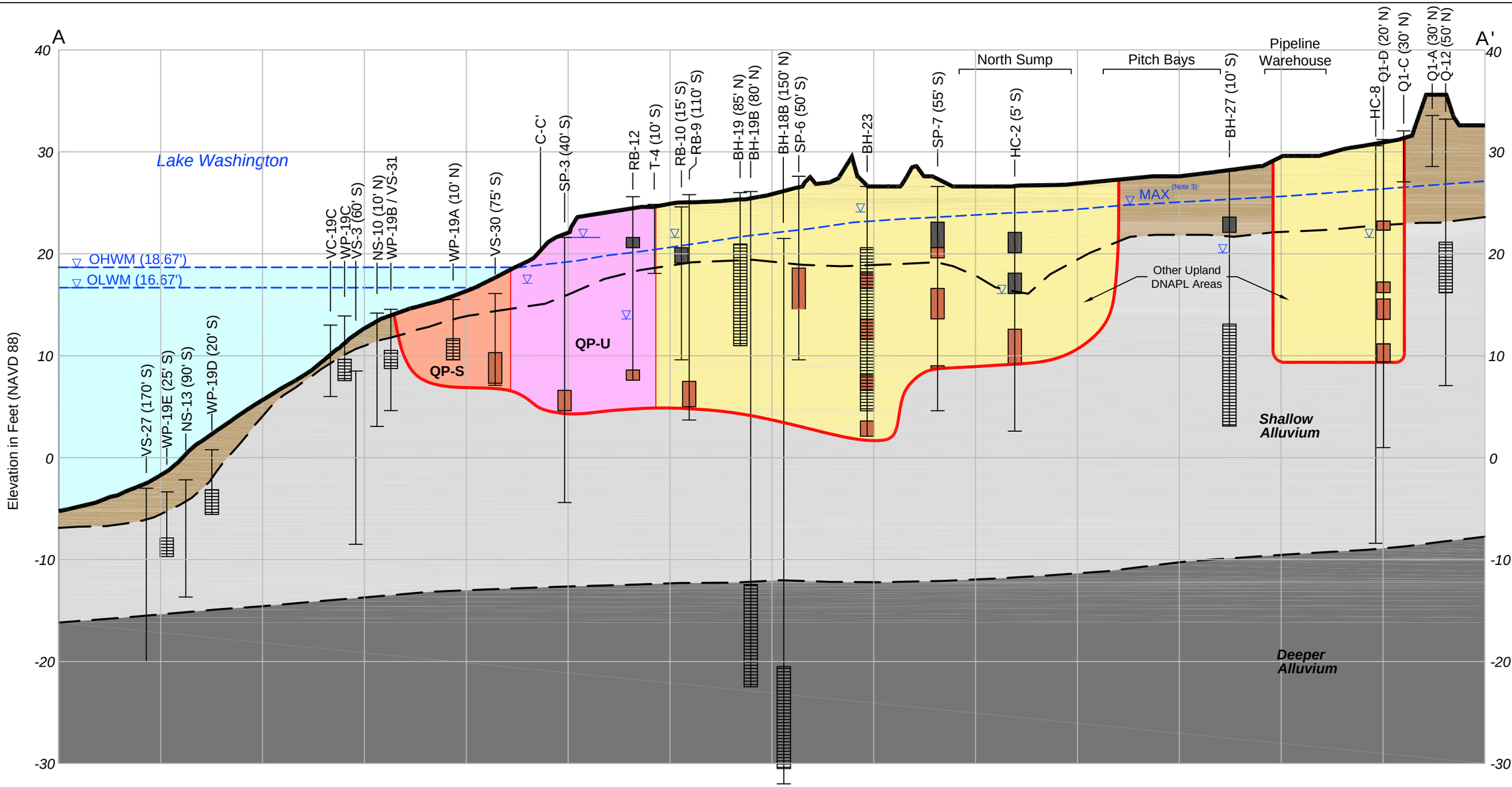
Renton, Washington

DRAFT FINAL

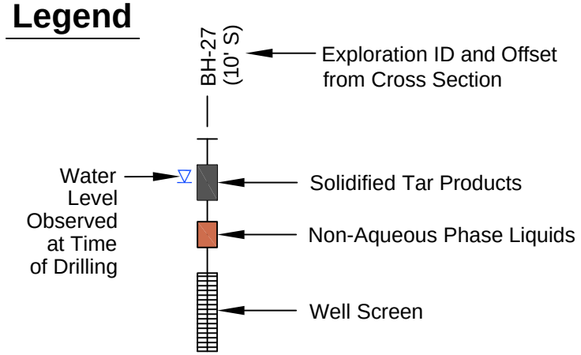
October 14, 2013

FIRM:	FIGURE NO.
ASPECT	4-1
DRAWN BY: JJP/DAH/SCC	

CAD Path: Q:\Quendall\020027 Quendall Terminals\2013-06 FS Draft Final\020027-41.dwg Figure 4-1 (11 x 17) || Date Saved: Oct 10, 2013 2:43pm || User: scudd



Legend



- Fill or Surface Sediment: Silt, Sand, Gravel, Wood and Mixed Debris
- Shallow Alluvium: Stratified Organic Silt, Peat, Sand
- Deeper Alluvium: Sand and Gravels
- Estimated Extent of DNAPL

Notes:
1. Refer to Figure 3-1 for exploration locations.
2. Figure 4-1 Notes and Legend also apply to this figure.
3. Maximum observed groundwater elevation based on periodic monitoring of shallow aquifer monitoring wells.

Horizontal Scale
0 — 100 — 200
Feet

Vertical Scale
0 — 10 — 20
Feet

Vertical Exaggeration x10

DRAFT FINAL
October 14, 2013

Estimated Extent of DNAPL along Cross Section A-A'

Quendall Terminals Feasibility Study Report
Renton, Washington

Aspect CONSULTING | ARCADIS | FIRM: ASPECT | DRAWN BY: JJP/DAH/SCC | FIGURE NO. 4-2

CAD Path: Q:\Quendall\020027 Quendall Terminals\2013-06 FS Draft Final\020027-42.dwg Figure 4-2 (11 x 17) || Coordinate System: NAD 1983 State Plane Washington North FIPS 4601 Feet || Date Saved: Jun 27, 2013 3:41pm || User: scudd

B

B'

Elevation in Feet (NAVD 88)

40
30
20
10
0
-10
-20
-30
-40

Lake Washington

OHWM (18.67')

OLWM (16.67')

(Note 3) MAX

WP-21F (38' S)
NS06-C1/C2 (15' N)
WP-21E (25' S)
WP-21D/VC21D
VS-16 (80' N)
VW-5 (90' S)
NS02-C1/C2 (50' S)
C (25' N)
VS-9 (100' N)
WP-21C (100' N)
WP-21B (100' N)/VS-35 (85' S)
WP-21A (100' N)/VS-36 (80' N)
RB-2
MC-17 (70' N)
BH-14 (50' S)
MC-8 (50' N)
MC-7 (25' N)
RB-1 (44' S)
BH-21B (15' N)
BH-21A (4' N)
BH-12 (60' N)
RB-16 (40' S)
SWB-8 (110' N)
RB-17 (15' S)
C-C'
HC-7 (5' N)
SP-1 (25' S)
MC-1 (30' S)
MC-10 (60' S)
BH-25A(R)
BH-25B
BH-25A
MC-18 (50' S)
TP-5 (60' S)
D-D'
MC-20 (70' S)
BH-9 (70' N)
HC-5 (15' S)
BH-30A/C (20' S)

MC

MC

MC

RR

Other Upland DNAPL Areas

Other Upland DNAPL Areas

Shallow Alluvium

Deeper Alluvium

-122.1' Bottom Elevation

Note: BH-30C well screen located from elevation -54' to -64'

Legend

MC-17 (70' N) — Exploration ID and Offset from Cross Section

Water Level Observed at Time of Drilling

Solidified Tar Products

Non-Aqueous Phase Liquids

Well Screen

Fill or Surface Sediment: Silt, Sand, Gravel, Wood and Mixed Debris

Shallow Alluvium: Stratified Organic Silt, Peat, Sand

Deeper Alluvium: Sand and Gravels

Estimated Extent of DNAPL

Notes:
1. Refer to Figure 3-1 for exploration locations.
2. Figure 4-1 Notes and Legend also apply to this figure.
3. Maximum observed groundwater elevation based on periodic monitoring of shallow aquifer monitoring wells.

Horizontal Scale

0 100 200

Feet

Vertical Scale

0 10 20

Feet

Vertical Exaggeration x10

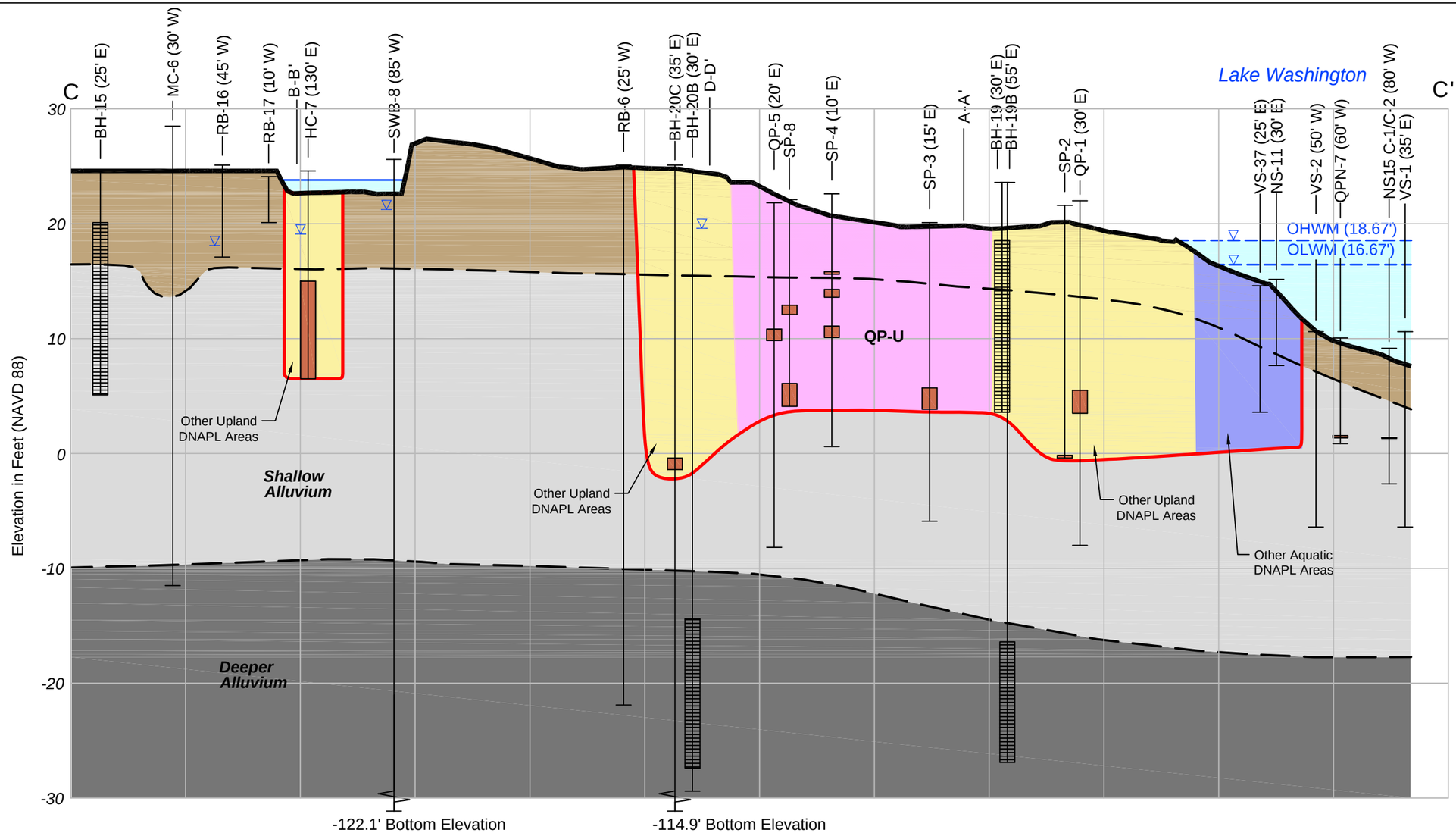
DRAFT FINAL
October 14, 2013

Estimated Extent of DNAPL along Cross Section B-B'

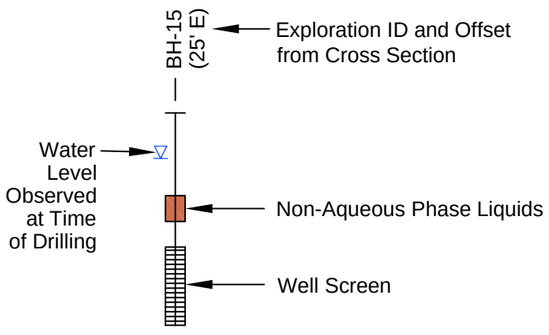
Quendall Terminals Feasibility Study Report
Renton, Washington

Aspect CONSULTING | ARCADIS | FIRM: ASPECT | DRAWN BY: JJP/DAH/SCC | FIGURE NO. 4-3

CAD Path: Q:\Quendall\020027 Quendall Terminals\2013-06 FS Draft Final\020027-43.dwg Figure 4-3 (11 x 17) || Coordinate System: NAD 1983 State Plane Washington North FIPS 4601 Feet || Date Saved: Aug 12, 2013 2:15pm || User: scudd



Legend



- Fill or Surface Sediment: Silt, Sand, Gravel, Wood and Mixed Debris
- Shallow Alluvium: Stratified Organic Silt, Peat, Sand
- Deeper Alluvium: Sand and Gravels
- Estimated Extent of DNAPL

Notes:
1. Refer to Figure 3-1 for exploration locations.
2. Figure 4-1 Notes and Legend also apply to this figure.

Horizontal Scale
0 100 200
Feet

Vertical Scale
0 10 20
Feet

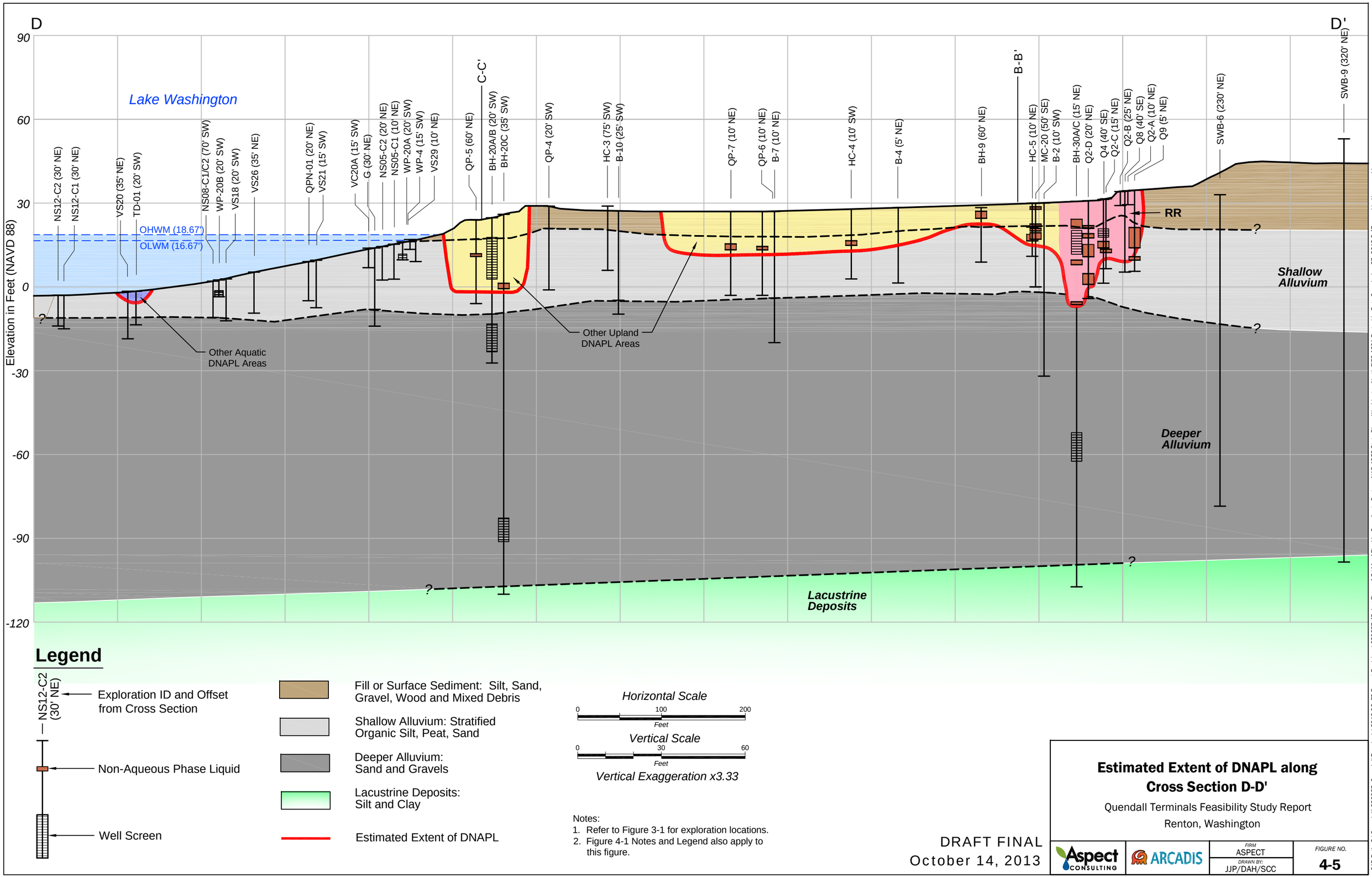
Vertical Exaggeration x10

DRAFT FINAL
October 14, 2013

Estimated Extent of DNAPL along Cross Section C-C'
Quendall Terminals Feasibility Study Report
Renton, Washington

Aspect CONSULTING | ARCADIS | FIRM: ASPECT | DRAWN BY: JJP/DAH/SCC | FIGURE NO. 4-4

CAD Path: Q:\Quendall\020027 Quendall Terminals\2013-06 FS Draft Final\020027-44.dwg Figure 4-4 (11 x 17) || Coordinate System: NAD 1983 State Plane Washington North FIPS 4601 Feet || Date Saved: Jun 27, 2013 3:44pm || User: scudd



Legend

NS12-C2 (30' NE) — Exploration ID and Offset from Cross Section

Non-Aqueous Phase Liquid

Well Screen

Fill or Surface Sediment: Silt, Sand, Gravel, Wood and Mixed Debris

Shallow Alluvium: Stratified Organic Silt, Peat, Sand

Deeper Alluvium: Sand and Gravels

Lacustrine Deposits: Silt and Clay

Estimated Extent of DNAPL

Horizontal Scale

0 100 200

Feet

Vertical Scale

0 30 60

Feet

Vertical Exaggeration x3.33

Notes:
1. Refer to Figure 3-1 for exploration locations.
2. Figure 4-1 Notes and Legend also apply to this figure.

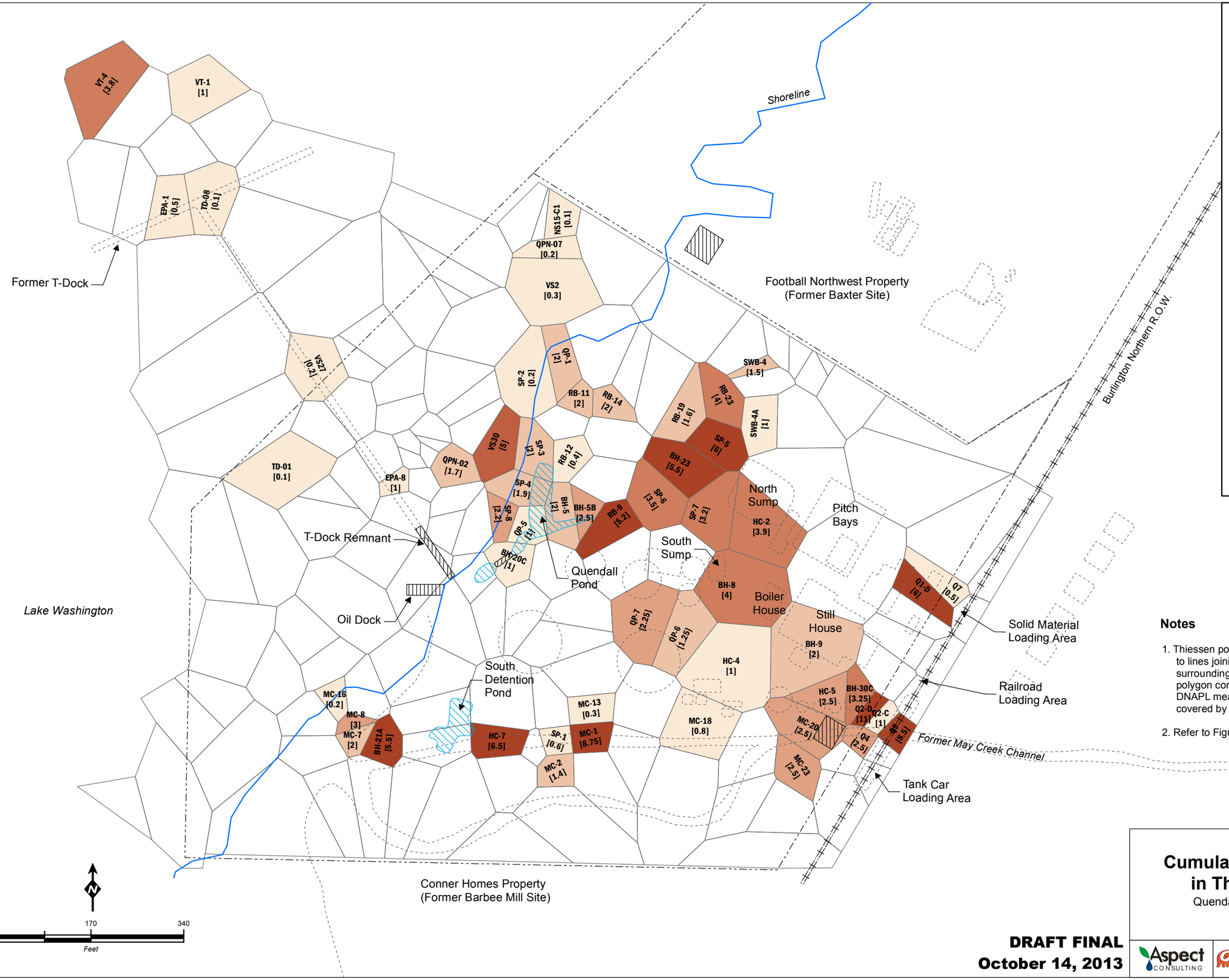
DRAFT FINAL
October 14, 2013

Estimated Extent of DNAPL along Cross Section D-D'

Quendall Terminals Feasibility Study Report
Renton, Washington

Aspect CONSULTING | ARCADIS | FIRM ASPECT | DRAWN BY: JJP/DAH/SCC | FIGURE NO. 4-5

CAD Path: Q:\Quendall\020027 Quendall Terminals\2012-06 FS Report Revisions\020027-45.dwg Figure 4-5 (11 x 17) || Coordinate System: NAD 1983 State Plane Washington North FIPS 4601 Feet || Date Saved: Jun 27, 2013 3:47pm || User:scudd



Thiessen Polygons by DNAPL Thickness (in Feet):

- > 0 - 1
- > 1 - 2
- > 2 - 3
- > 3 - 4
- > 4 - 5
- > 5

Labels:

Location w/ DNAPL: HC-4 [1] (*Boring ID*; *DNAPL cumulative thickness in feet*) *Location w/o DNAPL:*

- Detention Pond
- Existing Structure
- Historical Feature
- Current Shoreline (Ordinary High Water)
- Property Line

Notes

1. Thiessen polygons are constructed as perpendicular bisectors to lines joining each boring location with those immediately surrounding it; the bisectors form a series of polygons, each polygon containing one boring; the cumulative thickness of DNAPL measured at the boring is assigned to the whole area covered by the enclosing polygon.
2. Refer to Figure 3-5 for notes regarding delineation of DNAPL.

DRAFT FINAL
October 14, 2013

Cumulative Thickness of DNAPL in Thiessen Polygon Areas

Quendall Terminals Feasibility Study Report
Renton, Washington

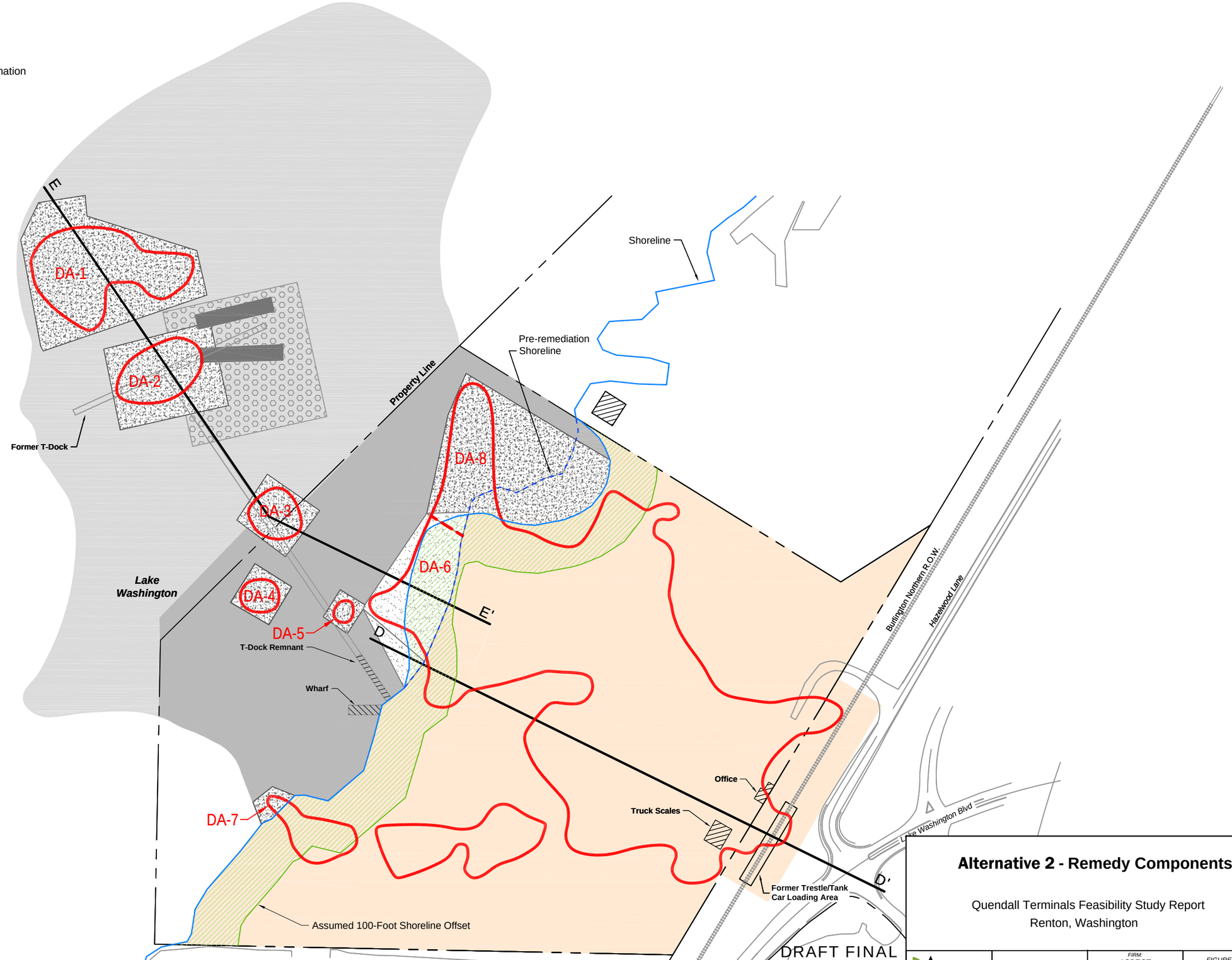
Aspect CONSULTING / ARCADIS	FIRM: ASPECT	DRAWN BY: SCC	FIGURE NO. 4-6

Legend

- D — D' : Cross Section Location and Designation
- Existing Structure
- DNR Dry Dock Cap
- DNR Dry Dock Concrete Hulls
- Estimated Extent of DNAPL
- Habitat Area
- Permeable Cap
- Enhanced Natural Recovery
- Engineered Sand Cap (Note 2)
- RCM Reactive Cap (Note 2)
- Amended Sand Reactive Cap
- DA-1 : Aquatic DNAPL Area

Notes:

1. Altered shoreline to result in no net loss of waters of the United States.
2. This alternative includes sediment removal (not shown on this figure) from the shoreline to approximately 75 feet offshore in areas where engineered sand cap and RCM reactive cap are to be placed, to maintain the existing nearshore area profile. Refer to Section 6.3.



N

0 200 400

Feet

DRAFT FINAL
October 14, 2013

Alternative 2 - Remedy Components

Quendall Terminals Feasibility Study Report
Renton, Washington

Aspect CONSULTING | ARCADIS

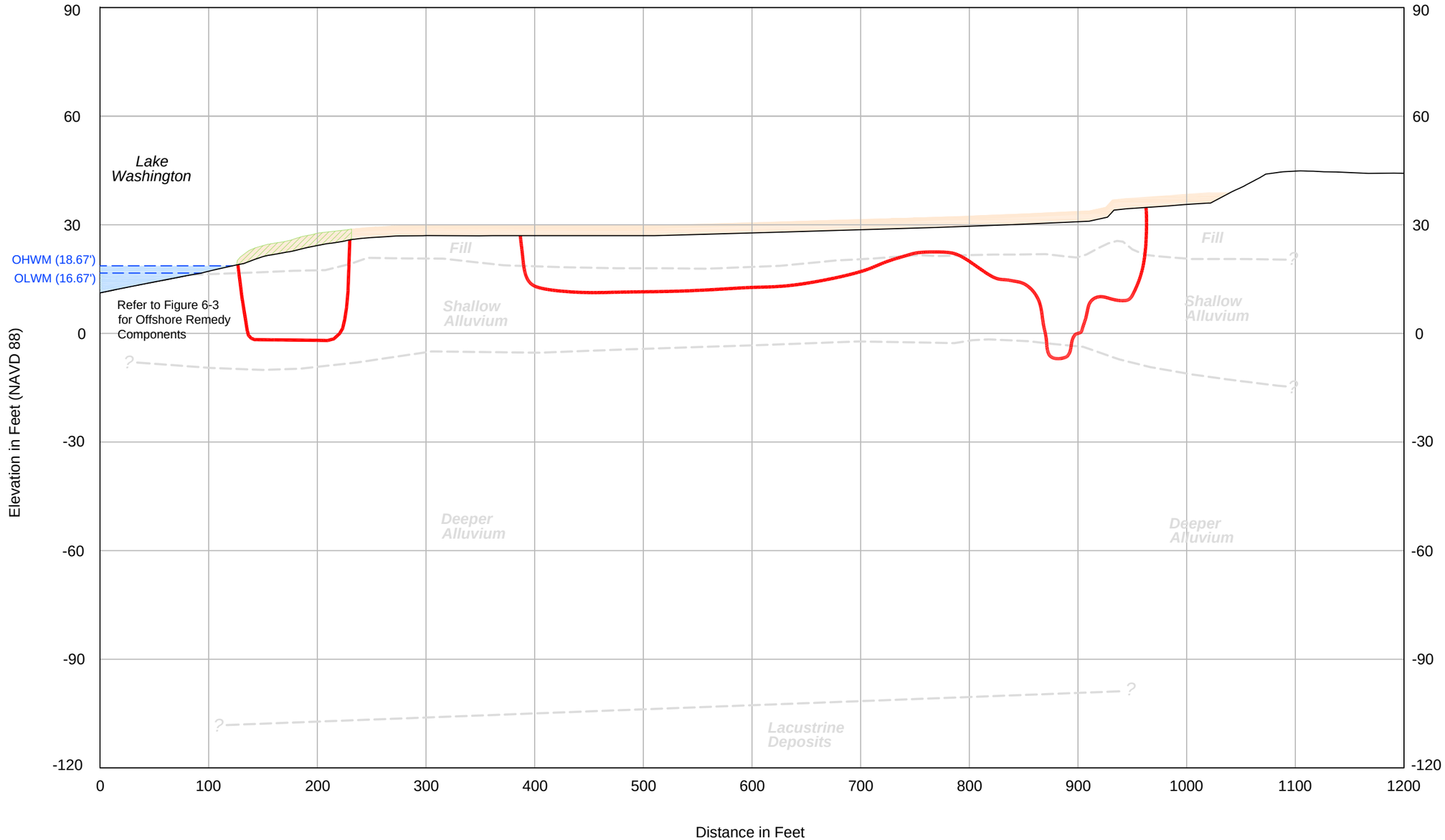
FIRM: ASPECT
DRAWN BY: JJP/PMB/ELG/SCC

FIGURE NO. 6-1

CAD Path: Q:\Quendall\020027 Quendall Terminals\2013-06 FS Draft Final\020027_Plan-Alternatives 2-8 (Shoreline Change).dwg ALT 2 NEW || Date Saved: Oct 09, 2013 11:24am || User: scudd

D

D'



Legend

- Permeable Cap
- Permeable Cap/Habitat Area
- Estimated Extent of DNAPL (Refer to Figure 4-5 for Basis.)

Horizontal Scale

0 100 200

Feet

Vertical Scale

0 30 60

Feet

Vertical Exaggeration x 3.33

DRAFT FINAL
October 14, 2013

Alternative 2 - Upland Remedy Components along Cross Section D-D'

Quendall Terminals Feasibility Study Report
Renton, Washington

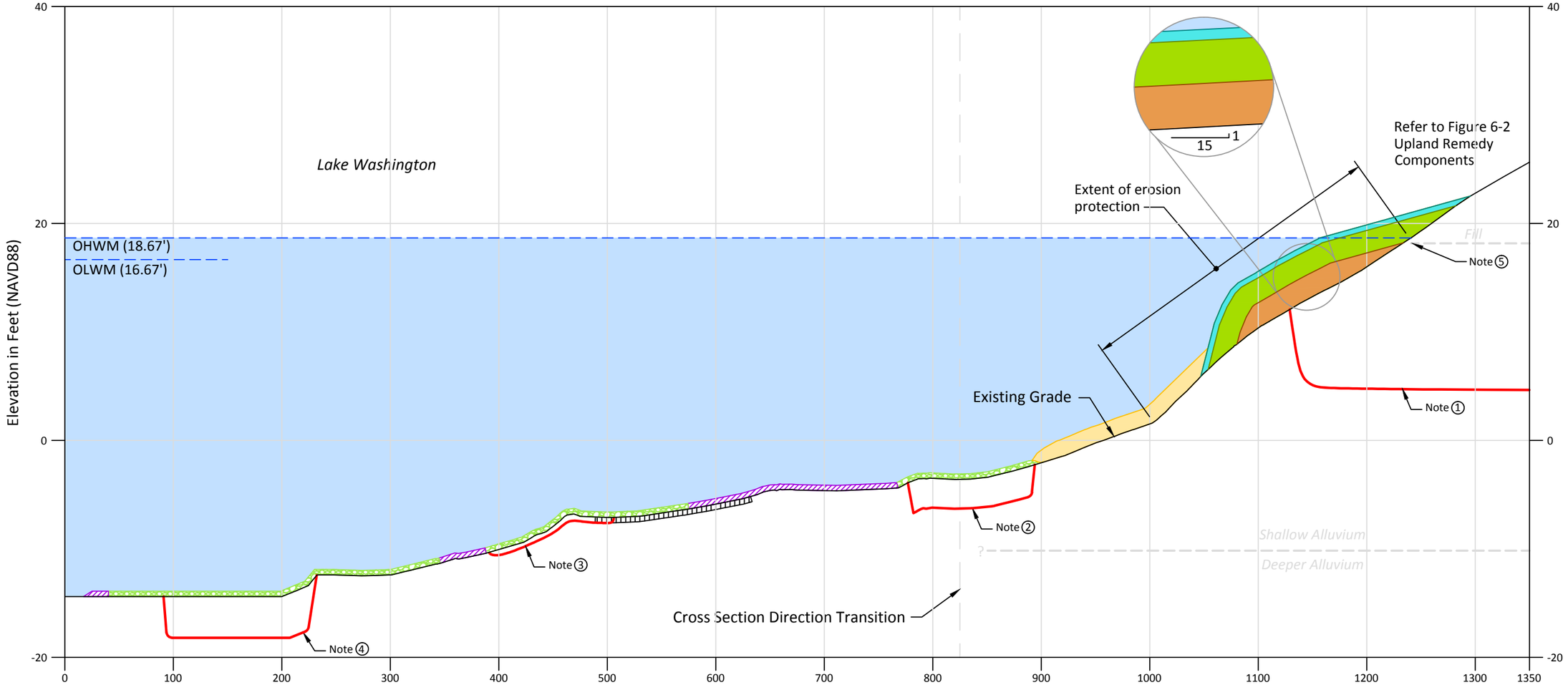
FIRM: ASPECT
DRAWN BY: JJP/PMB/ELG/SCC

FIGURE NO. 6-2

CAD Path: Q:\Quendall\020027 Quendall Terminals\2013-06 FS Draft Final\020027_SectionD-Alternatives 2-8.dwg ALT 2 NEW || Date Saved: Oct 08, 2013 5:09pm || User: scudd

E

E'



Legend:

- Existing DNR Dry Dock Cap
- Estimated extent of DNAPL, based on maximum depth of DNAPL observed in the noted explorations (see Figure 3-1 for exploration locations)
- RCM Reactive cap (organoclay RCM covered by 0.5 ft of sand with erosion protection as required)
- Amended Sand Reactive Cap:
  - 0.5 ft of aquatic habitat friendly material
  - 2.0 ft of clean sand
  - 2.0 ft of sand (90%) and organoclay (10%) mix
- Engineered sand cap (1.5 ft of sand with erosion protection as required)
- Enhanced Natural Recovery (0.5 ft of sand)

Notes:

1. Boring SP-3 and sediment core VS 30
2. Sediment core VS 27
3. Sediment cores EPA-1 and TD 08
4. Sediment cores VT 4 and VT 1
5. Only offshore remedy components are depicted in this figure

Horizontal Scale

0 100 200

Feet

Vertical Scale

0 10 20

Feet

Vertical Exaggeration x 10

DRAFT FINAL
October 14, 2013

Alternative 2 - Offshore Remedy Components along Cross Section E-E'

Quendall Terminals Feasibility Study Report
Renton, Washington

Aspect Consulting | ARCADIS

FIRM: ARCADIS
DRAWN BY: BKD

FIGURE NO. 6-3

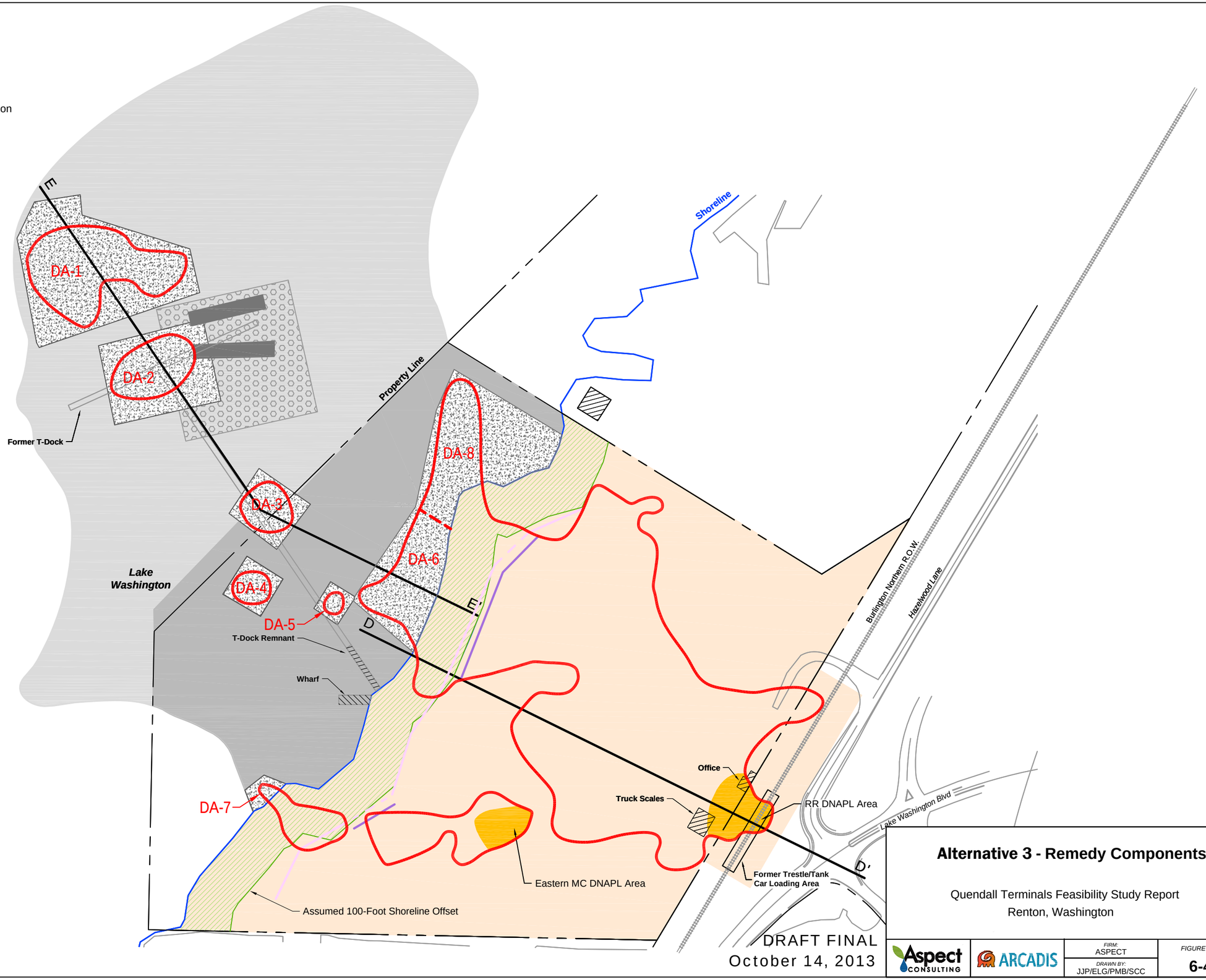
CAD Path: G:\ENVCAD\SYRACUSE\ACT\WA000907\0000\00001\DWG\REPORT\000907G01.dwg 6-3 || Date Saved: Oct 03, 2013 1:30pm || User: bdeclercq

Legend

- D — D' Cross Section Location and Designation
- Existing Structure
- DNR Dry Dock Cap
- DNR Dry Dock Concrete Hulls
- Estimated Extent of DNAPL
- Permeable Treatment Gate
- Impermeable Funnel
- DNAPL Collection Trench
- Habitat Area
- Permeable Cap
- Solidified Soil
- Enhanced Natural Recovery
- Engineered Sand Cap (Note 1)
- RCM Reactive Cap (Note 1)
- DA-1 Aquatic DNAPL Area

Note:

1. This alternative includes sediment removal (not shown on this figure) from the shoreline to approximately 75 feet offshore in areas where engineered sand cap and RCM reactive cap are to be placed, to maintain the existing nearshore area profile. Refer to Section 6.3.



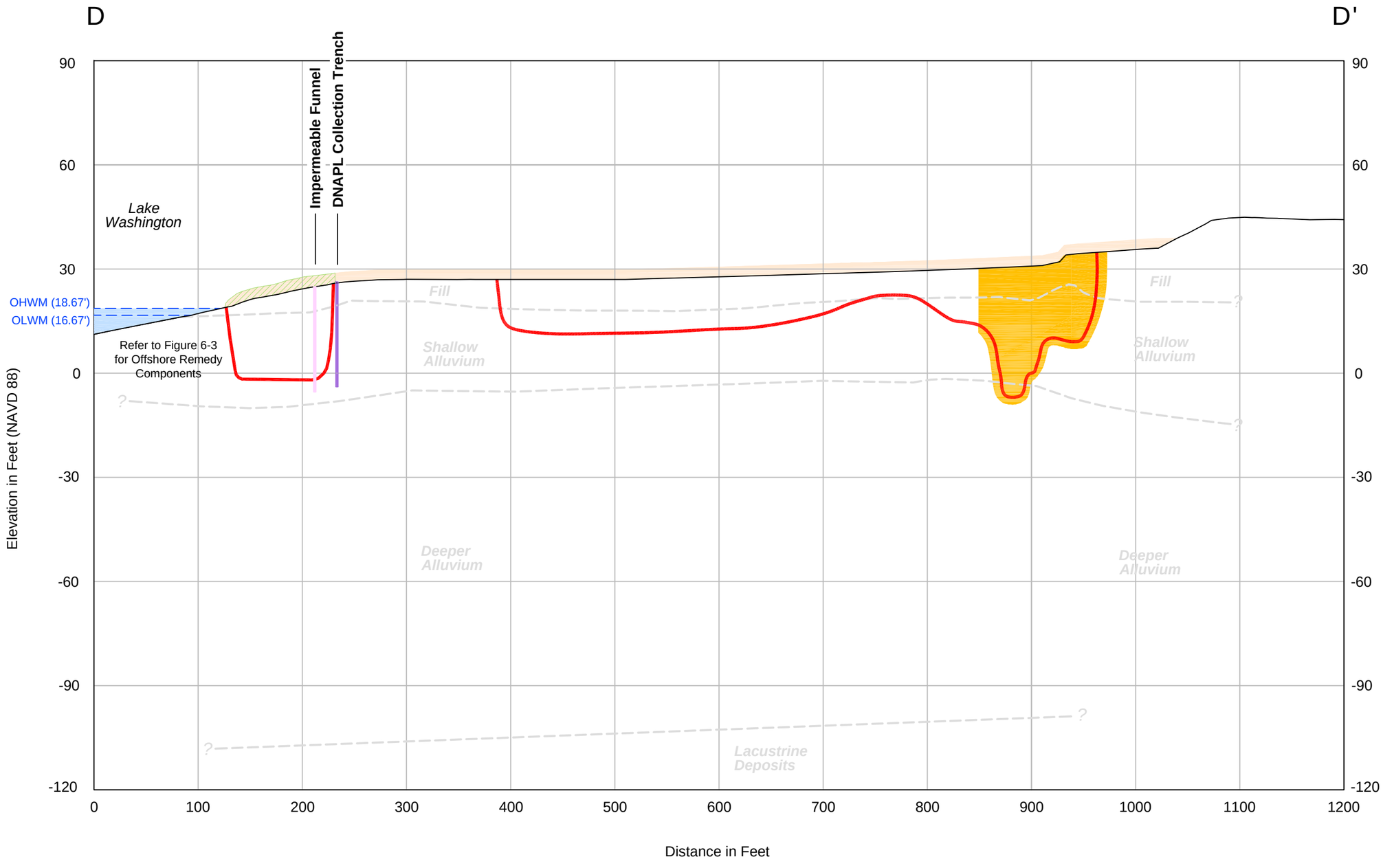
Alternative 3 - Remedy Components

Quendall Terminals Feasibility Study Report
Renton, Washington

DRAFT FINAL
October 14, 2013

FIRM:	FIGURE NO.
ASPECT	6-4
DRAWN BY: JJP/ELG/PMB/SCC	

CAD Path: Q:\Quendall\020027 Quendall Terminals\2013-06 FS Draft Final\020027_Plan-Alternatives 2-8.dwg ALT 3 NEW || Date Saved: Oct 11, 2013 10:41am || User: scudd



Legend

- Solidified Soil
- Permeable Cap
- Permeable Cap/Habitat Area
- Estimated Extent of DNAPL (Refer to Figure 4-5 for Basis.)

Horizontal Scale

0 100 200

Feet

Vertical Scale

0 30 60

Feet

Vertical Exaggeration x 3.33

DRAFT FINAL
October 14, 2013

Alternative 3 - Upland Remedy Components along Cross Section D-D'

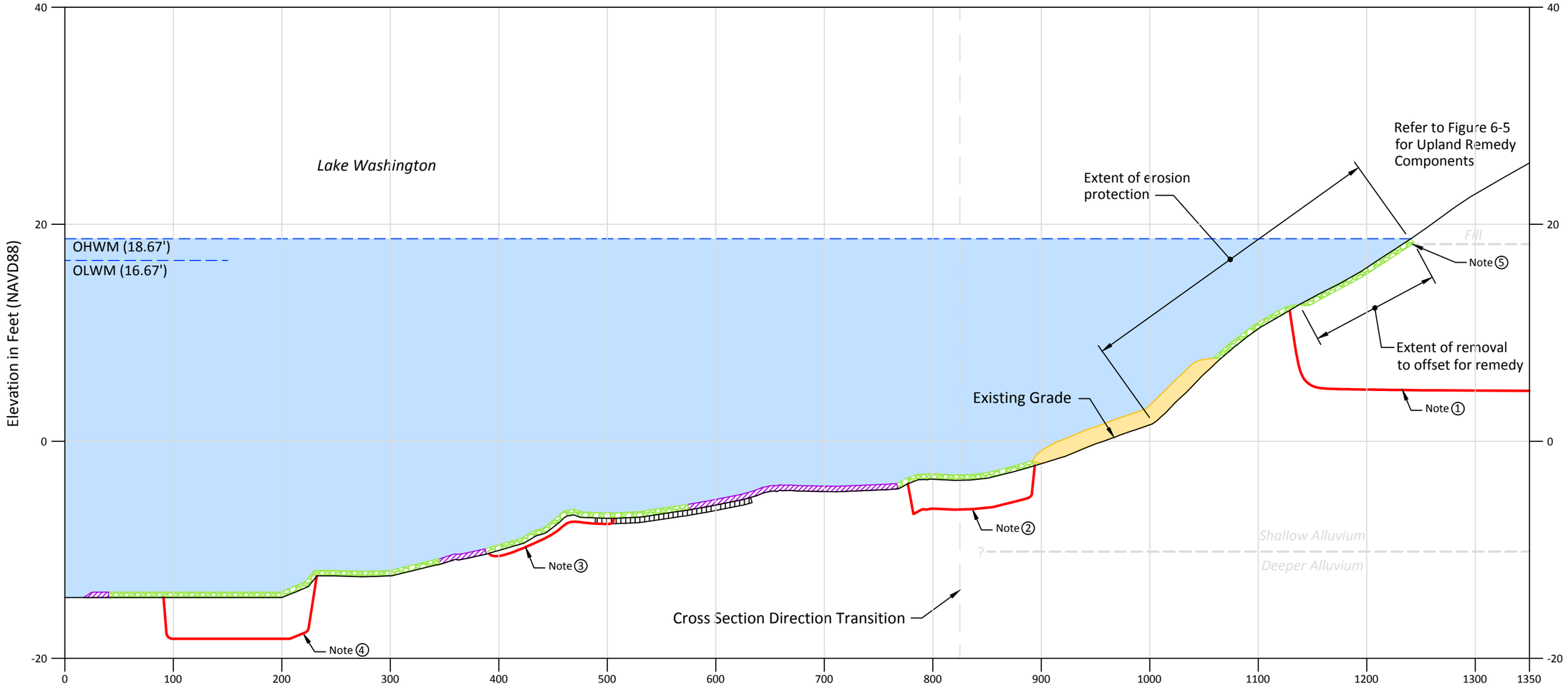
Quendall Terminals Feasibility Study Report
Renton, Washington

Aspect CONSULTING / ARCADIS		FIRM: ASPECT DRAWN BY: JJP/PMB/ELG/SCC	FIGURE NO. 6-5

CAD Path: Q:\Quendall\020027 Quendall Terminals\2013-06 FS Draft Final\020027_SectionD-Alternatives 2-8.dwg ALT 3 NEW || Date Saved: Oct 08, 2013 5:09pm || User: scudd

E

E'



Legend:

- Existing DNR Dry Dock Cap
- Estimated extent of DNAPL, based on maximum depth of DNAPL observed in the noted explorations (see Figure 3-1 for exploration locations)
- RCM Reactive cap (organoclay RCM covered by 0.5 ft of sand with erosion protection as required)
- Engineered sand cap (1.5 ft of sand with erosion protection as required)
- Enhanced Natural Recovery (0.5 ft of sand)

Notes:

1. Boring SP-3 and sediment core VS 30
2. Sediment core VS 27
3. Sediment cores EPA-1 and TD 08
4. Sediment cores VT 4 and VT 1
5. Only offshore remedy components are depicted in this figure

Horizontal Scale
0 100 200
Feet

Vertical Scale
0 10 20
Feet

Vertical Exaggeration x 10

DRAFT FINAL
October 14, 2013

Alternative 3 - Offshore Remedy Components along Cross Section E-E'

Quendall Terminals Feasibility Study Report
Renton, Washington

Aspect CONSULTING | ARCADIS

FIRM: ARCADIS
DRAWN BY: BKD

FIGURE NO.
6-6

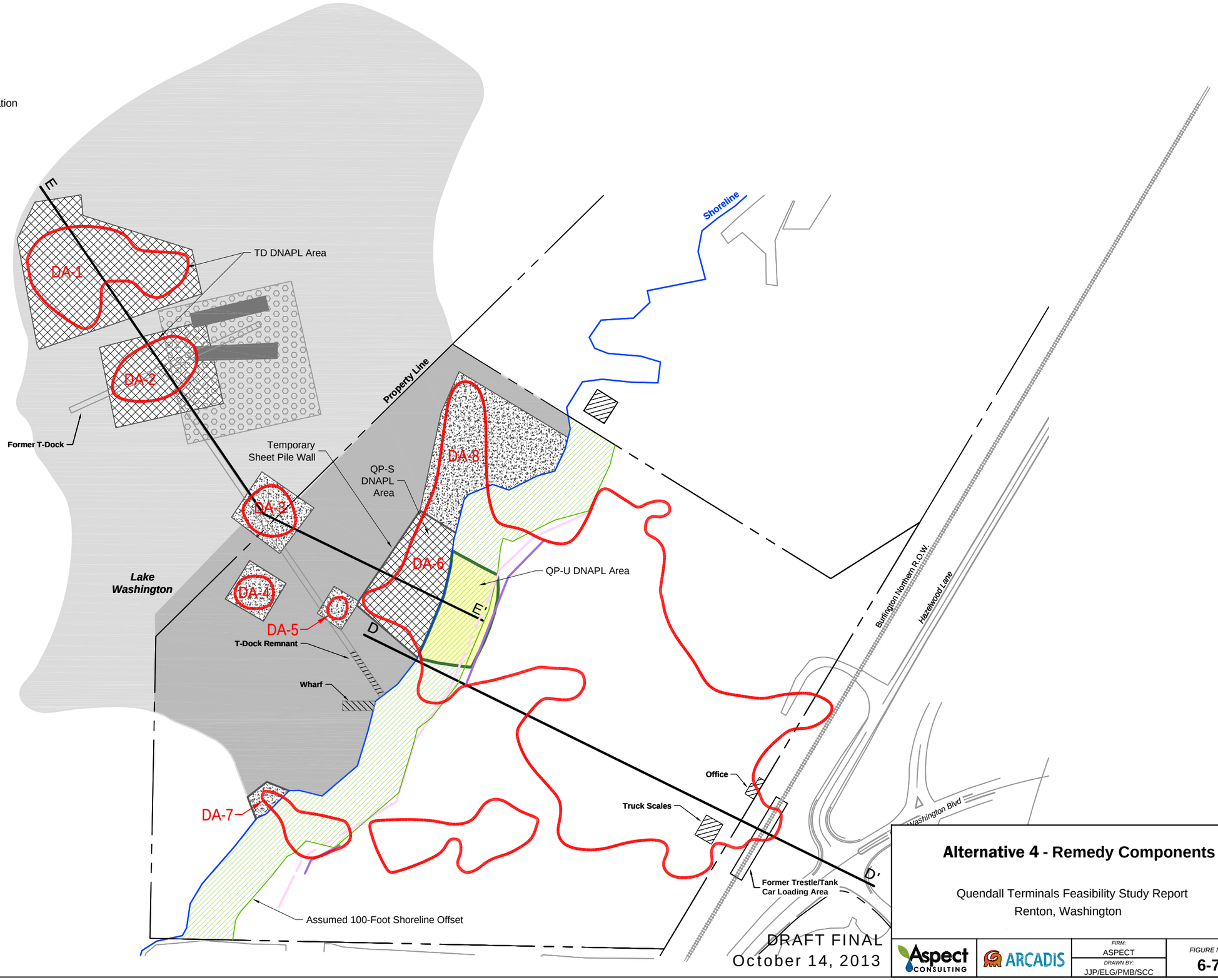
CAD Path: G:\ENVCAD\SYRACUSE\ACT\WA000907\0000\00001\DWG\REPORT\000907G01.dwg 6-6 || Date Saved: Oct 03, 2013 1:34pm || User: bdeclercq

Legend

- D — D' Cross Section Location and Designation
- Existing Structure
- DNR Dry Dock Cap
- DNR Dry Dock Concrete Hulls
- Estimated Extent of DNAPL
- Permeable Treatment Gate
- Impermeable Funnel
- DNAPL Collection Trench
- Habitat Area
- Soil Excavation Cell
- Enhanced Natural Recovery
- Engineered Sand Cap (Note 2)
- Dredge Area
- RCM Reactive Cap (Note 2)
- Excavated Soil and Backfill
- DA-1 Aquatic DNAPL Area

Notes:

1. This alternative also includes permeable upland cap similar to Alternative 3. Refer to Figure 6-4 for cap extent.
2. This alternative includes sediment removal (not shown on this figure) from the shoreline to approximately 75 feet offshore in areas where engineered sand cap and RCM reactive cap are to be placed, to maintain the existing nearshore area profile. Refer to Section 6.3.



Alternative 4 - Remedy Components

Quendall Terminals Feasibility Study Report
Renton, Washington

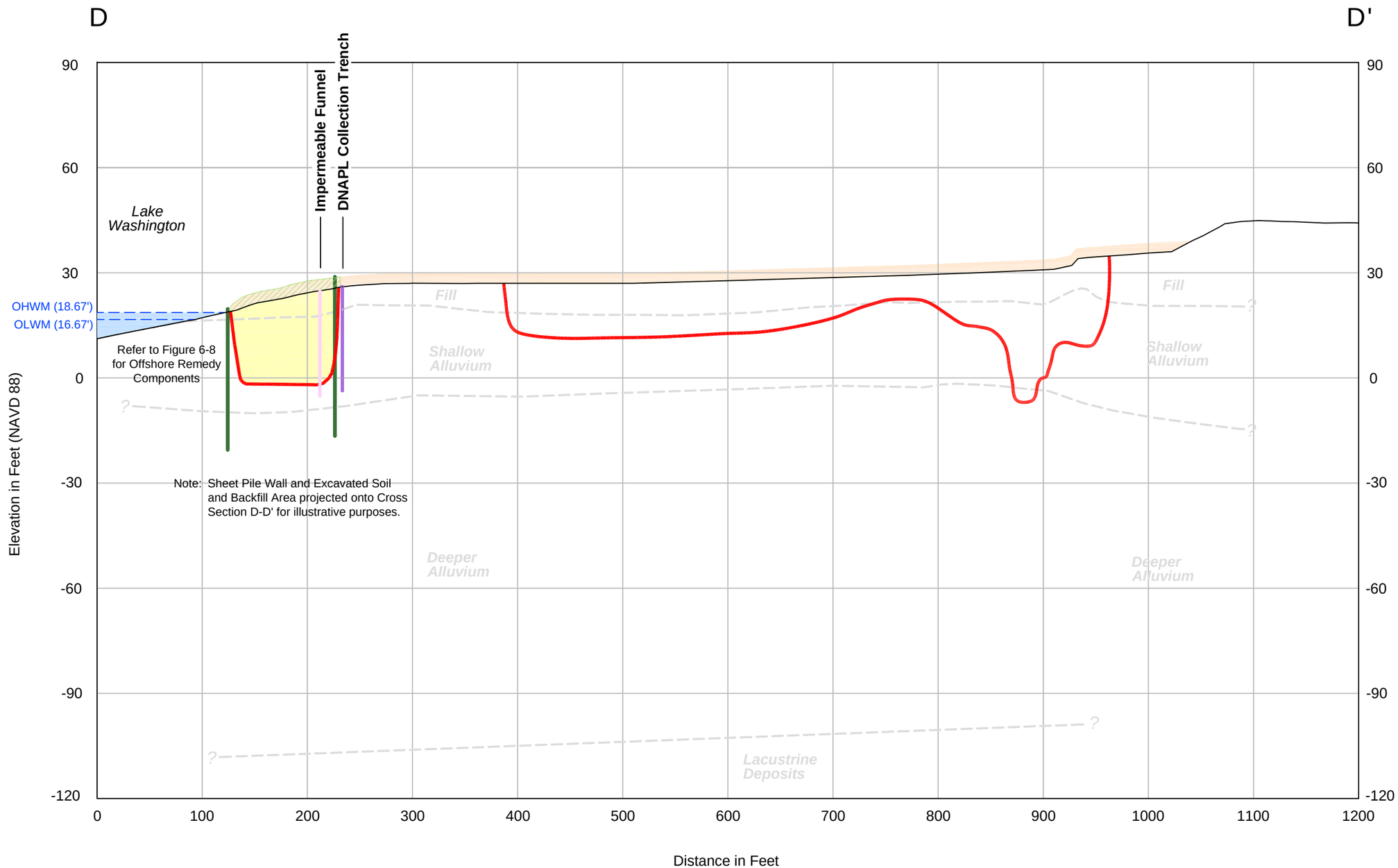
DRAFT FINAL
October 14, 2013

Aspect Consulting | ARCADIS

FIRM: ASPECT
DRAWN BY: JJP/ELG/PMB/SCC

FIGURE NO. 6-7

CAD Path: Q:\Quendall\020027 Quendall Terminals\2013-06 FS Draft Final\020027_Plan-Alternatives 2-8.dwg ALT 4 NEW || Date Saved: Oct 11, 2013 10:39am || User: scudd



Legend

- Excavated Soil and Backfill
- Permeable Cap
- Permeable Cap/Habitat Area
- Estimated Extent of DNAPL (Refer to Figure 4-5 for Basis.)
- Temporary Sheet Pile Wall

Horizontal Scale
0 100 200
Feet

Vertical Scale
0 30 60
Feet

Vertical Exaggeration x 3.33

DRAFT FINAL
October 14, 2013

Alternative 4 - Upland Remedy Components along Cross Section D-D'

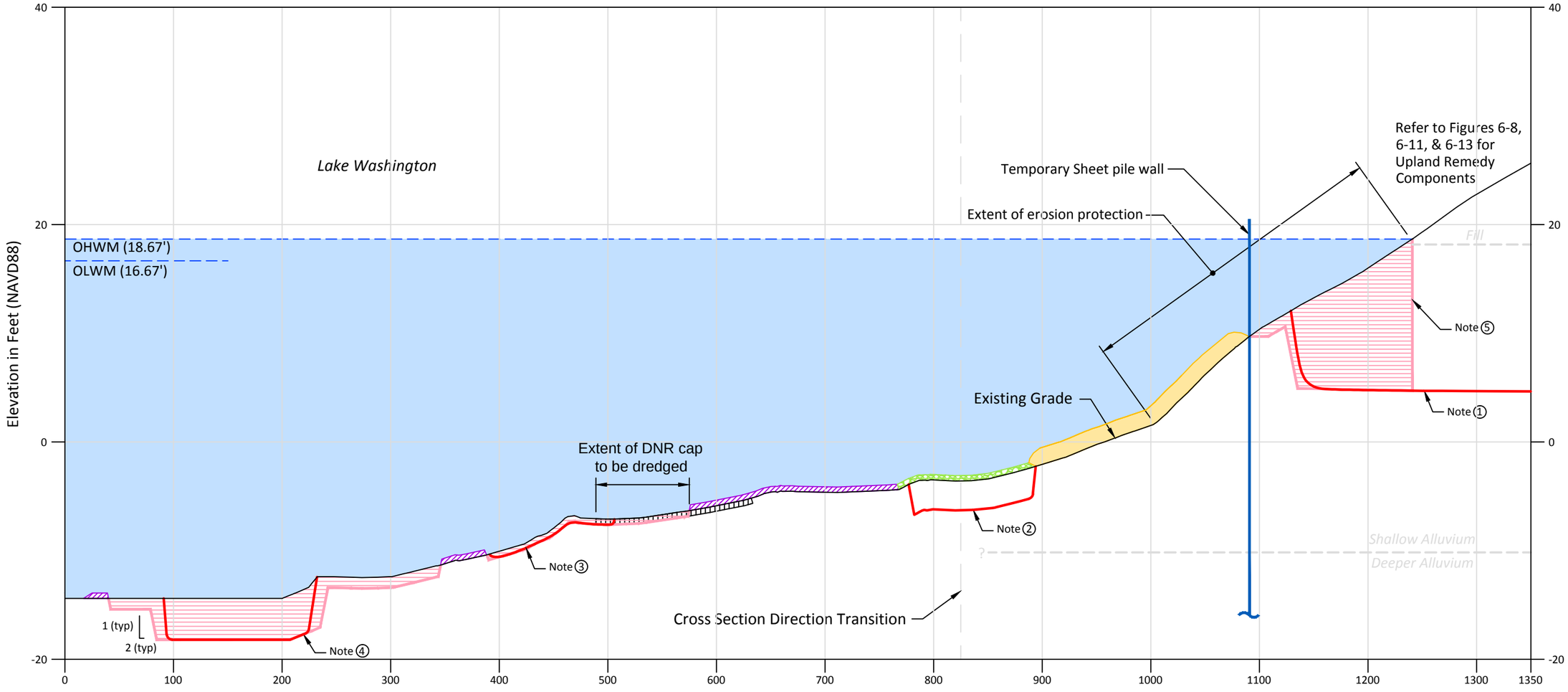
Quendall Terminals Feasibility Study Report
Renton, Washington

Aspect CONSULTING | ARCADIS | FIRM: ASPECT | DRAWN BY: JJP/PMB/ELG/SCC | FIGURE NO. 6-8

CAD Path: Q:\Quendall\020027 Quendall Terminals\2013-06 FS Draft Final\020027_SectionD-Alternatives 2-8.dwg ALT 4 NEW | | Date Saved: Oct 08, 2013 5:10pm | | User: scudd

E

E'



Legend:

- Existing DNR Dry Dock Cap
- Estimated extent of DNAPL, based on maximum depth of DNAPL observed in the noted explorations (see Figure 3-1 for exploration locations)
- RCM Reactive cap (organoclay RCM covered by 0.5 ft of sand with erosion protection as required)
- Engineered sand cap (1.5 ft of sand with erosion protection as required)
- Enhanced Natural Recovery (0.5 ft of sand)
- Dredging (removal to designated depths, residual cover placement, and backfilled as required)

Notes:

① Boring SP-3 and sediment core VS 30
② Sediment core VS 27
③ Sediment cores EPA-1 and TD 08
④ Sediment cores VT 4 and VT 1
⑤ Only offshore remedy components are depicted in this figure

Horizontal Scale
0 100 200
Feet

Vertical Scale
0 10 20
Feet

Vertical Exaggeration x 10

DRAFT FINAL
October 14, 2013

Alternatives 4, 5, & 6 - Offshore Remedy Components along Cross Section E-E'

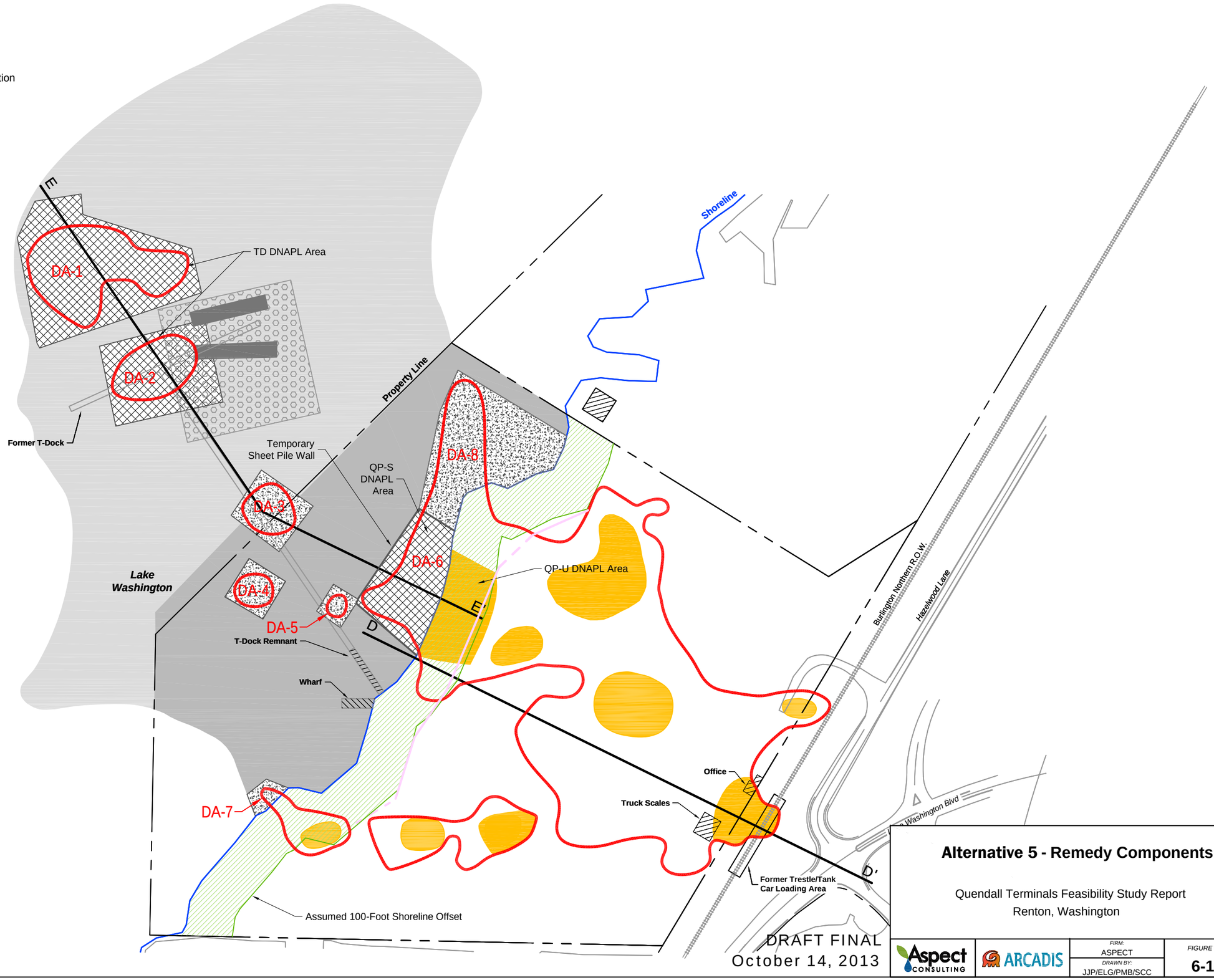
Quendall Terminals Feasibility Study Report
Renton, Washington

Aspect CONSULTING | ARCADIS | FIRM: ARCADIS | DRAWN BY: BKD | FIGURE NO. 6-9

CAD Path: G:\ENVCAD\SYRACUSE\ACT\WA000907\0000\00001\DWG\REPORT\000907G01.dwg 6-9 || Date Saved: Oct 03, 2013 1:31pm || User: bdeleroq

Legend

- D — D' Cross Section Location and Designation
- Existing Structure
- DNR Dry Dock Cap
- DNR Dry Dock Concrete Hulls
- Estimated Extent of DNAPL
- Permeable Treatment Gate
- Impermeable Funnel
- Habitat Area
- Solidified Soil
- Enhanced Natural Recovery
- Engineered Sand Cap (Note 2)
- Dredge Area
- RCM Reactive Cap (Note 2)
- DA-1 Aquatic DNAPL Area



Notes:

1. This alternative also includes permeable upland cap similar to Alternative 3. Refer to Figure 6-4 for cap extent.
2. This alternative includes sediment removal (not shown on this figure) from the shoreline to approximately 75 feet offshore in areas where engineered sand cap and RCM reactive cap are to be placed, to maintain the existing nearshore area profile. Refer to Section 6.3.

N

0 200 400

Feet

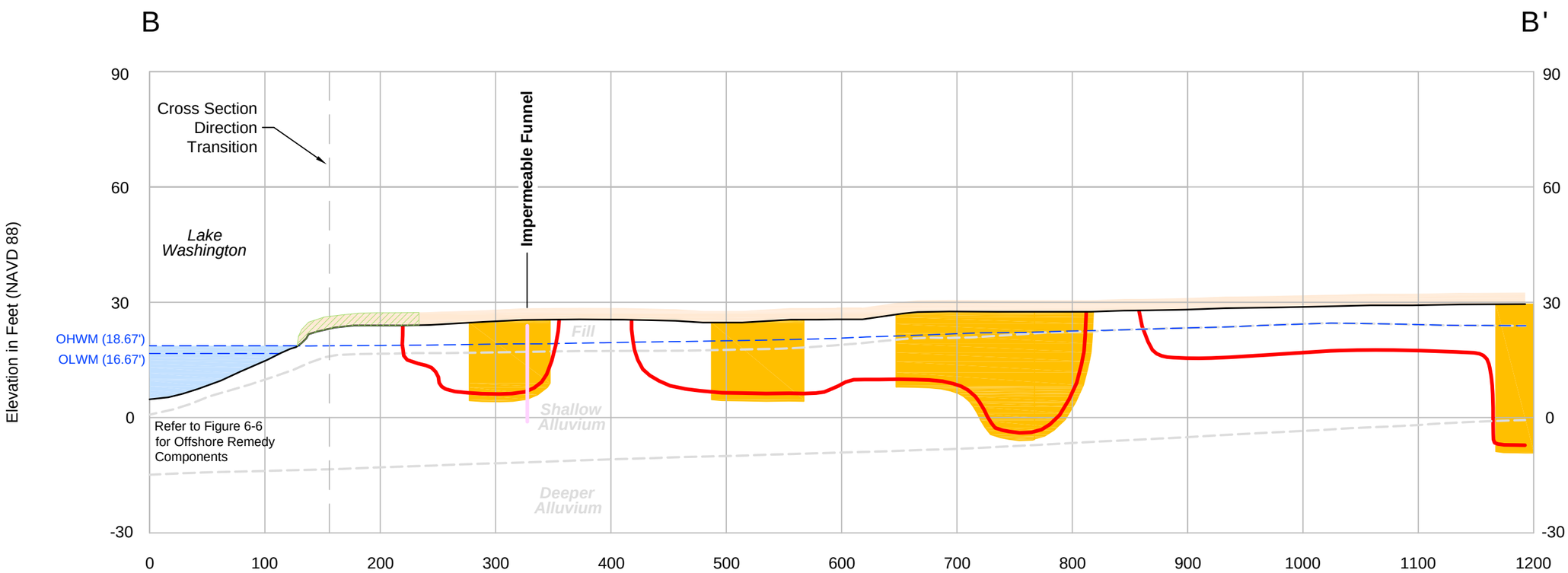
DRAFT FINAL
October 14, 2013

Alternative 5 - Remedy Components

Quendall Terminals Feasibility Study Report
Renton, Washington

FIRM:	FIGURE NO.
ASPECT	6-10
DRAWN BY: JJP/ELG/PMB/SCC	

CAD Path: Q:\Quendall\020027 Quendall Terminals\2013-06 FS Draft Final\020027_Plan-Alternatives 2-8.dwg ALT 5 NEW || Date Saved: Oct 11, 2013 10:56am || User: scudd



Legend

- Solidified Soil
- Permeable Cap
- Permeable Cap/Habitat Area
- Estimated Extent of DNAPL (Refer to Figure 4-5 for Basis.)

Horizontal Scale
0 100 200
Feet

Vertical Scale
0 30 60
Feet

Vertical Exaggeration x 3.33

DRAFT FINAL
October 14, 2013

Alternative 5 - Upland Remedy Components along Cross Section B-B'

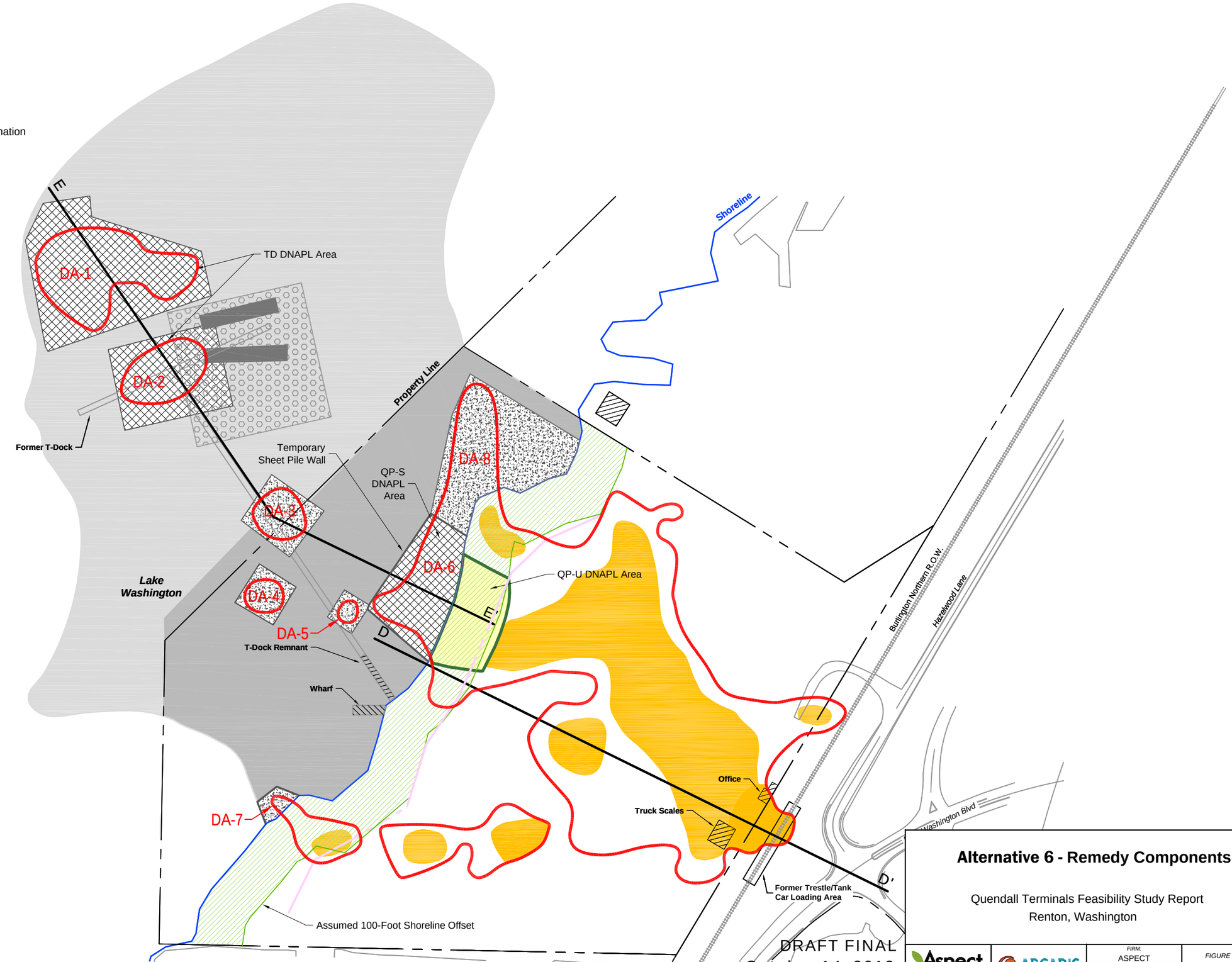
Quendall Terminals Feasibility Study Report
Renton, Washington

FIRM: ASPECT
DRAWN BY: JJP/PMB/ELG/SCC
FIGURE NO. 6-11

CAD Path: Q:\Quendall\020027 Quendall Terminals\2013-06 FS Draft Final\020027_SectionB-Alternate 5.dwg ALT 5 NEW || Date Saved: Oct 08, 2013 5:15pm || User: scudd

Legend

- D — D' : Cross Section Location and Designation
- Existing Structure
- DNR Dry Dock Cap
- DNR Dry Dock Concrete Hulls
- Estimated Extent of DNAPL
- Permeable Treatment Gate
- Impermeable Funnel
- Habitat Area
- Solidified Soil (to 20 foot depth)
- Soil Excavation Cell
- Enhanced Natural Recovery
- Engineered Sand Cap (Note 2)
- Dredge Area
- RCM Reactive Cap (Note 2)
- Excavated Soil and Backfill
- DA-1 : Aquatic DNAPL Area



Notes:

1. This alternative also includes permeable upland cap similar to Alternative 3. Refer to Figure 6-4 for cap extent.
2. This alternative includes sediment removal (not shown on this figure) from the shoreline to approximately 75 feet offshore in areas where engineered sand cap and RCM reactive cap are to be placed, to maintain the existing nearshore area profile. Refer to Section 6.3.

N

0 200 400

Feet

Alternative 6 - Remedy Components

Quendall Terminals Feasibility Study Report
Renton, Washington

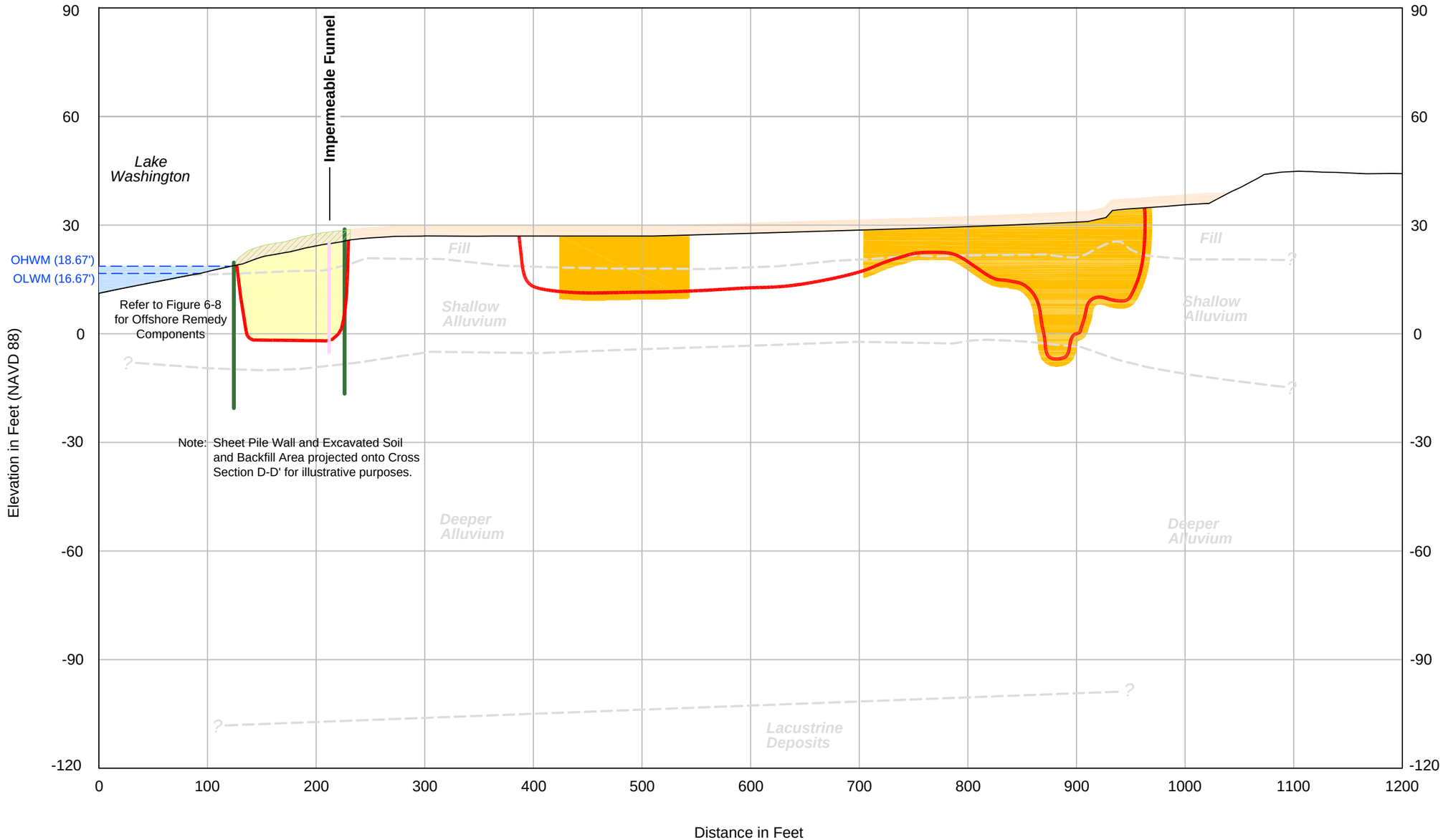
DRAFT FINAL
October 14, 2013

Aspect Consulting | ARCADIS | FIRM: ASPECT | DRAWN BY: JJP/ELG/PMB/SCC | FIGURE NO. 6-12

CAD Path: Q:\Quendall\020027 Quendall Terminals\2013-06 FS Draft Final\020027_Plan-Alternatives 2-8.dwg ALT 6 NEW || Date Saved: Oct 11, 2013 10:58am || User: scudd

D

D'



Legend

- Solidified Soil
- Excavated Soil and Backfill
- Permeable Cap
- Permeable Cap/Habitat Area
- Estimated Extent of DNAPL (Refer to Figure 4-5 for Basis.)
- Temporary Sheet Pile Wall

Horizontal Scale
0 100 200
Feet

Vertical Scale
0 30 60
Feet

Vertical Exaggeration x 3.33

DRAFT FINAL
October 14, 2013

Alternative 6 - Upland Remedy Components along Cross Section D-D'

Quendall Terminals Feasibility Study Report
Renton, Washington

Aspect CONSULTING | ARCADIS

FIRM: ASPECT
DRAWN BY: JJP/PMB/ELG/SCC

FIGURE NO. **6-13**

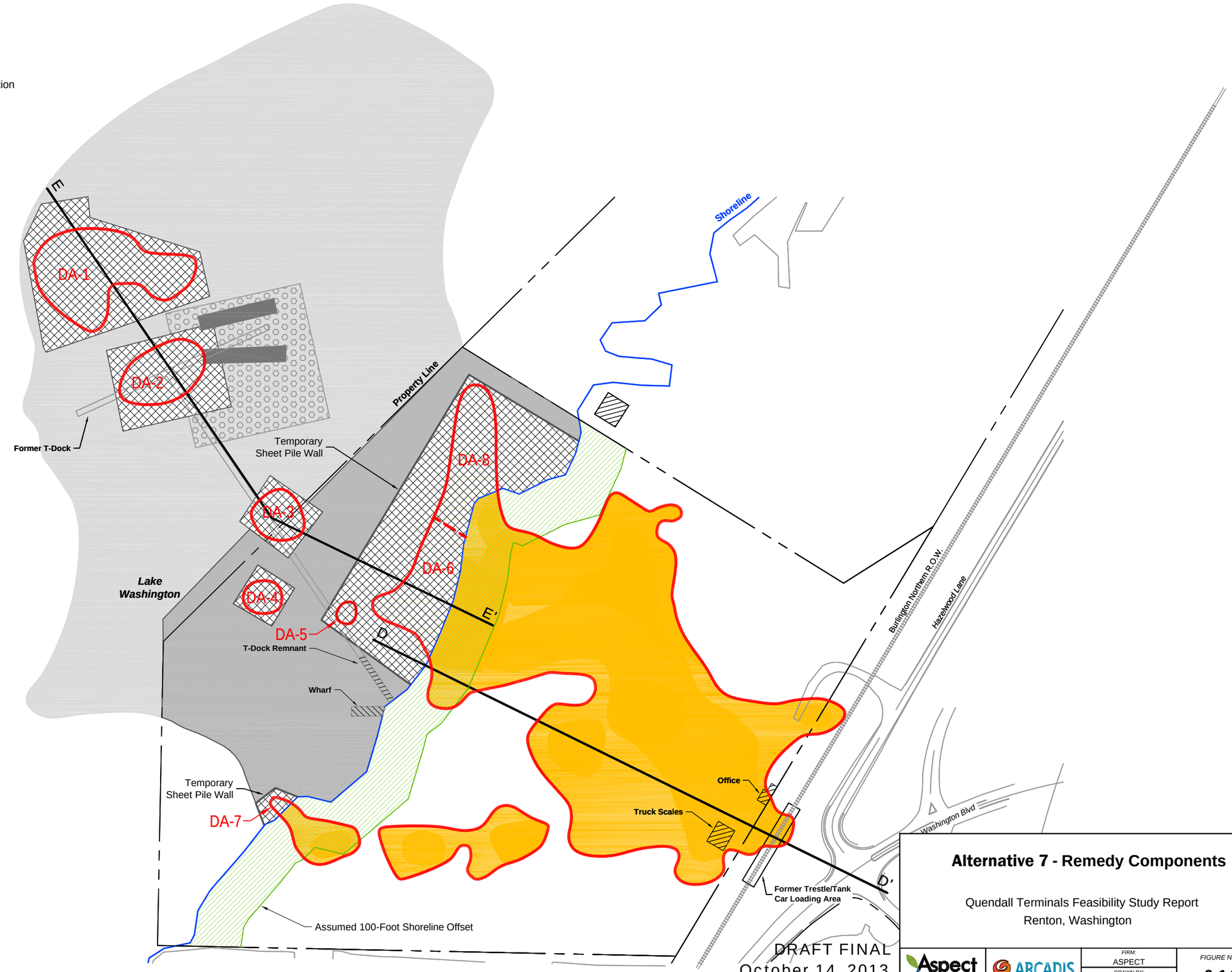
CAD Path: Q:\Quendall\020027 Quendall Terminals\2013-06 FS Draft Final\020027_SectionD-Alternatives 2-8.dwg ALT 6 NEW || Date Saved: Oct 08, 2013 5:11pm || User: scudd

Legend

- D — D' : Cross Section Location and Designation
- Existing Structure
- DNR Dry Dock Cap
- DNR Dry Dock Concrete Hulls
- Estimated Extent of DNAPL
- Habitat Area
- Solidified Soil
- Enhanced Natural Recovery
- Engineered Sand Cap (Note 2)
- Dredge Area
- DA-1 : Aquatic DNAPL Area

Notes:

1. This alternative also includes permeable upland cap similar to Alternative 3. Refer to Figure 6-4 for cap extent.
2. This alternative includes sediment removal (not shown on this figure) from the shoreline to approximately 75 feet offshore in areas where engineered sand cap is to be placed, to maintain the existing nearshore area profile. Refer to Section 6.3.



Alternative 7 - Remedy Components

Quendall Terminals Feasibility Study Report
Renton, Washington

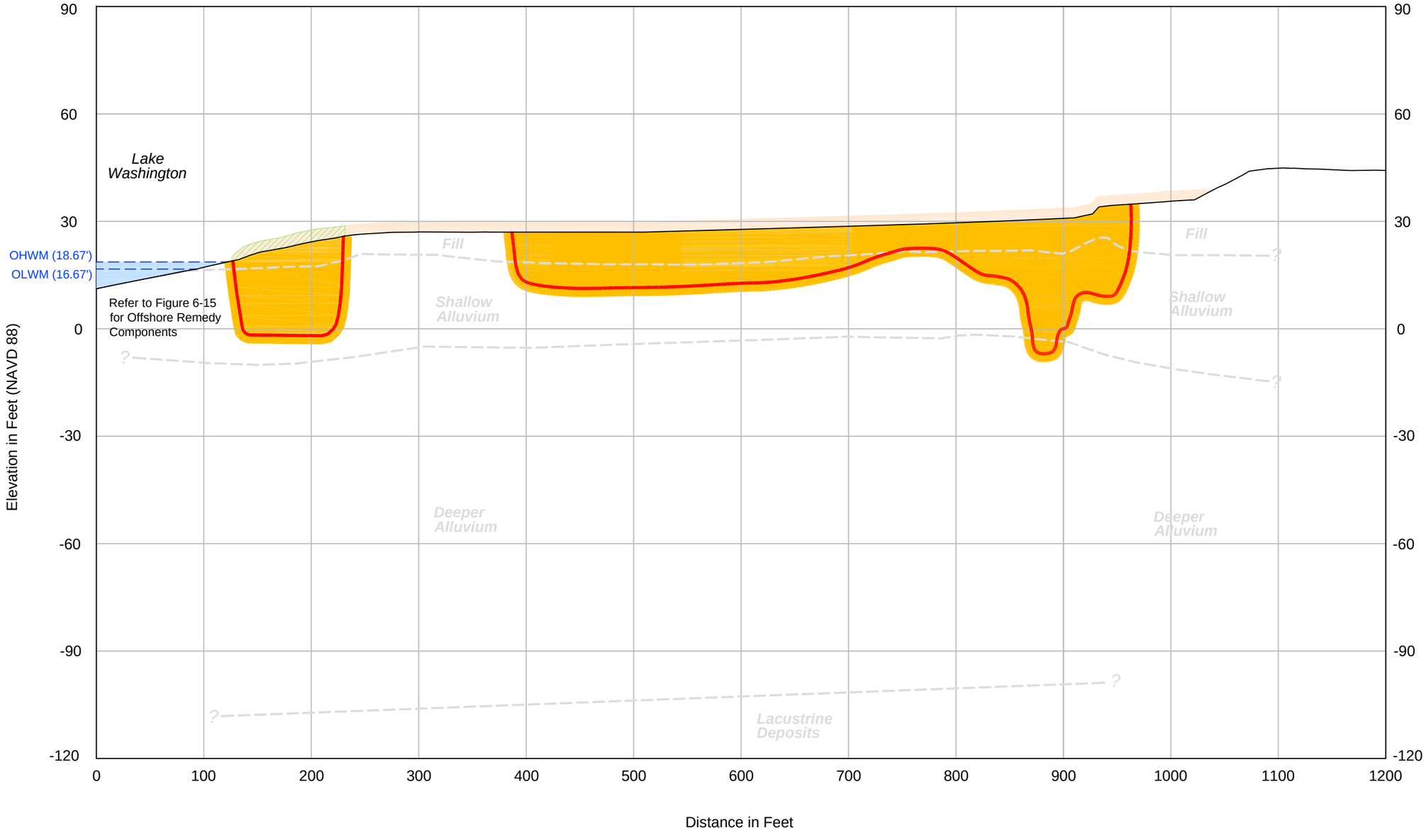
DRAFT FINAL
October 14, 2013

FIRM:	FIGURE NO.
ASPECT	6-14
DRAWN BY: JJP/ELG/PMB/SCC	

CAD Path: Q:\Quendall\020027 Quendall Terminals\2013-06 FS Draft Final\020027_Plan-Alternatives 2-8.dwg ALT 7 NEW || Date Saved: Oct 11, 2013 10:51am || User: scudd

D

D'



Legend

- Solidified Soil
- Permeable Cap
- Permeable Cap/Habitat Area
- Estimated Extent of DNAPL (Refer to Figure 4-5 for Basis.)

Horizontal Scale

0 100 200

Feet

Vertical Scale

0 30 60

Feet

Vertical Exaggeration x 3.33

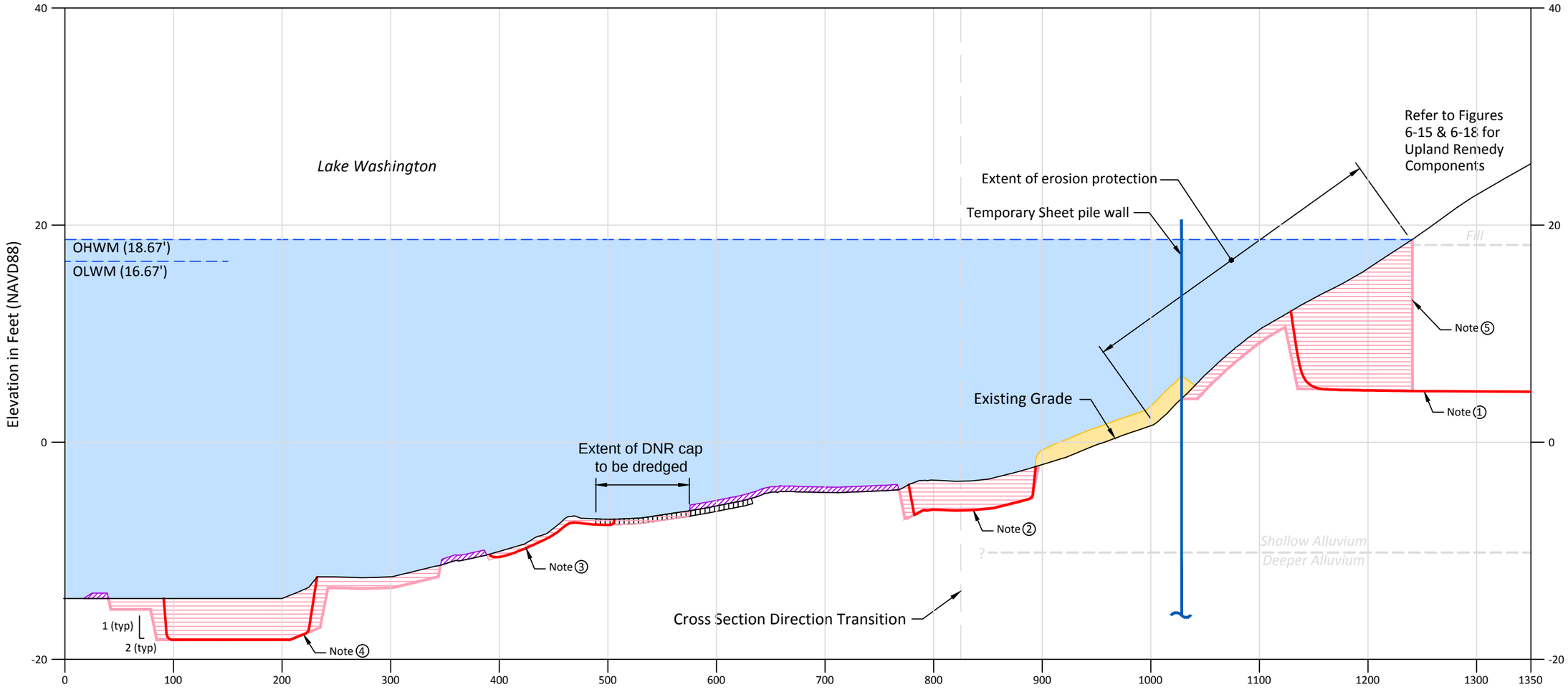
DRAFT FINAL
October 14, 2013

Alternative 7 - Upland Remedy Components along Cross Section D-D'

Quendall Terminals Feasibility Study Report
Renton, Washington

Aspect Consulting | ARCADIS | FIRM: ASPECT | DRAWN BY: JJP/PMB/ELG/SCC | FIGURE NO. 6-15

CAD Path: Q:\Quendall\0\20027 Quendall Terminals\2013-06 FS Draft Final\0\20027_SectionD-Alternatives 2-8.dwg ALT 7 NEW || Date Saved: Oct 08, 2013 5:12pm || User: scudd



Legend:

- Existing DNR Dry Dock Cap
- Estimated extent of DNAPL, based on maximum depth of DNAPL observed in the noted explorations (see Figure 3-1 for exploration locations)
- Engineered sand cap (1.5 ft of sand with erosion protection as required)
- Enhanced Natural Recovery (0.5 ft of sand)
- Dredging (removal to designated depths, residual cover placement, and backfilled as required)

Notes:

① Boring SP-3 and sediment core VS 30
② Sediment core VS 27
③ Sediment cores EPA-1 and TD 08
④ Sediment cores VT 4 and VT 1
⑤ Only offshore remedy components are depicted in this figure

Horizontal Scale
0 100 200
Feet

Vertical Scale
0 10 20
Feet

Vertical Exaggeration x 10

DRAFT FINAL
October 14, 2013

Alternatives 7 & 8 - Offshore Remedy Components along Cross Section E-E'

Quendall Terminals Feasibility Study Report
Renton, Washington

FIRM:	FIGURE NO.
ARCADIS	6-16
DRAWN BY: BKD	

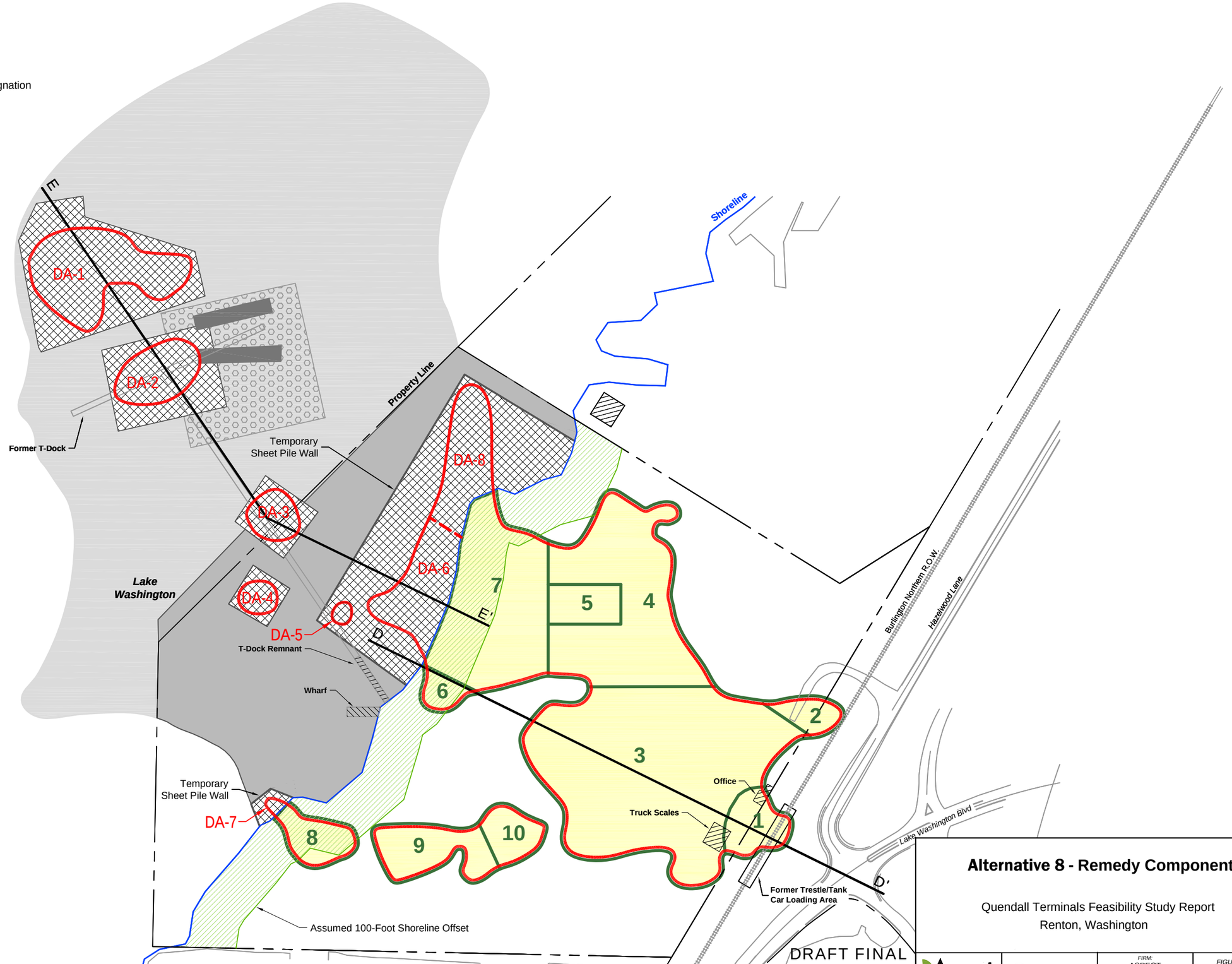
CAD Path: G:\ENVCAD\SYRACUSE\ACT\WA000907\0000\00001\DWG\REPORT\000907G01.dwg 6-16 || Date Saved: Oct 03, 2013 1:31pm || User: bdeclercq

Legend

- D — D' : Cross Section Location and Designation
- Existing Structure
- DNR Dry Dock Cap
- DNR Dry Dock Concrete Hulls
- Estimated Extent of DNAPL
- 5 : Soil Excavation Cell
- Habitat Area
- Excavated Soil and Backfill
- Enhanced Natural Recovery
- Engineered Sand Cap (Note 2)
- Dredge Area
- DA-1 : Aquatic DNAPL Area

Notes:

1. This alternative also includes permeable upland cap similar to Alternative 3. Refer to Figure 6-4 for cap extent.
2. This alternative includes sediment removal (not shown on this figure) from the shoreline to approximately 75 feet offshore in areas where engineered sand cap is to be placed, to maintain the existing nearshore area profile. Refer to Section 6.3.



DRAFT FINAL
October 14, 2013

Alternative 8 - Remedy Components

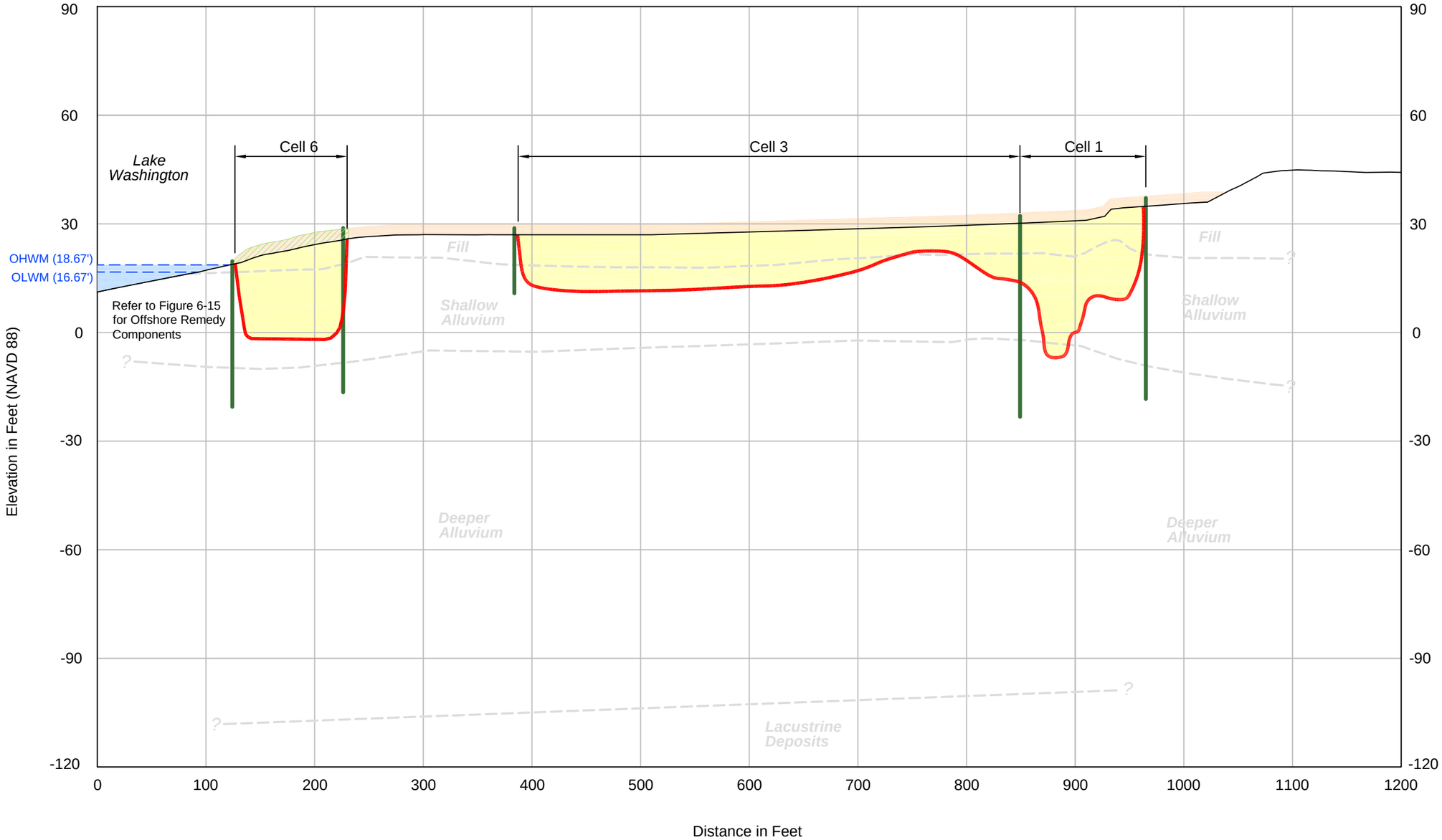
Quendall Terminals Feasibility Study Report
Renton, Washington

FIRM:	FIGURE NO.
ASPECT	6-17
DRAWN BY: JJP/ELG/PMB/SCC	

CAD Path: Q:\Quendall\020027 Quendall Terminals\2013-06 FS Draft Final\020027_PlanAlternatives 2-8.dwg ALT 8 NEW || Date Saved: Oct 11, 2013 11:04am || User: scudd

D

D'



Legend

- Excavated Soil and Backfill
- Permeable Cap
- Permeable Cap/Habitat Area
- Estimated Extent of DNAPL (Refer to Figure 4-5 for Basis.)
- Temporary Sheet Pile Wall

Horizontal Scale

0 — 100 — 200

Feet

Vertical Scale

0 — 30 — 60

Feet

Vertical Exaggeration x 3.33

DRAFT FINAL
October 14, 2013

Alternative 8 - Upland Remedy Components along Cross Section D-D'

Quendall Terminals Feasibility Study Report
Renton, Washington

Aspect Consulting | ARCADIS | FIRM: ASPECT | DRAWN BY: JJP/PMB/ELG/SCC | FIGURE NO. 6-18

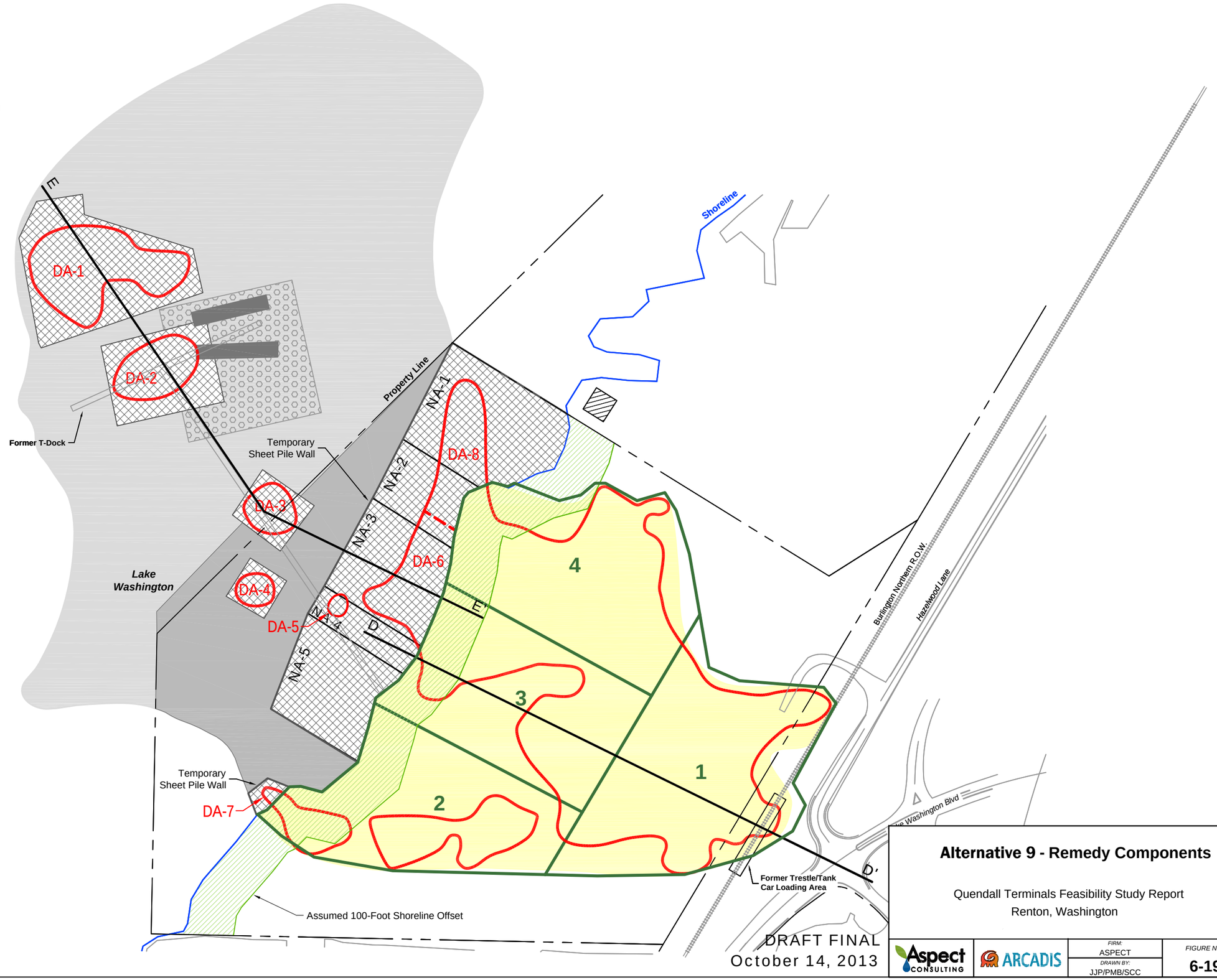
CAD Path: Q:\Quendall\020027 Quendall Terminals\2013-06 FS Draft Final\020027_SectionD-Alternatives 2-8.dwg ALT 8 NEW | | Date Saved: Oct 08, 2013 5:13pm | | User: scudd

Legend

- D — D' Cross Section Location and Designation
- Existing Structure
- DNR Dry Dock Cap
- DNR Dry Dock Concrete Hulls
- Estimated Extent of DNAPL
- 4 Soil Excavation Cell
- Habitat Area
- Enhanced Natural Recovery
- Engineered Sand Cap (Note 3)
- Dredge Area
- Excavated and Backfilled or Solidified Soil
- NA-1 Sediment Excavation Cell
- DA-1 Aquatic DNAPL Area

Notes:

1. Soil removal and sediment dredging areas based on maximum extent of DNAPL and of cPAHs and arsenic exceeding PRGs in groundwater and porewater.
2. This alternative also includes permeable upland cap similar to Alternative 3. Refer to Figure 6-4 for cap extent.
3. This alternative includes sediment removal (not shown on this figure) from the shoreline to approximately 75 feet offshore in area where engineered sand cap is to be placed, to maintain the existing nearshore area profile. Refer to Section 6.3.



Alternative 9 - Remedy Components

Quendall Terminals Feasibility Study Report
Renton, Washington

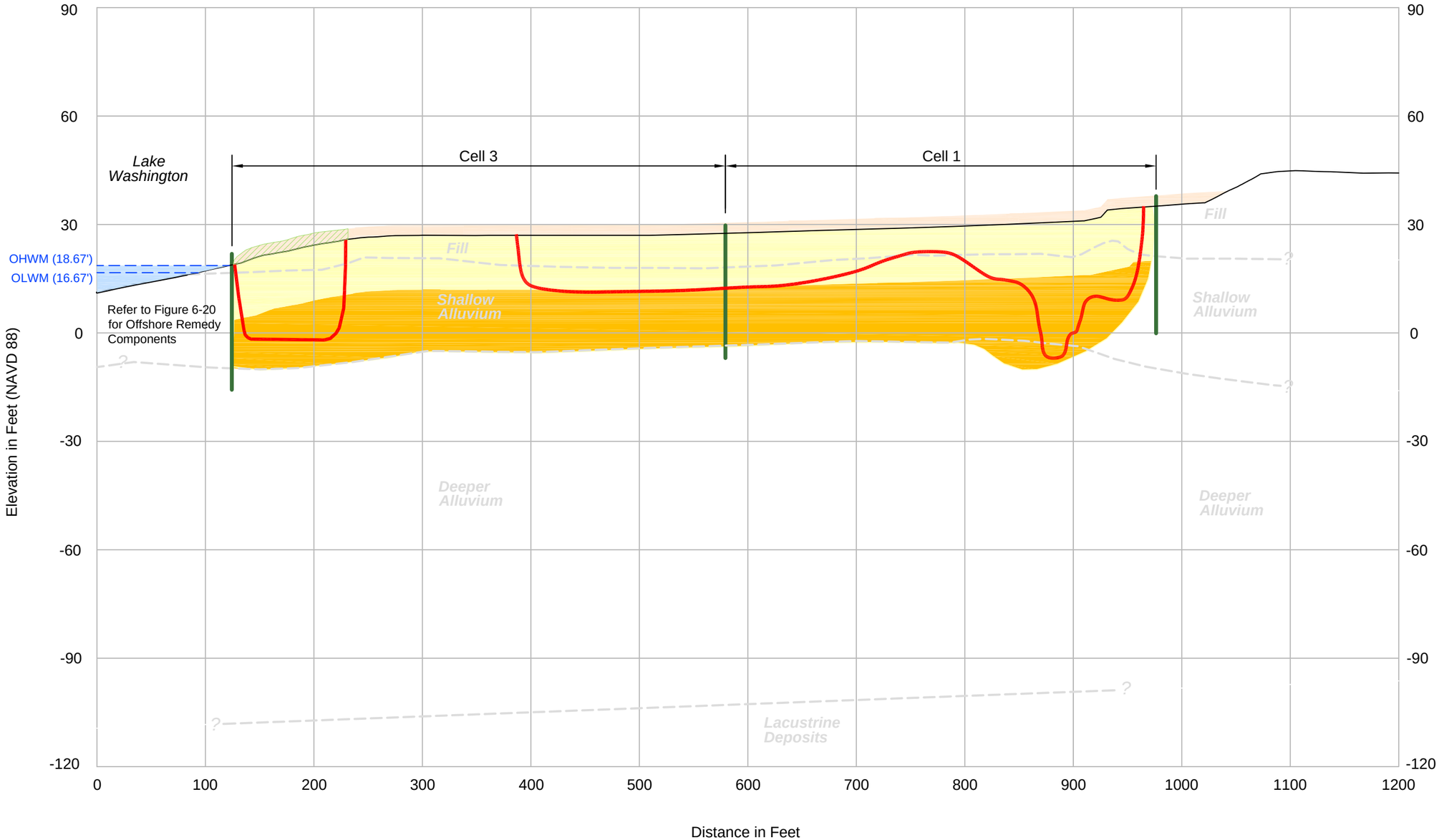
DRAFT FINAL
October 14, 2013

FIRM:	FIGURE NO.
ASPECT	6-19
DRAWN BY: JJP/PMB/SCC	

CAD Path: Q:\Quendall\020027 Quendall Terminals\2013-06 FS Draft Final\020027_Plan-Alternatives 9-10.dwg ALT 9 NEW || Coordinate System: NAD 1983 State Plane Washington North FIPS 4601 Feet || Date Saved: Oct 10, 2013 4:38pm || User: scudd

D

D'



Legend

- Solidified Soil
- Excavated Soil and Backfill
- Permeable Cap
- Permeable Cap/Habitat Area
- Estimated Extent of DNAPL (Refer to Figure 4-5 for Basis.)
- Temporary Sheet Pile Wall

Horizontal Scale
0 100 200
Feet

Vertical Scale
0 30 60
Feet

Vertical Exaggeration x 3.33

DRAFT FINAL
October 14, 2013

Alternative 9 - Upland Remedy Components along Cross Section D-D'

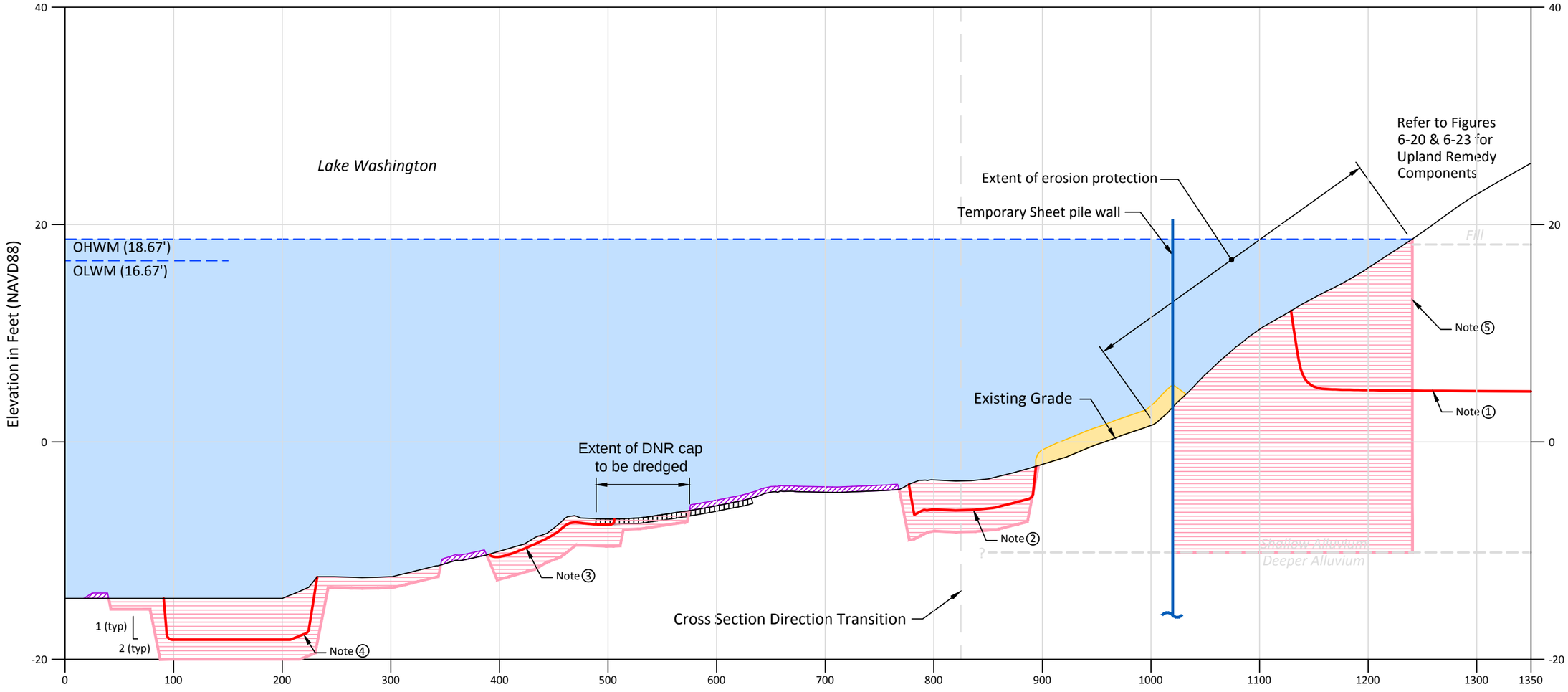
Quendall Terminals Feasibility Study Report
Renton, Washington

Aspect CONSULTING | ARCADIS | FIRM: ASPECT | DRAWN BY: JJP/PMB/ELG/SCC | FIGURE NO. 6-20

CAD Path: Q:\Quendall\020027 Quendall Terminals\2013-06 FS Draft Final\020027_SectionD-Alternate 09.dwg|ALT 9 NEW || Date Saved: Oct 08, 2013 5:17pm || User: scudd

E

E'



Legend:

- Existing DNR Dry Dock Cap
- Estimated extent of DNAPL, based on maximum depth of DNAPL observed in the noted explorations (see Figure 3-1 for exploration locations)
- Engineered sand cap (1.5 ft of sand with erosion protection as required)
- Enhanced Natural Recovery (0.5 ft of sand)
- Dredging (removal to designated depths, residual cover placement, and backfilled as required)

Notes:

① Boring SP-3 and sediment core VS 30
② Sediment core VS 27
③ Sediment cores EPA-1 and TD 08
④ Sediment cores VT 4 and VT 1
⑤ Only offshore remedy components are depicted in this figure

Horizontal Scale
0 100 200
Feet

Vertical Scale
0 10 20
Feet

Vertical Exaggeration x 10

DRAFT FINAL
October 14, 2013

Alternatives 9 & 10 - Offshore Remedy Components along Cross Section E-E'

Quendall Terminals Feasibility Study Report
Renton, Washington

Aspect CONSULTING | ARCADIS | FIRM: ARCADIS | DRAWN BY: BKD | FIGURE NO. 6-21

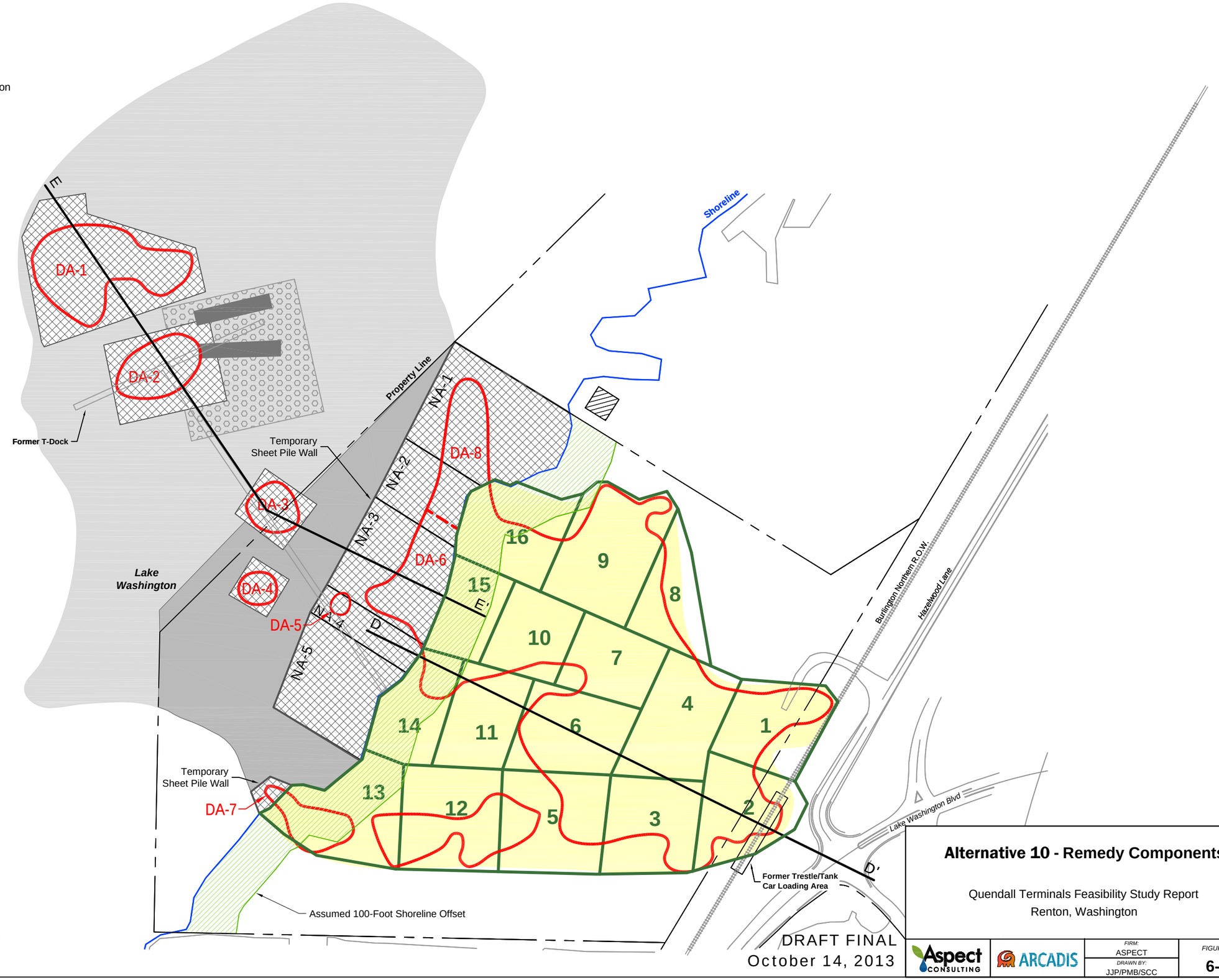
CAD Path: G:\ENVCAD\SYRACUSE\ACT\WA000907\0000\00001\DWG\REPORT\000907G01.dwg 6-21 || Date Saved: Oct 03, 2013 1:32pm || User: bdeclercq

Legend

- D — D' Cross Section Location and Designation
- Existing Structure
- DNR Dry Dock Cap
- DNR Dry Dock Concrete Hulls
- Estimated Extent of DNAPL
- 4 Soil Excavation Cell
- Habitat Area
- Enhanced Natural Recovery
- Engineered Sand Cap (Note 3)
- Dredge Area
- Excavated Soil and Backfill
- NA-1 Sediment Excavation Cell
- DA-1 Aquatic DNAPL Area

Notes:

1. Soil removal and sediment dredging areas based on maximum extent of DNAPL and of cPAHs and arsenic exceeding PRGs in groundwater and porewater.
2. This alternative also includes permeable upland cap similar to Alternative 3. Refer to Figure 6-4 for cap extent.
3. This alternative includes sediment removal (not shown on this figure) from the shoreline to approximately 75 feet offshore in area where engineered sand cap is to be placed, to maintain the existing nearshore area profile. Refer to Section 6.3.



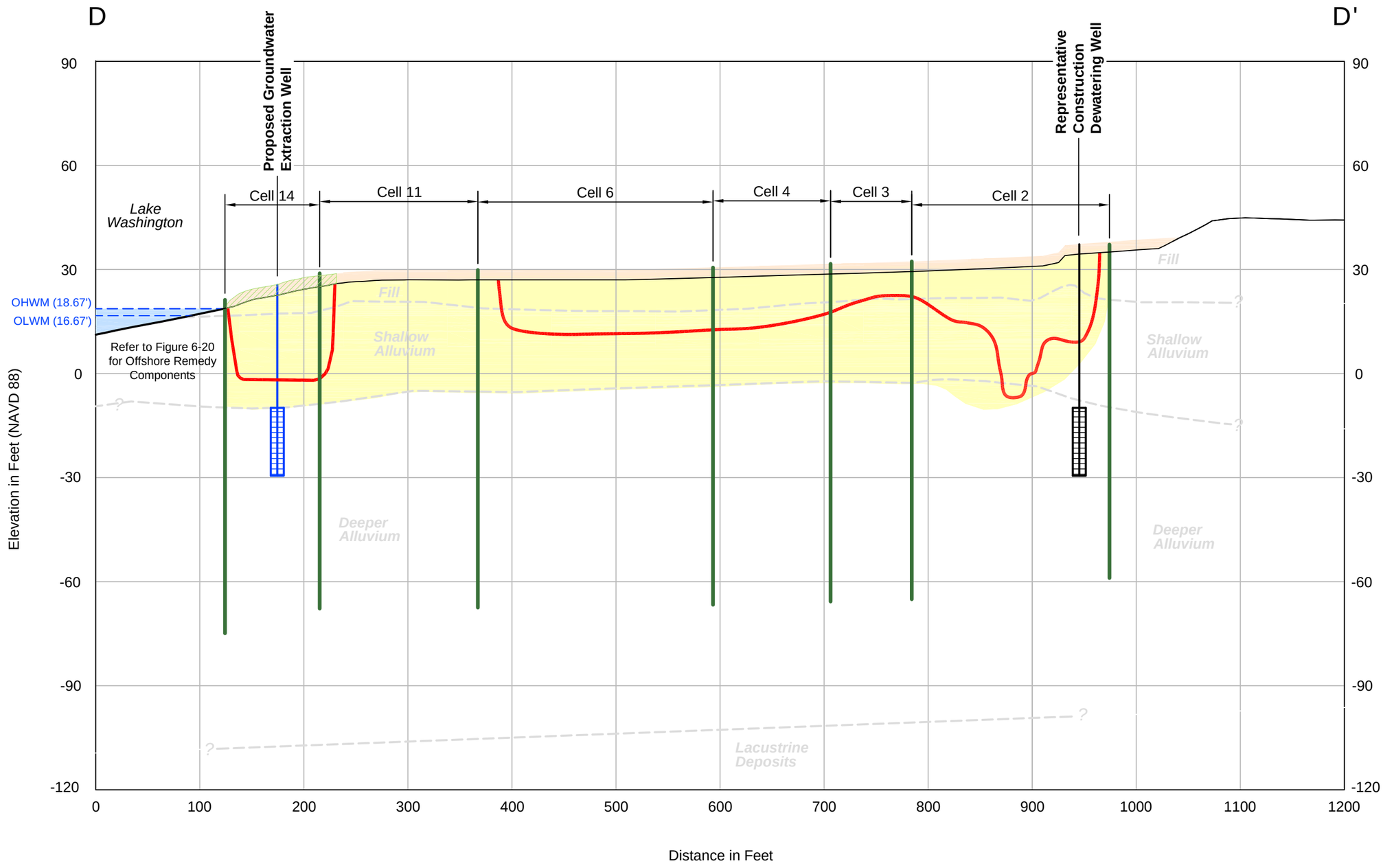
Alternative 10 - Remedy Components

Quendall Terminals Feasibility Study Report
Renton, Washington

DRAFT FINAL
October 14, 2013

FIRM:	FIGURE NO.
ASPECT	6-22
DRAWN BY: JJP/PMB/SCC	

CAD Path: Q:\Quendall\020027 Quendall Terminals\2013-06 FS Draft Final\020027_Plan-Alternatives 9-10.dwg ALT 10 NEW || Coordinate System: NAD 1983 State Plane Washington North FIPS 4601 Feet || Date Saved: Oct 10, 2013 4:41pm || User: scudd



Legend

- Excavated Soil and Backfill
- Permeable Cap
- Permeable Cap/Habitat Area
- Estimated Extent of DNAPL (Refer to Figure 4-5 for Basis.)
- Temporary Sheet Pile Wall

Horizontal Scale
0 100 200
Feet

Vertical Scale
0 30 60
Feet

Vertical Exaggeration x 3.33

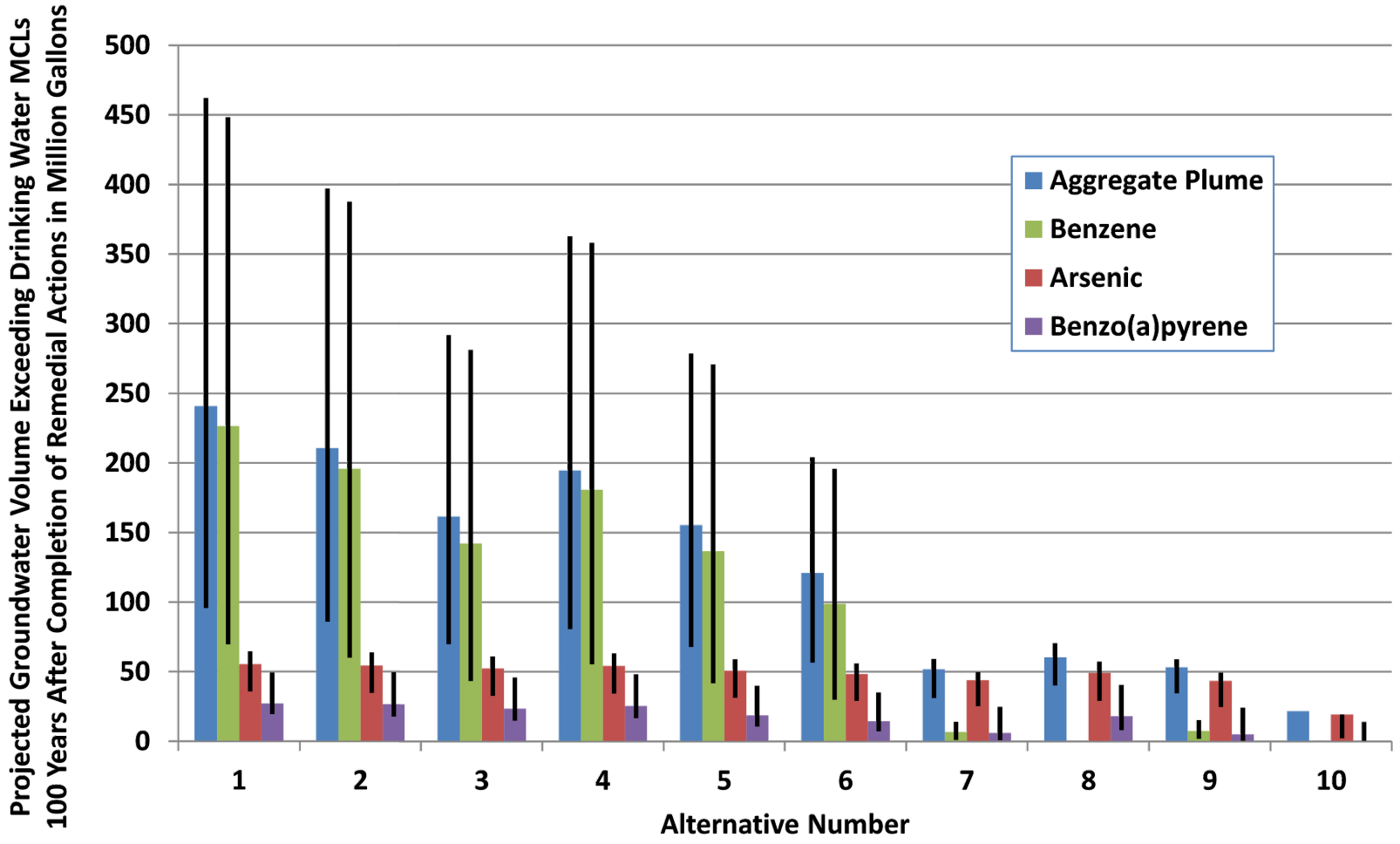
DRAFT FINAL
October 14, 2013

Alternative 10 - Upland Remedy Components along Cross Section D-D'

Quendall Terminals Feasibility Study Report
Renton, Washington

Aspect CONSULTING | ARCADIS | FIRM: ASPECT | DRAWN BY: JJP/PMB/ELG/SCC | FIGURE NO. 6-23

CAD Path: Q:\Quendall\020027 Quendall Terminals\2013-06 FS Draft Final\020027_SectionD-Alternate 10.dwg ALT 10 NEW || Date Saved: Oct 08, 2013 5:18pm || User: scudd



Note:
Black bars for Alternatives 1, 7, and 8 represent results of a sensivity analysis. Black bars for other alternatives are estimates derived from sensitivity analysis results. See Appendix A for details.

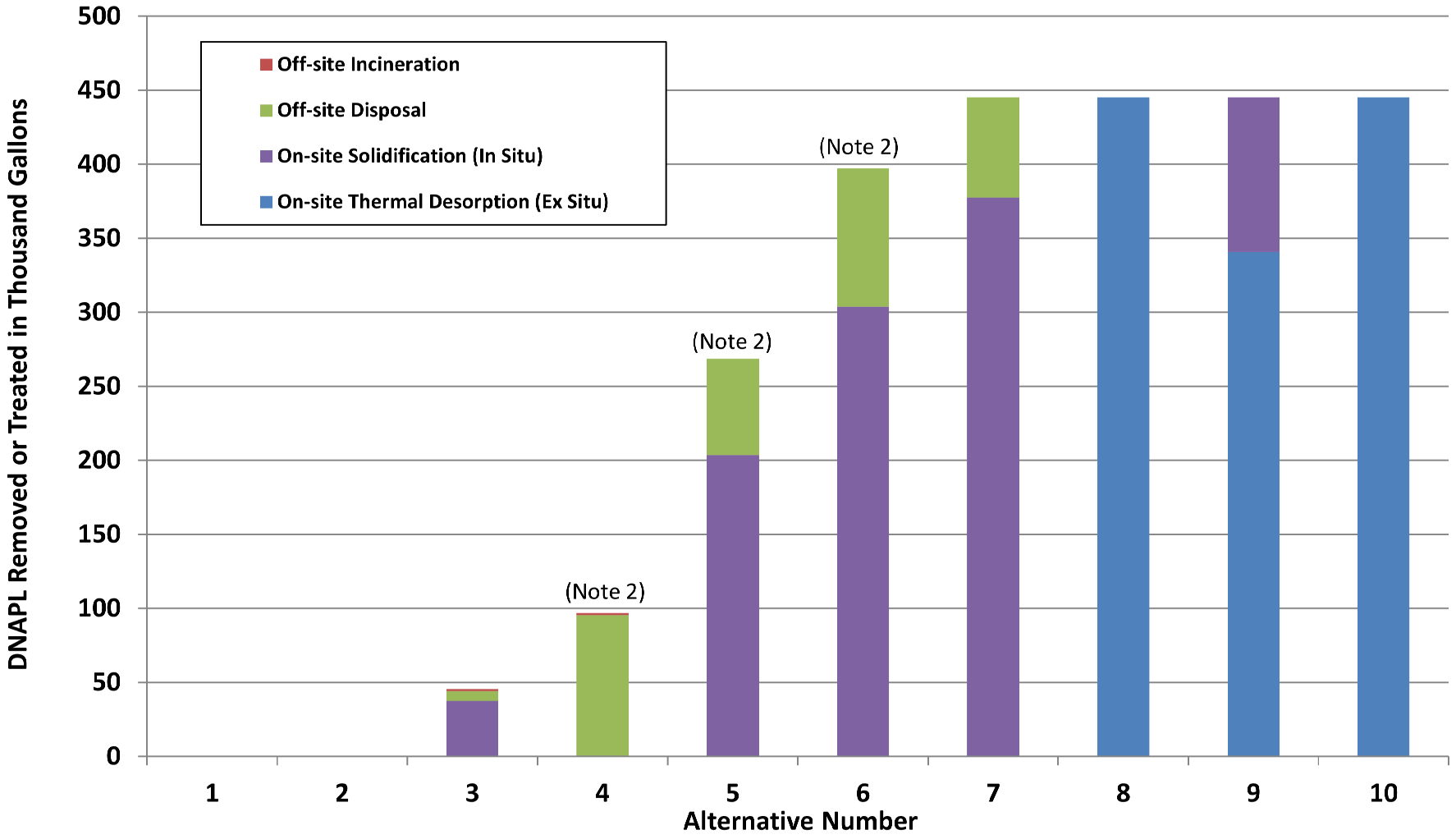
DRAFT FINAL
October 14, 2013

Projected Groundwater Restoration
100 Years After Implementation
of Alternative Remedial Actions

Quendall Terminals Feasibility Study Report
Renton, Washington

Aspect CONSULTING / ARCADIS	FIRM: ASPECT	DRAWN BY: JJP/SCC	FIGURE NO. 7-1

CAD Path: Q:\Quendall\020027 Quendall Terminals\2013-06 FS Draft Final\020027-71.dwg 7-1 || Date Saved: Oct 01, 2013 10:45am || User: scudd



Notes:

1. Refer to Table 7-2 for a summary of the DNAPL volumes depicted on this bar chart.
2. Partial treatment/removal in this alternative includes treatment/removal of DNAPL with the greatest future exposure risk (i.e., the QP-U, QP-S, and TD DNAPL Areas).

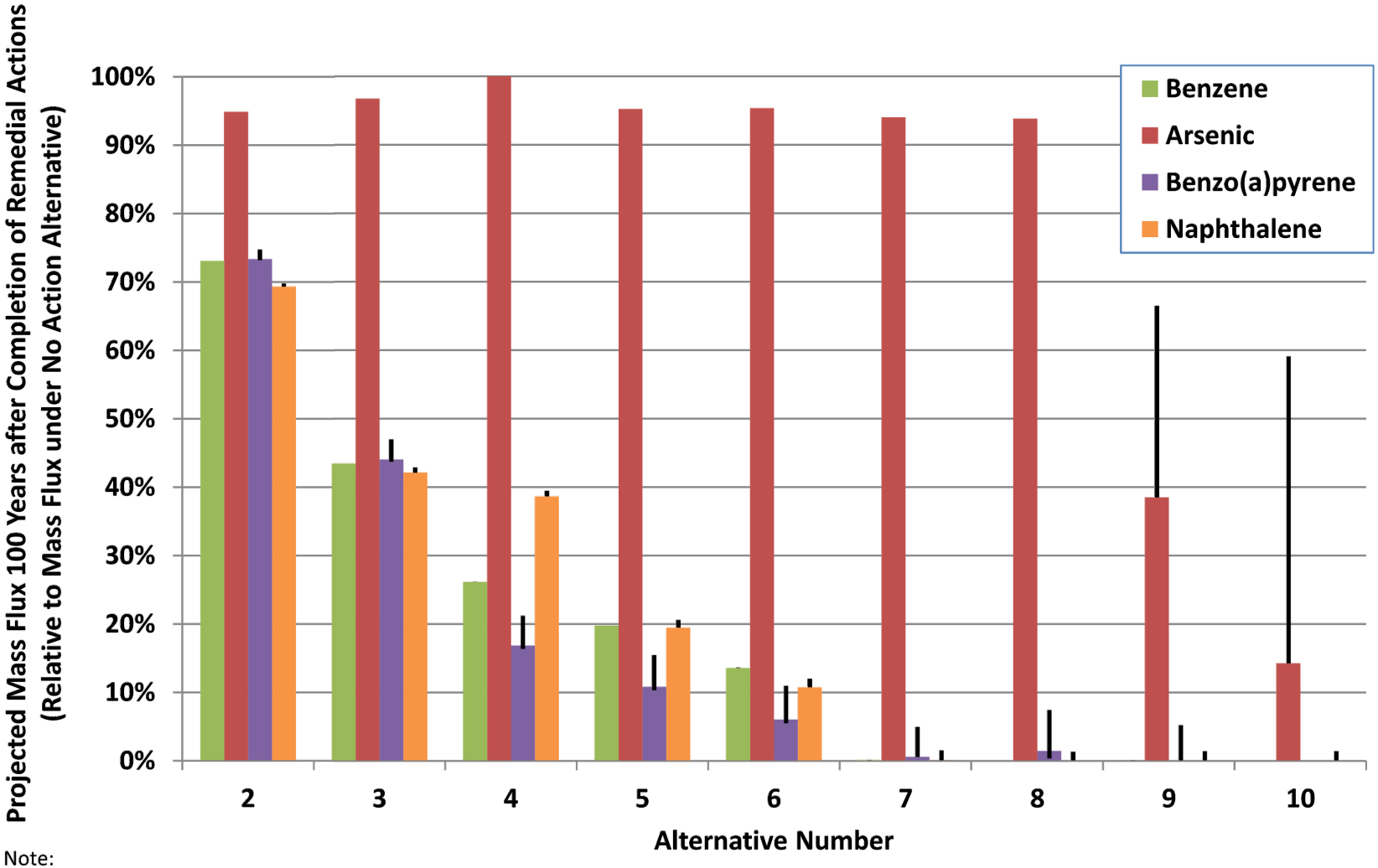
DRAFT FINAL
October 14, 2013

Estimated DNAPL Volumes Removed or Treated Under Alternative Remedial Actions

Quendall Terminals Feasibility Study Report
Renton, Washington

Aspect CONSULTING / ARCADIS	FIRM: ASPECT DRAWN BY: JJP/SCC	FIGURE NO. 7-2

CAD Path: Q:\Quendall\020027 Quendall Terminals\2013-06 FS Draft Final\020027-71.dwg 7-2 || Date Saved: Oct 10, 2013 4:54pm || User: scudd



Note:

Mass Flux estimates include only mass contributed from upland contamination. See section A3.6 of Appendix A for details of mass flux calculations. Black bars for alternatives 1, 7, and 8 represent results of a sensivity analysis. Black bars for other alternatives are estimates derived from sensitivity analysis results. See Appendix A for details.

Projected Reduction in Contaminant Mass Flux to Sediments 100 Years After Implementation of Alternative Remedial Actions

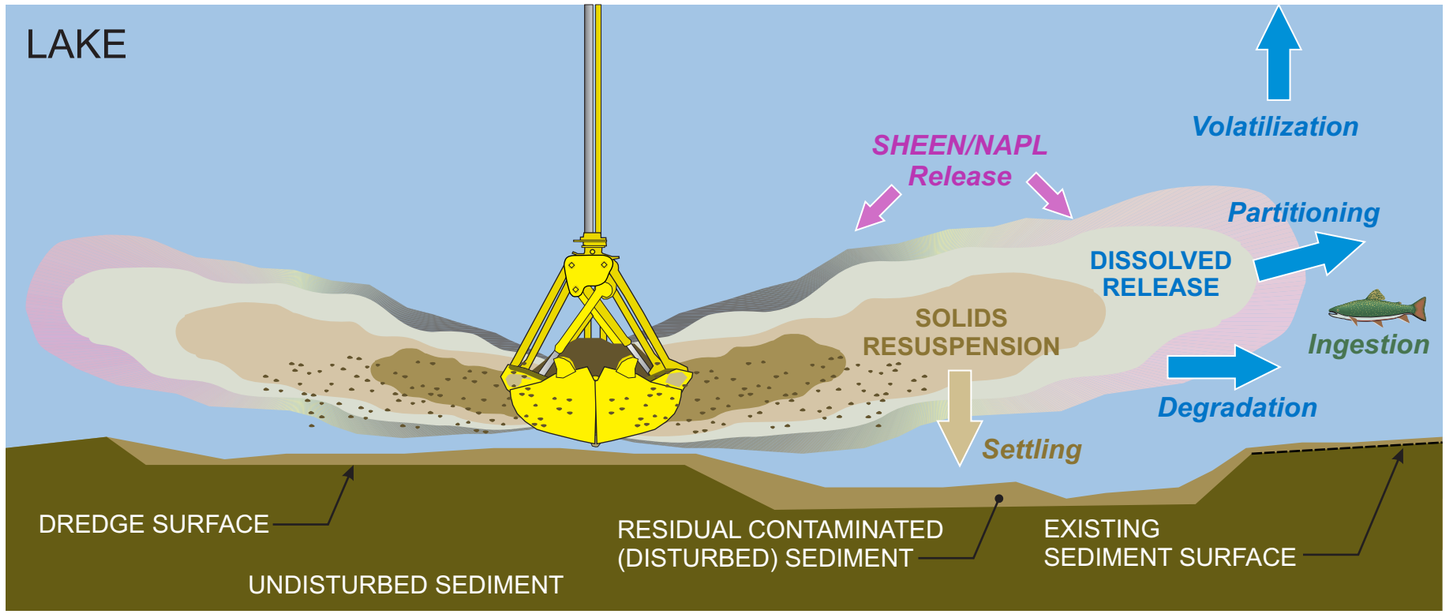
Quendall Terminals Feasibility Study Report

Renton, Washington

DRAFT FINAL
October 14, 2013

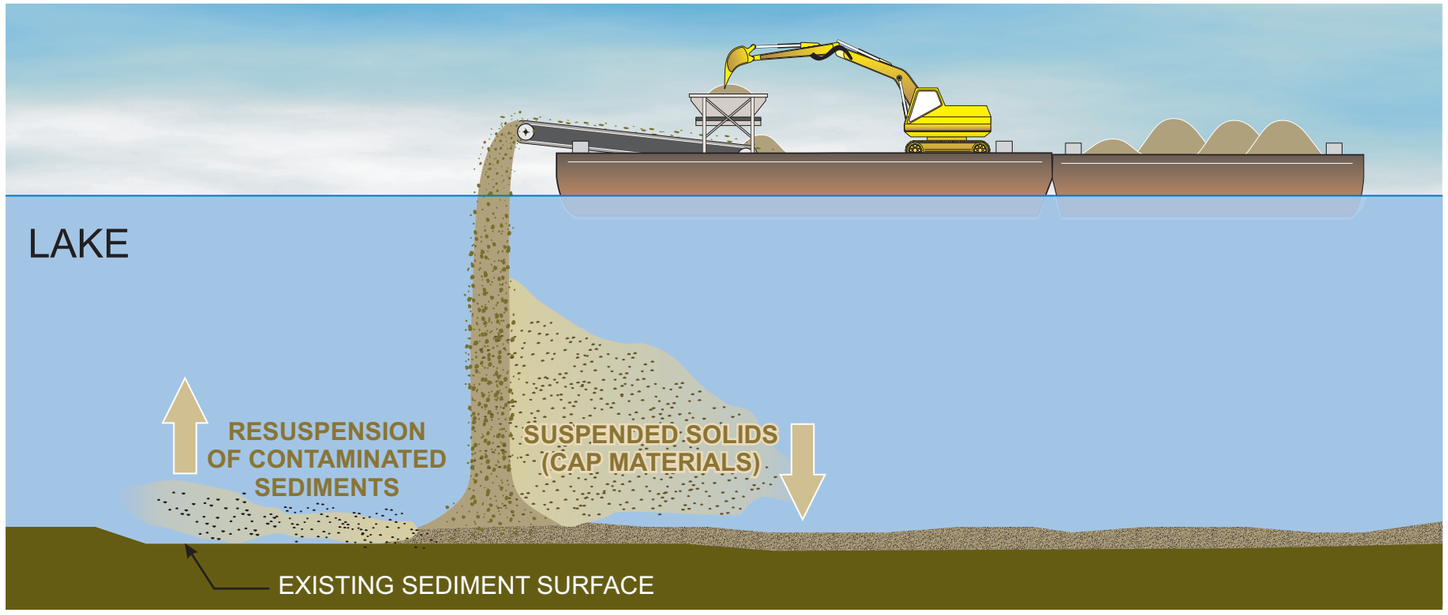
Aspect CONSULTING / ARCADIS	FIRM: ASPECT	DRAWN BY: JJP/SCC	FIGURE NO. 7-3

CAD Path: Q:\Quendall\020027 Quendall Terminals\2013-06 FS Draft Final\020027-71.dwg 7-3 || Date Saved: Oct 01, 2013 10:44am || User: scudd



NOT TO SCALE

POTENTIAL IMPACTS OF DREDGING



NOT TO SCALE

POTENTIAL IMPACTS OF CAPPING

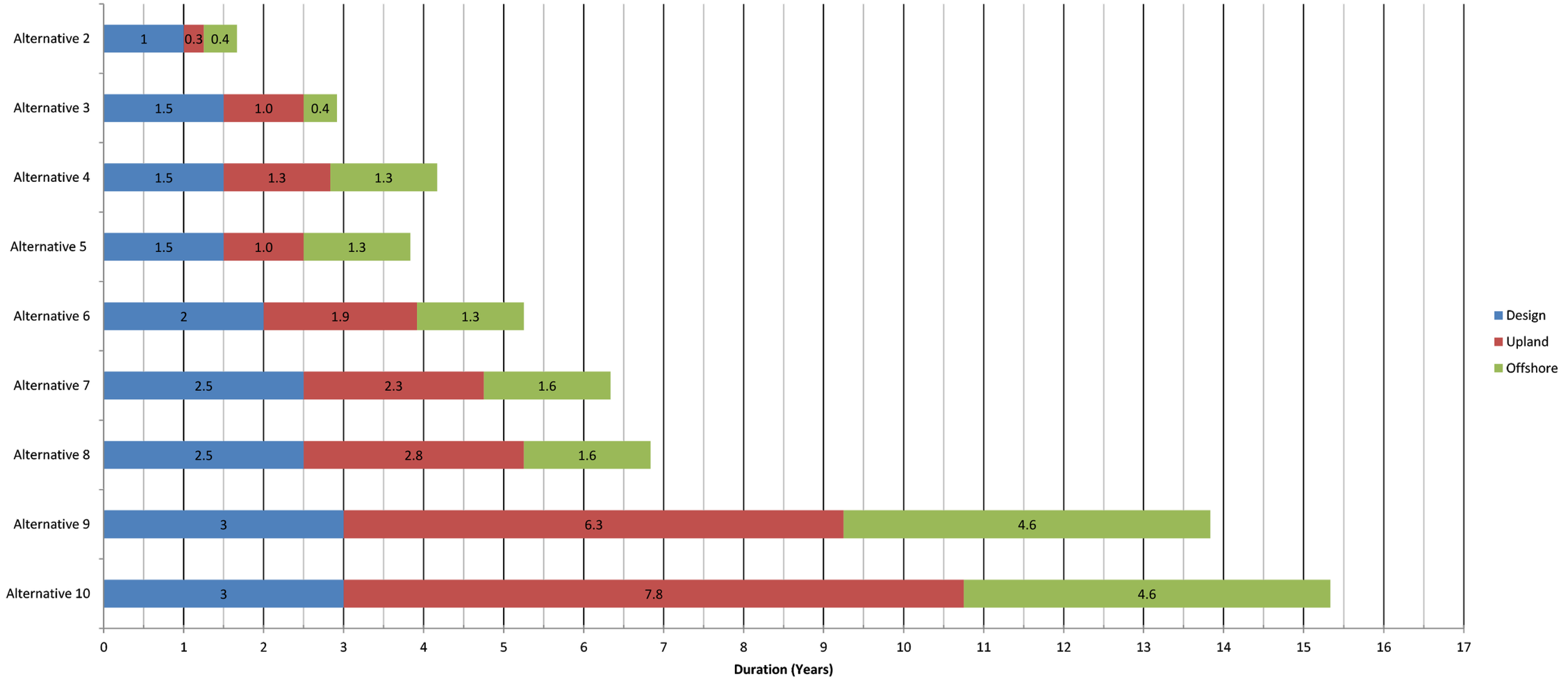
Potential Short-Term Impacts of Sediment Capping and Dredging

Quendall Terminals Feasibility Study Report
Renton, Washington

DRAFT FINAL
October 14, 2013

Aspect CONSULTING	ARCADIS	FIRM: ARCADIS DRAWN BY:	FIGURE NO. 7-4

10/03/2013 SYRACUSE, NY-ENV/CAD-DJHOWES
WA000907/0000/00003/CDR/00907G04.CDR



Notes:

1) Construction durations include work stoppage for the fish window for offshore work conducted outside of the sediment removal enclosures. It is assumed that work within the enclosures may be conducted within the fish window (outside the in-water work window).

2) The construction durations assume that upland work is completed prior to offshore work implementation. However, some upland and offshore work may be conducted concurrently.

DRAFT FINAL
October 14, 2013

Summary of Estimated Remedy Design and Construction Durations

Quendall Terminals Feasibility Study Report
Renton, Washington

Aspect CONSULTING / ARCADIS	FIRM: ASPECT	DRAWN BY: JJP/SCC	FIGURE NO. 7-5

CAD Path: Q:\Quendall\020027 Quendall Terminals\2013-06 FS Draft Final\020027-7-1.dwg 7-5 | | Date Saved: Sep 16, 2013 2:20pm | | User: scudd



FEASIBILITY STUDY APPENDICES

Quendall Terminals Site

Prepared for: U.S. Environmental Protection Agency, Region 10

Project No. 020027 • October 14, 2013 Draft Final

On behalf of

Altino Properties, Inc. and

J.H. Baxter & Co.

Prepared by

Aspect Consulting, LLC and

Arcadis U.S., Inc.

APPENDIX A

Groundwater Modeling

Contents

A1 Introduction A-1

A2 Groundwater Model Background A-2

A3 Evaluation of Remedial Alternatives A-3

A3.1 Modifications to Develop FS Groundwater Model A-4

A3.1.1 Structural Modifications A-4

A3.1.2 Transport Parameter Modifications A-4

A3.1.3 Simplifying Assumptions A-7

A3.1.4 Modifications to Simulate Remedial Actions A-7

A3.2 Initial Conditions and Hydrocarbon Source Boundary Conditions for FS Remedial Alternatives A-8

A3.2.1 Initial Conditions and Source Boundary Conditions for Benzene, Benzo(a)pyrene, and Naphthalene A-8

A3.2.2 Initial Conditions for Arsenic A-9

A3.2.3 Comparison to Measured Concentrations A-10

A3.3 Groundwater Model Simulation of Remedial Technologies A-11

A3.4 Development of FS Remedial Alternatives A-13

A3.5 Groundwater Model Simulation of Remedial Alternatives A-15

A3.6 Remedial Alternatives Groundwater Model Results A-19

A3.7 Sensitivity Analysis of FS Groundwater Model Results A-21

A3.7.1 Sensitivity Analysis Results A-21

A4 Excavation Dewatering Analysis A-23

A4.1 Modifications to Develop Dewatering Groundwater Model A-23

A4.2 Constructability Assumptions A-24

A4.3 Dewatering Groundwater Modeling Approach A-24

A4.4 Dewatering Groundwater Modeling Results A-25

A5 Additional Evaluations for Alternative 9 and 10 ..... A-26

A5.1 Restoration Timeframe Sensitivity Analysis A-27

A5.1.1 Aquifer Heterogeneity A-27

A5.1.2 Excavation Residuals Sensitivity Analysis A-29

A5.2 Pump and Treat System Optimization A-30

A5.3 Construction Dewatering - Alternatives 9 and 10 ..... A-31

A5.3.1 Excavation Dewatering (Shallow Alluvium) A-31

A5.3.2 Depressurization of Deeper Alluvium A-31

A5.3.3 Estimated Excavation Dewatering Flow Rates (Shallow Alluvium) A-31

A5.3.4 Estimated Depressurization Flow Rates (Deeper Alluvium) A-32

A6 References for Appendix A A-34

List of Tables

A-1 Contaminant Fate and Transport Parameters
A-2 Measured Dissolved Oxygen Concentrations
A-3 Source Area Concentrations
A-4 Case Studies for Solidification of Coal Tar and Creosote Constituents
A-5 Development of Remedial Alternatives
A-6 Evaluation of Remedial Alternatives – Aggregate Plume Volumes
A-7 Evaluation of Remedial Alternatives by COC
A-8 Groundwater Discharge to Lake Washington
A-9 Parameter Sensitivity Analysis
A-10 Sensitivity Analysis Results by COC
A-11 Sensitivity Analysis Results – Aggregate Plume Volume
A-12 Estimated Sensitivity Analysis Results – Aggregate Plume Volume
A-13 Estimated Sensitivity Results by COC – Plume Volume
A-14 Estimated Sensitivity Results by COC – Plume Mass
A-15 Estimated Sensitivity Results by COC – Mass Flux
A-16 Dewatering Estimates – Wet Excavation
A-17 Dewatering Estimates – Dry Excavation
A-18 Fine Grain Layers in the Deeper Alluvium
A-19 Restoration Potential Fate and Transport Model Results
A-20 Dewatering Estimates for Locations near the Railroad Area and Shoreline

List of Figures

A-1 Hydrocarbon Source Zones
A-2 Modeled Hydrocarbon Source Zones – Plan View
A-3 Modeled Hydrocarbon Source Zones – Cross Section View
A-4 Model Simulated Pre-remediation Benzene Plume – Plan View
A-5 Model Simulated Pre-remediation Naphthalene Plume – Plan View
A-6 Model Simulated Pre-remediation Benzo(a)pyrene Plume – Plan View

A-7 Model Simulated Pre-remediation Arsenic Plume – Plan View

A-8 Model Simulated Pre-remediation Benzene Plume – Cross Section View

A-9 Model Simulated Pre-remediation Naphthalene Plume – Cross Section View

A-10 Model Simulated Pre-remediation Benzo(a)pyrene Plume – Cross Section View

A-11 Model Simulated Pre-remediation Arsenic Plume – Cross Section View

A-12 DNAPL Treatment Areas Evaluated for Alternative Development

A-13 Model Simulated Benzene Plume – Plan View

A-14 Model Simulated Naphthalene Plume – Plan View

A-15 Model Simulated Benzo(a)pyrene Plume – Plan View

A-16 Model Simulated Arsenic Plume – Plan View

A-17 Model Simulated Aggregate Plume – Plan View

A-18 Model Simulated Benzene Plume – Cross Section View

A-19 Model Simulated Naphthalene Plume – Cross Section View

A-20 Model Simulated Benzo(a)pyrene Plume – Cross Section View

A-21 Model Simulated Arsenic Plume – Cross Section View

A-22 Sensitivity Analysis Results – Aggregate Plume Volume

A-23 Linear Interpolation of Sensitivity Analysis Results – Aggregate Plume Volume

A-24 Estimated Sensitivity Analysis Results – Aggregate Plume Volume Exceeding Drinking Water PRGs

A-25 Estimated Sensitivity Analysis Results – Aggregate Plume Volume Exceeding Drinking Water MCLs Only

A-26 Sensitivity Analysis Results by COC – Plume Volume

A-27 Linear Interpolation of Sensitivity Analysis Results by COC – Plume Volume

A-28 Estimated Sensitivity Analysis Results by COC – Plume Volume

A-29 Sensitivity Analysis Results by COC – Plume Mass

A-30 Linear Interpolation of Sensitivity Analysis Results by COC – Plume Mass

A-31 Estimated Sensitivity Analysis Results by COC – Plume Mass

A-32 Sensitivity Analysis Results by COC – Mass Flux

A-33 Linear Interpolation of Sensitivity Analysis Results by COC – Mass Flux

A-34 Estimated Sensitivity Analysis Results by COC – Mass Flux

A-35 Pump and Treat Capture Analysis – Plan View

A-36 Pump and Treat Capture Analysis – Cross Section View

A1 Introduction

This appendix documents the use of groundwater flow and contaminant fate and transport modeling to support the Quendall Terminals Site (Site) Feasibility Study (FS). The primary objective of FS groundwater modeling is to simulate groundwater flow and contaminant fate and transport at the Site to support the following FS tasks:

- Development and evaluation of FS remedial alternatives, including: 1) how technologies addressing groundwater contamination may be applied to achieve the preliminary remediation goals (PRGs) for one or more of the four primary chemicals of concern (COCs); 2) estimating the relative restoration timeframe; and 3) estimating the relative reduction in the volume of contaminated groundwater (groundwater plume volume), contaminant mass, and contaminant mass flux; and
- Evaluation of conceptual dewatering design, including pumping and drawdown estimates for construction dewatering, to support cost estimating.

Groundwater modeling simulations are discussed and the results evaluated in Sections 3, 6, 7, and 8 of the main text of this FS. Section 3 includes a description of the geologic conditions and hydrogeologic conceptual site model (CSM) that form the basis for the groundwater flow model. In Section 6, which assembles and describes 10 remedial alternatives, the groundwater model is used to develop conceptual design parameters such as dewatering flowrates and treatment areas. Modeling predictions of alternative effectiveness at restoring groundwater (including achieving groundwater maximum contaminant levels [MCLs], reducing the volume of contaminated groundwater, and reducing the flux of contaminants in groundwater) are used in the detailed analysis of alternatives in Section 7 and the comparative analysis of alternatives in Section 8.

A2 Groundwater Model Background

FS groundwater modeling is based on the groundwater flow and contaminant fate and transport model originally developed in support of the Site's Remedial Investigation (RI) Report (Anchor QEA and Aspect 2012). The groundwater model is a MODFLOW-based (MacDonald and Harbaugh 1988), three-dimensional numerical model of groundwater flow across the Site. The groundwater model uses the code MT3DMS (Zheng and Wang 1999), an update to the original MT3D code (Zheng 1990), to simulate contaminant fate and transport. Documentation of the construction and calibration of the groundwater model used to support preparation of the RI Report is provided in Appendix D of the RI Report (Anchor QEA and Aspect 2012).

The original RI groundwater model that was developed and described in Appendix D of the RI Report (Anchor QEA and Aspect 2012), has been refined and used for two general purposes in the FS:

1. Development and evaluation of FS remedial alternatives. This FS groundwater modeling task used modifications to both the groundwater flow and contaminant fate and transport components from the RI groundwater model to produce the groundwater model results described in Section A3 of this appendix.
2. Evaluation of FS conceptual dewatering design criteria. This FS groundwater modeling task used modifications to only the groundwater flow component of the RI groundwater model to produce the groundwater model results described in Section A4 of this appendix.

The groundwater model structure, groundwater flow boundary conditions, and flow parameters used to perform groundwater modeling tasks in the FS remain unchanged from those used in the RI groundwater model with the following exceptions: modifications to the grid to increase vertical resolution and the addition and/or modification of boundary conditions and parameters to simulate elements of remedial alternatives or dewatering systems consistent with the description of the alternatives presented in Section 6 of the FS. The specific structural modifications to the groundwater model used to evaluate FS remedial alternatives and determine FS dewatering design criteria are detailed in Sections A3 and A4 of this appendix, respectively.

Several groundwater modeling evaluations specific to Alternatives 9 and 10 were completed early in the FS process using slightly different groundwater model assumptions and construction than the analyses described in Sections A3 and A4. Differences in the groundwater model include different initial concentration conditions and local grid discretization. These earlier evaluations included optimizing the conceptual design of a pump and treat polishing system for Alternative 9, determining construction dewatering design criteria for Alternatives 9 and 10, and evaluating the potential effect of Deep Aquifer heterogeneity and potential excavation residuals on restoration timeframe on Alternative 10. For these analyses, we do not expect that the differences in the groundwater model construction significantly affect the results or conclusions; therefore, these earlier evaluations were not reanalyzed using the updated groundwater model described in Sections A3 and A4. Groundwater model construction and results for these earlier evaluations are described in more detail in Section A5.

A3 Evaluation of Remedial Alternatives

The FS groundwater model was used to simulate changes in concentrations of the four primary COCs (benzene, benzo(a)pyrene[1], naphthalene, and arsenic; refer to Section 3.5 of the FS main text) in Site groundwater following implementation (i.e., completion of construction) of individual remedial alternatives. The groundwater modeling approach used for this evaluation was a four-step process as follows:

1. In the first step, the distribution of dense non-aqueous phase liquid (DNAPL) observed at the Site (Section 3 of the FS main text) was represented as a source of contamination in the groundwater model by placing constant groundwater concentration boundary conditions (based on existing Site data) in the groundwater model cells corresponding to DNAPL-impacted soil.

2. In the second step, the groundwater model was run for 100 years to simulate the time since the creosote plant began operation, and to "propagate" the dissolved phase plumes. The propagated plumes were used to generate an approximate representation of the Site's downgradient pre-remediation concentration distributions for each of the three primary hydrocarbon COCs (benzene, benzo[a]pyrene, and naphthalene) derived from the hydrocarbon source2.

3. In the third step, the hydrocarbon source (constant groundwater concentration boundary condition) and the pre-remediation concentrations of each of the four primary COCs were modified to reflect implementation of the remedial alternative being evaluated to generate a post-remedy initial condition and boundary conditions for each of the alternatives. For example, for an area where DNAPL would be removed as part of an alternative, the hydrocarbon source (constant groundwater concentration boundary condition) was removed and the pre-remediation concentrations of each of the four primary COCs were set to zero (conservatively assuming no residual soil or groundwater contamination remaining following remedial construction).

4. In the fourth step, the FS groundwater model was then run using those post-remedy boundary conditions and initial conditions for an additional 100 years to predict the groundwater concentrations of the primary COCs, 100 years following completion of construction of the remedial action.

This groundwater modeling evaluation is intended to be used as a predictive tool to provide relative results based on a consistent set of assumptions for comparative evaluation of the range of remedial alternatives. Simplifying assumptions were made in order to represent the complexities of Site conditions in the groundwater model and simulate the transport of the primary COCs. Because of the simplifying assumptions, the

[1] Benzo(a)pyrene is modeled to represent total carcinogenic polycyclic aromatic hydrocarbons (cPAHs; as a benzo[a]pyrene equivalent).
[2] The term "hydrocarbon source" is specific to the groundwater model. "DNAPL source" is a more general term and is used in the main text.

groundwater model results should be viewed as an approximate representation of actual outcomes (see Section A3.2.3 for examples that illustrate the differences between modeled and actual conditions). Therefore, results should be used to compare the relative benefit of different alternatives rather than as absolute predictions of actual outcomes.

The sections listed below and that follow, describe construction and use of the FS groundwater model in the evaluation of the remedial alternatives:

- Section A3.1 describes the modifications to the RI groundwater model used to develop the FS groundwater model;
- Section A3.2 describes the methods used to establish contaminant fate and transport boundary conditions and initial conditions;
- Section A3.3 details the alternative-specific modifications to the groundwater model to evaluate the effect of different remedial technologies;
- Section A3.4 describes groundwater modeling conducted to aid alternative development;
- Sections A3.5 describes simulation of the alternatives;
- Section A3.6 describes results of the alternative evaluation; and
- Section A3.7 documents the sensitivity analysis.

A3.1 Modifications to Develop FS Groundwater Model

The following modifications were made to the groundwater flow and contaminant fate and transport components of the RI groundwater model to develop the FS groundwater model. The modifications include both structural modifications and updates to contaminant fate and transport parameters as described below.

A3.1.1 Structural Modifications

Structural modifications were made to the RI groundwater model to facilitate its use for evaluation of remedial alternatives in the FS. The groundwater model developed for the FS includes inserting 19 additional layers to increase vertical resolution for simulation of remedial alternatives that include solidification (Alternatives 3, 5, 6, 7, and 9). Eight additional groundwater model layers were added by evenly splitting layers 3 (top of the Shallow Aquifer) through 10 (deepest layer) of the RI groundwater model in half. The top layer of the Deep Aquifer was then subdivided by adding two, 2- to 3-foot-thick,layers at the top of the Deep Aquifer to facilitate simulation of DNAPL at the top of the Deep Aquifer. The geometry of hydrostratigraphic zones and groundwater model boundaries were unchanged. The grid change was applied to all remedial alternatives to maintain consistency for volume calculations.

A3.1.2 Transport Parameter Modifications

The contaminant fate and transport parameters for the hydrocarbon primary COCs used in the FS groundwater modeling were consistent with assumptions used in the RI groundwater model. For the FS analyses, transport of arsenic was added, assuming a sorption coefficient (K_d) of 29 liters per kilogram (L/kg) as presented in the Washington State Department of Ecology (Ecology) Model Toxics Control Act (MTCA) regulation

(Washington Administrative Code [WAC] 173-340-900 Table 747-3). Arsenic decay was not simulated because arsenic does not decay. These parameters are presented in Table A-1. While parameters remained unchanged from the RI version of the groundwater model, a few select parameters were re-evaluated in detail to ensure they satisfy the purposes of the FS; those evaluations are discussed in the sections below.

A3.1.2.1 Contaminant Degradation

The value used for the half-life of benzene was re-evaluated because the half-life has a large effect on the groundwater model results as is shown in the sensitivity analysis (Section A-3.7). As described below, benzene likely undergoes biodegradation in Site groundwater under anaerobic conditions. A benzene half-life value of 720 days was used in both the RI and FS groundwater models and is our best estimate of anaerobic degradation of benzene on the Site. This best estimate and the range of half-lives used in the sensitivity analysis are consistent with those in applicable published literature under anaerobic conditions. A review of Site groundwater conditions, a summary of half-lives used in previous Site evaluations, and a discussion of the half-life values used in the FS based on an updated literature review are provided below.

- **Review of Groundwater Conditions.** At low dissolved oxygen (DO) levels (e.g., 1 mg/L), anaerobic respiration is the dominant biodegradation mechanism (Aaronson 1997). Site RI data show very low DO concentrations (average of 0.77 mg/L for all wells sampled in 2008 and 2009[3]; see Table A-2) that are consistent with anaerobic conditions. Other groundwater conditions observed at the Site, such as elevated dissolved iron, also indicate anaerobic conditions. Anaerobic conditions are common at sites containing significant sources of organic carbon, which serve as a food source for indigenous bacteria. At the Site, both natural (e.g., peat) and anthropogenic (e.g., DNAPL) sources of organic carbon are present.
- **Summary of Half-Lives Used in Previous Site Evaluations.** Previous transport modeling of the Site by Retec 1998 used column testing results reported in a treatability study (Retec 1997) and literature values reported in the Handbook of Environmental Degradation Rates (Howard et al. 1991) as a basis for degradation rates, as follows:
    - Aerobic Conditions: Retec modeled degradation for an aerated treatment system using a range of half-life values based on aerated column testing results and aerobic rates reported in Howard et al. 1991. The test protocol for the treatability study column testing was designed to simulate conditions representative of the peak performance achievable from an aeration system; therefore, influent DO concentrations to the test columns were maintained at 6 mg/L.
    - Anaerobic Conditions: Anaerobic benzene half-lives considered by Retec 1998 were based on the values reported in Howard et al. 1991, ranged

[3] Data collected in 2008 and 2009 are considered most representative of Site conditions for two reasons: 1) they are the most recent available data and 2) some of the older groundwater data was collected using bailers, which can bias DO measurements high.

from 112 to 720 days. However, Retec assumed no degradation for model simulations that represented no aeration.

Half-lives based on the Retec treatability study column test results are not representative of current conditions at the Site because DO measured on site is far less than what would be expected under aerated conditions. Therefore the values resulting from column testing were not considered for the RI or FS groundwater model.

- **FS Half-Lives Values Used Based on Updated Literature Review.** For the FS, an updated review of the literature for anaerobic biodegradation was conducted. A more extensive review of laboratory and field studies is provided in Aronson 1997. This review indicated anaerobic half-lives for benzene determined under field studies ranged from 220 days to no degradation.

  The longer of the anaerobic half-life values reported in Howard et al. 1991 (720 days for benzene) was selected as an appropriate mid-range value for the FS groundwater model, based on the range of half-life values derived from representative field studies (Aronson 1997). The 720-day half-life is the same that was used in fate-and-transport modeling for the RI Report (Anchor and Aspect, 2012).

  A sensitivity analysis was also performed (discussed in Section A3.7) which included a shorter half-life for benzene (112 days) that is based on laboratory studies (Howard et al. 1991). This value is lower than the shortest half-life rate (220 days) derived from field studies reviewed by Aronson 1997.

  Representative half-life values for naphthalene and benzo(a)pyrene where derived similarly, as follows:

  - Retec 1998 assumed values for chrysene were representative of benzo(a)pyrene. This assumption was retained for the RI and FS groundwater models. The longer anaerobic half-life reported for chrysene in Howard et al. 1991 (4,000 days) was assumed for benzo(a)pyrene in the FS groundwater model; the shorter anaerobic half-life for chrysene reported in Howard et al. 1991 (1,484 days) was used as the lower bound in the sensitivity analysis.
  - Only one anaerobic half-life for naphthalene was reported in Howard 1991 (258 days); therefore, this value was used for the FS groundwater transport modeling. To arrive at the lower bound for the naphthalene half-life sensitivity analysis (40 days), the naphthalene half-life was reduced an amount proportional to the reduction of the benzene half-life (84 percent).

Fill Sorption Coefficient (Kd)

The sorption coefficient (K_d) parameter defines sorption processes in the groundwater transport model, and K_d values used in the groundwater model are based on the fraction of organic content (f_{oc}) assumed in each hydrostratigraphic unit. The groundwater model uses the same K_d in the fill as in the Deeper Alluvium. Previous modeling at the Site (Retec 1998) assumed a K_d value in the fill that is equal to the value in the Shallow

Alluvium because a higher f_{oc} was assumed in the fill due to the presence of woody debris. While a K_d value based on a higher f_{oc} may be more appropriate for some materials in the Fill Unit, the difference in K_d in the fill is expected to have a *de minimis* effect on the groundwater model results because the fill is only partially saturated and the saturated fill makes up a very small portion of the active model domain. Therefore, the K_d value used in the RI groundwater model was retained in the FS groundwater model and considered adequate for the purposes of the FS.

A3.1.3 Simplifying Assumptions

The FS groundwater model makes two simplifying assumptions that were evaluated for the FS. These assumptions are as follows:

1. Homogeneous Deep Aquifer. The groundwater model assumes the Deep Aquifer is homogeneous when in actuality; it contains lenses of lower permeability material where higher concentrations may persist for a longer duration than what the groundwater model predicts for the assumed homogeneous materials.

2. No Excavation Residuals. When simulating excavation of contaminated soil, the groundwater model assumes that no residual groundwater or soil contamination remains in the excavated volume after construction. Groundwater model simulation of excavations is discussed in Section A3.

These assumptions were also included in the RI version of the groundwater model and were not modified; however, they are mentioned here because they may have a significant effect on the potential for the most aggressive alternatives to achieve drinking water MCLs for Site COCs, and the results of the evaluation of remedial alternatives should be considered with this in mind. Any contribution to concentrations from fine-grained layers or excavation residual would be in addition to the groundwater-model-predicted concentrations resulting from this remedial alternative evaluation presented in Section A3.6. The effect of these simplifying assumptions on the groundwater model results was evaluated in a sensitivity analysis conducted during groundwater modeling early in the FS process, as discussed in Section A5. Based on the sensitivity analysis, the FS groundwater model likely underpredicts restoration timeframes for recalcitrant compounds (e.g., benzo(a)pyrene and arsenic) and therefore should be viewed as a best case scenario. The restoration timeframe for more easily degraded compounds (e.g., benzene) is less sensitive to these parameters.

A3.1.4 Modifications to Simulate Remedial Actions

The contaminant fate and transport parameters discussed above are intended to simulate current Site conditions. In some cases however, contaminant fate and transport parameter values were changed specific to individual remedial technologies as described below in Section A3.3: Groundwater Model Simulation of Remedial Technologies and Section A3.5: Groundwater Model Simulation of Remedial Alternatives. Changes to contaminant fate and transport parameters as part of the sensitivity analysis are described in Section A3.7.

A3.2 Initial Conditions and Hydrocarbon Source Boundary Conditions for FS Remedial Alternatives

Initial conditions for each remedial alternative groundwater model run were developed to represent concentrations of the four primary COCs throughout the Site immediately following implementation of the alternative (see Section 6 of the FS main text for detailed descriptions of each alternative).

These initial conditions are specific to each alternative and vary depending on how implementation of an alternative is expected to alter the pre-remediation concentrations. This subsection describes the manner in which the pre-remediation (present day) concentrations were established and how they were then modified to establish post-remedy initial conditions (i.e., represent Site conditions immediately following completion of construction of the remedial action) for each alternative.

A3.2.1 Initial Conditions and Source Boundary Conditions for Benzene, Benzo(a)pyrene, and Naphthalene

Source propagation was used when possible to define the initial condition following implementation of a remedial alternative for two reasons: 1) to address the variability of observed (empirical) dissolved phase concentrations and uncertainty in concentration distribution across the Site and 2) because it provides a consistent basis for comparing remedial alternatives. When initial conditions are simply assigned and not generated by the groundwater model, the subsequent simulated transport can be largely a result of the initial conditions readjusting to fit the transport field and source distribution. These adjustments are difficult to parse out from the changes to concentrations caused by the stresses on the groundwater model that represent remedial technologies, especially when sources remain in the alternative being simulated. Pre-remediation concentrations for the DNAPL-related primary COCs (benzene, benzo(a)pyrene, and naphthalene) were generated with simulated hydrocarbon sources within the groundwater model based on the distribution of the hydrocarbon source (DNAPL). Because hydrocarbon sources are left in place in many of the alternatives, groundwater-model-propagated pre-remediation concentrations provide a better relative comparison of plume reduction. Pre-remediation hydrocarbon concentrations were generated using the following methodology:

- The pre-remediation dissolved and sorbed soil concentrations for benzene, benzo(a)pyrene, and naphthalene were produced with constant groundwater concentration boundary conditions representing DNAPL as hydrocarbon sources. The Thiessen polygon distribution of DNAPL depth and lateral extent (depicted on Figure 4.4-5 of the RI Report and on Figure A-1) was used to define hydrocarbon-source zones in the FS groundwater model.
- Values for the constant groundwater concentration boundary conditions for benzo(a)pyrene[4] and naphthalene were assumed to be the average of concentrations detected in groundwater from Shallow Alluvium monitoring wells and groundwater grab samples in DNAPL-impacted areas (BH-19, BH-21A, BH-

[4] Total cPAH concentration as benzo(a)pyrene equivalent were used to calculate the benzo(a)pyrene boundary condition concentration.

25A(R), BH-20A, BH-5, BH-23, RW-NS-1, RW-QP-1, and Q9[5]) and reported in the RI Report (Anchor QEA and Aspect 2012). Average concentrations were 133 micrograms per liter [µg/L] for benzo(a)pyrene and 11,000 µg/L naphthalene (see Table A-3).

Values for the constant concentration boundary conditions for benzene were also assumed to be the average concentration detected in DNAPL-impacted areas, but were separated into the following five different zones to reflect spatial variability:

- Zone 1 includes well BH-21A (average concentration of 4 µg/L, but benzene was not simulated in this boundary condition because the concentration is exceeded by nearby plume concentrations; if simulated, the boundary condition would artificially remove benzene mass from the aquifer);
- Zone 2 includes Wells BH-25A(R) and Q9 (average concentration of 1,100 µg/L);
- Zone 3 includes well Q-14W (benzene was not detected; therefore, benzene was not simulated in this zone);
- Zone 4 includes wells BH-23 and RW-NS1 (average concentration of 200 µg/L); and
- Zone 5 includes wells BH-5, BH-19, BH-20A, and RW-QP1 (average concentration of 12,000 µg/L).

Associated solid-phase concentrations were calculated by the groundwater model by applying the respective Kd values and assuming equilibrium. Figure A-1 shows the distribution and concentration of the hydrocarbon sources. Data used to produce these estimates are summarized in Table A-3. Figures A-2 and A-3 depict the source boundary conditions as implemented in the groundwater model.

- The groundwater model was then run for 100 years to simulate the time since the creosote plant started operation.

After establishing pre-remediation conditions, the resulting pre-remediation dissolved and sorbed concentrations for each of the DNAPL-related COCs were then altered consistent with the alternative being simulated and imported as the initial condition. Changes to hydrocarbon source constant groundwater concentration boundary conditions were also made consistent with the alternative being simulated. Adjustments to concentrations and boundary conditions for each of the remediation technologies are described in Section A3.3.

A3.2.2 Initial Conditions for Arsenic

No soil source of arsenic has been identified at the Site so it is not possible to generate pre-remedial arsenic concentrations by source propagation; therefore, pre-remedial concentrations for arsenic were identified based on groundwater data reported in the RI Report (Anchor QEA and Aspect 2012). The average arsenic concentration in areas

[5] The benzo(a)pyrene concentration at Q9 was excluded from averaging because the concentration exceeds solubility.

exceeding the arsenic MCL (39 µg/L)[6] was input as the pre-remediation concentration in the groundwater model. The lateral extent of the arsenic plume in the Shallow Aquifer was limited to the extent shown on Figure 5.2-16 of the RI Report (Anchor QEA and Aspect 2012). Similarly, the lateral extent in the Deep Aquifer was limited to the extent shown on Figure 5.2-17 of the RI Report (Anchor QEA and Aspect 2012). The bottom of the simulated arsenic plume is approximately 60 feet below ground surface (bgs), based on the groundwater data from well BH-20B and BH-20C. Pre-remediation concentrations outside of the arsenic plume are set to the Puget Sound-area background concentration of 5 µg/L as specified by Ecology (Ecology 2001; Table 720-1). Solid-phase concentrations were input into the groundwater model by applying the K_d value of 29 L/kg and assuming equilibrium.

The resulting pre-remediation dissolved and sorbed concentrations for arsenic were then altered relative to the alternative being simulated and imported as the initial condition to the groundwater model.

A3.2.3 Comparison to Measured Concentrations

Figures A-4 through A-7 compare, in plan view, groundwater-model-generated pre-remediation plume extents to the plume extents presented in the RI and summarized in Section 3 of the FS. Groundwater model-generated plume extents are similarly compared in cross section on Figures A-8 through A-11. Plume extents presented in Section 3 are based on a combination of empirical data with groundwater modeling and professional judgment where data is limited (as described in Section 3 of the main text). In particular, limited data are available to define the vertical extent of contaminant plumes in the Deep Aquifer and the westward extent of plumes beneath the lake, which correspond to the areas where the groundwater model predictions deviate the most from the plumes estimated for the RI. Main differences include the following:

- The groundwater model predicts the benzene and naphthalene plumes extend farther west than estimated in Section 3. The extents in Section 3 were based on available sediment porewater data (collected from shallow sediments) and predicted groundwater flow paths, but did not consider the potential effect of dispersion (which would increase the plume extent) or biodegradation (which could decrease plume extent). No data is available in deep groundwater offshore; therefore, there is uncertainty in the actual extent of the plumes in the area between the inner harbor line and the T-Dock.
- The groundwater model predicts the benzo(a)pyrene plumes do not extend as far west as estimated in Section 3. This prediction is likely due to the fact that the westerly extent in the Section 3 was based on empirical data in shallow offshore sediments, but the groundwater model did not include DNAPL in shallow offshore sediments as source terms.
- The groundwater model predicts that the vertical extent of benzo(a)pyrene in the BH-30C area is greater than estimated in Section 3. There is uncertainty in both estimates. Groundwater model uncertainties result from groundwater model simplifications (e.g., coarse vertical discretization of the Deep Aquifer with a

[6] The overall average concentration was used for simplicity because the average concentration in the Shallow and Deep Aquifers (29 and 47 µg/L, respectively) were similar.

layer thickness of approximately 10 feet), and uncertainties in groundwater model parameters (e.g., the magnitude of vertical dispersivity). Empirical data in this area is limited: DNAPL (the assumed source of benzo(a)pyrene) is present at a depth of 33.75 feet, and the top of the well screen for BH-30C is at a depth of 85 feet. As described in Section 3.5 of the FS, the vertical extent of benzo(a)pyrene at this location was estimated based on soil data from the Shallow Alluvium, which identified elevated concentrations of benzo(a)pyrene in soil up to 7 feet below DNAPL occurrences. Based on this data, the Section 3 estimated vertical extent of benzo(a)pyrene was based on adjusting the groundwater modeled extent to extend a maximum of 7 feet below the deepest DNAPL occurrences.

The groundwater model incorporates simplifying assumptions to represent the complex Site conditions including assumptions of geology, contaminant distribution, and dispersivity and degradation parameters. During groundwater model calibration, some groundwater model parameters were adjusted to more closely match the groundwater model output with empirical data for COC concentrations. However, it was not possible to match all empirical data. For example, varying dispersivity to account for naphthalene detected at deep well BH-20C resulted in the groundwater model over predicting benzene concentrations at the same well. Due to the complexity of subsurface conditions at the Site, the groundwater model results only approximate the observed (empirical) groundwater concentration distribution.

The groundwater model is meant to be used as a relative tool, meaning it is intended to compare the relative effect of different remedies, and the relative effectiveness of remedial options to reduce plumes and restoration timeframe. As described above in Section A3.2.1, setting initial conditions in the groundwater model using source propagation provides a more realistic groundwater model of contaminant distribution between areas, and the relative effect of different remedial actions on contaminant distribution are more apparent.

Necessary groundwater modeling simplifications result in differences between groundwater model predictions and actual conditions; however, we do not expect these differences to significantly affect the comparative evaluation of alternatives. While the absolute numbers such as predicted plume volume or contaminant mass should be considered approximate, the relative effect of different actions on reducing plume volume and contaminant mass are valid. Groundwater model results are meant to be interpreted in a relative manner as a means to compare the remediation potential of the different alternatives.

A3.3 Groundwater Model Simulation of Remedial Technologies

Each remedial alternative is composed of a combination of one or more of the following remedial technologies[7]:

- Impermeable upland cap;

[7] Technologies with no significant effect on groundwater flow or contaminant fate and transport in groundwater (e.g., sediment capping) were not simulated by the groundwater model.

- Funnel and gate treatment wall;
- DNAPL/soil solidification;
- DNAPL/soil excavation; and
- Pump and treat.

A detailed description of each of these technologies and how they would be applied is presented in Sections 5 and 6 of this FS. The remedial technologies are simulated within the groundwater model by modifying flow and transport parameters, and/or boundary conditions. In some cases, new boundary conditions were specified to simulate structural elements of the technologies (i.e., slurry walls). Modifications specific to each remedial technology include the following:

- **Impermeable Upland Cap.** An impermeable cap is assumed in the uplands because future development is expected to result in reduced recharge in the uplands as described in Section 6.2 of the FS. The cap is simulated in the groundwater model with a recharge boundary condition value equal to 0 inches/year.
- **Funnel and Gate Treatment Wall.** A funnel and gate system consists of two structures: a slurry wall along the shoreline and two 100-foot-long permeable reactive barriers (PRBs). The funnel and gate extends from the ground surface to approximately 30 feet bgs. The slurry wall element of the funnel and gate was simulated in the groundwater model using MODFLOW's wall boundary condition available in the horizontal flow barrier (HFB) package (Hsieh and Freckleton 1993). The wall boundary condition simulates groundwater flow barriers by applying a specified horizontal conductance (horizontal hydraulic conductivity multiplied by flow length) value between groundwater model grid cells. The conductance of the slurry walls in the funnel and gate was set at 8.5 x 10^{-4} feet squared per day (ft^2/day) to simulate a 3-foot-thick wall with a horizontal hydraulic conductivity of 2.8 x 10^{-3} feet/day (1.0 x 10^{-6} centimeters/second [cm/sec]). The PRBs were simulated in the groundwater model using a constant concentration boundary condition set to the COC-specific PRG (5 µg/L for benzene, 0.2 µg/L for benzo(a)pyrene, and 1.4 µg/L for naphthalene; arsenic is not treated). Use of the constant concentration boundary condition allows mass in excess of the PRG to be removed from the groundwater model, thereby simulating concentration reduction to PRG levels consistent with PRB design.

  The horizontal hydraulic conductivity of the PRB was scaled (16.56 ft/day) to simulate a 3-foot-thick PRB with a horizontal hydraulic conductivity of 28 feet/day (1.0 x 10^{-2} cm/sec) in the 25-foot-wide groundwater model cell.
- **DNAPL/Soil Solidification.** This technology reduces leaching of dissolved DNAPL-related COCs by physically mixing DNAPL and soil with low-permeability grout. This reduces the hydraulic conductivity of soil. Solidification was simulated in the groundwater model by changing the hydraulic conductivity, and porosity of groundwater model grid cells within the solidified volume. Based on commonly reported values for grout and clay in literature (Yey et al. 2000) and typical values for solidified soil at remediation sites (EPA 2009), hydraulic

conductivity and porosity was specified at 2.8 x 10^{-3} feet/day (1.0 x 10^{-6} cm/sec) and 0.06, respectively. The effective porosity value specified is 0.06 and is based on measured effective porosity of bentonite reported in the literature (Yey et al. 2000). The hydraulic conductivity for solidified soil was specified at 2.8 x 10^{-3} feet/day (1.0 x 10^{-6} cm/sec) based on typical values for solidified soil at remediation sites which ranged from 1 x 10^{-5} to 2 x 10^{-7} cm/sec (EPA 1999,EPA 2009, EPRI 2007, and Wilk 2007). For comparison, Table A-4 presents a summary of representative sites where solidification was implemented to contain creosote and coal tar along with the hydraulic conductivities achieved in the solidified soils.

- **DNAPL/Soil Excavation.** The excavation of DNAPL and soil was simulated by removing constant concentration boundary conditions representing DNAPL from groundwater model grid cells within the excavation. To simulate the clean backfill, the hydraulic conductivity of excavated groundwater model grid cells was altered and their sorbed and dissolved initial conditions were set to a concentration of 0 µg/L for all COCs. As discussed in Section A3.1.3, this assumes there are no residual soil and groundwater concentrations. Actual background concentrations would vary based on backfill type and groundwater chemistry. If backfilled soil contributes arsenic to groundwater, or if benzo(a)pyrene in groundwater from neighboring excavation cells recontaminates excavated areas, the restoration timeframe would be longer.

  Initial conditions outside the excavated area were unchanged from pre-remediation levels. The excavations were backfilled with one of two types of material, as follows:

  1. If excavated in the wet, gravel backfill was placed below the water table with an assumed horizontal conductivity of 28 feet/day (1.0 x 10^{-2} cm/sec); or

  2. If excavated in the dry and the excavated soil is treated and used as backfill, then the fill was assumed to have a horizontal conductivity of 0.28 feet/day (1.0 x 10^{-4} cm/sec).

  The ratio of horizontal to vertical conductivity was assumed to be 10:1 for both types of backfill.

- **Pump and Treat.** The pump and treat system assumed six wells pumping at an individual rate of 15 gallons per minute (gpm). The wells were placed along the shoreline and screened near the top of the Deep Aquifer approximately 30 to 50 feet bgs. The techniques used to model the configuration and pumping rates of this system are the result of groundwater-model-aided optimization performed early on in the FS process. Pump and treat optimization is described in Section A5.2.

A3.4 Development of FS Remedial Alternatives

The FS groundwater model was used in the development of remedial alternatives. Additional documentation of the development of remedial alternatives is provided in

Sections 5 and 6 of the FS main text. Specific uses of the groundwater model for alternative development included the following:

- **RR DNAPL Area Treatment.** The FS groundwater model was used to compare the effectiveness of solidification versus excavation (removal) of DNAPL on the plume volume to inform development of Alternatives 3, 5, and 6. The three comparison scenarios are as follows:
    - **Comparison of Backfill Materials.** Excavation of DNAPL in the RR DNAPL Area (Area 1) with off-site disposal of soil and replacement with clean imported fill is compared to on-site treatment and backfill with treated soil.
    - **Comparison of Remedial Technologies and Treatment Areas**. For the RR DNAPL Area, *in situ* solidification was compared to excavation, on-site treatment, and backfill with treated soil. Solidification and excavation of different area combinations for more extensive treatment beyond the RR DNAPL Area were also evaluated to determine the resulting effect on groundwater restoration, as described in Section 6.3.3.1 of the FS main text. Areas evaluated are listed in Table A-5 and shown on Figure A-12. Estimated plume volume reductions resulting from these comparisons are summarized in Table A-5.
    - **Pump and Treat Optimization**. The conceptual design of the pump and treat system for Alternative 10 was developed early in the FS process and is documented in Section A5. The effectiveness of this pump and treat system to reduce restoration timeframes in Alternative 10 was evaluated by comparing the restoration timeframes of the optimized pump and treat system with two variations: one with the pump and treat system removed and one with an additional well located in the area with the highest post remediation concentration (located beneath deep DNAPL-impacted soil in the RR DNAPL Area). The resulting restoration timeframes of benzene and naphthalene were compared.

When compared to no pumping, optimized pump and treat is predicted to accelerate the restoration of naphthalene by 10 years and to have no effect on benzene restoration[8].

The differences between the effect of pump and treat on the restoration timeframe of benzene compared to naphthalene are due to the smaller half-life used for benzene. A greater proportion of benzene is removed by degradation rather than flushing and so its restoration timeframe is less sensitive to pump and treat.

Additional pumping from concentration hotspots is not estimated to provide additional benefit. When the additional pump and treat well was added to the hot spot, the resulting restoration timeframe was 14 years and 46 years for benzene and naphthalene, respectively. Both are within the 3-year printing resolution of the groundwater model when compared to the groundwater model results using the optimized pump and treat system (Table A-7).

[8] With the pump and treat system removed, the benzene restoration timeframe was reported at 13 years, 1 year less than the restoration timeframe result under optimized pumping. However, the difference is within the resolution of the groundwater model output (3 years).

- Funnel and Gate Optimization. Multiple lengths of the PRB gates in Alternatives 3 through 6 were evaluated using the FS groundwater model to verify that the length of the gates would not create significant groundwater mounding. The evaluation concluded that two 100-foot-long gates limited groundwater mounding to several feet below ground surface, with a maximum mounding height of 1.5 feet. In addition, a maximum groundwater flow velocity of 1.1 feet/day was simulated through the gate, occurring in the Fill Unit. This groundwater flow velocity was used to inform the PRB design (see Appendix E of this FS for details).

  The potential for the funnel to induce lateral spreading of groundwater contamination was also evaluated. The potential for lateral spreading was determined not a risk as demonstrated by the simulated plumes for Alternatives 3 through 6, which are shown on Figures A-13 through A-17; the simulated plumes do not show an expanded lateral extent relative to current conditions (Alternative 1 – No Action).

- **Potential Spreading Induced by Soil Solidification.** The potential for soil solidification to induce spreading of groundwater contamination was evaluated. The potential for lateral spreading was determined not to be a risk as demonstrated by the simulated plumes for Alternatives 3, 5, 6, 7, and 9 relative to Alternative 1 (see Figures A-13 through A-17); the simulated plumes do not show an expanded lateral extent relative to No Action conditions (Alternative 1). The simulated plumes for these alternatives along cross sections (see Figures A-18 through A-21) also show no significant vertical spreading of contamination relative to No Action (Alternative 1) conditions. Because the extent of plume spreading was not significant, potential mitigation components for spreading (e.g., upgradient drains) were not evaluated with the groundwater model.

A3.5 Groundwater Model Simulation of Remedial Alternatives

This section details the combination of remedial technologies and how the modifications described above in Section A3.3 were incorporated into the FS groundwater model to simulate each of the remedial alternatives. Once the initial conditions were established to reflect Site conditions following completion of remedial construction for each alternative, the groundwater model was then run for a 100-year period to predict the change in groundwater concentrations for the primary COCs over that period of time. The remedial alternatives are as follows:

- **Alternative 1.** Alternative 1 assumes no remedial action occurs at the Site. Pre-remediation groundwater model results and pre-remediation arsenic concentrations were input unaltered as initial conditions and no other changes to the groundwater model were made.

- **Alternative 2.** Alternative 2 includes an impermeable cap applied to the upland portion of the Site, excluding the 100-foot-wide habitat area along the shoreline (shown on Figure 6-1 of the FS main text).

- **Alternative 3.** Alternative 3 includes the impermeable cap, a funnel and gate treatment wall, and solidification of deep DNAPL-impacted soil in the RR DNAPL Area and in the vicinity of MC-1.
    - All groundwater model grid cells simulating DNAPL-impacted soil within the zone shown on Figure 6-4 of the FS main text were assumed to be solidified. In addition, a one-cell buffer (approximately 25 feet) around the zones and an approximate 2-foot-thick layer below the zones was solidified.
    - The funnel and gate design shown on Figure 6-4 was replicated in the groundwater model in model layers 2 (ground surface) through 8 (approximately 30 feet bgs). The geometry, as specified in the FS groundwater model, differs slightly from the feature shown on Figure 6-4 to fit the resolution of the groundwater model grid.
    - The impermeable cap was applied to Site uplands, but excluded the 100-foot-wide habitat area along the shoreline (shown on Figure 6-1 of the FS main text).

- **Alternative 4.** Alternative 4 includes the impermeable cap, a funnel and gate treatment wall, and excavation and removal of DNAPL-impacted soil in the Quendall Pond Upland (QP-U) DNAPL Area.
    - The funnel and gate design shown on Figure 6-7 of the FS main text was replicated in the groundwater model in model layers 2 (ground surface) through 8 (approximately 30 feet bgs). The geometry, as specified in the FS groundwater model, differs slightly from the feature shown on Figure 6-7 to fit the resolution of the groundwater model grid.
    - The footprint of the excavation in the groundwater model follows the design shown for Alternative 4 on Figure 6-7 of the FS main text and extends approximately 19 feet deep. Similarly, the geometry is slightly different from the design to fit the groundwater model grid. Backfill is assumed to be gravel with relatively high hydraulic conductivity (1.0×10^{-2} cm/sec).
    - The impermeable cap was applied to Site uplands, but excluded the 100-foot-wide habitat area along the shoreline (shown on Figure 6-1 of the FS main text).

- **Alternative 5.** Alternative 5 includes the impermeable cap and funnel and gate, with the addition of solidification of soil containing 4 or more feet (cumulative thickness) of DNAPL to a maximum depth of 20 feet bgs, the QP-U DNAPL Area, and all deep DNAPL-impacted soil in the RR DNAPL Area and in the vicinity of MC-1.
    - The following DNAPL zones were solidified: All groundwater model cells within the shallow DNAPL zones shown on Figure 6-10 of the FS main text were solidified to a depth of approximately 20 feet bgs and groundwater model cells within deep DNAPL zones were solidified to 2 feet below the DNAPL. In addition, a one-cell buffer (approximately 25 feet) around all the treated zones was solidified.

  - The funnel and gate design shown on Figure 6-10 was replicated in the groundwater model in model layers 2 (ground surface) through 8 (approximately 30 feet bgs). The geometry, as specified in the FS groundwater model, differs slightly from the feature shown on Figure 6-10 to fit the resolution of the groundwater model grid.
  - The impermeable cap was applied to Site uplands, but excluded the 100-foot-wide habitat area along the shoreline (shown on Figure 6-1 of the FS main text).

- **Alternative 6.** Alternative 6 includes an impermeable cap, funnel and gate, solidification of soil containing 2 or more feet (cumulative thickness) of DNAPL to a maximum depth of 20 feet bgs, solidification of deep DNAPL-impacted soil in the RR DNAPL Area and in the vicinity of MC-1, and excavation and removal of DNAPL-impacted soil in the Quendall Pond Upland (QP-U) DNAPL Area.
  - The footprint of the QP-U DNAPL Area excavation in the groundwater model follows the design shown for Alternative 6 on Figure 6-12 of the FS main text and extends approximately 19 feet deep. The geometry is slightly different from the design to fit the groundwater model grid. Backfill is assumed to be gravel with relatively high hydraulic conductivity (1.0×10^{-2} cm/sec).
  - All groundwater model cells within the shallow DNAPL zones shown on Figure 6-12 of the FS main text were solidified to a depth of approximately 20 feet bgs and groundwater model cells within deep DNAPL zones were solidified to 2 feet below the DNAPL-impacted soil. In addition, a one-cell buffer (approximately 25 feet) around all the treated zones was solidified.
  - The funnel and gate design shown on Figure 6-12 was replicated in the groundwater model in model layers 2 (ground surface) through 8 (approximately 30 feet bgs). The geometry, as specified in the FS groundwater model, differs slightly from the feature shown on Figure 6-12 to fit the resolution of the groundwater model grid.
  - The impermeable cap was applied to Site uplands, but excluded the 100-foot-wide habitat area along the shoreline (shown on Figure 6-1 of the FS main text).

- **Alternative 7.** Alternative 7 includes solidification of all upland DNAPL-impacted soil and the impermeable upland cap featured in previous alternatives.
  - All groundwater model cells representing a hydrocarbon-source zone (Figure A-2 and A-3) were assumed to be solidified. In addition, a one-cell buffer (approximately 25 feet) around the zones and an approximate 2-foot-thick layer below the source was solidified.
  - The impermeable cap was applied to Site uplands, but excluded the 100-foot-wide habitat area along the shoreline. Recharge over solidified soil outside of the cap was also set to zero.

- **Alternative 8.** Alternative 8 features excavation of all upland DNAPL-impacted soil and the installation of the funnel and gate and the impermeable upland cap.
    - All groundwater model cells representing hydrocarbon source areas (as depicted on Figure A-2 and A-3) were excavated. The backfill in Alternative 8 was assumed to be excavated soil that is treated and reused as backfill. Backfill is assumed to have a relatively low hydraulic conductivity (1.0×10^{-4} cm/sec).
    - The funnel and gate was simulated in the groundwater model from model layer 2 (fill) through 8 (approximately 30 feet bgs). The groundwater model assumes a funnel and gate treatment wall but subsequently, the wall was removed from the alternative because it did not add significant benefit.
    - The impermeable cap was applied to Site uplands, but excluded the 100-foot-wide habitat area along the shoreline.

- **Alternative 9.** Approximately the upper 15 feet of the Shallow Alluvium within the area of MCL exceedances is excavated in Alternative 9. This alternative also includes solidification of DNAPL-impacted soil below 15 feet bgs, and the upland cap.
    - Groundwater model cells representing hydrocarbon-source zones (as depicted on Figure A-2 and A-3) that are more than approximately 15 feet bgs[9] were assumed to be solidified, including a one-cell buffer around the zones and an approximate 2-foot-thick cell below the hydrocarbon source. Groundwater model cells within the Site uplands that were shallower than approximately 15 feet bgs were assumed to be excavated and backfilled with low hydraulic conductivity treated soil (1.0×10^{-4} cm/sec).
    - Similar to previous alternatives, the cap was applied to the Site uplands, excluding the 100-foot-wide habitat area along the shoreline (shown on Figure 6-1 of the FS main text).

- **Alternative 10.** Alternative 10 features excavation of all Shallow Alluvium soils within the area of MCL exceedances and the installation of the impermeable upland cap and the pump and treat system.
    - Only benzene, naphthalene, and arsenic are simulated with the groundwater model for Alternative 10. The alternative is designed to completely remove benzo(a)pyrene source material and the groundwater model assumes no contaminated residuals. Therefore, the groundwater model prediction should be that benzo(a)pyrene would restore immediately. However, the modeled pre-remediation extent of benzo(a)pyrene is greater than the modeled extent of soil removal; therefore, the groundwater model (if run for benzo[a]pyrene) would still predict exceedances.

[9] Based on resolution in cell grid; actual depth ranges from 13 to 27 feet bgs, with an average of 15 feet bgs.

- The entire Shallow Alluvium within Site uplands within the area of the benzo(a)pyrene and arsenic plumes is assumed to be excavated in Alternative 10. Low hydraulic conductivity treated soil (1.0×10^{-4} cm/sec) is used to backfill the excavation.
- The pump and treat system was simulated in the groundwater model as described in the Section A5.2.
- Similar to previous alternatives, the cap was applied to the Site uplands, excluding the 100-foot wide habitat area along the shoreline (shown on Figure 6-1 of the FS main text).

A3.6 Remedial Alternatives Groundwater Model Results

Empirical Site data were used to estimate flow and contaminant transport parameters and source concentrations used in the groundwater model to best represent pre- and post-remedy concentrations for the remedial alternatives. As previously indicated, the groundwater model incorporates simplifying assumptions to provide an approximate representation of complex Site conditions. These simplifying assumptions introduce inherent uncertainty in the groundwater model results. To address the uncertainty, the groundwater modeling assumptions are consistently applied in evaluating the range of alternatives. Further, the groundwater model results are evaluated in relative versus absolute terms. By evaluating a result on a large diffuse scale such as plume volume and, more importantly, comparing the relative change in the groundwater model results, much of the uncertainty associated with absolute predictions by the contaminant transport model is mitigated. Therefore, the results presented below should be interpreted within a comparative analysis of the relative benefit from each alternative.

Groundwater model results for the evaluation of the remedial alternatives are presented in Tables A-6 and A-7. The extent of groundwater contamination predicted by the groundwater model is illustrated as plume extent in plan view on Figures A-13 through A-17, and in cross section on Figures A-18 through A-21. The contaminant transport model results were calculated at 3-year time intervals to assess restoration timeframe over the entire 100 year simulation period. The groundwater model output at time 100 years was processed to produce different metrics to compare the individual remedial alternatives after 100 years of implementation. These metrics include the following:

- **Plume Volume.** The aggregate plume volume is defined as the volume of groundwater that exceeds the PRG of one or more of the primary Site COCs (5 µg/L for benzene, 0.2 µg/L for benzo(a)pyrene, 1.4 µg/L for naphthalene, and 10 µg/L for arsenic). The volume was calculated from the groundwater model output by summing the volume of cells (17 ft^3 to 33,000 ft^3 per cell; 4,400 ft^3 on average) whose concentration exceeded one or more of the PRGs, and then multiplying the sum by the effective porosity (0.25). In alternatives that include solidification (Alternatives 3, 5, 6, 7, and 9), only the volume outside of solidified soil is included in the calculation. Plume volumes are presented in Table A-6 for the Shallow Aquifer and Deep Aquifer combined, and for the upland Deep Aquifer only. Volumes are reported in units of millions of gallons of groundwater.

Plume volumes for each of the primary Site COCs for the Shallow Aquifer and Deep Aquifer combined were also calculated and are presented in Table A-7. The groundwater model results indicate arsenic plumes for Alternatives 1 through 9 that are larger than the pre-remediation plume. The expansion of these plumes is the result of not using modeled source propagation to define the initial conditions for arsenic. The increase in arsenic plume volume is due to the groundwater model adjusting the assigned concentrations to establish a new equilibrium across groundwater model cells based on concentration gradient. More discussion of the use of plume propagation to produce initial conditions and the implications are presented in Section A3.2.

- **Mass Flux:** The Mass Flux for each primary Site COC was calculated for each of the alternatives at the groundwater model boundary representing the lakebed sediments. These are not estimates of the total mass flux to Lake Washington because they do not include sediment processes or offshore DNAPL. Rather, the results were used to compare the relative reduction in mass flux into the lakebed sediments for each alternative. The mass flux results generated by the groundwater model were used to only provide a relative comparison between remedial alternatives and were not used as inputs to the Reible sediment transport model discussed in Appendix B. For that model, empirical sediment porewater data were used.
- **Dissolved Plume Contaminant Mass.** Dissolved plume contaminant mass was calculated for each of the primary Site COCs under each remedial alternative. Dissolved mass was calculated by summing the products of COC concentration, porosity, and volume of model cells within each plume. In alternatives that include solidification (Alternatives 3, 5, 6, 7, and 9), only the mass outside of solidified soil was included in the calculation. These results are presented in Table A-7.
- **Restoration Timeframe.** The restoration timeframe of each of the primary Site COCs was estimated as the time in years when predicted concentrations in every groundwater model grid cell were below their respective PRG as presented in Table A-6. The groundwater model results indicate that none of the remedial alternatives achieves groundwater restoration (defined as concentrations for each of the four primary Site COCs below their respective PRGs) for all of the Site COCs. However, Alternatives 8 and 10 achieve restoration of benzene and naphthalene. Alternative 10 would achieve restoration of benzo(a)pyrene before the end of the model run (100 years), but this restoration is based on the unrealistic assumption that the entire source of benzo(a)pyrene is removed and there are no excavation or dredging residuals. A sensitivity analysis (see Section A5.1) indicates that residuals would cause benzo(a)pyrene MCLs to be exceeded for more than 100 years.
- **Relation to University of Texas (UT) Model.** Groundwater discharge fluxes were also calculated to evaluate seepage rate reduction associated with upland capping and funnel and gate technologies, to support sediment modeling presented in Appendix B3 of this FS. Groundwater discharge flux for offshore and nearshore areas are tabulated in Table A-8.

A3.7 Sensitivity Analysis of FS Groundwater Model Results

Contaminant fate and transport input parameters for the FS groundwater model were based on site-specific data, literature values, and best professional judgment as discussed in Section A3.2. A sensitivity analysis was conducted to assess relative uncertainty in the FS groundwater model results attributable to contaminant fate and transport parameter assumptions. Using Alternatives 1, 7, and 8, a sensitivity analysis of the sorption coefficient (K_d), half-life, and source area concentration was conducted. The parameters were varied one at a time while the two remaining values were held at base value. The values used in the sensitivity analysis are described below and are presented in Table A-9:

- **K_d.** Five hundred percent (five times) of the base K_d was used as the high K_d value. Twenty percent (one fifth) of the base value was used for the low value for symmetry.
- **Half-Life.** Arsenic does not decay and, therefore, was not included in the sensitivity analysis. Half-life ranges for hydrocarbons were set as follows:
    - **Benzene.** The FS groundwater model uses the mid-range anaerobic half-life for benzene of 720 days (see Section A3.1.2) as a base value. In the sensitivity analysis, the lowest anaerobic half-life reported in Howard et al. 1991 was used for the low half-life value, and a value of five times the base half-life (3,600 days) within the reported range of half-lives estimated from field studies (220 days to no degredation: Aronson 1997) was used for the high half-life value.
    - **Naphthalene.** Because only one anaerobic half-life was reported for naphthalene (Howard et al. 1991), the naphthalene low half-life was reduced from the base value by the same proportion as for benzene. The high half-life value was taken as 500 percent of the base value.
    - **Benzo(a)pyrene.** The low anaerobic half-life was set to 1,484 days, the lowest anaerobic half-life reported for chrysene in Howard et al.1991. Benzo(a)pyrene decay was not simulated in the high half-life sensitivity run.
- **Source Area Concentration.** The high and low source area concentrations were 150 and 50 percent, respectively, of the base value used in the groundwater model. This base value was calculated from the mean of detected concentrations within the source areas, and the high and low values fall within the range of detected values.

A3.7.1 Sensitivity Analysis Results

The sensitivity analysis results for individual COCs are presented in Table A-10 and sensitivity analysis results as aggregate plume volume are presented in Table A-11. The aggregate results were reduced to produce the maximum variation from the base results to produce Figure A-22. The brackets on Figure A-22 reflect the sensitivity results that were maximum departures from the base groundwater model results (worst case and best case). Best case results are from the parameter set that produced the smallest value and

worst case results are results from the parameter set that produced the largest value. The bars on Figures A-22 represent the base case groundwater model result presented in Section A3.6. In addition, Figure A-22 compares aggregate plumes of groundwater that exceed PRGs, as well as aggregate plumes of groundwater that exceed only MCLs (5 µg/L for benzene, 0.2 µg/L for benzo(a)pyrene, and 10 µg/L for arsenic). The aggregate plumes that exceed only MCLs do not include naphthalene, which has no MCL.

Sensitivity analysis was only performed on Alternatives 1, 7, and 8. The variability in aggregate plume volume groundwater model results of the remaining alternatives were estimated by a linear interpolation and extrapolation of the sensitivity analysis results from Alternatives 1, 7, and 8. Linear regression of sensitivity analysis-derived best and worst case volumes (when compared to base case groundwater model results) were generated for Alternatives 1, 7, and 8 and those regressions are shown on Figure A-23. The resulting regressions were then used to estimate best case and worst case aggregate plume volumes for the remaining alternatives. For example, the estimated best case value for an alternative is estimated as the y value of a point that falls on the best case regression line and has an x value equal to that alternative's base case result. Figure A-23 shows groundwater model results generally fit close to their regression lines and have a minimum R-squared value of 0.992; therefore, the linear approximation provides a reasonable estimate of sensitivity results for the remaining alternatives' best case and worst case. Results estimated by interpolation and extrapolation are shown for the aggregate plume exceeding PRGs on Figure A-24 and for the aggregate plume exceeding only MCLs (excludes naphthalene) on Figure A-25. The bars on Figures A-24 and A-25 represent the base case groundwater model result as described above in Section A3.6 and the brackets for Alternatives 2, 3, 4, 5, 6, 9, and 10 represent the variation estimated from the alternatives base result and the linear regressions presented on Figure A-22. Table A-12 presents both the variation in aggregate plume volume derived from sensitivity analysis (Alternatives 1, 7, and 8) and the linear regression-derived variation (estimated).

Sensitivity analysis results by COC were treated similarly to aggregate plume results. Sensitivity analysis results of plume volume by COC are shown on Figure A-26, their linear regression is shown on Figure A-27 and the sensitivity analysis-derived and linear regression-derived variation in plume volume by COC are displayed on Figure A-28 and in Table A-13. Similarly, sensitivity analysis results of plume mass by COC are shown on Figure A-29, their linear regression is shown on Figure A-30, and the sensitivity analysis-derived and linear regression-derived variation in plume mass by COC are displayed on Figure A-31 and in Table A-14. Lastly, similar to previously discussed metrics, sensitivity analysis results of mass flux by COC are shown on Figure A-32, their linear regression is shown on Figure A-33, and the sensitivity analysis-derived and linear regression-derived variation in mass flux by COC are displayed on Figure A-34 and in Table A-15. See Section A3.6 for a definition of plume volume, plume mass, and mass flux.

A4 Excavation Dewatering Analysis

The FS groundwater model was used to evaluate pumping rates required to achieve excavation dewatering criteria for Site remedial alternatives. To effectively remove and handle contaminated soil and to maintain excavation stability, dewatering would be required during soil excavation to meet two goals:

1. Dewater the contaminated soil located below the water table such that excavation occurs either in unsaturated (dry) conditions or the water level is lowered enough to allow installation of shoring; and
2. Depressurize the Deep Aquifer to prevent destabilization of the excavation bottom. The Deep Aquifer is a semi-confined aquifer with a potentiometric surface (head) 20 to 40 feet above the bottom of the Shallow Alluvium.

The FS groundwater model was used to estimate dewatering rates of excavations (for soil removal and DNAPL collection trench installation) in Alternatives 3 4, 6, and 8. Dewatering required for Alternative 9 and 10 was estimated with groundwater modeling completed early in the FS process, which is presented in Section A5.

The following sections discuss three topics: structural and boundary condition modifications to the RI groundwater model to develop the groundwater model used to evaluate FS dewatering criteria (Section A4.1), the constructability assumptions that determine dewatering criteria (Section A4.2), and dewatering groundwater model results (Section A4.3).

A4.1 Modifications to Develop Dewatering Groundwater Model

The following modifications were made to the groundwater flow component of the RI groundwater model for the FS dewatering evaluation. These modifications include both structural modifications and the addition of boundary conditions, such as the following:

- The addition of four to five layers in the Shallow and Deep Aquifers to improve the vertical resolution of excavation boundary conditions (i.e., sheet pile walls and dewatering wells).
- The addition of sheet pile walls simulated with MODFLOW's HFB Package. HFB boundary conditions were inserted between groundwater model cells around the perimeter of the excavation cell and extend from model layer 1 to the approximate sheet pile embedment depth reported in Tables A-16 and A-17**.** The HFB boundary conditions were given a small conductance value (1×10^{-20} cm^2/sec) to make them effectively impermeable.
- Dewatering wells were inserted in the groundwater model using the multi-node well package (Halford and Hanson 2002). Wells were placed within the sheet pile wall enclosures**.** Wells were screened in the top 10 to 15 feet of the Deep Aquifer, with the top of the screens being at the interface of the Shallow and Deep

Aquifers. The hydraulic conductivity of cells within excavation cells from groundwater model layer 2 to the approximate excavation depth listed in Tables A-16 and A-17 were given a large value (1.0×10^9 feet/day) to simulate an open excavation.

- Recharge was reduced to 0 inches/year within the excavation.

A4.2 Constructability Assumptions

Dewatering criteria are dependent on constructability assumptions. Excavations can either be done in the wet or in the dry. The minimum drawdown required for dry excavations is prescribed by the maximum depth of the excavation; in the case of wet excavations, minimum drawdown is determined by constructability requirements for installation of tieback anchors in the shoring walls.

Maximum excavation depths are presented in Tables A-16 and A-17. Calculations and assumptions used to estimate constructability requirements are detailed in Appendix F of this FS and the requirements are as follows:

- Tieback anchors for shoring walls are not required for excavations shallower than 16 feet and, therefore, do not require depressurization if done in the wet;
- Excavations between 16 and 22 feet deep require a minimum depth to water of 8 feet bgs to accommodate construction of tieback anchors;
- Excavations between 22 and 27 feet deep require a minimum depth to water of 13 feet bgs to accommodate construction of tieback anchors; and
- Excavation between 27 and 34 feet require a minimum depth to water of 19 feet bgs to accommodate construction of tieback anchors.

In addition to dewatering requirements in the Shallow Aquifer, the Deep Aquifer must also be depressurized to prevent destabilization of the excavation floor. For the purposes of this analysis, it was assumed that the confined head at the top of the Deep Aquifer must be below the minimum elevation of the excavation floor for a dry excavation. In wet excavations, the head in the top of the Deep Aquifer must be at or below the elevation of the static water level within the excavation. The maximum excavation depths (minimum excavation elevation) and constructability requirements were used to determine the dewatering criteria targets for pumping optimization using the dewatering groundwater model.

A4.3 Dewatering Groundwater Modeling Approach

Dewatering and depressurization flow rates were estimated using the groundwater model in an iterative process in which pumping rates and the number of wells were adjusted until dewatering criteria were achieved under steady state conditions.

Dewatering and/or depressurization flow rates were estimated for each of the cells shown on Figure 6-17 of the FS main text (Alternative 8), for the Quendall Pond cell depicted on Figure 6-6 of the FS main text (Alternatives 4 and 6), and for the DNAPL collection trench depicted on Figure 6-4 of the FS main text (Alternatives 3 and 4).

A4.4 Dewatering Groundwater Modeling Results

Groundwater model results for the dewatering evaluation for wet excavations are presented in Table A-16. Similarly, results for dry excavation dewatering are presented in Table A-17. Because of the confined head in the Deep Aquifer, it is estimated that excavations requiring dewatering of the Shallow Aquifer would also require depressurization of the Deep Aquifer.

A5 Additional Evaluations for Alternative 9 and 10

This section describes groundwater modeling done early in the FS process (Early FS groundwater model) for the following purposes:

- To perform additional sensitivity analysis on the effect of two parameters on groundwater-model-predicted restoration timeframe for Alternative 10: 1) the presence of heterogeneities in the Deeper Alluvium and 2) the presence of contaminated residuals after excavation;
- To develop conceptual design criteria, including optimal well locations and flow rate, of a pump and treat system used in Alternative 10; and
- To estimate construction dewatering flow rates needed to facilitate removal of contaminated materials as part of Alternatives 9 and 10.

Similar to the evaluations presented in previous sections, this evaluation uses a refined version of the groundwater flow and contaminant transport model documented in Appendix D of the RI (Anchor QEA and Aspect 2012). The Early FS groundwater model described in this section features the same flow and transport parameters as the FS groundwater model documented in Sections A3 and A4 of this appendix, but has the following differences:

- Concentrations specified for the DNAPL boundary conditions for the Early FS groundwater model were based on data provided in the draft RI Report, while the concentrations for the FS groundwater model were based on data provided in the final RI Report. Differences were as follows:
    - For benzene, 2,800 µg/L was used in all DNAPL zones that were a source of benzene in the Early FS groundwater model, rather than zone-specific concentrations noted on Figure A-3 (ranging between 200 and 12,000 µg/L);
    - For naphthalene, 16,000 µg/L was used in the Early FS groundwater model rather than 11,000 µg/L shown on Figure A-3;
    - For benzo(a)pyrene, 20 µg/L was used in the Early FS groundwater model rather than 130 µg/L shown on Figure A-3; and
    - For arsenic, 53 µg/L was used in the Early FS groundwater model rather than 39 µg/L.
- Zone 3 depicted on Figure A-1 was included as a source in the Early FS groundwater model.
- The Early FS groundwater model included 11 model layers rather than 20 in the FS groundwater model. The Early FS groundwater model includes the 10 layers that comprise the RI model and one additional 2-foot-thick layer located at the top of the Deep Aquifer, used to simulate the DNAPL present at the top of the Deep Aquifer near the Railroad Area. Additional layers were added for the simulation of aquifer heterogeneity as described in Section A5.1.1.

- Transport model results for the Early FS groundwater model were printed at a resolution of up to 15 years rather than 3 years.

These differences are not expected to significantly alter the results or conclusions of the analyses described in this section.

The sensitivity analysis is described in Section A5.1. The optimization of the pump and treat system is documented in Section A5.2. The dewatering evaluation used to support cost estimates for the implementation of Alternatives 9 and 10 are documented in Section A5.3.

A5.1 Restoration Timeframe Sensitivity Analysis

The groundwater model was used to simulate the restoration timeframe following the assumed removal of sources from the Shallow Alluvium and DNAPL from the Deeper Alluvium (Alternative 10). The steps to setup and run the groundwater model to estimate the restoration timeframe were the same as for the FS groundwater model, except that 200-year restoration periods (in addition to 100-year restoration periods) were also conducted for selected conditions when MCLs were not achieved within 100 years.

The effect of varying groundwater model input assumptions on groundwater model results (i.e., sensitivity analyses) was evaluated to assess the range of uncertainty in the groundwater model predictions. Model input parameters evaluated in the sensitivity analyses included the following:

- **Aquifer heterogeneity.** The FS groundwater model assumes the Deeper Alluvium is homogeneous. However, based on Site boring logs, some areas of the upper portion of the Deeper Alluvium exhibits heterogeneous conditions, including low-permeability lenses of silt and silty sand within a matrix of more uniform sand and gravel. Some portions of the Deep Aquifer, particularly at greater depths, exhibit more homogeneous characteristics and do not appear to contain low-permeability layers of silt or silty sand.
- **Presence of excavation residuals.** The FS groundwater model assumes no residual contamination left behind after removal actions, which is deemed to be highly unlikely due to the complexity of the Site.

The following sections describe groundwater model modifications to evaluate aquifer heterogeneity (Section A5.1.1) and groundwater model modifications to evaluate excavation residuals (Section A5.1.2).

A5.1.1 Aquifer Heterogeneity

A common approach for constructing larger-scale groundwater models is to use an equivalent porous media approach to define aquifer parameters. This approach assumes that, on a site-wide scale, changes in groundwater velocities from smaller-scale aquifer heterogeneities are represented by averaging aquifer parameters (i.e., hydraulic conductivity) resulting in an average flux. However, this assumption is often not appropriate when simulating contaminant transport or evaluating individual chemical transport processes on a smaller scale (Zheng et al. 1995).

The Deeper Alluvium is predominantly sand and gravel but silty sand lenses and silt lenses are also present. For example, borings BH-5B, BH-21B, and SWB-3 contain intervals of silty sand between 1- and 9-feet thick near the top of the Deeper Alluvium, and borings BH-5B and BH-30C have a 0.5-foot thick silt lens from 45 to 50 feet bgs. Based on a review of the boring logs, two representative lower-permeability lenses within the Deeper Alluvium were incorporated into the groundwater flow model: a silty sand layer, 5-feet thick, approximately 45 feet bgs; and a silt layer 0.5-foot thick at 50 feet bgs. A summary of the boring log analysis is presented in Table A-18.

A sensitivity analysis to evaluate the potential impact of fine-grained layers in the Deeper Alluvium on groundwater model results was conducted using the Early FS groundwater model. Site heterogeneity was evaluated using the following modification to the groundwater model:

- A finer-grained layer was placed in the middle of the Site as a representative case. In actuality, low-permeability layers were observed within the upper portions of the Deeper Alluvium at multiple locations across the Site, including on the eastern (e.g., BH-30C) and western (e.g., BH-20C) areas of the Site. The full distribution of all fine grain layers throughout the Deeper Alluvium is unknown; therefore, this evaluation was completed at the scale of the single representative fine-grained layer placed within the groundwater model. Results must be interpreted while considering that this is one of many fine-grained layers present in the groundwater model. Lower-permeability zones were placed within the site-wide groundwater model so that groundwater flow within the zones and interaction between the fine-grained zones and surrounding sand and gravel were calculated by the groundwater model.
- Horizontal hydraulic conductivity for the finer-grained units was estimated from Table 2.2 of Freeze and Cherry (1979) at 1×10^{-4} cm/s and 1×10^{-6} cm/s for the silty sand and silt, respectively. Anisotropy (ratio of horizontal to vertical hydraulic conductivity) was assumed to be the same as for the rest of the Deeper Alluvium (40:1). The silty sand zone was assumed over an area of 80 by 85 feet and the silt zone was assumed over an area of 40 by 45 feet; both are longer in the direction of groundwater flow. Based on the small area of the zones relative to the groundwater model grid spacing, the grid spacing was telescoped (refined) to 5 feet. To better resolve vertical flow paths, 15 additional layers were also added to the groundwater model grid.
- Dispersivity was reduced within fine-grained zones to simulate dispersion over a shorter flow path length (versus site-wide transport). Longitudinal dispersivity within the fine-grained zones is assumed to be 0.5-foot, and transverse and vertical dispersivity are assumed to be 0.05-foot and 0.005-foot, respectively. Initial concentrations within the finer-grained zones were specified at 8,400 µg/L for benzene (as measured at BH-20B, one of the locations where finer-grained layers have been observed), 6,400 µg/L for naphthalene, 20 µg/L for benzo(a)pyrene, and 53 µg/L for arsenic.

The entire groundwater model domain was used for this analysis and initial conditions outside of the fine-grained layers remained unchanged from the baseline simulation. Since this evaluation focuses on the scale of a single representative fine-grained layer,

additional virtual observation wells were added to the groundwater model cells within the fine-grain zones with the highest concentration after the groundwater model simulation, or in the cells where COC concentrations remained above the MCLs the longest during the groundwater model simulations.

Restoration timeframes were estimated for three pumping scenarios: no pumping, pumping at the optimized pumping rate (90 gpm: see Section A5.2), and pumping at twice the optimized pumping rate. Restoration timeframes calculated under these scenarios assuming a homogeneous aquifer or a heterogeneous aquifer are presented in Table A-19. If restoration for a COC is not achieved within the timeframe of the groundwater model (100 or 200 years), the highest remaining concentration of that COC is provided. In this analysis concentrations were compared to the following cleanup levels: 1.4 µg/l for naphthalene, 5 µg/L for benzene, 0.2µg/L for benzo(a)pyrene, and 10 µg/L for arsenic. Results were as follows:

- When Deeper Alluvium heterogeneity is simulated within the natural flushing (i.e., no pumping) scenario, benzene attenuates to concentrations below the MCL within 30 years. Arsenic and benzo(a) pyrene still exceed their respective MCLs after 100 years. The highest residual arsenic concentration is 53 µg/L and the highest residual benzo(a)pyrene concentration is 20 µg/L, both located within low-permeability layers of the Deeper Alluvium.
- Under the homogeneous natural flushing assumption, benzene in the Deeper Alluvium attenuates to concentrations below the MCL of 5 µg/L within 13 years. Naphthalene attenuates below the PRG (1.4 µg/L) within 53 years. Groundwater-modeled predicted concentrations of arsenic and benzo(a)pyrene in groundwater exceed their respect MCLs after 200 years. The highest residual arsenic concentration in the Deeper Alluvium is 33 µg/L (MCL equal to 10 µg/L) and the highest residual benzo(a)pyrene concentration is 4.2 µg/L (MCL equal to 0.2 µg/L).

Pump and treat results in a slight improvement (reduction) in the restoration timeframes under both heterogeneous and homogeneous assumptions. Doubling the optimized extraction flowrate (based on plume capture) did not significantly improve restoration timeframe under either heterogeneous or homogeneous assumptions.

A5.1.2 Excavation Residuals Sensitivity Analysis

Contaminant removal by excavation could leave behind residual contamination at the base of the excavation. This section evaluates the potential for such residuals to extend the restoration timeframe.

The potential contribution from residual contamination was evaluated by inserting a 2-inch layer of contaminated Shallow Alluvium soil at the base of the Shallow Alluvium, representing residual benzene and benzo(a)pyrene. In total, seven additional layers were added to the groundwater model to allow simulation of contaminant transport at a higher resolution. These seven included the approximately 2-inch layer and six layers below it. The initial conditions applied to the groundwater model assumed sorbed concentrations of 5 milligrams/kilograms (mg/kg) (benzene) and 10 mg/kg (benzo[a]pyrene) within the 2-inch layer throughout the Site. The initial dissolved concentrations were calculated assuming soil:water equilibrium by applying their respective K_d values. The groundwater

model simulates 100 years of transport following the excavation and assumes a natural gradient and a homogeneous Deeper Alluvium. Initial COC concentrations in the Deeper Alluvium were set to zero to estimate the contribution from the residual layer.

Including the residual contamination layer in the groundwater model run did not increase the time (13 years) for benzene to attenuate below the MCL relative to that estimated by the natural flushing simulation. The residual layer contributed to a maximum additional benzo(a)pyrene concentration of 1.3 µg/L after 100 years. The estimated volume of groundwater exceeding the benzo(a)pyrene MCL was 14 million gallons. This value was used for the error bar shown on Figure A-28 for benzo(a)pyrene plume volume under Alternative 10.

A5.2 Pump and Treat System Optimization

Pumping wells were introduced to the groundwater model to evaluate the effect of pump and treat on the restoration timeframe. The groundwater model was first used to optimize extraction well placement and pumping rate so as to achieve complete plume capture (described below). The new groundwater flow field for the pumping condition was then imported into the contaminant fate and transport model to predict contaminant elution and, as a result, restoration timeframe.

Pumping wells are simulated within the MODFLOW groundwater model using the multi-node well package (Halford and Hanson 2002). The Multi-node well package simulates pumping across multiple MODFLOW layers and calculates drawdown within the well. The package takes into account the head, hydraulic conductivity and grid spacing of pumping cells, and represents the pumping impacts across multiple layers within the groundwater model.

The number, location, and flow rate of groundwater pumping wells was adjusted under steady state conditions to optimize hydraulic capture while reducing total volume extracted. Each pumping well was screened in the top of the Deeper Alluvium, approximately 30 to 50 feet bgs, to optimize capture of contaminated groundwater.

MODFLOW's particle tracking package, MODPATH (Pollack 1994), was used to evaluate the effectiveness of capture. MODPATH results show the advective movement of particles as flow lines through an established groundwater flow field. Three lines of 100 particles (elements used to designate flow lines) representing the extent of the arsenic, benzene, and benzo(a)pyrene plumes were placed across the Site, approximately 10 feet below the top of the Deeper Alluvium. The particles were then traced forward through the groundwater model to represent the capture area. As the flow rate increased, the width of capture also increased. Complete groundwater capture is achieved when all flow lines from the plume edges are captured by the wells.

Particle tracks representing capture predicted by the groundwater model are presented on Figures A-35 and A-36. Based on the groundwater modeling, steady-state hydraulic capture is achieved with a minimum of six wells and a total flow rate of 90 gpm distributed evenly between the wells (15 gpm/well). This configuration was implemented in the contaminant transport model. Capture was also achieved by a flow rate of 80 gpm from 12 wells. The 90 gpm scenario was chosen because it would require less infrastructure and, therefore, lower capital costs.

A5.3 Construction Dewatering - Alternatives 9 and 10

To effectively remove and handle contaminated soil and to maintain excavation stability, dewatering would be required during soil excavation to meet two goals: 1) dewater the saturated contaminated soil in place such that excavation occurs in unsaturated conditions and 2) depressurize the Deeper Alluvium to prevent heaving or destabilization of the excavation bottom. The Deeper Alluvium is a semi-confined aquifer with a potentiometric surface (head) 20 to 40 feet above the bottom of the Shallow Alluvium.

A5.3.1 Excavation Dewatering (Shallow Alluvium)

Means and methods for dewatering the Shallow Alluvium would be determined during remedial design but may include temporary sumps within the open excavation and/or well points outside the excavation. Sumps are an effective means of dewatering excavations within lower permeability material where the groundwater heads need only to be depressed several feet. If sumps are inadequate for dewatering, closely-spaced vacuum well points outside the excavation footprint would be required.

A5.3.2 Depressurization of Deeper Alluvium

Reduction of head in the Deeper Alluvium would require pumping wells screened across the Deeper Alluvium. Pumping wells have the ability to effectively dewater large areas in permeable sediments and may produce large amounts of water. Dewatering pumping wells typically consist of 6- to 12-inch casings installed in 10- to 16-inch boreholes. Screen designs and filter packs are specified based on the grain size of the water-bearing zone. Submersible pumps are generally placed inside the well casing near the bottom of the screened interval.

To limit the potential for contaminant carry down, depressurization wells would be completed using double casing drilling techniques (sealing off the Shallow Alluvium prior to advancing drilling through the Shallow Alluvium and into the Deeper Alluvium) similar to that done during installation of wells BH-30C and BH-20C.

A5.3.3 Estimated Excavation Dewatering Flow Rates (Shallow Alluvium)

An analytical solution was used to estimate dewatering required for implementation of Alternative 9. The volume of water required to effectively dewater an excavation within the Shallow Alluvium is directly proportional to the average hydraulic conductivity of the Shallow Alluvium and increases the closer the excavation is to Lake Washington.

For open excavations (i.e., no groundwater cutoff), preliminary volumes for dewatering were first estimated analytically by assuming an equivalent well radius (Powers 1992) equal to that of an expected excavation cell size ranging from 0.1- to 1-acre to an average depth of 20 feet bgs[10]. Assuming the hydraulic conductivities and excavation heads from the calibrated groundwater model, we estimate that 60 to 100 gpm would flow into an excavation near the Railroad Area (BH-30) under steady-state conditions. Flow rates would increase with decreasing distance to Lake Washington. Near the shoreline (e.g.,

[10] As noted, the estimated dewatering flowrate was based on an assumed average excavation depth of 20 feet. Alternative 9 assumes an average excavation depth of 15 feet; therefore, this evaluation is considered conservative.

near BH-20), estimated flow rates range from 300 to greater than 1,000 gpm for cell sizes ranging from 0.1- to 1-acre, respectively.

The calculation assumes steady state conditions, whereas initial flow rates would be greater to reduce aquifer storage. The estimate does not account for surface runoff potentially entering the excavation.

If sheet piles or other methods are used to isolate excavation cells and limit lateral leakage from the Shallow Alluvium, seepage would occur through the bottom of the excavation. Assuming an average excavation depth of 20 feet, an average of 15 feet below the water table, approximately 1 to 56 gpm would enter an excavation cell of 0.1 to 4 acres, respectively.

A5.3.4 Estimated Depressurization Flow Rates (Deeper Alluvium)

Depressurization of the Deep Aquifer would be required for excavations included in Alternative 10. Flow rates required to depressurize the Deeper Alluvium unit were calculated by a similar method assuming the head in the aquifer needs to be lowered to the same elevation as the excavation bottom, at an average depth of 35 feet bgs, for a net zero gradient across soils underlying the excavation. Assuming the hydraulic conductivities and excavation heads from the groundwater model, we estimate that several thousand gpm would need to be withdrawn from the Deeper Alluvium to achieve the necessary 32 feet of drawdown under steady-state conditions.

The higher hydraulic conductivity (3×10^{-2} cm/sec) of the Deeper Alluvium requires the higher flow rates to achieve depressurization; therefore, groundwater cutoff should be considered to reduce flow rates to achievable levels. Using the calibrated groundwater flow model, depressurization flow rates were predicted with assumed increasing sheet pile embedment. Sheet piles would be driven through the Shallow Alluvium, thereby cutting off shallow groundwater inflow to the excavation (which is also significant near shore). Because of the anisotropic nature of the Deeper Alluvium, increased sheet pile embedment into the Deeper Alluvium forces longer vertical groundwater flow paths and lower groundwater flow rates.

Estimated depressurization flow rates for the Railroad Area and shoreline are presented in Table A-20. They range from 52 to 740 gpm for an excavation cell size ranging from 0.25 to 2 acres with sheet piles driven 1.5 times the depth of the Shallow Alluvium and dewatering depth of 35 to 40 feet bgs. For similar size cells, the flow rates decrease to 100 to 400 gpm when the sheet pile wall is advanced 20 additional feet. The required flow rate to dewater a 2-acre area with sheet piles advanced to 1.5 times the Shallow Aquifer thickness plus an additional 40 feet is estimated to be 400 gpm; the estimate is 570 gpm when sheet piles are only advanced an additional 20 feet.

In all scenarios, the depressurization wells were placed inside the sheet pile wall and screened in the upper 20 feet of the Deeper Alluvium. An excavation encompassing the entire Site with a sheet pile embedment of approximately 80 feet bgs would require a dewatering rate of approximately 2,500 gpm as predicted by the groundwater model; however, at this large pumping rate, there are significant boundary affects, particularly at the upgradient constant head boundary, that lead to significant overestimation of required pumping.

The required number and location (spacing) of depressurization wells would be determined during remedial design, but preliminary groundwater modeling suggests a minimum of four wells arranged evenly within the interior of the sheet pile wall would be required to effectively dewater a 1-acre excavation located near the shoreline. The induced downward gradient along the outside of the sheet pile wall with the deepest embedment is 0.07 feet/foot. The depressurization radius of influence (defined as 0.5 feet of drawdown) would extend approximately 1,600 feet from the excavation.

A6 References for Appendix A

Anchor QEA and Aspect, 2012, Remedial Investigation, Quendall Terminals Site, Renton, Washington, Prepared for U.S. Environmental Protection Agency, Region 10, on behalf of Altino Properties, Inc. and J.H Baxter & Company, September 2012.

Aaronson, 1997, Anaerobic Biodegradation of Organic Chemicals in Groundwater: A Summary of Field and Laboratory Studies, Dallas Aronson and Phillip Howard, Environmental Science Center, November 12, 1997.

EPA, 1999, A Resource for MGP Site Characterization and Remediation. U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response, 1999.

EPA, 2009, Technology Performance Review: Selecting and Using Solidification/Stabilization Treatment for Site Remediation, U.S. Environmental Protection Agency, Office of Research and Development, 2009.

ERPI, 2007, Handbook of Remedial Alternatives for MGP Sites with Contaminated sediments. Publication # 1012592, Electric Power Research Institute, Palo Alto, California, February 2007.

Freeze, R.A., and Cherry J.A., 1979, Groundwater, Prentice -Hall, Inc., Englewood Cliffs, New Jersey.

Halford, K. J., and J. T. Hanson, 2002, User Guide for the Drawdown-Limited, Multi-Node Well (MNW) Package for the U.S. Geological Survey's Modular Three-Dimensional Finite-Difference Ground-Water Flow Model, Versions MODFLOW-96 and MODFLOW-2000, U.S. Geological Survey Open File Report 02-293.

Hart Crowser, 1997, Final Remedial Investigation, Quendall Terminals Uplands, Renton, Washington, Report Approved by Washington Department of Ecology, April 1997.

Hsieh, Paul A. and John R. Freckleton, 1993, Documentation of a Computer Program to Simulate Horizontal-Flow Barriers Using the U.S. Geological Survey's Modular Three-Dimensional Finite-Difference Ground-Water Flow Model, U.S. Geological Survey Open File Report 92-477.

Howard, Philip H., William F. Jarvis, William N. Meylan, and Edward M. Michalenko, 1991, Handbook of Environmental Degradation Rates, Lewis Publishers, Michigan.

MacDonald, M. G. and A.W. Harbaugh, 1988, MODFLOW, A Modular Three Dimensional Finite-Difference Groundwater Flow Model: U.S. Geological Survey Techniques of Water-Resource Investigation, Book 6, Chapter A1, p. 586.

Pollack, D. W., 1994, User's Guide for MODPATH/MODPATH-PLOT, Version 3: A particle tracking post-processing package for MODFLOW the U.S. Geological Survey finite-difference ground-water flow model, U.S. Geological Survey Open File Report 94-464.

Powers, P.J., 1992, construction Dewatering, John Wiley & Sons, INC.Zheng, C. and Bennet, G. D., 2002, Applied Contaminant Transport Modeling, Second Edition, John Wiley and Sons, Inc., New York.

Retec, 1997, Report for Treatability Testing of Sediments and Groundwater for Port Quendall. Prepared for Port Quendall Company. Oct 30, 1997.

Retec, 1998, Port Quendall Groundwater Modeling and Analysis of Alternatives, Prepared for Port Quendall Company, January 9, 1998.

Washington State Department of Ecology (Ecology), 2001, Model Toxics Control Act Cleanup Regulation, Chapter 173-340 WAC, Publication No. 94-06, Amended February 12, 2001.

Wilk, 2007, Principles of Solidification/Stabilization and Use at Brownfield Sites. Charles M. Wilk, Portland Cement Association, Waste Management Conference, Tucson, AZ, February 25 – March 1, 2007.

Yey, Yi-Jang, Cheng-Haw Lee, and Shih-Tsu Chen, 2000. A Tracer Method to Determine Hydraulic Conductivity and Effective Porosity of Saturated Clays Under Low Gradients, Groundwater 38, no. 4; 522-529.

Zheng, C., 1990, MT3D, A Modular Three-Dimensional Transport Model for Simulation of Advection, Dispersion, and Chemical Reactions of Contaminant in Groundwater Systems, Report to the Kerr Environmental Research Laboratory, U.S. Environmental Protection Agency, Ada, Oklahoma.

Zheng, C. and Gordon D. Bennett., 1995, Applied Contaminant Transport Modeling: Theory and Practice, Van Nostrand Reinhold, New York.

Zheng, C. and Wang, P., 1999, MT3DMS, A Modular Three-Dimensional Multi-species Transport Model for Simulation of Advection, Dispersion, and Chemical Reactions of Contaminants in Groundwater Systems: Documentation and User's Guide, U.S. Army Corps of Engineers, U.S. Army Engineer Research and Development Center, Vicksburg, Mississippi, SEREDP-99-1.

Table A-1 Contaminant Fate and Transport Parameters[1]

Quendall Terminals
Renton, Washington

Hydrostratigraphic Unit	f_{oc}[2]	K_d[3] (L/kg)			
		Benzene	Naphthalene	Benzo(a)pyrene	Arsenic[4]
Fill	0.09%	0.054	0.55	256	29
Shallow Alluvium	0.29%	0.18	1.8	856	29
Deep Alluvium	0.09%	0.054	0.55	256	29
Lake Sediments	0.29%	0.18	1.8	856	29

Contaminant	Half Life (days)[5]
Benzene	720
Naphthalene	258
Benzo(a)pyrene	4,000
Arsenic	Not Simulated

Notes:

Longitudinal dispersivity equals 7.5 feet, transverse dispersivity equals 1 foot, and vertical dispersivity equals 0.75 feet.

[1] Bulk density assumed constant at 1.7 g/cm^3 as in previous modeling studies (Retec 1998). Log K_{oc} assumed equal to 1.79 L/kg for benzene, 2.8 L/kg for naphthalene, and 5.47 for benzo(a)pyrene (Hart Crowser 1997 and Retec 1998).

[2] Referenced from Hart Crowser (1997) and Retec (1998).

[3] Soil/water sorption coefficient (K_d) = f_{oc} * K_{oc} .

[4] K_d for arsenic is from WAC 173-340-900, Table 747-3.

[5] Based on anaerobic half lives found in the literature and past modeling studies (Howard 1991, Aaronson 1997, and Retec 1998) as discussed in Section A3.1.2.

Abbreviations:

f_{oc} = fraction organic carbon
L/kg = liters per kilogram
K_d = sorption coefficient
K_{oc} = soil organic carbon-water partitioning coefficient
MTCA = Model Toxics Control Act

Table A-2 Measured Dissolved Oxygen Concentrations

Quendall Terminals
Renton, Washington

Monitoring Well	Temperature (°C)	Conductivity (µmhos/cm)	Dissolved Oxygen (mg/L)	ORP (mV)
BH-5A	14.69	348	0.62	213.5
BH-5B	15.06	445	1.14	-398.5
BH-18A	12.12	986	0.91	188.7
	15.21	900	0.9	53.9
BH-18B	13.1	309	0.5	235.9
	13.92	324	0.28	72.3
BH-19	11.67	877	1.34	227.2
	15.47	996	0.93	-80.8
BH-19B	12.51	406	0.51	229
	14.6	374	1.99	-384
BH-20A	13.23	467	0.45	203.2
	15.22	515	1.41	-378
BH-20B	13.12	450	0.26	204.8
	14.11	536	0.71	-52.9
BH-20C	16.09	153	1.44	-298
BH-21A	17.99	762	0.61	-51.4
BH-21B	12.8	512	0.56	196.1
	14.16	551	0.69	-96.5
BH-22	11.88	352	1.08	-13.2
BH-23	14.66	950	1.65	-322.1
BH-24	13.23	658	0.99	248.2
	13.86	773	0.4	-375
BH-25AR	17.4	731	0.35	-64.9
BH-26A	14.64	387	0.3	-3.7
BH-26B	12.99	604	0.24	-88
BH-28	13.17	490	0.91	220.8
	12.76	473	0.44	-67.8
BH-28B	13.41	353	1.18	230
BH-29A	15.6	482	0.2	-84.3
BH-29B	14.51	559	0.25	12.3
BH-30C	12.44	162	0.39	-433
RW-NS-1	14.15	1044	0.42	118.8
Average	14.04	554.00	0.77	-27.13

Notes:
Data referenced from Table C-3 of Appendix C of the Quendall RI (Anchor QEA and Aspect 2012).

Abbreviations:
°C = degrees Celsius
mg/L - milligram(s) per liter
mV = millivolts
ORP = oxidation-reduction potential
µmhos/cm = micro ohms per centimeter

Table A-3 Source Area Concentrations[1]

Quendall Terminals
Renton, Washington

DNAPL-Related COC Concentrations

Monitoring Well	Benzo(a)pyrene Concentration (µg/L)	Naphthalene Concentration (µg/L)	Benzene Concentration (µg/L)[2]				
			Zone 1	Zone 2	Zone 3	Zone 4	Zone 5
BH-5	362	16,000	-	-	-	-	31,000
BH-19	ND	25	-	-	-	-	59
BH-21A	24.6	2,100	4	-	-	-	-
BH-20A	11.7	10,000	-	-	-	-	7,900
BH-25A(R)	ND	11,000	-	510	-	-	-
BH-23	ND	300	-	-	-	350	-
RW-NS1	ND	760	-	-	-	58	-
RW-QP1	ND	11,000	-	-	-	-	7,700
Q9	Footnote 3	45,000	-	1,600	-	-	-
Q14-W	-	-	-	-	ND	-	-
Average	**133**	**11,000**	**4**[4]	**1,100**	**ND**[5]	**200**	**12,000**

Arsenic Concentrations

Monitoring Well	Arsenic Concentration (µg/L)
BH-19	25.3
BH-5A	53.8
BH-5	21.5
BH-25A(R)	13.5
BH-5B	10.3
BH-20B	50.9
BH-21B	109
BH-26B	31.8
BH-28B	34.2
Average	**39**

Notes:

[1] COC concentrations from RI Report Figures 5.2-1, 5.2-2, 5.2-8, 5.2-9, 5.2-14, 5.2-16 and 5.2-17 (Anchor QEA and Aspect 2012).

[2] Benzene DNAPL zones are shown on Figures A-1, A-2, and A-3.

[3] Excluded from average because value exceeded COC solubility.

[4] Not simulated in the model because of relative low concentration.

[5] Non-detect; therefore, not simulated in the groundwater model.

- Dash indicates well not located in hydrocarbon source zone.

Abbreviations:

COC = Chemicals of concern
ND = COC was not detected and therefore not included in average concentration value.
µg/L = micrograms per liter

Table A-4 Case Studies for Solidification of Coal Tar and Creosote Constituents

Quendall Terminals
Renton, Washington

Site Name	Site Location	Date	Hydraulic Conductivity	Source
South 8th Street Landfill Superfund Site	West Memphis, AR	1999-2000	$1x10^{-5}$ cm/sec	EPA 2009
Georgia Power Company - Manufactured Gas Plant	Columbus, GA	1992-1993	$1x10^{-5}$ cm/sec	EPA 1999; EPRI 2003
Wisconsin Fuel and Light - former MGP facility	Manitowoc, WI	1994-1995	$1.8x10^{-7}$ cm/sec	EPA 1999
J.H. Baxter - Renton Site	Renton, WA	2004	$1.x10^{-5}$ cm/sec	Wilk 2007; Hainsworth 2011
American Creosote Works	Jackson, TN	1999-2000	$1.x10^{-5}$ cm/sec	Wilk 2007; Hainsworth 2011

Abbreviations:
cm/sec = centimeters per second

Table A-5 Development of Remedial Alternatives

Quendall Terminals
Renton, Washington

Comparison of Backfill Materials

Backfill Type	Treatment Area	Volume of DNAPL Treated in Gallons[1]	Percent of Plume Remaining[2]		
			Benzene	Naphthalene	Benzo(a)pyrene
Treated Soil[3]	Area 1	29,281	68%	87%	97%
Imported Fill[4]	Area 1	29,281	68%	88%	96%

Comparison of Remedial Technologies and Treatment Areas

Remedial Technology	Treatment Areas	Volume of DNAPL Treated in Gallons[1]	Percent of Plume Remaining[2]		
			Benzene	Naphthalene	Benzo(a)pyrene
***In Situ* Solidification[5, 6]**	Area 1	29,281	66%	85%	99%
	Area 1 and 2	53,897	58%	82%	99%
	Area 1 through 3	87,422	52%	78%	99%
Excavation[3]	Area 1	29,281	71%	87%	97%
	Area 1 and 2	53,897	62%	83%	93%
	Area 1 through 3	87,422	53%	77%	87%
	Areas 1, 4, 5, and 6	145,480	61%	85%	83%

Notes:

[1]Volume calculation documented in Appendix E.

[2] Percent of pre-remediation plume volume remaining after 100 years after alternative implementation.

[3] Assumes excavation of DNAPL, on-site treatment, and backfill with treated soil ($K=1.0 \times 10^{-4}$ cm/s).

[4] Assumes excavation of DNAPL with off-site disposal and replacement with clean imported fill ($K= 1.0 \times 10^{-2}$ cm/s).

[5] Assumes *in situ* solidification of DNAPL.

[6] Percent plume remaining includes solidified zone.

Table A- 6 Evaluation of Remedial Alternatives - Aggregate Plume Volumes

Quendall Terminals
Renton, Washington

Alternative	Aggregate Plume Volume in MG[1]			
	All Aquifers Combined		Upland Deep Aquifer	
	Exceeds PRGs	Exceeds MCLs	Exceeds PRGs	Exceeds MCLs
Pre-Remediation	321	234	73.0	45.9
Alternative 1	323	241	73.5	46.6
Alternative 2	287	211	70.2	43.3
Alternative 3	233	162	57.0	32.7
Alternative 4	273	195	70.2	43.0
Alternative 5	224	155	57.3	32.8
Alternative 6	184	121	47.8	25.2
Alternative 7	65.0	51.7	23.3	16.0
Alternative 8	60.6	60.6	16.5	16.5
Alternative 9	74.4	53.3	26.0	16.2
Alternative 10	21.5	21.5	10.2	10.2

Alternative	Aggregate Plume Volume as Percent[1]			
	All Aquifers Combined		Upland Deep Aquifer	
	Exceeds PRGs	Exceeds MCLs	Exceeds PRGs	Exceeds MCLs
Alternative 2	89%	87%	96%	93%
Alternative 3	72%	67%	78%	70%
Alternative 4	85%	81%	96%	92%
Alternative 5	69%	65%	78%	70%
Alternative 6	57%	50%	65%	54%
Alternative 7	20%	21%	32%	34%
Alternative 8	19%	25%	22%	35%
Alternative 9	23%	22%	35%	35%
Alternative 10	7%	9%	14%	22%

Notes:
[1] Reported relative to Alternative 1.

Abbreviations:
MCL = Maximum Contaminant Level (excludes naphthalene)
MG = millions of gallons of groundwater
PRG = Preliminary Remediation Goal

Table A-7 Evaluation of Remedial Alternatives by COC

Quendall Terminals
Renton, Washington

Alternative	Plume Volume (MG)				Plume Contaminant Mass (kg)			
	Benzene	Naphthalene	B[a]P	Arsenic	Benzene	Naphthalene	B[a]P	Arsenic
Pre-Remediation	226	292	23.3	31.6	317	990	5.71	4.54
Alternative 1	226	292	27.0	55.2	317	990	6.10	4.50
Alternative 2	196	262	26.6	54.5	284	907	6.04	4.61
Alternative 3	142	215	23.4	52.4	236	689	5.15	4.47
Alternative 4	181	256	25.3	54.0	191	789	5.46	4.61
Alternative 5	137	207	18.5	50.8	155	471	3.12	4.26
Alternative 6	98.8	171	14.4	48.4	98	258	1.55	3.96
Alternative 7	6.83	33.5	5.99	43.8	0.80	1.29	0.09	3.40
Alternative 8	0.00	0.00	18.0	49.3	0.01	0.00	0.49	3.92
Alternative 9	7.58	40.1	5.10	43.5	3.17	4.26	0.09	3.21
Alternative 10	0.00	0.00	0.00	19.1	0.00	0.00	0.04	2.10

Alternative	Mass Flux at Mudline (kg/year)				Restoration Timeframe (years)			
	Benzene	Naphthalene	B[a]P	Arsenic	Benzene	Naphthalene	B[a]P	Arsenic
Pre-Remediation	292	363	2	Not Estimated	>100	>100	>100	>100
Alternative 1	292	363	2.0	5.2	>100	>100	>100	>100
Alternative 2	213	252	1.5	4.9	>100	>100	>100	>100
Alternative 3	127	153	0.9	5.0	>100	>100	>100	>100
Alternative 4	76	140	0.3	5.2	>100	>100	>100	>100
Alternative 5	58	71	0.2	4.9	>100	>100	>100	>100
Alternative 6	40	39	0.1	4.9	>100	>100	>100	>100
Alternative 7	0.4	0.4	0.01	4.9	>100	>100	>100	>100
Alternative 8	0.03	0.01	0.03	4.8	28	98	>100	>100
Alternative 9	0.2	0.1	0.00	2.0	>100	>100	>100	>100
Alternative 10	0.00	0.00	0.00	0.7	14	46	0[2]	>100

Notes:

[1] Reported relative to Alternative 1.

[2] Modeling results do not include the potential contribution of residuals resulting from removal actions (i.e., excavation or dredging). It is expected, based on a model sensitivity analysis (see Appendix A, Section A5.1.2.2), that residuals will result in benzo(a)pyrene exceedances after 100 years for all alternatives, including Alternative 10.

Abbreviations:

B[a]P = benzo(a)pyrene
COC = chemical of concern
kg = kilograms
kg/year = kilograms per year
MG = millions of gallons of groundwater

Table A-7 Evaluation of Remedial Alternatives by COC

Quendall Terminals
Renton, Washington

Alternative	Plume Volume as Percent[1]				Plume Contaminant Mass as Percent[1]			
	Benzene	Naphthalene	B[a]P	Arsenic	Benzene	Naphthalene	B[a]P	Arsenic
Alternative 2	86%	90%	99%	99%	90%	92%	99%	103%
Alternative 3	63%	74%	87%	95%	74%	70%	84%	99%
Alternative 4	80%	88%	94%	98%	60%	80%	90%	102%
Alternative 5	60%	71%	69%	92%	49%	48%	51%	95%
Alternative 6	44%	59%	53%	88%	31%	26%	25%	88%
Alternative 7	3%	11%	22%	79%	0%	0%	2%	76%
Alternative 8	0%	0%	67%	89%	0%	0%	8%	87%
Alternative 9	3%	14%	19%	79%	1%	0%	1%	71%
Alternative 10	0%	0%	0%[2]	35%	0%	0%	1%	47%

Alternative	Mass Flux at Mudline as Percent[1]			
	Benzene	Naphthalene	B[a]P	Arsenic
Alternative 2	73%	69%	73%	95%
Alternative 3	43%	42%	44%	97%
Alternative 4	26%	39%	17%	101%
Alternative 5	20%	19%	11%	95%
Alternative 6	14%	11%	6%	95%
Alternative 7	0%	0%	1%	94%
Alternative 8	0%	0%	1%	94%
Alternative 9	0%	0%	0%	38%
Alternative 10	0%	0%	0%	14%

Table A-8 Groundwater Discharge to Lake Washington

Quendall Terminals
Renton, Washington

	Darcy Flux to Lake Washington (cm/s)		Darcy Flux to Lake Washington (cm/year)	
	Nearshore	**Offshore**	**Nearshore**	**Offshore**
Current Conditions (No remedial technologies implemented)				
Maximum	1.7E-05	3.1E-06	543	96.8
Average	5.6E-06	2.4E-06	177[1]	74.6
Upland Capping				
Maximum	1.4E-05	3.0E-06	427	94.4
Average	4.7E-06	2.3E-06	147[2]	72.8
Upland Capping and Funnel and Gate System				
Maximum	1.3E-05	3.1E-06	397	99.2
Average	4.0E-06	2.5E-06	126	78.1

Notes:

[1] Value used to model current conditions and calibrate the UT model (refer to Appendix B2, Section B2-3.2.1.3).

[2] Value used to model nearshore cap conditions using UT model (refer to Appendix B2, Section B-4.2.2.2).

Abbreviations:

cm/s = centimeters per second
cm/year = centimeters per year
UT = University of Texas

Table A-9 Parameter Sensitivity Analysis[1]

Quendall Terminals
Renton, Washington

Decay Sensitivity Analysis[2]

	Half Life (days)			
	Benzene	**Benzo(a)pyrene**	**Naphthalene**	**Arsenic**
High Half Life	3,600	Not Simulated	1,290	Not Simulated
Low Half Life	112	1,484	40	Not Simulated

K_d Sensitivity Analysis[3]

	Hydrostratigraphic Unit	**K_d (L/kg)**			
		Benzene	**Benzo(a)Pyrene**	**Naphthalene**	**Arsenic**
High K_d	Shallow Alluvium	0.9	4,280	9	145
	Lake Sediments	0.9	4,280	9	145
	Fill	0.27	1,280	2.75	145
	Deeper Alluvium	0.27	1,280	2.75	145
Low K_d	Shallow Alluvium	0.036	171.2	0.36	5.8
	Lake Sediments	0.036	171.2	0.36	5.8
	Fill	0.0108	51.2	0.11	5.8
	Deeper Alluvium	0.0108	51.2	0.11	5.8

Source Concentration Sensitivity Analysis[4]

	Concentration (µg/L)							
				Benzene				
	Benzo(a)pyrene	**Naphthalene**	**Arsenic**	**Zone 1**	**Zone 2**	**Zone 3**	**Zone 4**	**Zone 5**
High Concentration	200	16,000	58	Not Simulated	1,600	Not Simulated	300	17,000
Low Concentration	70	5,300	19	Not Simulated	530	Not Simulated	100	5,800

Notes:

[1] Base parameter values are reported in Tables A-1 and A-2.

[2] Half Life end members are lowest estimated anaerobic half life (Howard 1991) and 500% of the base values.

[3] K_d end members are 500% and 20% of base values.

[4] Concentration end members are 50% and 150% of base parameters.

Abbreviations:

L/kg = liters per kilogram
µg/L = micrograms per liter

Table 10 - Sensitivity Analysis Results by COC

Quendall Terminals
Renton, Washington

Sensitivity Model Run	Plume Volume (MG)				Plume Contaminant Mass (kg)			
	Benzene	Naphthalene	B[a]P	Arsenic	Benzene	Naphthalene	B[a]P	Arsenic
Alternative 1								
Base Parameters	226.47	292.13	27.00	55.24	316.57	989.62	6.10	4.50
High Half Life	448.33	643.39	27.00	55.24	406.20	1,577.42	6.10	4.50
Low Half Life	69.63	76.14	26.98	55.24	204.73	597.35	6.09	4.50
High K_d	226.70	290.23	19.50	41.10	316.73	989.20	5.43	4.62
Low K_d	226.45	292.05	49.41	36.40	316.47	989.66	8.12	1.86
High Concentration	254.03	310.81	28.04	64.66	452.22	1,439.55	9.17	6.84
Low Concentration	173.91	251.95	25.08	35.86	152.30	476.66	3.21	1.92
Alternative 7								
Base Parameters	6.68	33.51	5.99	43.85	0.80	1.29	0.09	3.40
High Half Life	14.08	310.95	6.00	43.85	1.62	19.24	0.09	3.40
Low Half Life	1.14	3.03	5.98	43.85	0.23	0.18	0.09	3.40
High K_d	8.00	186.80	1.00	30.27	1.03	44.01	0.01	3.27
Low K_d	6.68	26.50	24.73	31.20	0.80	0.88	0.56	1.71
High Concentration	9.32	42.44	6.72	49.79	1.20	1.93	0.14	5.10
Low Concentration	3.49	19.39	4.95	25.41	0.34	0.57	0.05	1.31
Alternative 8								
Base Parameters	0.01	0.00	18.02	49.30	0.01	0.00	0.49	3.92
High Half Life	0.01	303.12	17.75	49.30	0.00	16.96	0.49	3.92
Low Half Life	0.00	0.00	17.73	49.30	0.00	0.00	0.48	3.92
High K_d	0.01	207.90	8.09	35.53	0.00	54.17	0.12	3.89
Low K_d	0.01	0.00	40.65	38.50	0.01	0.00	1.63	2.17
High Concentration	0.01	0.37	19.07	57.21	0.01	0.00	0.73	5.94
Low Concentration	0.01	0.00	15.36	29.19	0.01	0.00	0.26	1.51

Abbreviations:

B[a]P = Benzo(a)pyrene
K_d = Sorption coefficient
kg = kilograms
MG = millions of gallons of groundwater

Table 10 - Sensitivity Analysis Results by COC

Quendall Terminals
Renton, Washington

Sensitivity Model Run	Mass Flux at Mudline (kg/year)				Restoration Timeframe (years)			
	Benzene	Naphthalene	B[a]P	Arsenic	Benzene	Naphthalene	B[a]P	Arsenic
Alternative 1								
Base Parameters	292.10	363.27	2.05	5.17	>100	>100	>100	>100
High Half Life	327.02	540.29	2.05	5.17	>100	>100	>100	>100
Low Half Life	230.29	208.39	2.04	5.17	>100	>100	>100	>100
High K_d	292.19	362.97	1.87	4.73	>100	>100	>100	>100
Low K_d	291.97	363.29	3.06	4.77	>100	>100	>100	>100
High Concentration	414.14	528.37	3.08	5.55	>100	>100	>100	>100
Low Concentration	141.19	175.03	1.08	4.78	>100	>100	>100	>100
Alternative 7								
Base Parameters	0.43	0.36	0.01	4.86	>100	>100	>100	>100
High Half Life	0.74	4.59	0.01	4.86	>100	>100	>100	>100
Low Half Life	0.24	0.16	0.01	4.86	>100	>100	>100	>100
High K_d	0.53	8.12	0.02	4.62	>100	>100	>100	>100
Low K_d	0.43	0.29	0.15	4.91	>100	>100	>100	>100
High Concentration	0.61	0.53	0.02	4.96	>100	>100	>100	>100
Low Concentration	0.21	0.17	0.01	4.75	>100	>100	>100	>100
Alternative 8								
Base Parameters	0.03	0.01	0.03	4.85	28	98	>100	>100
High Half Life	0.04	3.07	0.03	4.85	85	>100	>100	>100
Low Half Life	0.02	0.00	0.03	4.85	6	18	>100	>100
High K_d	0.03	7.37	0.00	4.64	85	>100	>100	>100
Low K_d	0.03	0.01	0.23	4.95	17	26	>100	>100
High Concentration	0.03	0.00	0.04	4.95	29	>100	>100	>100
Low Concentration	0.03	0.01	0.02	4.74	24	90	>100	>100

Abbreviations:
B[a]P = Benzo(a)pyrene
K_d = Sorption coefficient
kg = kilograms
MG = millions of gallons of groundwater

Table A-11 Sensitivity Analysis Results - Aggregate Plume Volume

Quendall Terminals
Renton, Washington

Sensitivity Model Run	Aggregate Plume Volume (MG)			
	All Aquifers Combined		Upland Deep Aquifer	
	Exceeds PRGs	Exceeds MCLs[1]	Exceeds PRGs	Exceeds MCLs[1]
Alternative 1				
Base Parameters	323	241	73	47
High Half Life	651	462	79	50
Low Half Life	108	96	35	27
High K_d	323	237	75	48
Low K_d	319	237	70	42
High Concentration	351	271	78	52
Low Concentration	269	183	66	37
Alternative 7				
Base Parameters	65	52	23	16
High Half Life	324	56	40	16
Low Half Life	49	49	16	16
High K_d	193	36	47	14
Low K_d	61	54	16	12
High Concentration	76	59	29	20
Low Concentration	40	31	12	8
Alternative 8				
Base Parameters	61	61	16	16
High Half Life	322	60	22	16
Low Half Life	60	60	16	16
High K_d	216	40	44	15
Low K_d	71	71	13	13
High Concentration	69	69	21	21
Low Concentration	40	40	8	8

Notes:

[1] Naphthalene is excluded because it does not have an MCL.

Abbreviations:

MCL = Maximum Contaminant Level
MG = millions of gallons of groundwater
PRG = Preliminary Remediation Goal

Table A-12 Estimated Sensitivity Analysis Results - Aggregate Plume Volume

Quendall Terminals
Renton, Washington

Alternative	Best Case Aggregate Plume Volume in MG			
	All Aquifers Combined		Upland Deep Aquifer	
	Exceeds PRGs	Exceeds MCLs	Exceeds PRGs	Exceeds MCLs
Alternative 1	108	96	34.6	27.2
Alternative 2	98	86	33.2	25.1
Alternative 3	84	70	27.1	18.2
Alternative 4	95	81	33.2	24.9
Alternative 5	82	68	27.2	18.3
Alternative 6	72	57	22.9	13.4
Alternative 7	40	31	12.4	7.5
Alternative 8	40	40	7.8	7.8
Alternative 9	43	35	12.8	7.6
Alternative 10	30	24	5.5	3.7

Alternative	Worst Case Aggregate Plume Volume in MG			
	All Aquifers Combined		Upland Deep Aquifer	
	Exceeds PRGs	Exceeds MCLs	Exceeds PRGs	Exceeds MCLs
Alternative 1	651	462	78.8	52.3
Alternative 2	606	397	76.6	48.8
Alternative 3	538	292	68.4	37.6
Alternative 4	588	363	76.7	48.5
Alternative 5	526	278	68.6	37.7
Alternative 6	476	204	62.7	29.6
Alternative 7	324	59	46.7	19.6
Alternative 8	322	70.5	43.7	20.8
Alternative 9	337	58.9	49.1	20.2
Alternative 10	271	0.0	39.2	13.8

Notes:
Values shaded in grey are estimated sensitivity results as described in Section A3.7.
Modeling results do not include the potential contribution of residuals resulting from removal actions (i.e., excavation or dredging). It is expected, based on a model sensitivity analysis (see Appendix A, Section A5.1.2.2), that residuals will result in benzo(a)pyrene exceedances after 100 years for all alternatives, including Alternative 10.

Abbreviations:
MCL = Maximum Contaminant Level
MG = millions of gallons of groundwater
PRG = Preliminary Remediation Goal

Table A-13 Estimated Sensitivity Results by COC - Plume Volume

Quendall Terminals
Renton, Washington

Alternative	Best Case Plume Volume (MG)			
	Benzene	Naphthalene	Benzo[a]pyrene	Arsenic
Alternative 1	70	76	20	36
Alternative 2	60	68	18	35
Alternative 3	43	55	15	33
Alternative 4	55	66	17	34
Alternative 5	42	53	11	31
Alternative 6	30	43	7	29
Alternative 7	1	3	1	25
Alternative 8	0	0	8	29
Alternative 9	2	8	0	25
Alternative 10	0	0	0	2

Alternative	Worst Case Worst Case Plume Volume in MG			
	Benzene	Naphthalene	Benzo[a]pyrene	Arsenic
Alternative 1	448	643	49	65
Alternative 2	388	605	50	64
Alternative 3	281	548	46	61
Alternative 4	358	598	48	63
Alternative 5	271	538	40	59
Alternative 6	196	495	35	56
Alternative 7	14	311	25	50
Alternative 8	0	303	41	57
Alternative 9	15	336	24	49
Alternative 10	0	288	0	18

Notes:

Values shaded in grey are estimated sensitivity results as described in Section A3.7.

Benzo[a]pyrene is expected to restore immediately following implementation of Alternative 10; therefore, benzo[a]pyrene plume volume is assumed to be 0 MG for Alternative 10.

Modeling results do not include the potential contribution of residuals resulting from removal actions (i.e., excavation or dredging). It is expected, based on a model sensitivity analysis (see Appendix A, Section A5.1.2.2), that residuals will result in benzo(a)pyrene exceedances after 100 years for all alternatives, including Alternative 10.

Values are rounded to the nearest whole number.

Abbreviations:

MCL = Maximum Contaminant Level
MG = millions of gallons of groundwater
PRG = Preliminary Remediation Goal

Table A-14 Estimated Sensitivity Results by COC - Plume Mass

Quendall Terminals
Renton, Washington

Alternative	Best Case Plume Mass (kg)			
	Benzene	Naphthalene	Benzo[a]pyrene	Arsenic
Alternative 1	152	477	3	2
Alternative 2	137	437	3	2
Alternative 3	113	332	3	2
Alternative 4	92	380	3	2
Alternative 5	74	227	2	2
Alternative 6	47	124	1	2
Alternative 7	0	0	0	1
Alternative 8	0	0	0	2
Alternative 9	1	2	0	1
Alternative 10	0	0	0	1

Alternative	Worst Case Worst Case Plume Mass (kg)			
	Benzene	Naphthalene	Benzo[a]pyrene	Arsenic
Alternative 1	452	1,577	9	7
Alternative 2	406	1,450	9	7
Alternative 3	337	1,112	8	7
Alternative 4	272	1,268	8	7
Alternative 5	221	776	5	6
Alternative 6	140	447	3	6
Alternative 7	2	44	1	5
Alternative 8	0	54	2	6
Alternative 9	5	55	1	5
Alternative 10	0	48	0	3

Notes:
Values shaded in grey are estimated sensitivity results as described in Section A3.7.
Benzo[a]pyrene is expected to restore immediately following implementation of Alternative 10; therefore, benzo[a]pyrene plume mass is assumed to be 0 kg for Alternative 10.

Values are rounded to the nearest whole number.

Abbreviations:
kg = kilograms
MCL = Maximum Contaminant Level
PRG = Preliminary Remediation Goal

Table A-15 Estimated Sensitivity Results by COC - Mass Flux

Quendall Terminals
Renton, Washington

Alternative	Best Case Mass Flux (kg/year)			
	Benzene	Naphthalene	Benzo[a]pyrene	Arsenic
Alternative 1	141	175	1	5
Alternative 2	103	121	1	5
Alternative 3	61	74	0	5
Alternative 4	37	68	0	5
Alternative 5	28	34	0	5
Alternative 6	19	19	0	5
Alternative 7	0	0	0	5
Alternative 8	0	0	0	5
Alternative 9	0	0	0	4
Alternative 10	0	0	0	3

Alternative	Worst Case Mass Flux (kg/year)			
	Benzene	Naphthalene	Benzo[a]pyrene	Arsenic
Alternative 1	414	540	3	6
Alternative 2	302	377	2	5
Alternative 3	180	232	1	5
Alternative 4	108	213	1	6
Alternative 5	82	111	0	5
Alternative 6	56	65	0	5
Alternative 7	1	8	0	5
Alternative 8	0	7	0	5
Alternative 9	0	8	0	4
Alternative 10	0	7	0	3

Notes:
Values shaded in grey are estimated sensitivity results as described in Section A3.7.
Values are rounded to the nearest whole number.

Abbreviations:
kg/year = kilograms per year
MCL = Maximum Contaminant Level
PRG = Preliminary Remediation Goal

Table A-16 Dewatering Estimates - Wet Excavation

Quendall Terminals
Renton, Washington

Excavation Cell	Area in Square Feet	Maximum Excavation Depth (feet bgs)	Estimated Dewatering Flow Rate (gpm)	Dewatering Depth (feet bgs)		Sheet Pile Embedment Depth (feet bgs)		Number of Wells
				Minimum	Maximum	Minimum	Maximum	
1	13,343	34	91	19	21	47	51	6
2	7,985	22	0	-	-	-	-	-
3	13,7060	14	0	-	-	-	-	-
4	80,281	18	137	9	20	38	49	4
5	12,790	24	0	-	-	-	-	-
6	5,541	27	68	13	19	53	62	3
7*	84,507	22	207	9	19	47	65	6
8	11,746	19	47	8	13	50	89	3
9	20,084	15	0	-	-	-	-	-
10	30,708	32	119	19	22	36	37	5
DNAPL Trench**	2,500	25	16	13	14	46	50	2
Quendall Pond	21,556	19	119	8	15	57	64	6

Notes:

* Excavation Cells 1 through 10 and the Quendall Pond excavation are included in Alternative 8.

** The DNAPL Trench is the collection trench included in Alternatives 3 through 7.

- The dash indicates that depressurization of the Deep Aquifer was not required.

Abbreviations:

bgs = below ground surface
gpm = gallons per minute

Table A-17 Dewatering Estimates - Dry Excavation

Quendall Terminals
Renton, Washington

Excavation Cell	Area in square feet	Maximum Excavation Depth (feet bgs)	Estimated Dewatering Flow Rate (gpm)	Dewatering Depth (feet bgs)		Sheet Pile Embedment Depth (feet bgs)		Number of Wells
				Minimum	Maximum	Minimum	Maximum	
1	13,343	34	202	34	38	47	51	6
2	7,985	22	94	22	25	44	49	2
3	13,7060	14	301	14	20	40	59	8
4	80,281	18	462	19	27	38	49	7
5	12,790	24	171	24	29	51	59	4
6	5,541	27	143	27	31	53	62	3
7	84,507	22	592	22	32	44	49	6
8*	11,746	19	143	19	23	50	89	3
9	20,084	15	119	15	19	50	53	3
10	30,708	32	228	32	34	45	47	6
DNAPL Trench**	2,500	26	50	25	27	46	50	2

Notes:

* Excavation Cells 1 through 10 are included in Alternative 8.

** DNAPL Trench is the collection trench included in Alternatives 3 through 7.

Abbreviations:

bgs = below ground surface
gpm = gallons per minute

Table A-18 Fine Grain Layers in the Deeper Alluvium

Quendall Terminals
Renton, Washington

Boring ID	Silty Sand Lens		Silt Lens	
	Depth to Top	Depth to Bottom	Depth to Top	Depth to Bottom
BH-5B	--	--	49.5	50
BH-19B	--	--	45.3	45.5
BH-20C	53	55.5	--	--
	62	62.5	--	--
	73.5	74.5	--	--
BH-21B	43	50	38	39.5
BH-29B	45	46	--	--
BH-30C	--	--	45.8	46.2
SWB-3	33	42	--	--
SWB-4B	33.5	39	--	--
SWB-8	51	52	--	--
	61	83	--	--

Notes:
Depths are reported in feet below ground surface.
Dashes indicate layer not found in present log

Table A19 - Restoration Potential Fate and Transport Model Results

Quendall Terminals
Renton, Washington

Sensitivity Analysis Scenario	Deeper Alluvium Assumption[1]	Pump and Treat[2]	Model Results - Time to Reach MCLs or PRGs[3] in Years[4] or Maximum Concentration			
			Naphthalene	Benzene	Benzo(a)pyrene	Arsenic
Comparison of Heterogeneous and Homogeneous Assumptions	Heterogeneous	None	45	30	> 100 Years (20 µg/L)	> 100 Years (53 µg/L)
		90 gpm	45	26	> 100 Years (20 µg/L*)	> 100 Years (53 µg/L)
		180 gpm	--	25	> 100 Years (20 µg/L*)	> 100 Years (53 µg/L)
	Homogeneous	None	53	13	> 250 Years (4.2 µg/L)	> 200 Years (33 µg/L)
		90 gpm	51	14	> 200 Years (3.8 µg/L)	> 200 Years (30 µg/L)
		180 gpm	--	14	> 200 Years (3.5 µg/L)	> 200 Years (16 µg/L)
Excavation Residual Analysis	Homogeneous	None	--	13	> 100 Years (1.3 µg/L)	--
		90 gpm	--	13	> 100 Years (3.3 µg/L)[5]	--

Notes:

-- Model scenario was not performed for indicated COC.

* Simulation used 30 µg/L as initial condition in the low-permeability layers and negligible reduction observed.

Reported result assumes initial concentration of 20 µg/L would also exhibit negligible reduction.

[1] Model runs that simulate a heterogeneous Deeper Alluvium include a representative silt and silty sand zone.

[2] Total pump and treat flow rate from 6 pumping wells near the shoreline.

[3] Naphthalene PRG = 1.4 µg/L, benzene MCL = 5 µg/L, benzo(a)pyrene MCL = 0.2 µg/L, and arsenic MCL = 10 µg/L.

[4] The maximum concentration at the end of the simulation is reported when the COC does not attenuate below the MCL within the modeled timeframe.

[5] A greater remaining concentration was observed with pumping because of stagnation created by pumping.

Abbreviations:

gpm = gallons per minute

MCL = Maximum Contaminant Level

MTCA = Model Toxics Control Act

µg/L = micrograms per liter

Table A-20 Dewatering Estimates for Locations near the Railroad Area and Shoreline

Quendall Terminals
Renton, Washington

Near Rail Road Area

Excavation Area	Sheet Pile Embedment Depth (bgs)	Dewater Depth (feet bgs)	Combined Pumping Rate (gpm)
2 Acres	1.5 x Shallow Alluvium Thickness	35 to 40	740
	1.5 x Shallow Alluvium Thickness + 20 Feet	35 to 40	510
	1.5 x Shallow Alluvium Thickness + 40 Feet	35 to 40	360
1 Acre	1.5 x Shallow Alluvium Thickness	35 to 40	570
	1.5 x Shallow Alluvium Thickness + 20 Feet	35 to 40	310
	1.5 x Shallow Alluvium Thickness + 40 Feet	35 to 40	200
0.5 Acres	1.5 x Shallow Alluvium Thickness	35 to 40	330
	1.5 x Shallow Alluvium Thickness + 20 Feet	35 to 40	160
	1.5 x Shallow Alluvium Thickness + 40 Feet	35 to 40	110
0.25 Acres	1.5 x Shallow Alluvium Thickness	35 to 40	180
	1.5 x Shallow Alluvium Thickness + 20 Feet	35 to 40	79
	1.5 x Shallow Alluvium Thickness + 40 Feet	35 to 40	52

Abbreviations:
bgs = below ground surface
gpm = gallons per minute

Table A-20 Dewatering Estimates for Locations near the Railroad Area and Shoreline

Quendall Terminals
Renton, Washington

Near the Shoreline

Excavation Area	Sheet Pile Embedment Depth bgs	Dewater Depth (feet bgs)	Combined Pumping Rate (gpm)
2 Acres	1.5 x Shallow Alluvium Thickness	35 to 45	940
	1.5 x Shallow Alluvium Thickness + 20 Feet	20 to 25 35 to 45	320 570
	1.5 x Shallow Alluvium Thickness + 40 Feet	20 to 25 35 to 45	210 400
1 Acre	1.5 x Shallow Alluvium Thickness	20 to 30 35 to 45	380 680
	1.5 x Shallow Alluvium Thickness + 20 Feet	20 to 30 35 to 45	210 350
	1.5 x Shallow Alluvium Thickness + 40 Feet	20 to 30 35 to 45	130 210
0.5 Acres	1.5 x Shallow Alluvium Thickness	20 to 30 35 to 45	230 400
	1.5 x Shallow Alluvium Thickness + 20 Feet	20 to 30 35 to 45	110 190
0.25 Acres	1.5 x Shallow Alluvium Thickness	20 to 30 35 to 45	110 210
	1.5 x Shallow Alluvium Thickness + 20 Feet	20 to 30 35 to 45	52 94

Abbreviations:
bgs = below ground surface
gpm = gallons per minute

Legend

- DNAPL Thiessen Polygon
- Hydrocarbon Source Zone
- Detention Pond
- Existing Structure
- Historical Structure
- Other Historical Feature
- Current Shoreline

Maximum DNAPL Depth in Feet

Imported to model as depth of DNAPL constant concentration boundary condition (i.e., hydrocarbon source).

- 6.0
- 12.0
- 18.0
- 24.0
- 33.0

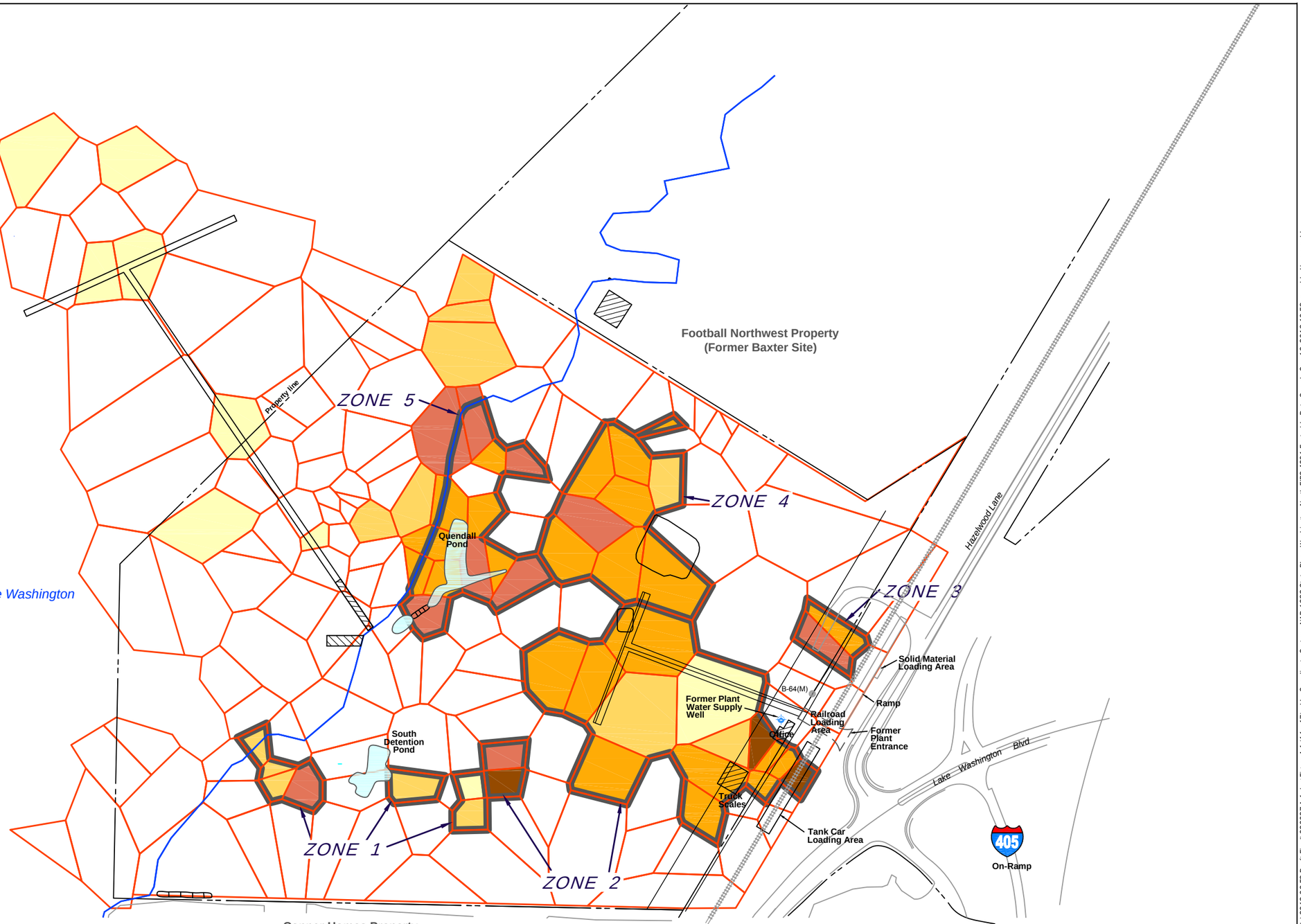
Notes

1. Modified from Figure 4.4-5 of Quendall Terminals RI Report (Anchor QEA and Aspect 2012).
2. Thiessen polygons based on midpoint between borings of adequate depth and characterization, truncated at property line.
3. See Appendix G, Figure G-1, and Table G-5 of the RI Report for maximum depth and area for each polygon.
4. DNAPL identified as oil-coated or oil-wetted soil. Sheen and stained soil not identified as DNAPL. See Section 4.3.1 for DNAPL definitions and Tables G-1 through G-4 in Appendix G of the RI Report for summaries of DNAPL characterization at each boring.

Source Concentration by Zone in µg/L

COC	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5
Benzene	NS	1,100	NS	200	12,000
Benzo(a)pyrene	133	133	NS	133	133
Naphthalene	11,000	11,000	NS	11,000	11,000

NS = Not Simulated



N

0 200 400

Feet

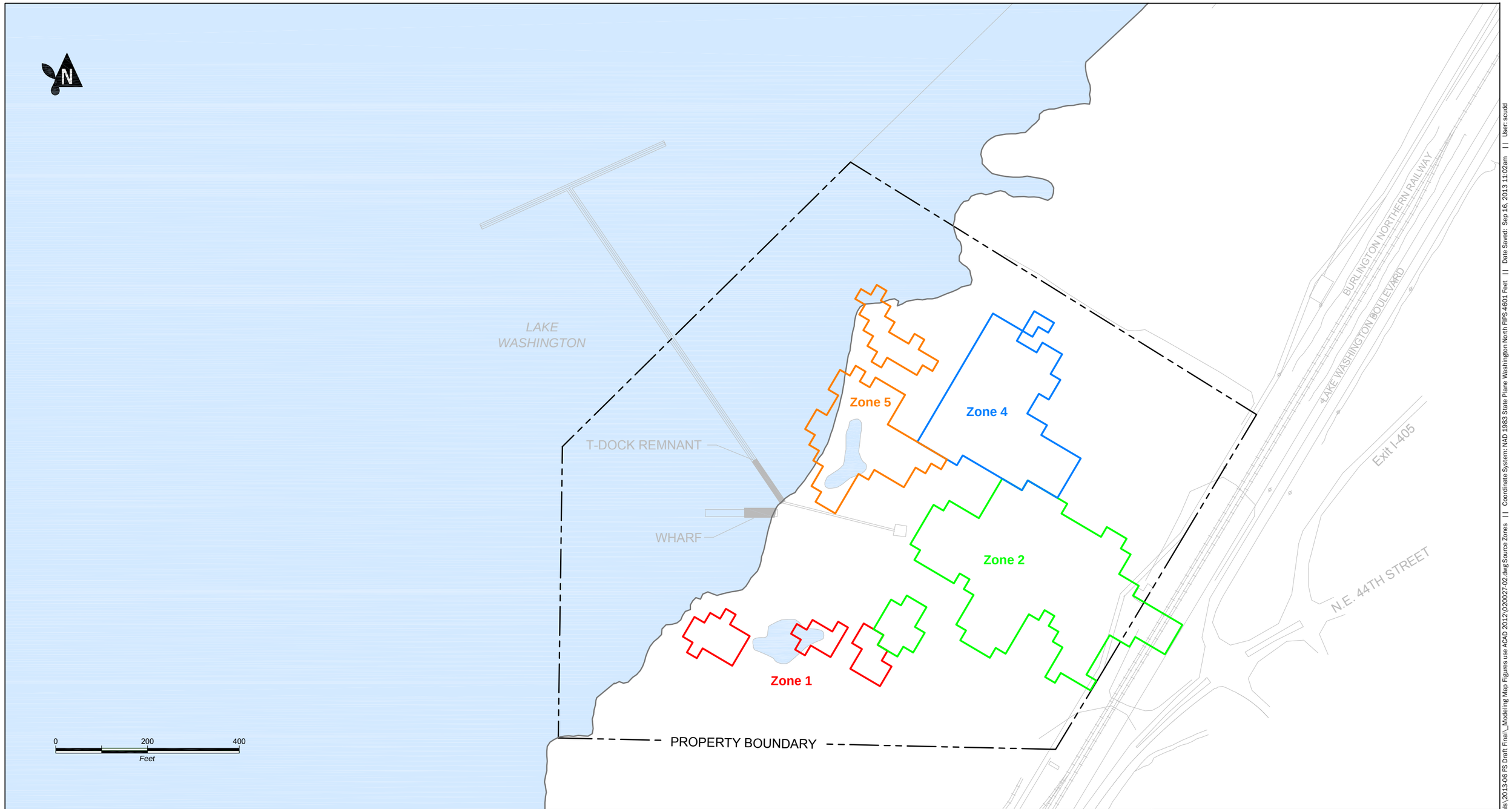
Hydrocarbon Source Zones

Quendall Terminals Feasibility Study Report
Renton, Washington

DRAFT FINAL
October 14, 2013

Aspect CONSULTING | ARCADIS | BY: SDM/PMB | REV BY: SCC | FIGURE NO. A-1

CAD Path: Q:\Quendall\0220027 Quendall Terminals\2013-06 FS Draft Final\0220027 A-1.dwg Figure A-1 (11 x 17) || Coordinate System: NAD 1983 State Plane Washington North FIPS 4601 Feet || Date Saved: Sep 16, 2013 10:58am || User: scudd



Legend

Hydrocarbon Source Zones

Source Concentration by Zone in µg/L					
COC	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5
Benzene	NS	1,100	NS	200	12,000
Benzo(a)pyrene	133	133	NS	133	133
Naphthalene	11,000	11,000	NS	11,000	11,000

NS = Not Simulated

DRAFT FINAL
October 14, 2013

Modeled Hydrocarbon Source Zones
Plan View

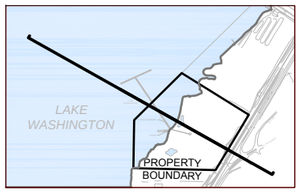
Quendall Terminals Feasibility Study Report
Renton, Washington

Aspect CONSULTING | ARCADIS | FIRM: ASPECT | DRAWN BY: SM/SCC | FIGURE NO. A-2

CAD Path: Q:\Quendall\020027 Quendall Terminals\2013-06 FS Draft Final_Modeling Map Figures use ACAD 2012\020027-02.dwg Source Zones || Coordinate System: NAD 1983 State Plane Washington North FIPS 4601 Feet || Date Saved: Sep 16, 2013 11:02am || User: scudd

West

East



Cross Section Location

Elevation in Feet (NAVD 88)

200 180 160 140 120 100 80 60 40 20 0 -20 -40 -60 -80 -100

Quendall Property

BH-20C

BH-30C

Lake Washington

16.7'

Zone 5

Zone 2

4000 3700 3400 3100 2700 2400 2100 1800 1500 1200 900 600 300 0

Distance in Feet

0 60 120
Feet
Vertical Exaggeration x 5

0 300 600
Feet
Horizontal

All elevations are in feet NAVD 88.

Legend

- Fill
- Shallow Alluvium
- Deeper Alluvium
- Lake Washington Sediments
- Constant Head Boundary Cell
- Quendall Property Boundary
- Hydrocarbon Source Zones

Source Concentration by Zone in µg/L					
COC	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5
Benzene	NS	1,100	NS	200	12,000
Benzo(a)pyrene	133	133	NS	133	133
Naphthalene	11,000	11,000	NS	11,000	11,000

NS = Not Simulated
Zones 1 & 4 are not visible because they are not bisected by this cross section.

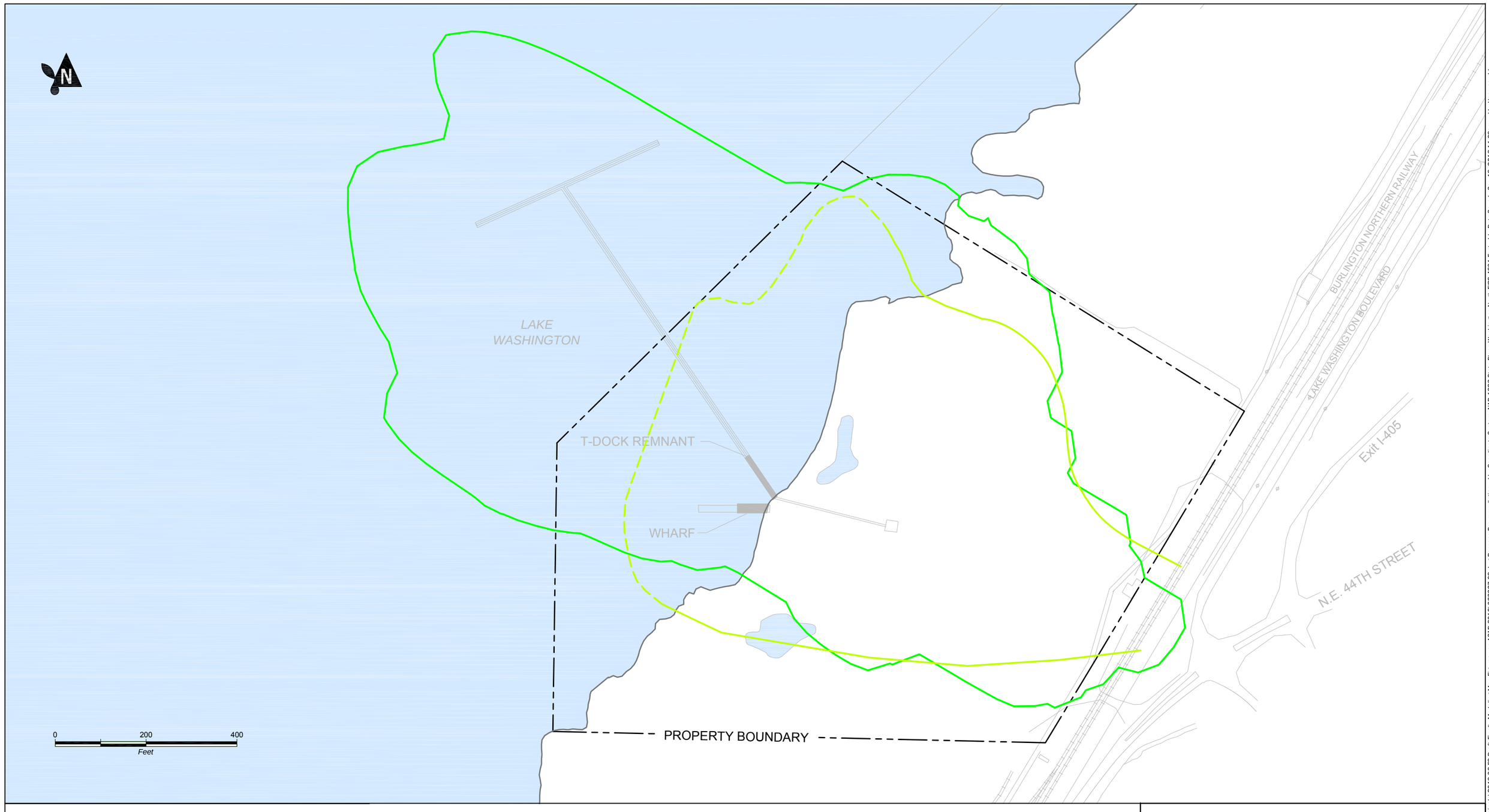
DRAFT FINAL
October 14, 2013

Modeled Hydrocarbon Source Zones Cross Section View

Quendall Terminals Feasibility Study Report
Renton, Washington

Aspect CONSULTING | ARCADIS | FIRM: ASPECT | DRAWN BY: SM/SCC | FIGURE NO. A-3

CAD Path: Q:\Quendall\0200027 Quendall Terminals\2013-06 FS Draft Final_Modeling Map Figures use ACAD 2012\0200027-03.dwg Source Zones || Coordinate System: NAD 1983 State Plane Washington North FIPS 4601 Feet || Date Saved: Sep 16, 2013 11:05am || User: scudd



Pre-remediation Plume Extent in Layer 2

- Benzene Plume from Model *(Equal to 5 µg/L Isoconcentration Contour)*[1]
- Benzene Plume from Site Data *(Equal to 5 µg/L Isoconcentration Contour)*[2]

Dashed line indicates estimate based on limited chemical data and groundwater flow paths, and does not include dispersion. See figures 3-6 and 3-8.

Notes:

1. Extents estimated by MODFLOW/MT3D assuming a hydrocarbon source for 100 years.
2. Extents estimated from groundwater data adapted from figure 3-6.
3. Groundwater modeling results should be used as a relative tool for comparison and not considered a prediction of actual conditions. For example, model-estimated benzo[a]pyrene plume volumes for all alternatives are larger than anticipated based on current site data, due to simplifying modeling assumptions (see Appendix A, Section A3.2).

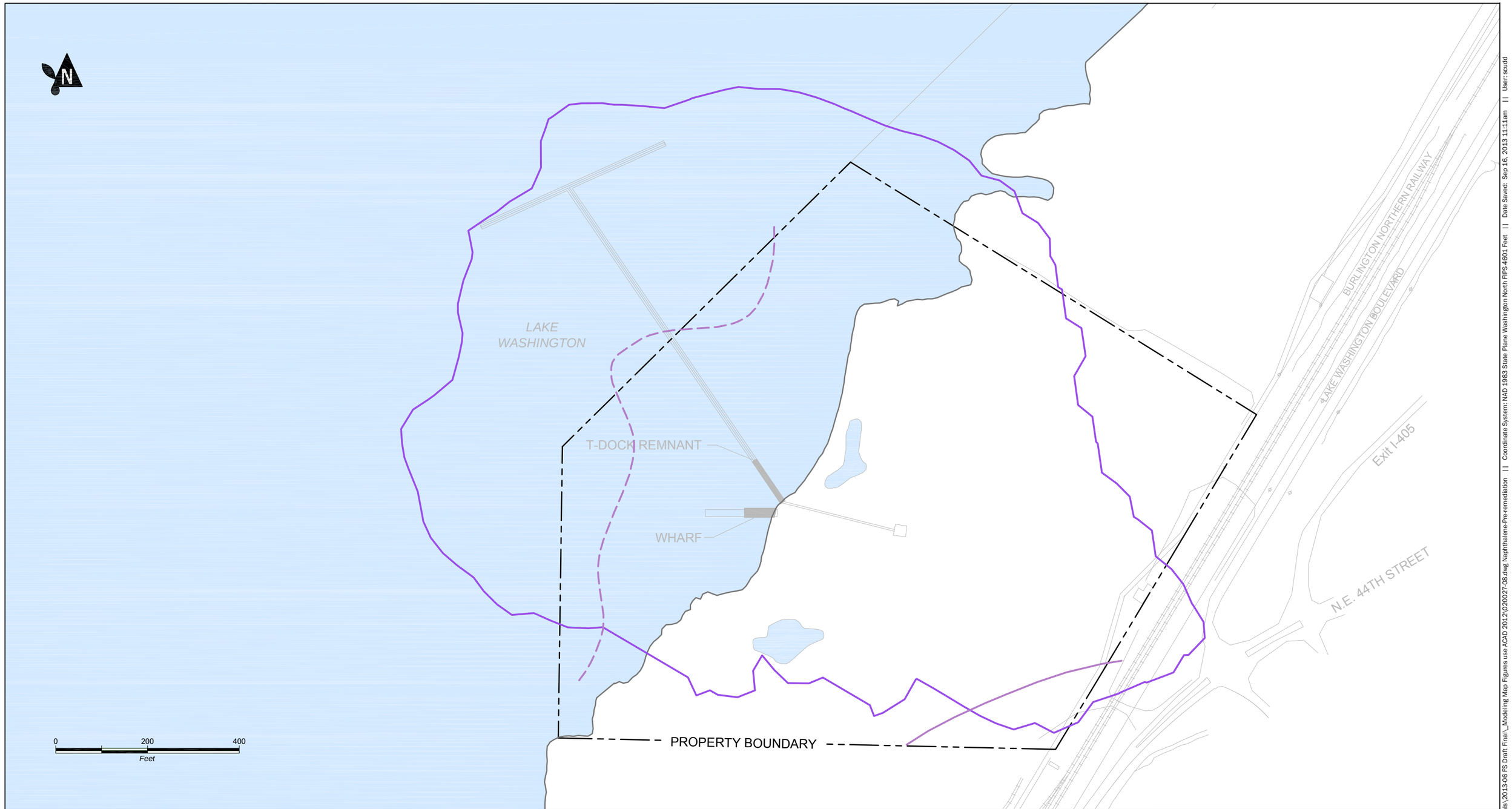
DRAFT FINAL
October 14, 2013

Model Simulated Pre-remediation Benzene Plume-Plan View

Quendall Terminals Feasibility Study Report
Renton, Washington

FIRM:	FIGURE NO.
ASPECT	A-4
DRAWN BY: SM/SCC	

CAD Path: Q:\Quendall\020027 Quendall Terminals\2013-06 FS Draft Final_Modeling Map Figures use ACAD 2012\020027-08.dwg Benzene-Pre-remediation || Coordinate System: NAD 1983 State Plane Washington North FIPS 4601 Feet || Date Saved: Sep 16, 2013 11:09am || User: scudd



Pre-remediation Plume Extent in Layer 2

- Naphthalene Plume from Model *(Equal to 1.4 µg/L Isoconcentration Contour)*[1]
- Naphthalene Plume from Site Data *(Equal to 1.4 µg/L Isoconcentration Contour)*[2]

Dashed line indicates estimate based on limited chemical data and groundwater flow paths, and does not include dispersion. See figures 3-6 and 3-8.

Notes:

1. Extents estimated by MODFLOW/MT3D assuming a hydrocarbon source for 100 years.
2. Extents estimated from groundwater data adapted from figure 3-6.
3. Groundwater modeling results should be used as a relative tool for comparison and not considered a prediction of actual conditions. For example, model-estimated benzo[a]pyrene plume volumes for all alternatives are larger than anticipated based on current site data, due to simplifying modeling assumptions (see Appendix A, Section A3.2).

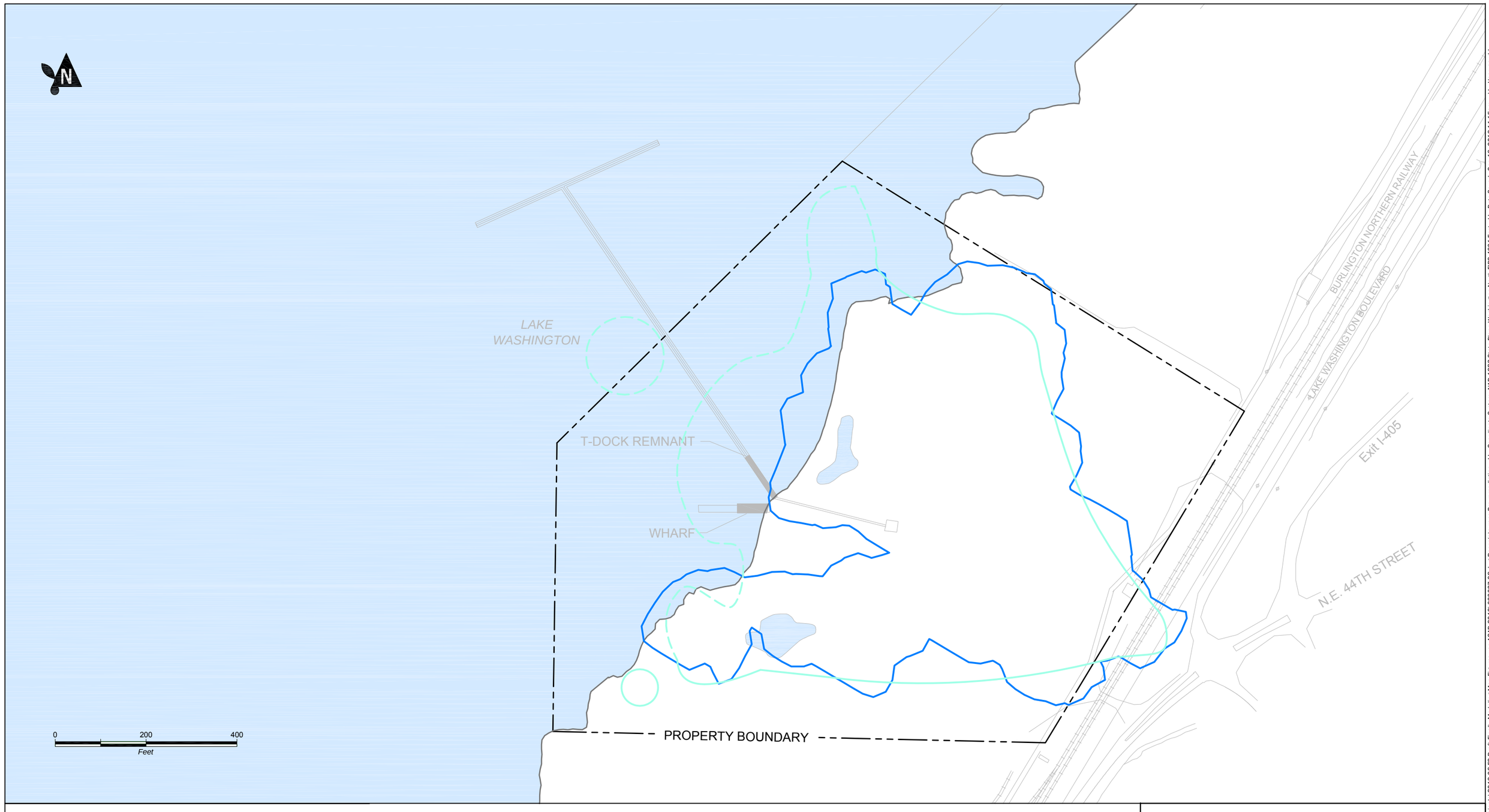
DRAFT FINAL
October 14, 2013

Model Simulated Pre-remediation Naphthalene Plume-Plan View

Quendall Terminals Feasibility Study Report
Renton, Washington

FIRM:	FIGURE NO.
ASPECT	A-5
DRAWN BY: SM/SCC	

CAD Path: Q:\Quendall\0.20027 Quendall Terminals\2013-06 FS Draft Final_Modeling Map Figures use ACAD 2012\020027-08.dwg Naphthalene-Pre-remediation || Coordinate System: NAD 1983 State Plane Washington North FIPS 4601 Feet || Date Saved: Sep 16, 2013 11:11am || User: scudd



Pre-remediation Plume Extent in Layer 2

- Benzo(a)pyrene Plume from Model *(Equal to 0.2 µg/L Isoconcentration Contour)*[1]
- Benzo(a)pyrene Plume from Site Data *(Equal to 0.2 µg/L Isoconcentration Contour)*[2]

Dashed line indicates estimate based on limited chemical data and groundwater flow paths, and does not include dispersion. See figures 3-6 and 3-8.

Notes:

1. Extents estimated by MODFLOW/MT3D assuming a hydrocarbon source for 100 years.
2. Extents estimated from groundwater data adapted from figure 3-6.
3. Groundwater modeling results should be used as a relative tool for comparison and not considered a prediction of actual conditions. For example, model-estimated benzo[a]pyrene plume volumes for all alternatives are larger than anticipated based on current site data, due to simplifying modeling assumptions (see Appendix A, Section A3.2).

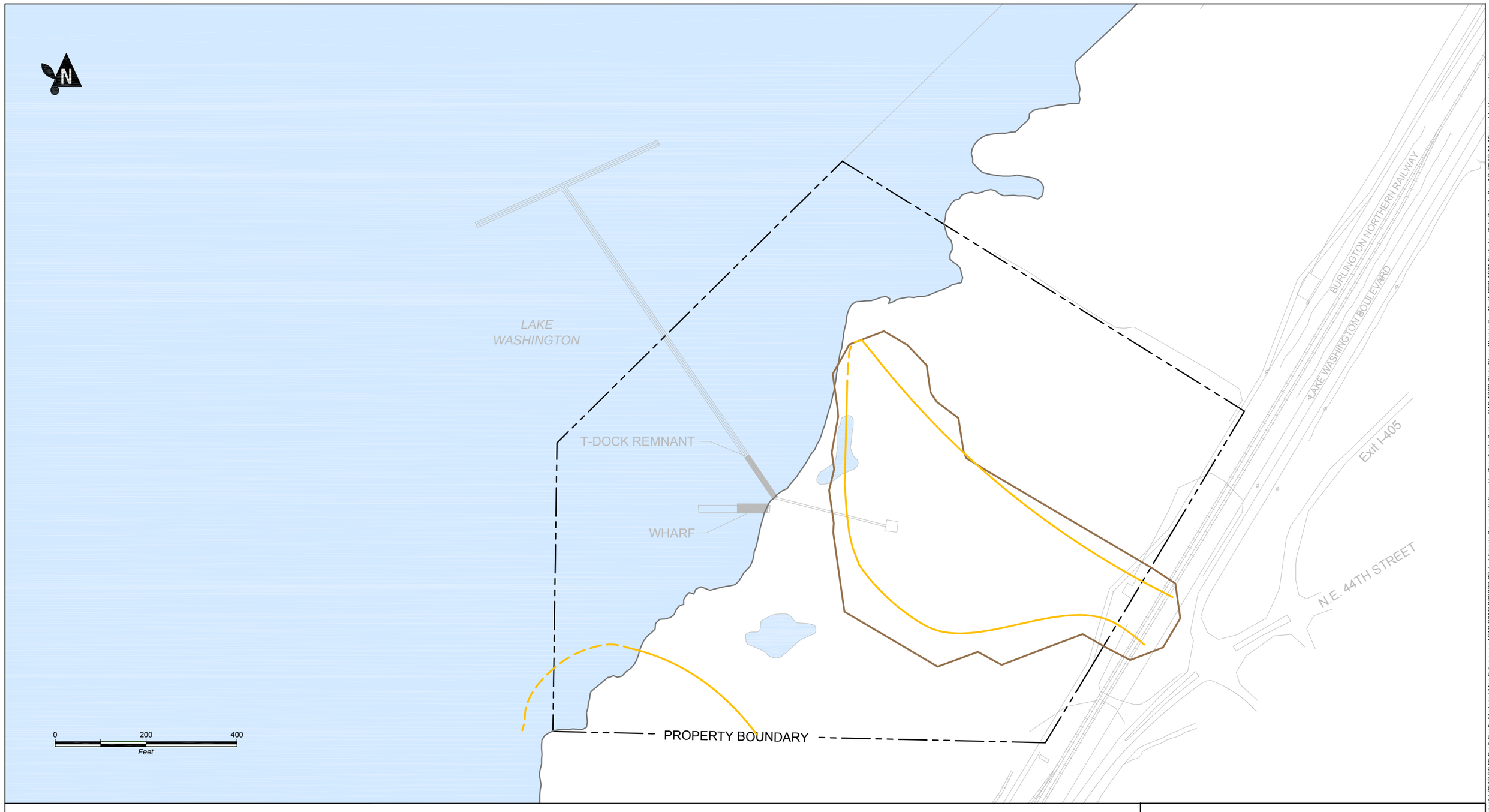
DRAFT FINAL
October 14, 2013

Model Simulated Pre-remediation Benzo(a)pyrene Plume-Plan View

Quendall Terminals Feasibility Study Report
Renton, Washington

FIRM:	FIGURE NO.
ASPECT	A-6
DRAWN BY: SM/SCC	

CAD Path: Q:\Quendall\020027 Quendall Terminals\2013-06 FS Draft Final_Modeling Map Figures use ACAD 2012\020027-08.dwg Benzo(a)pyrene-Pre-remediation || Coordinate System: NAD 1983 State Plane Washington North FIPS 4601 Feet || Date Saved: Sep 16, 2013 11:15am || User: scudd



Pre-remediation Plume Extent in Layer 2

- Arsenic Plume from Model *(Equal to 10 µg/L Isoconcentration Contour)*[1]
- Arsenic Plume from Site Data *(Equal to 10 µg/L Isoconcentration Contour)*[2]

Dashed line indicates estimate based on limited chemical data and groundwater flow paths, and does not include dispersion. See figures 3-6 and 3-8.

Notes:

1. Extents estimated by MODFLOW/MT3D assuming a hydrocarbon source for 100 years.
2. Extents estimated from groundwater data adapted from figure 3-6.
3. Groundwater modeling results should be used as a relative tool for comparison and not considered a prediction of actual conditions. For example, model-estimated benzo[a]pyrene plume volumes for all alternatives are larger than anticipated based on current site data, due to simplifying modeling assumptions (see Appendix A, Section A3.2).

DRAFT FINAL
October 14, 2013

Model Simulated Pre-remediation Arsenic Plume-Plan View

Quendall Terminals Feasibility Study Report
Renton, Washington

Aspect CONSULTING | ARCADIS

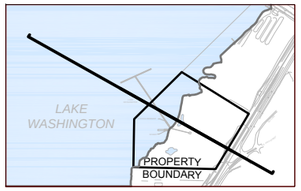
FIRM: ASPECT
DRAWN BY: SM/SCC

FIGURE NO.
A-7

CAD Path: Q:\Quendall\020027 Quendall Terminals\2013-06 FS Draft Final_Modeling Map Figures use ACAD 2012\020027-08.dwg Arsenic-Pre-remediation || Coordinate System: NAD 1983 State Plane Washington North FIPS 4601 Feet || Date Saved: Sep 16, 2013 11:16am || User: scudd

West

East



Cross Section Location

Elevation in Feet (NAVD 88)

200
180
160
140
120
100
80
60
40
20
0
-20
-40
-60
-80
-100

Quendall Property

BH-20C

BH-30C

Lake Washington

16.7'

4000 3700 3400 3100 2700 2400 2100 1800 1500 1200 900 600 300 0

Distance in Feet

0 60 120
Feet
Vertical Exaggeration x 5

0 300 600
Feet
Horizontal

All elevations are in feet NAVD 88.

Legend

- Fill
- Shallow Alluvium
- Deeper Alluvium
- Lake Washington Sediments
- Constant Head Boundary Cell
- Quendall Property Boundary

Pre-remediation Plume Extent in Column 76

- Benzene Plume from Model *(Equal to 5 µg/L Isoconcentration Contour)*[1]
- Benzene Plume from Site Data *(Equal to 5 µg/L Isoconcentration Contour)*[2]

Dashed line indicates estimate based on limited chemical data and groundwater flow paths, and does not include dispersion. See figures 3-6 and 3-8.

Notes:

1. Extents estimated by MODFLOW/MT3D assuming a hydrocarbon source for 100 years.
2. Extents estimated from groundwater data adapted from figure 3-8.
3. Groundwater modeling results should be used as a relative tool for comparison and not considered a prediction of actual conditions. For example, model-estimated benzo[a]pyrene plume volumes for all alternatives are larger than anticipated based on current site data, due to simplifying modeling assumptions (see Appendix A, Section A3.2).

DRAFT FINAL
October 14, 2013

Model Simulated Pre-remediation Benzene Plume-Cross Section View

Quendall Terminals Feasibility Study Report
Renton, Washington

Aspect CONSULTING | ARCADIS

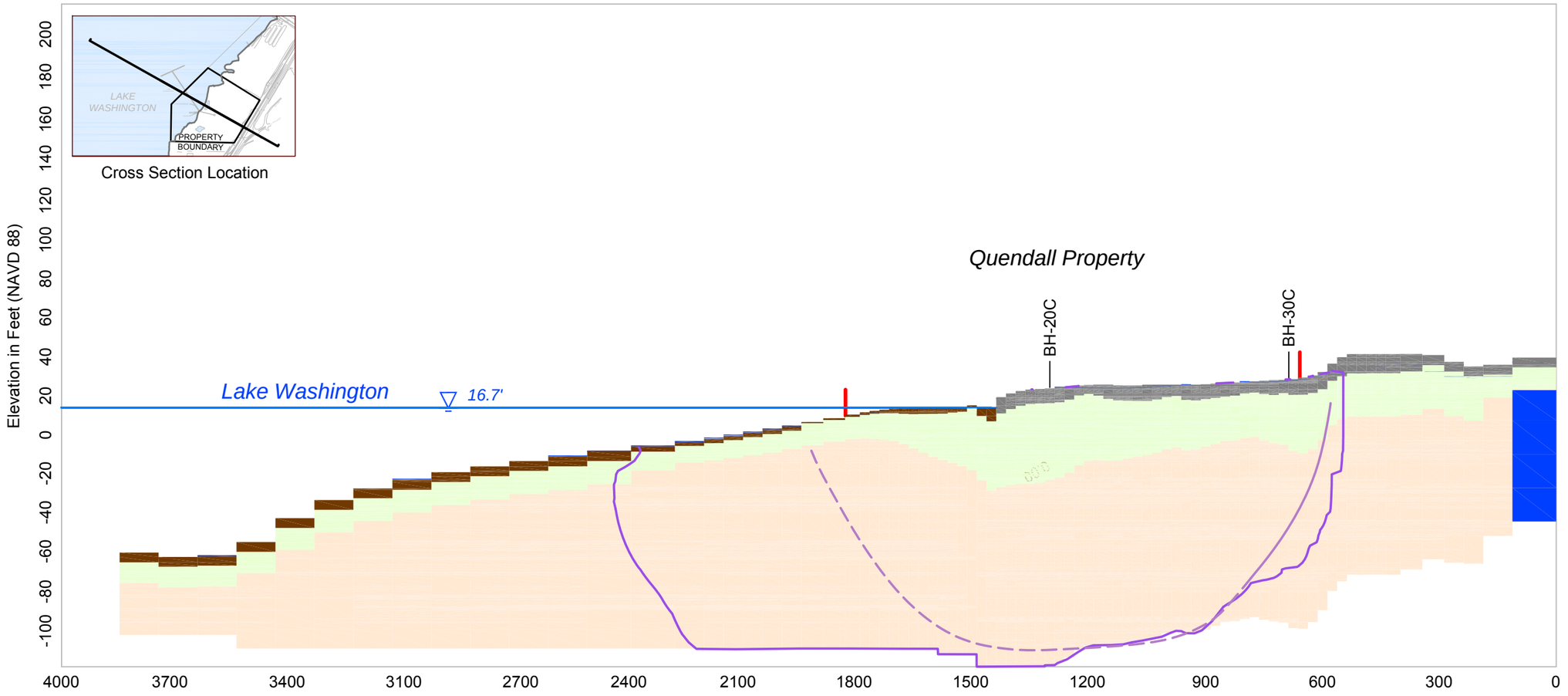
FIRM: ASPECT
DRAWN BY: SM/SCC

FIGURE NO.
A-8

CAD Path: Q:\Quendall\020027 Quendall Terminals\2013-06 FS Draft Final_Modeling Map Figures use ACAD 2012\020027-10.dwg Benzene || Coordinate System: NAD 1983 State Plane Washington North FIPS 4601 Feet || Date Saved: Sep 16, 2013 11:32am || User: scudd

West

East



0 60 120
Feet
Vertical Exaggeration x 5

0 300 600
Feet
Horizontal

All elevations are in feet NAVD 88.

Legend

- Fill
- Shallow Alluvium
- Deeper Alluvium
- Lake Washington Sediments
- Constant Head Boundary Cell
- Quendall Property Boundary

Pre-remediation Plume Extent in Column 76

- Naphthalene Plume from Model *(Equal to 1.4 µg/L Isoconcentration Contour)*[1]
- Naphthalene Plume from Site Data *(Equal to 1.4 µg/L Isoconcentration Contour)*[2]

Dashed line indicates estimate based on limited chemical data and groundwater flow paths, and does not include dispersion. See figures 3-6 and 3-8.

Notes:

1. Extents estimated by MODFLOW/MT3D assuming a hydrocarbon source for 100 years.
2. Extents estimated from groundwater data adapted from figure 3-8.
3. Groundwater modeling results should be used as a relative tool for comparison and not considered a prediction of actual conditions. For example, model-estimated benzo[a]pyrene plume volumes for all alternatives are larger than anticipated based on current site data, due to simplifying modeling assumptions (see Appendix A, Section A3.2).

DRAFT FINAL
October 14, 2013

Model Simulated Pre-remediation Naphthalene Plume-Cross Section View

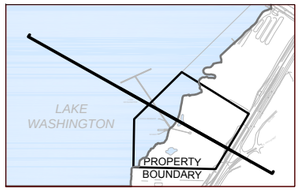
Quendall Terminals Feasibility Study Report
Renton, Washington

Aspect Consulting | ARCADIS | FIRM: ASPECT | DRAWN BY: SM/SCC | FIGURE NO. A-9

CAD Path: Q:\Quendall\020027 Quendall Terminals\2013-06 FS Draft Final_Modeling Map Figures use ACAD 2012\020027-10.dwg Naphthalene || Coordinate System: NAD 1983 State Plane Washington North FIPS 4601 Feet || Date Saved: Sep 16, 2013 11:34am || User: scudd

West

East



Cross Section Location

Elevation in Feet (NAVD 88)

200
180
160
140
120
100
80
60
40
20
0
-20
-40
-60
-80
-100

Quendall Property

BH-20C

BH-30C

Lake Washington

16.7'

4000
3700
3400
3100
2700
2400
2100
1800
1500
1200
900
600
300
0

Distance in Feet

0 60 120
Feet
Vertical Exaggeration x 5

0 300 600
Feet
Horizontal

All elevations are in feet NAVD 88.

Legend

- Fill
- Shallow Alluvium
- Deeper Alluvium
- Lake Washington Sediments
- Constant Head Boundary Cell
- Quendall Property Boundary

Pre-remediation Plume Extent in Column 76

- Benzo(a)pyrene Plume from Model *(Equal to 0.2 µg/L Isoconcentration Contour)*[1]
- Benzo(a)pyrene Plume from Site Data *(Equal to 0.2 µg/L Isoconcentration Contour)*[2]

Dashed line indicates estimate based on limited chemical data and groundwater flow paths, and does not include dispersion. See figures 3-6 and 3-8. Dashed extent is based on Site data adjusted based on soil data in the Shallow Alluvium.

Notes:

1. Extents estimated by MODFLOW/MT3D assuming a hydrocarbon source for 100 years. Model may over predict the extent of benzo[a]pyrene in the Deep Aquifer due to modeling artifacts (see section A3.2.3).
2. Extents estimated from groundwater data adapted from figure 3-8.
3. Groundwater modeling results should be used as a relative tool for comparison and not considered a prediction of actual conditions. For example, model-estimated benzo[a]pyrene plume volumes for all alternatives are larger than anticipated based on current site data, due to simplifying modeling assumptions (see Appendix A, Section A3.2).

DRAFT FINAL
October 14, 2013

Model Simulated Pre-remediation Benzo(a)pyrene Plume-Cross Section View

Quendall Terminals Feasibility Study Report
Renton, Washington

Aspect CONSULTING | ARCADIS

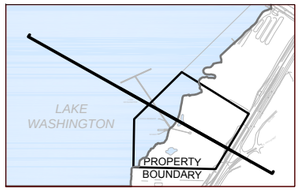
FIRM: ASPECT
DRAWN BY: SM/SCC

FIGURE NO.
A-10

CAD Path: Q:\Quendall\020027 Quendall Terminals\2013-06 FS Draft Final_Modeling Map Figures use ACAD 2012\020027-10.dwg Benzo(a)pyrene || Coordinate System: NAD 1983 State Plane Washington North FIPS 4601 Feet || Date Saved: Sep 16, 2013 11:37am || User: scudd

West

East



Cross Section Location

Elevation in Feet (NAVD 88)

200
180
160
140
120
100
80
60
40
20
0
-20
-40
-60
-80
-100

Quendall Property

BH-20C

BH-30C

Lake Washington

16.7'

4000
3700
3400
3100
2700
2400
2100
1800
1500
1200
900
600
300
0

Distance in Feet

0 60 120
Feet
Vertical Exaggeration x 5

0 300 600
Feet
Horizontal

All elevations are in feet NAVD 88.

Legend

- Fill
- Shallow Alluvium
- Deeper Alluvium
- Lake Washington Sediments
- Constant Head Boundary Cell
- Quendall Property Boundary

Pre-remediation Plume Extent in Column 76

- Arsenic Plume from Model *(Equal to 10 µg/L Isoconcentration Contour)*[1]
- Arsenic Plume from Site Data *(Equal to 10 µg/L Isoconcentration Contour)*[2]

Dashed line indicates estimate based on limited chemical data and groundwater flow paths, and does not include dispersion. See figures 3-6 and 3-8.

Notes:

1. Extents estimated by MODFLOW/MT3D assuming a hydrocarbon source for 100 years.
2. Extents estimated from groundwater data adapted from figure 3-8.
3. Groundwater modeling results should be used as a relative tool for comparison and not considered a prediction of actual conditions. For example, model-estimated benzo[a]pyrene plume volumes for all alternatives are larger than anticipated based on current site data, due to simplifying modeling assumptions (see Appendix A, Section A3.2).

DRAFT FINAL
October 14, 2013

Model Simulated Pre-remediation Arsenic Plume-Cross Section View

Quendall Terminals Feasibility Study Report
Renton, Washington

Aspect CONSULTING | ARCADIS | FIRM: ASPECT | DRAWN BY: SM/SCC | FIGURE NO. A-11

CAD Path: Q:\Quendall\020027 Quendall Terminals\2013-06 FS Draft Final_Modeling Map Figures use ACAD 2012\020027-10.dwg Arsenic || Coordinate System: NAD 1983 State Plane Washington North FIPS 4601 Feet || Date Saved: Sep 16, 2013 11:38am || User: scudd

Legend

- DNAPL Thiessen Polygon
- DNAPL Treatment Area
- Detention Pond
- Existing Structure
- Historical Structure
- Other Historical Feature
- Current Shoreline

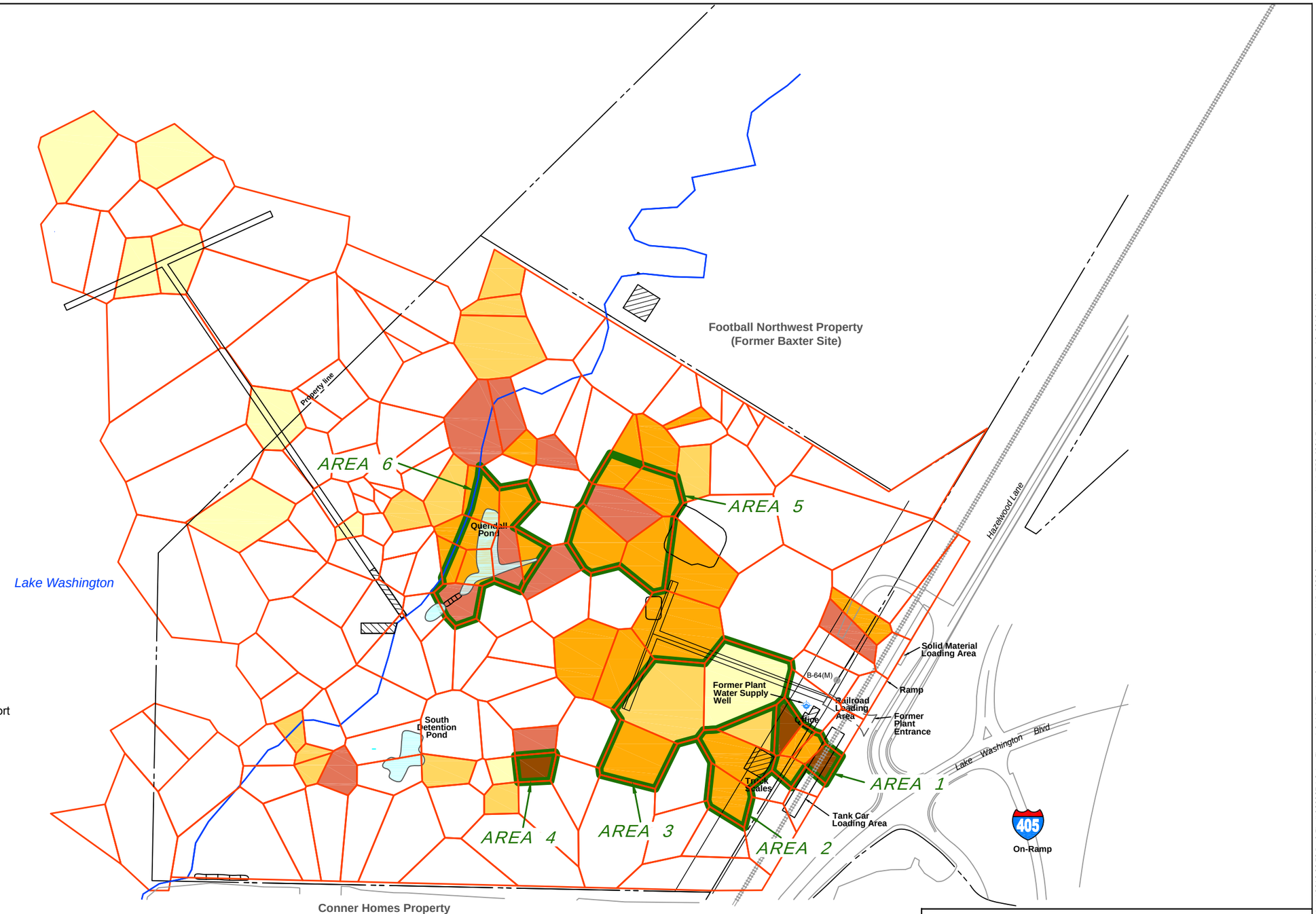
Maximum DNAPL Depth in Feet

Imported to model as depth of DNAPL constant concentration boundary condition (i.e., hydrocarbon source).

- 6.0
- 12.0
- 18.0
- 24.0
- 33.0

Notes

1. Modified from Figure 4.4-5 of Quendall Terminals RI Report (Anchor QEA and Aspect 2012).
2. Thiessen polygons based on midpoint between borings of adequate depth and characterization, truncated at property line.
3. See Appendix G, Figure G-1, and Table G-5 of the RI Report for maximum depth and area for each polygon.
4. DNAPL identified as oil-coated or oil-wetted soil. Sheen and stained soil not identified as DNAPL. See Section 4.3.1 for DNAPL definitions and Tables G-1 through G-4 in Appendix G of the RI Report for summaries of DNAPL characterization at each boring.
5. Refer to Table A-5 for area combinations evaluated.



N

0 200 400

Feet

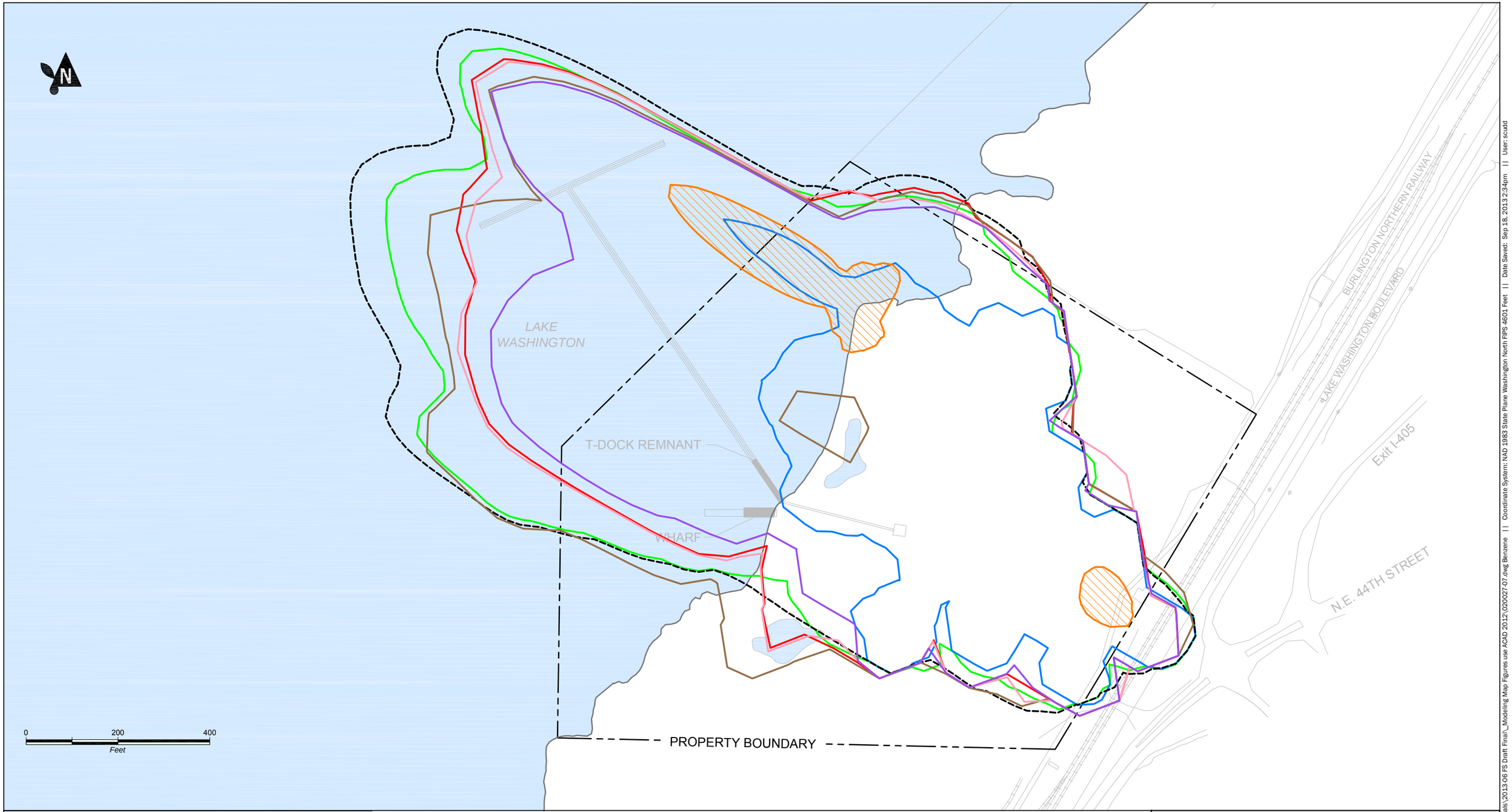
DRAFT FINAL
October 14, 2013

DNAPL Treatment Areas Evaluated for Alternative Development

Quendall Terminals Feasibility Study Report
Renton, Washington

Aspect CONSULTING / ARCADIS	FIRM: ASPECT	DRAWN BY: JJP/PMB/SCC	FIGURE NO. A-12

CAD Path: Q:\Quendall\020027 Quendall Terminals\2013-06 FS Draft Final\020027 A-2.dwg Figure A-2 (11 x 17) || Coordinate System: NAD 1983 State Plane Washington North FIPS 4601 Feet || Date Saved: Sep 13, 2013 11:43am || User: scudd



Plume Extent in Layer 2 *(Equal to 5 µg/L Isoconcentration Contour)*

- Alternative 1
- Alternative 2
- Alternative 3
- Alternative 4
- Alternative 5
- Alternative 6
- Alternative 7
- NA[1] Alternative 8
- Alternative 9
- NA[1] Alternative 10

Notes:

1. Alternatives 8 and 10 are not depicted because they result in no concentrations exceeding 5 µg/L.
2. Extents estimated by MODFLOW/MT3D. Alternative extents assume hydrocarbon source for 100 years, followed by implementation of alternative, and finally 100 years of attenuation.
3. Groundwater modeling results should be used as a relative tool for comparison and not considered a prediction of actual conditions. For example, model-estimated benzo[a]pyrene plume volumes for all alternatives are larger than anticipated based on current site data, due to simplifying modeling assumptions (see Appendix A, Section A3.2).

DRAFT FINAL
October 14, 2013

Model Simulated Benzene Plume
Plan View

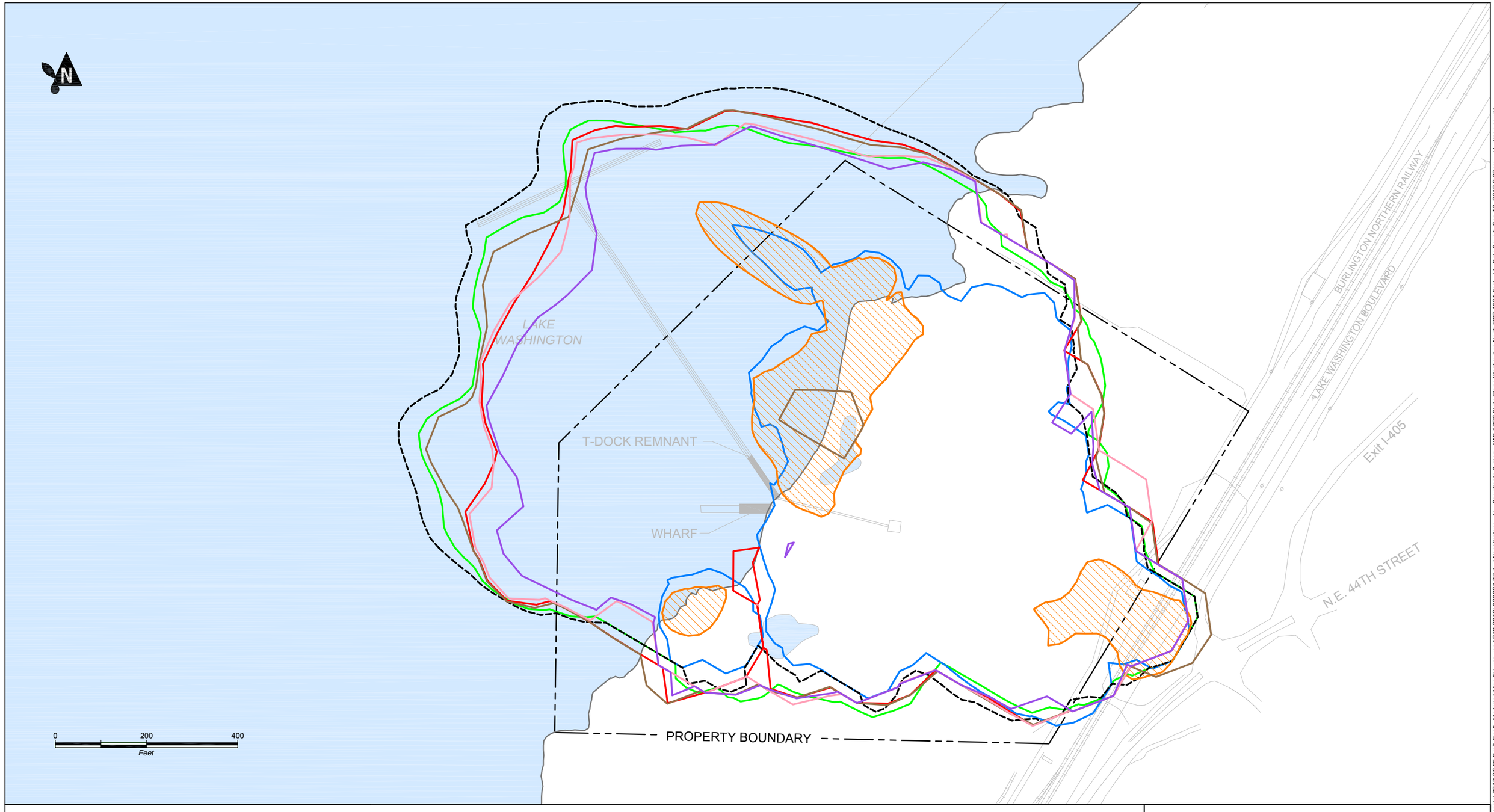
Quendall Terminals Feasibility Study Report
Renton, Washington

Aspect CONSULTING | ARCADIS

FIRM: ASPECT
DRAWN BY: SM/SCC

FIGURE NO.
A-13

CAD Path: Q:\Quendall\020027 Quendall Terminals\2013-06 FS Draft Final_Modeling Map Figures use ACAD 2012\020027-07.dwg Benzene || Coordinate System: NAD 1983 State Plane Washington North FIPS 4601 Feet || Date Saved: Sep 18, 2013 2:34pm || User: scudd



Plume Extent in Layer 2 *(Equal to 1.4 µg/L Isoconcentration Contour)*

- Alternative 1
- Alternative 2
- Alternative 3
- Alternative 4
- Alternative 5
- Alternative 6
- Alternative 7
- NA[1] Alternative 8
- Alternative 9
- NA[1] Alternative 10

Notes:

1. Alternatives 8 and 10 are not depicted because they result in no concentrations exceeding 1.4 µg/L.
2. Extents estimated by MODFLOW/MT3D. Alternative extents assume hydrocarbon source for 100 years, followed by implementation of alternative, and finally 100 years of attenuation.
3. Layer 2 is the shallowest active layer and approximates the maximum plume extent for most alternatives. Alternative 9, however, produces a plume extent that is greater in deeper layers (see Figure A-19).
4. Groundwater modeling results should be used as a relative tool for comparison and not considered a prediction of actual conditions. For example, model-estimated benzo[a]pyrene plume volumes for all alternatives are larger than anticipated based on current site data, due to simplifying modeling assumptions (see Appendix A, Section A3.2).

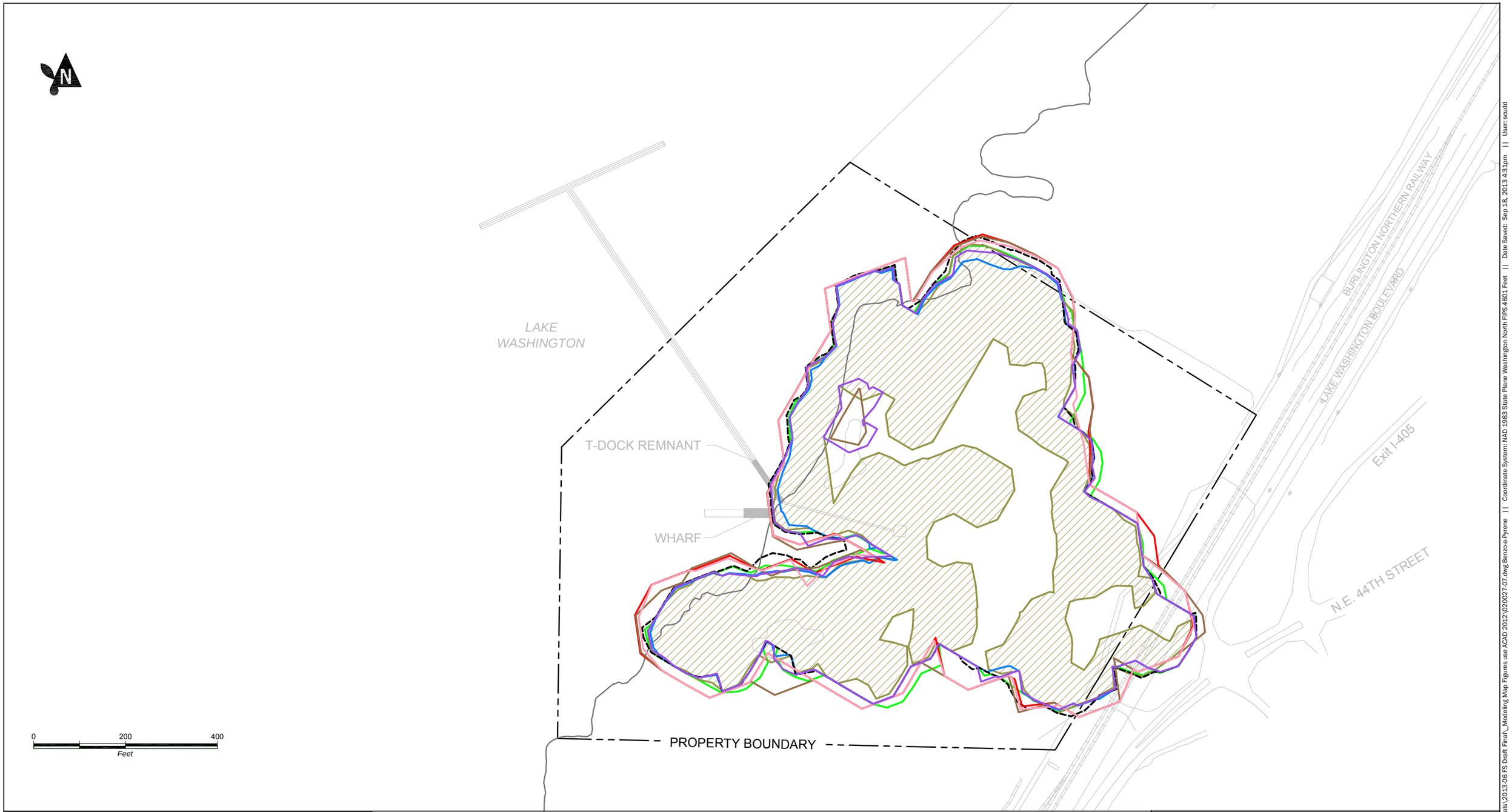
DRAFT FINAL
October 14, 2013

Model Simulated Naphthalene Plume Plan View

Quendall Terminals Feasibility Study Report
Renton, Washington

Aspect CONSULTING | ARCADIS | FIRM: ASPECT | DRAWN BY: SM/SCC | FIGURE NO. A-14

CAD Path: Q:\Quendall\020027 Quendall Terminals\2013-06 FS Draft Final_Modeling Map Figures use ACAD 2012\020027-07.dwg Naphthalene || Coordinate System: NAD 1983 State Plane Washington North FIPS 4601 Feet || Date Saved: Sep 18, 2013 2:39pm || User: scudd



Plume Extent in Layer 2 *(Equal to 0.2 µg/L Isoconcentration Contour)*

- Alternative 1
- Alternative 2
- Alternative 3
- Alternative 4
- Alternative 5
- Alternative 6
- Alternative 7
- Alternative 8
- NA[2] Alternative 9
- NA[3] Alternative 10

Note:

1. Extents estimated by MODFLOW/MT3D. Alternative extents assume hydrocarbon source for 100 years, followed by implementation of alternative, and finally 100 years of attenuation.
2. No exceedances predicted in layer 2 for Alternative 9; however, exceedances are predicted in deeper layers (see figure A-20).
3. Modeling results do not include the potential contribution of residuals resulting from removal actions (i.e., excavation or dredging). It is expected, based on a model sensitivity analysis (see Appendix A, Section A5.1.2.2), that residuals will result in benzo[a]pyrene exceedances after 100 years for all alternatives, including Alternative 10.
4. Groundwater modeling results should be used as a relative tool for comparison and not considered a prediction of actual conditions. For example, model-estimated benzo[a]pyrene plume volumes for all alternatives are larger than anticipated based on current site data, due to simplifying modeling assumptions (see Appendix A, Section A3.2).

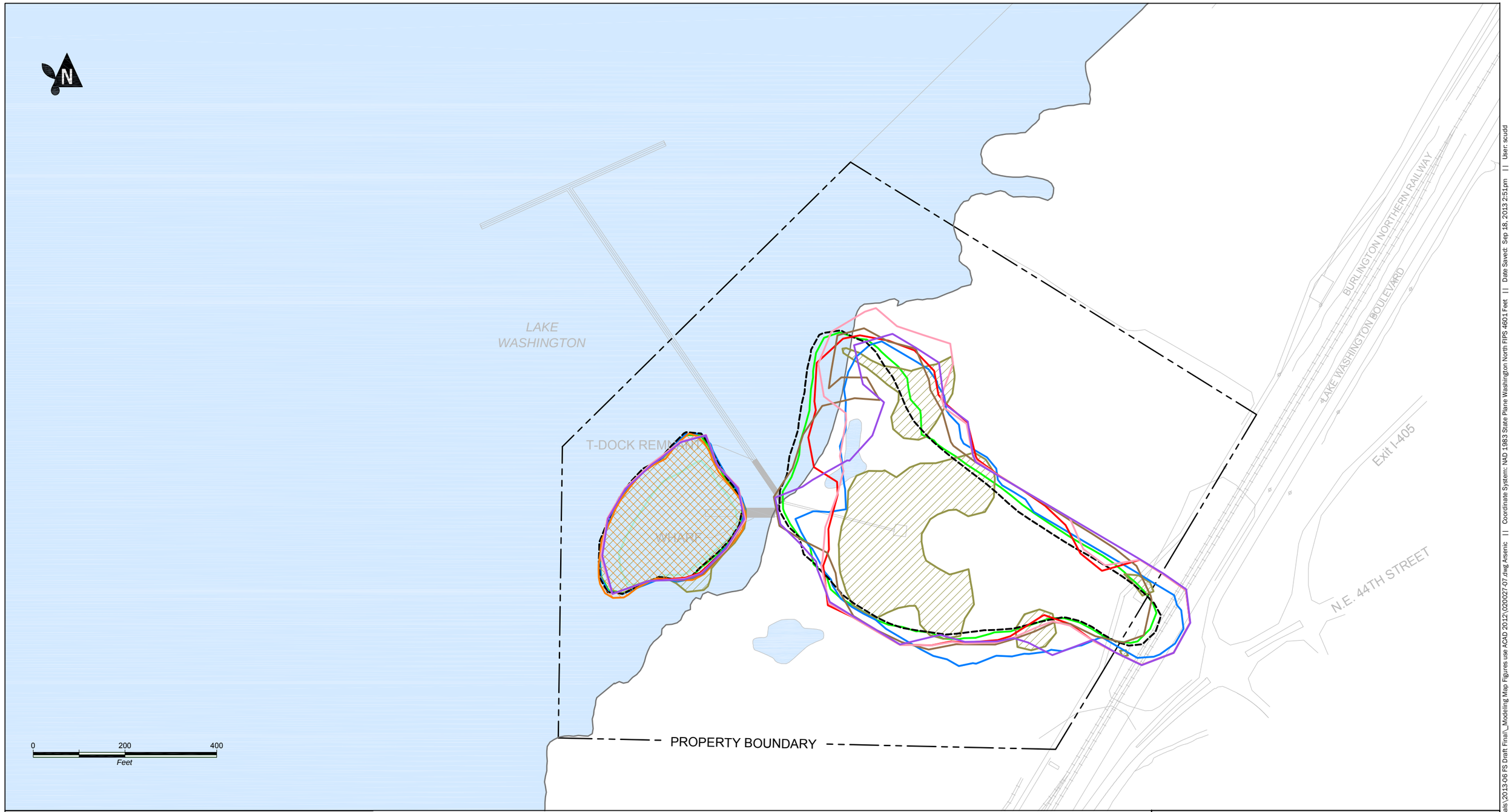
DRAFT FINAL
October 14, 2013

Model Simulated Benzo(a)pyrene Plume Plan View

Quendall Terminals Feasibility Study Report
Renton, Washington

Aspect CONSULTING | ARCADIS | FIRM: ASPECT | DRAWN BY: SM/SCC | FIGURE NO. A-15

CAD Path: Q:\Quendall\020027 Quendall Terminals\2013-06 FS Draft Final_Modeling Map Figures use ACAD 2012\020027-07.dwg Benzo-a-Pyrene || Coordinate System: NAD 1983 State Plane Washington North FIPS 4601 Feet || Date Saved: Sep 18, 2013 4:31pm || User: scudd



Plume Extent in Layer 2 *(Equal to 10 µg/L Isoconcentration Contour)*

- Alternative 1
- Alternative 2
- Alternative 3
- Alternative 4
- Alternative 5
- Alternative 6
- Alternative 7
- Alternative 8
- Alternative 9
- Alternative 10

Notes:

1. Extents estimated by MODFLOW/MT3D. Alternative extents assume 100 years of attenuation following implementation of alternative.
2. Layer 2 is the shallowest active layer and approximates the maximum plume extent for most alternatives. Alternatives 8, 9, and 10, however, produce plume extents that are greater in deeper layers (see Figure A-21).
3. Groundwater modeling results should be used as a relative tool for comparison and not considered a prediction of actual conditions. For example, model-estimated benzo[a]pyrene plume volumes for all alternatives are larger than anticipated based on current site data, due to simplifying modeling assumptions (see Appendix A, Section A3.2).

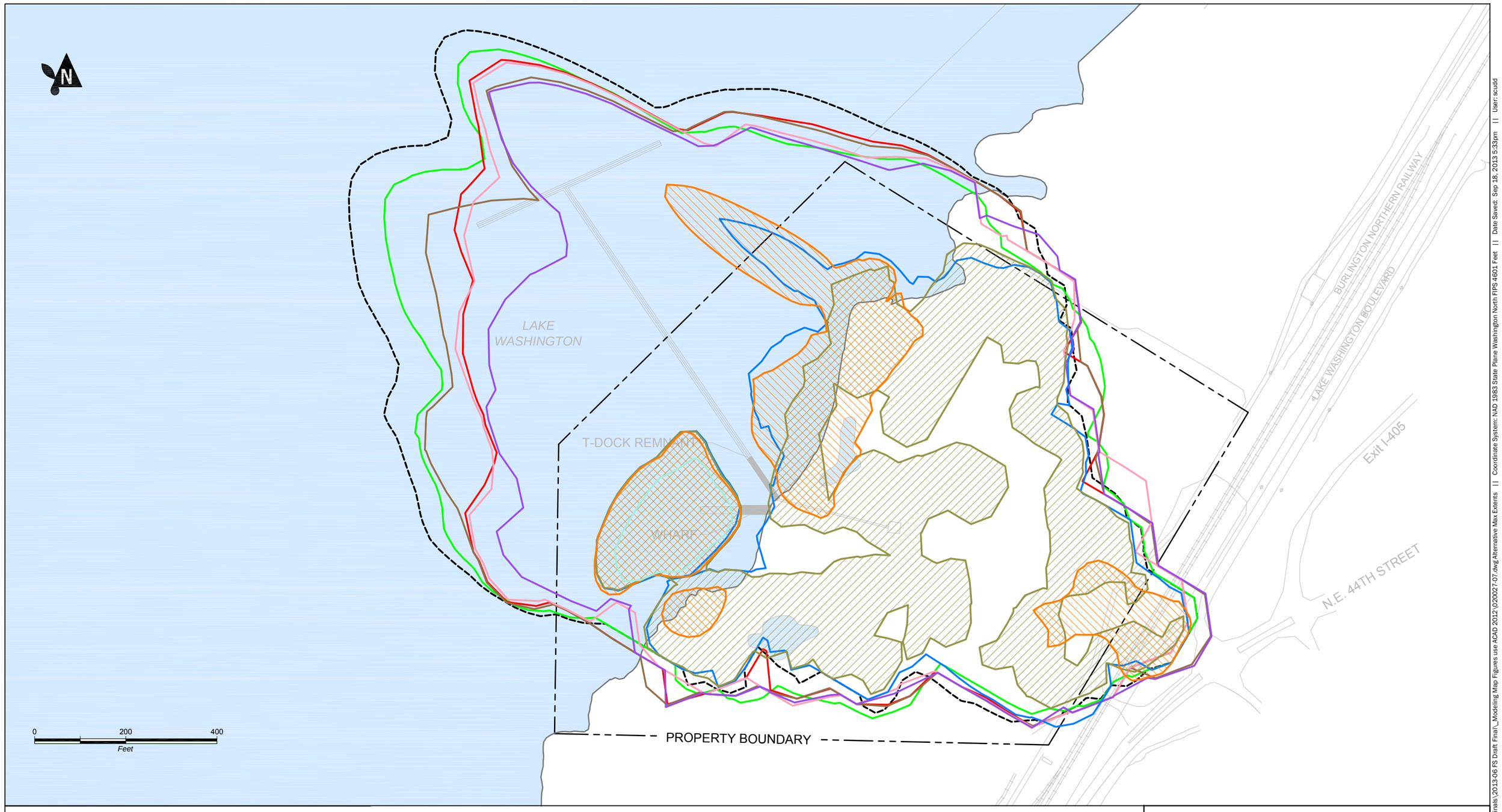
DRAFT FINAL
October 14, 2013

Model Simulated Arsenic Plume
Plan View

Quendall Terminals Feasibility Study Report
Renton, Washington

Aspect Consulting / ARCADIS	FIRM: ASPECT	DRAWN BY: SM/SCC	FIGURE NO. A-16

CAD Path: Q:\Quendall \020027 Quendall Terminals\2013-06 FS Draft Final_Modeling Map Figures use ACAD 2012\020027-07.dwg Arsenic || Coordinate System: NAD 1983 State Plane Washington North FIPS 4601 Feet || Date Saved: Sep 18, 2013 2:51pm || User: scudd



Plume Extent in Layer 2 *(includes groundwater that exceeds any groundwater PRGs[2])*

- Alternative 1
- Alternative 2
- Alternative 3
- Alternative 4
- Alternative 5
- Alternative 6
- Alternative 7
- Alternative 8
- Alternative 9
- Alternative 10

Notes:

1. Extents estimated by MODFLOW/MT3D. Alternative extents simulate 100 years of attenuation following implementation of alternative.
2. Groundwater PRGs : *Napthalene 1.4 µg/L*, *Arsenic 10 µg/L*, *Benzene 5 µg/L*, *Benzo(a)Pyrene 0.2 µg/L*
3. Layer 2 is the shallowest active layer and approximates the maximum plume extent for most alternatives. Alternatives 9 and 10, however, produces a plume extent that is greater in deeper layers.
4. Groundwater modeling results should be used as a relative tool for comparison and not considered a prediction of actual conditions. For example, model-estimated benzo[a]pyrene plume volumes for all alternatives are larger than anticipated based on current site data, due to simplifying modeling assumptions (see Appendix A, Section A3.2).

DRAFT FINAL
October 14, 2013

Model Simulated Aggregate Plume
Plan View

Quendall Terminals Feasibility Study Report
Renton, Washington

Aspect CONSULTING | ARCADIS

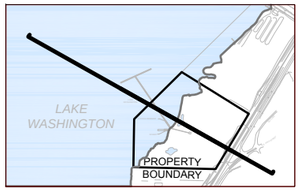
FIRM: ASPECT
DRAWN BY: SM/SCC

FIGURE NO.
A-17

CAD Path: Q:\Quendall\020027 Quendall Terminals\2013-06 FS Draft Final_Modeling Map Figures use ACAD 2012\020027-07.dwg Alternative Max Extents || Coordinate System: NAD 1983 State Plane Washington North FIPS 4601 Feet || Date Saved: Sep 18, 2013 5:33pm || User: scudd

West

East



Cross Section Location

Elevation in Feet (NAVD 88)

200 180 160 140 120 100 80 60 40 20 0 -20 -40 -60 -80 -100

Quendall Property

BH-20C

BH-30C

Lake Washington

16.7'

4000 3700 3400 3100 2700 2400 2100 1800 1500 1200 900 600 300 0

Distance in Feet

0 60 120
Feet
Vertical Exaggeration x 5

0 300 600
Feet
Horizontal

All elevations are in feet NAVD 88.

Legend

- Fill
- Shallow Alluvium
- Deeper Alluvium
- Lake Washington Sediments
- Constant Head Boundary Cell
- Quendall Property Boundary

Plume Extent in Column 76 *(Equal to 5 µg/L Isoconcentration Contour)*

- Alternative 1
- Alternative 2
- Alternative 3
- Alternative 4
- Alternative 5
- Alternative 6
- Alternative 7
- NA[1] Alternative 8
- Alternative 9
- NA[1] Alternative 10

Notes:

1. Alternatives 8 and 10 are not depicted because they result in no concentrations exceeding 5 µg/L.
2. Extents estimated by MODFLOW/MT3D. Alternative extents assume hydrocarbon source for 100 years, followed by implementation of alternative, and finally 100 years of attenuation.
3. Groundwater modeling results should be used as a relative tool for comparison and not considered a prediction of actual conditions. For example, model-estimated benzo[a]pyrene plume volumes for all alternatives are larger than anticipated based on current site data, due to simplifying modeling assumptions (see Appendix A, Section A3.2).

DRAFT FINAL
October 14, 2013

Model Simulated Benzene Plume Cross Section View

Quendall Terminals Feasibility Study Report
Renton, Washington

Aspect CONSULTING | ARCADIS

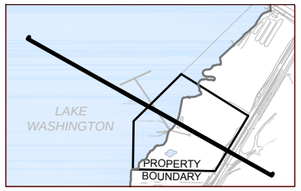
FIRM: ASPECT
DRAWN BY: SM/SCC

FIGURE NO.
A-18

CAD Path: Q:\Quendall\020027 Quendall Terminals\2013-06 FS Draft Final\020027-11 Benzene.dwg Benzene || Coordinate System: NAD 1983 State Plane Washington North FIPS 4601 Feet || Date Saved: Sep 19, 2013 10:41am || User: scudd

West

East



Cross Section Location

Elevation in Feet (NAVD 88)

200
180
160
140
120
100
80
60
40
20
0
-20
-40
-60
-80
-100

Quendall Property

BH-20C

BH-30C

Lake Washington

16.7'

4000
3700
3400
3100
2700
2400
2100
1800
1500
1200
900
600
300
0

Distance in Feet

0 60 120
Feet
Vertical Exaggeration x 5

0 300 600
Feet
Horizontal

All elevations are in feet NAVD 88.

Legend

- Fill
- Shallow Alluvium
- Deeper Alluvium
- Lake Washington Sediments
- Constant Head Boundary Cell
- Quendall Property Boundary

Plume Extent in Column 76 *(Equal to 1.4 µg/L Isoconcentration Contour)*

- Alternative 1
- Alternative 2
- Alternative 3
- Alternative 4
- Alternative 5
- Alternative 6
- Alternative 7
- NA[1] Alternative 8
- Alternative 9
- NA[1] Alternative 10

Notes:

1. Alternatives 8 and 10 are not depicted because they result in no concentrations exceeding 1.4 µg/L.
2. Extents estimated by MODFLOW/MT3D. Alternative extents assume hydrocarbon source for 100 years, followed by implementation of alternative, and finally 100 years of attenuation.
3. Groundwater modeling results should be used as a relative tool for comparison and not considered a prediction of actual conditions. For example, model-estimated benzo[a]pyrene plume volumes for all alternatives are larger than anticipated based on current site data, due to simplifying modeling assumptions (see Appendix A, Section A3.2).

DRAFT FINAL
October 14, 2013

Model Simulated Naphthalene Plume Cross Section View

Quendall Terminals Feasibility Study Report
Renton, Washington

Aspect Consulting | ARCADIS

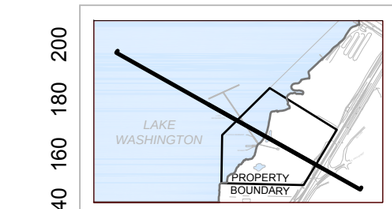
FIRM: ASPECT
DRAWN BY: SM/SCC

FIGURE NO.
A-19

CAD Path: Q:\Quendall\020027 Quendall Terminals\2013-06 FS Draft Final\020027-10 Naphthalene.dwg Naphthalene || Coordinate System: NAD 1983 State Plane Washington North FIPS 4601 Feet || Date Saved: Sep 19, 2013 10:58am || User: scudd

West

East



Cross Section Location

Elevation in Feet (NAVD 88)

200
180
160
140
120
100
80
60
40
20
0
-20
-40
-60
-80
-100

Quendall Property

BH-20C

BH-30C

Lake Washington

16.7'

4000
3700
3400
3100
2700
2400
2100
1800
1500
1200
900
600
300
0

Distance in Feet

0 60 120
Feet
Vertical Exaggeration x 5

0 300 600
Feet
Horizontal

All elevations are in feet NAVD 88.

Legend

- Fill
- Shallow Alluvium
- Deeper Alluvium
- Lake Washington Sediments
- Constant Head Boundary Cell
- Quendall Property Boundary

Plume Extent in Column 76 *(Equal to 0.2 µg/L Isoconcentration Contour)*

- Alternative 1
- Alternative 2
- Alternative 3
- Alternative 4
- Alternative 5
- Alternative 6
- Alternative 7
- Alternative 8
- Alternative 9
- Alternative 10

NA[2]

Note:

1. Extents estimated by MODFLOW/MT3D. Alternative extents assume hydrocarbon source for 100 years, followed by implementation of alternative, and finally 100 years of attenuation.
2. Modeling results do not include the potential contribution of residuals resulting from removal actions (i.e., excavation or dredging). It is expected, based on a model sensitivity analysis (see Appendix A, Section A5.1.2.2), that residuals will result in benzo[a]pyrene exceedances after 100 years for all alternatives, including Alternative 10.
3. Groundwater modeling results should be used as a relative tool for comparison and not considered a prediction of actual conditions. For example, model-estimated benzo[a]pyrene plume volumes for all alternatives are larger than anticipated based on current site data, due to simplifying modeling assumptions (see Appendix A, Section A3.2).

DRAFT FINAL
October 14, 2013

Model Simulated Benzo(a)pyrene Plume Cross Section View

Quendall Terminals Feasibility Study Report
Renton, Washington

Aspect Consulting | ARCADIS

FIRM: ASPECT
DRAWN BY: SM/SCC

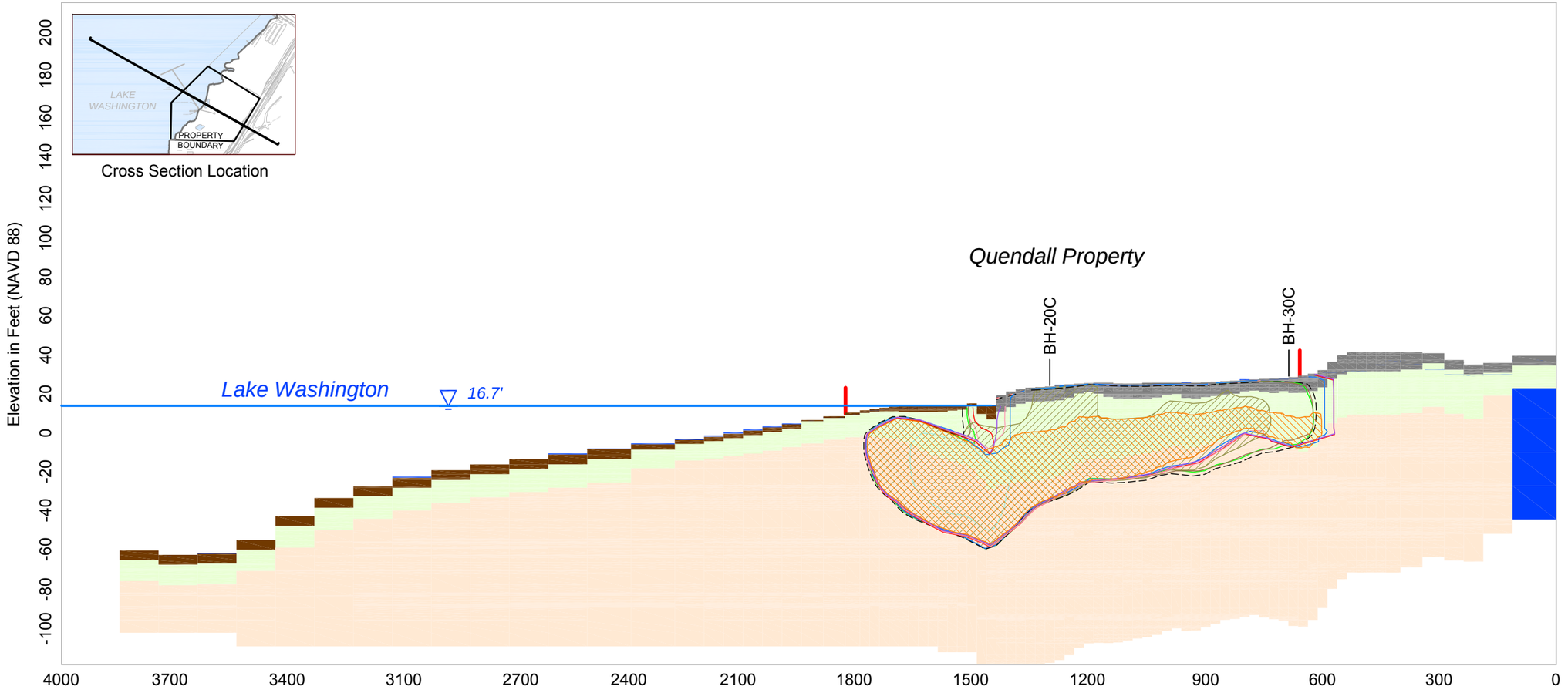
FIGURE NO.
A-20

C4D Path: Q:\Quendall\020027 Quendall Terminals\2013-06 FS Draft Final\020027-12 Benzo-a-pyrene.dwg Benzo(a)Pyrene || Coordinate System: NAD 1983 State Plane Washington North FIPS 4601 Feet || Date Saved: Sep 19, 2013 11:03am || User: scudd

West

East

Cross Section Location



0 60 120
Feet
Vertical Exaggeration x 5

0 300 600
Feet
Horizontal

All elevations are in feet NAVD 88.

Legend

- Fill
- Shallow Alluvium
- Deeper Alluvium
- Lake Washington Sediments
- Constant Head Boundary Cell
- Quendall Property Boundary

Plume Extent in Column 76 *(Equal to 10 µg/L Isoconcentration Contour)*

- Alternative 1
- Alternative 2
- Alternative 3
- Alternative 4
- Alternative 5
- Alternative 6
- Alternative 7
- Alternative 8
- Alternative 9
- Alternative 10

Notes:

1. Extents estimated by MODFLOW/MT3D. Alternative extents assume 100 years of attenuation following implementation of alternative.
2. Groundwater modeling results should be used as a relative tool for comparison and not considered a prediction of actual conditions. For example, model-estimated benzo[a]pyrene plume volumes for all alternatives are larger than anticipated based on current site data, due to simplifying modeling assumptions (see Appendix A, Section A3.2).

DRAFT FINAL
October 14, 2013

Model Simulated Arsenic Plume Cross Section View

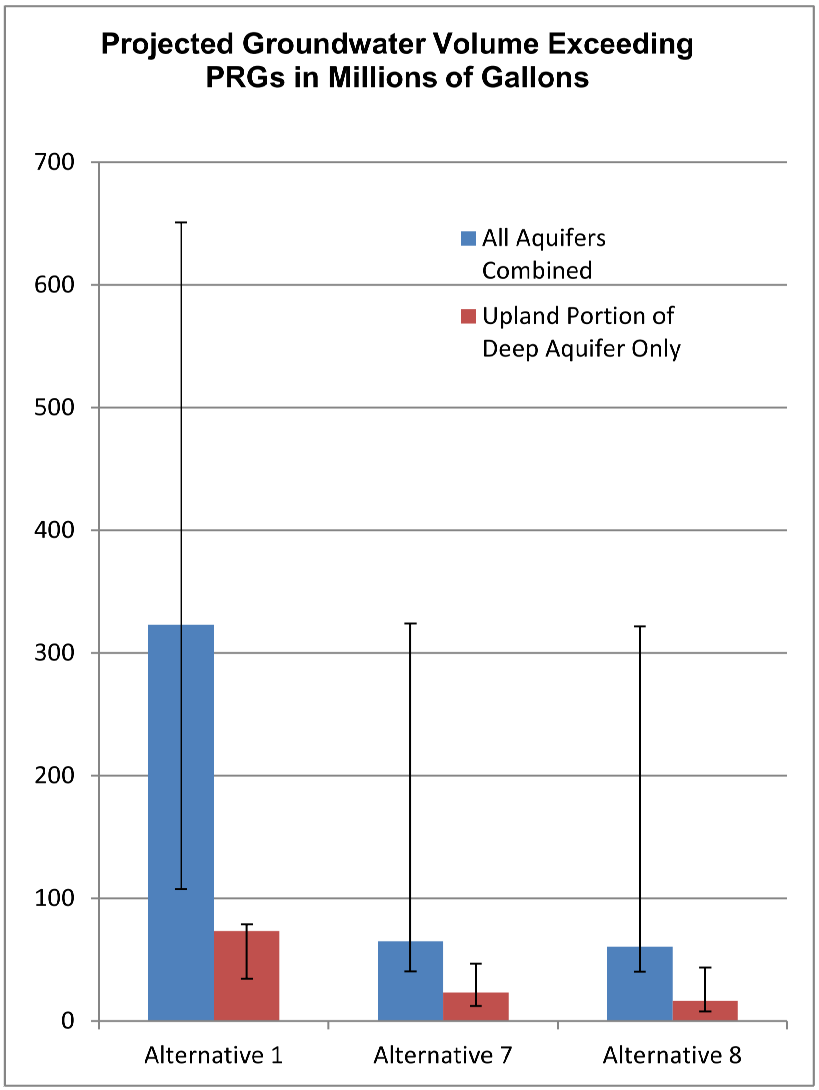
Quendall Terminals Feasibility Study Report
Renton, Washington

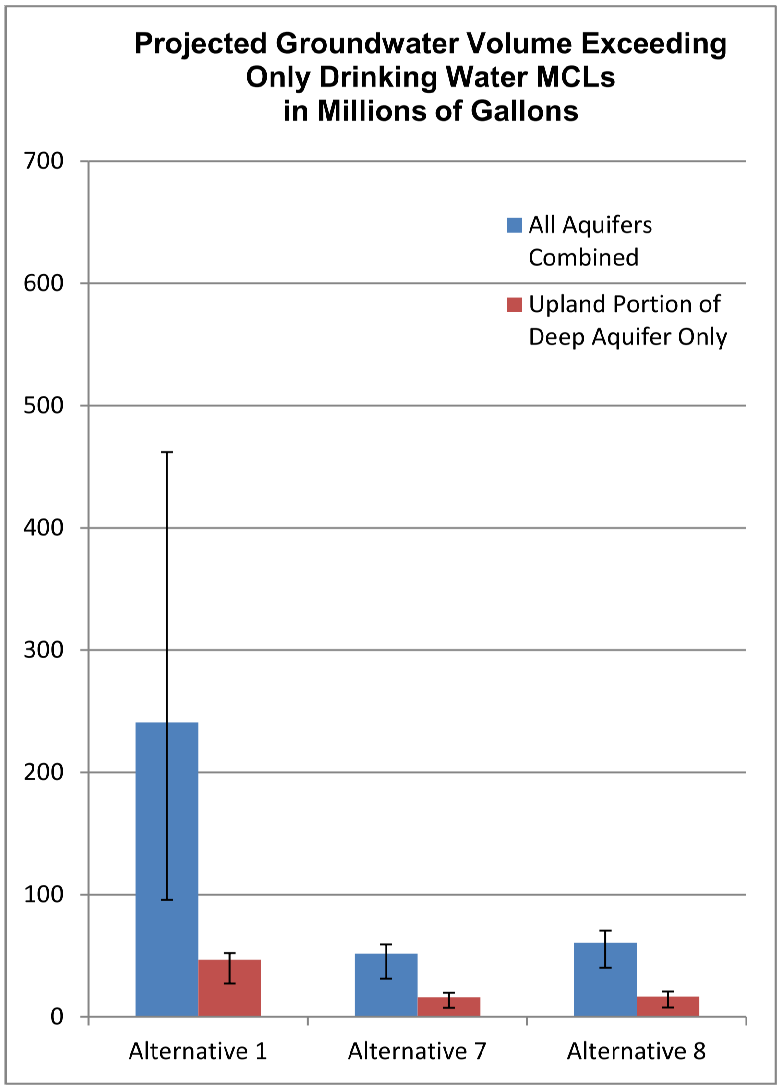
Aspect CONSULTING | ARCADIS

FIRM: ASPECT
DRAWN BY: SM/SCC

FIGURE NO.
A-21

CAD Path: Q:\Quendall\020027 Quendall Terminals\2013-06 FS Draft Final\020027-09 Arsenic.dwg Arsenic || Coordinate System: NAD 1983 State Plane Washington North FIPS 4601 Feet || Date Saved: Sep 23, 2013 1:23pm || User: scudd





Note:
1. Error bar represents range between best and worst cases.

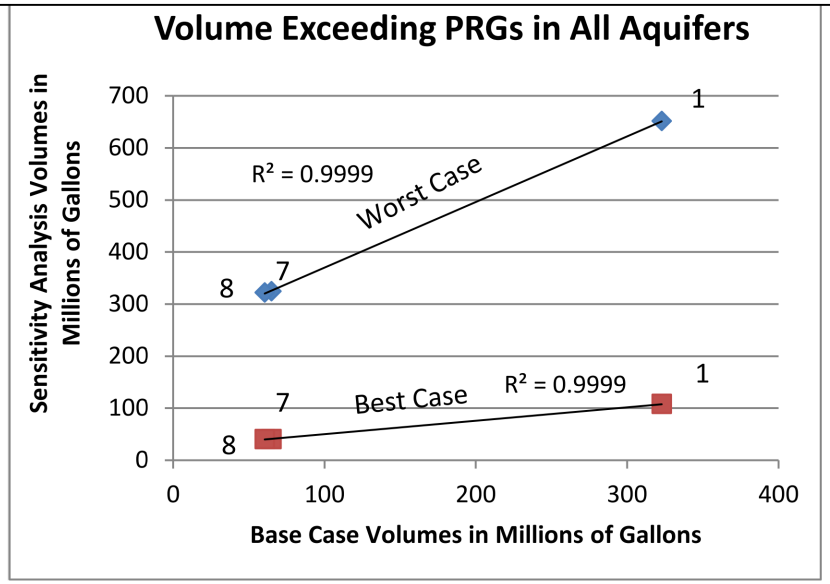
DRAFT FINAL
October 14, 2013

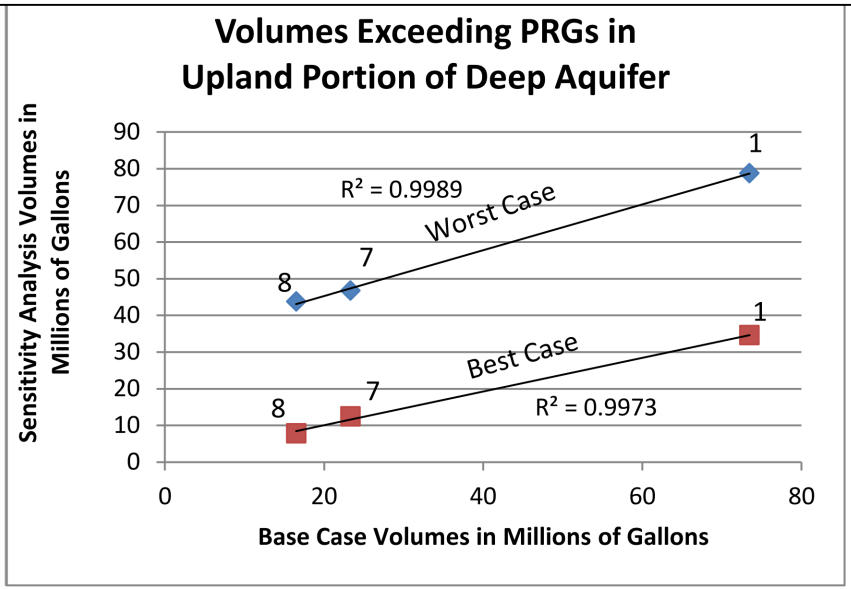
Sensitivity Analysis Results
Aggregate Plume Volume

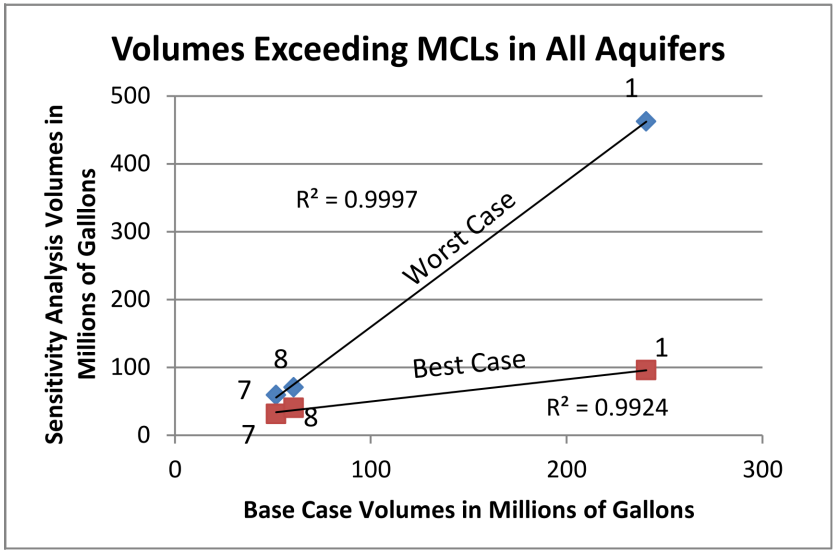
Quendall Terminals Feasibility Study Report
Renton, Washington

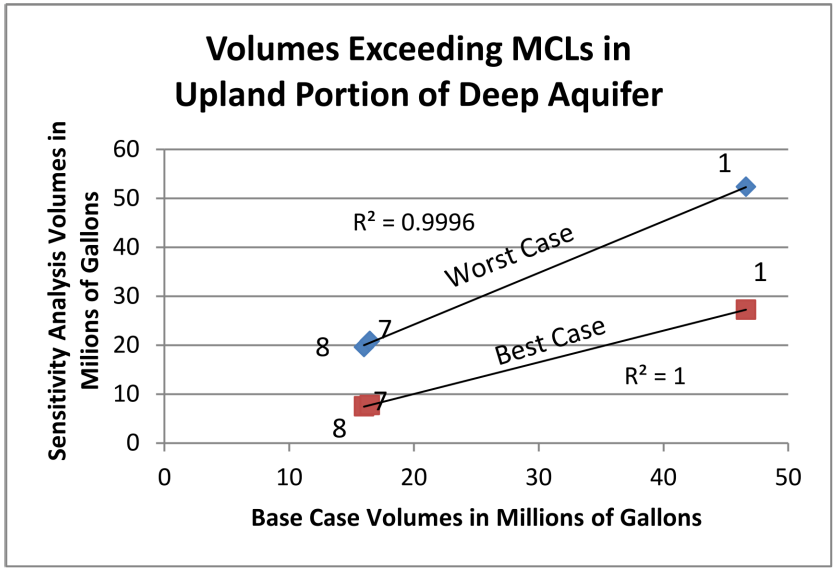
Aspect CONSULTING / ARCADIS		FIRM: ASPECT DRAWN BY: JJP/SCC	FIGURE NO. A-22

CAD Path: Q:\Quendall\020027 Quendall Terminals\2013-06 FS Draft Final\020027-A-22 thru A-34.dwg A-22 || Date Saved: Oct 10, 2013 12:43pm || User: scudd









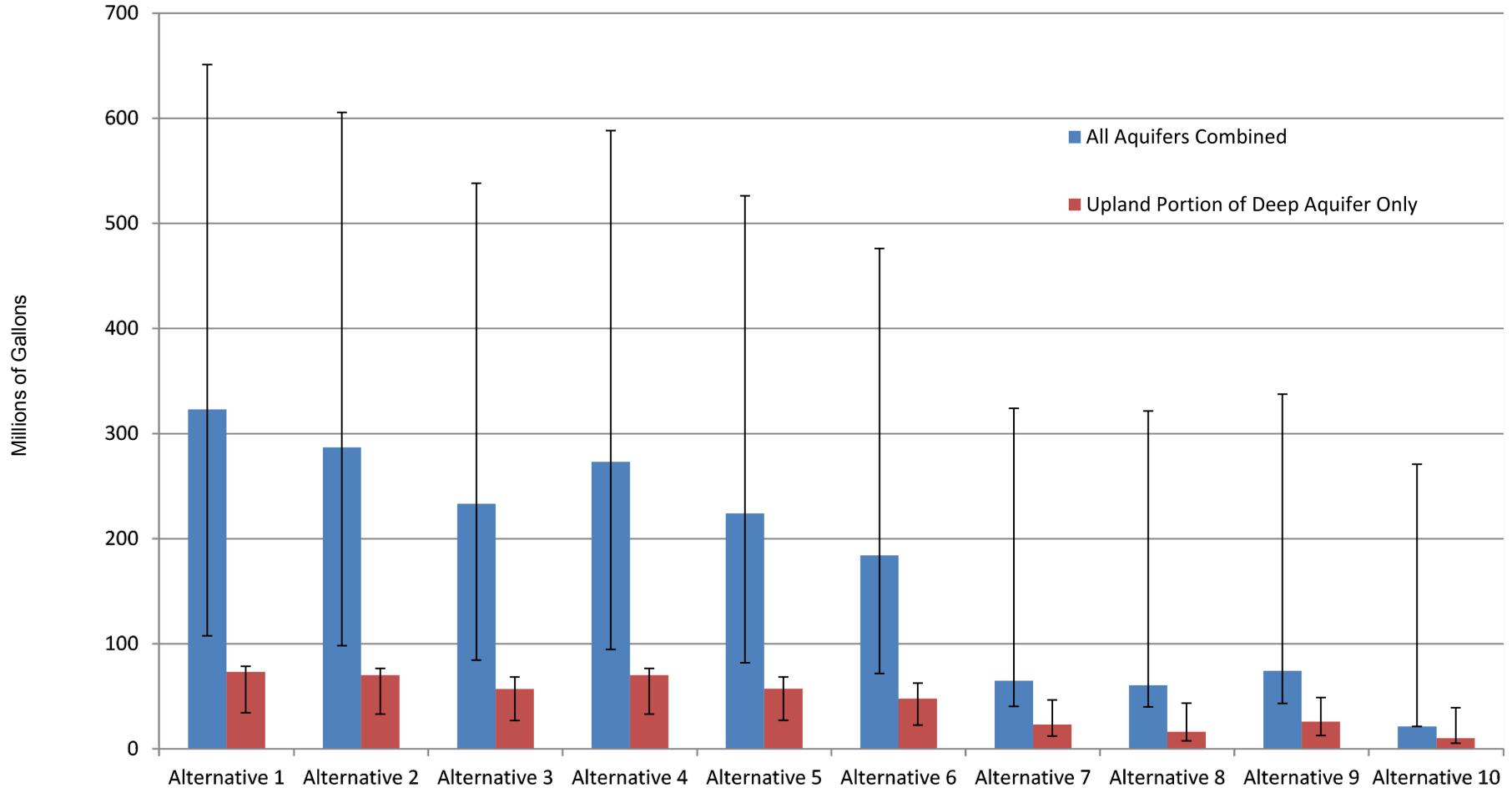
CAD Path: Q:\Quendall\020027 Quendall Terminals\2013-06 FS Draft Final\020027-A-22 thru A-34.dwg A-23 | | Date Saved: Oct 10, 2013 12:26pm | | User: scudd

Linear Interpolation of Sensitivity Analysis Results-Aggregate Plume Volume

Quendall Terminals Feasibility Study Report
Renton, Washington

DRAFT FINAL
October 14, 2013

FIRM: ASPECT	FIGURE NO. A-23
DRAWN BY: JJP/SCC	



Notes:

1. Groundwater modeling results should be used as a relative tool for comparison and not considered a prediction of actual conditions. For example, model-estimated benzo[a]pyrene volumes for all alternatives are larger than anticipated based on current site data, due to simplifying modeling assumptions (see Appendix A, Section A3.2).
2. Modeling results do not include the potential contribution of residuals resulting from removal actions (i.e., excavation or dredging). It is expected, based on a model sensitivity analysis (see Appendix A, Section A5.1.2), that residuals will result in benzo[a]pyrene exceedances after 100 years for all alternatives, including Alternative 10.
3. Error bar represents range between best and worst cases.

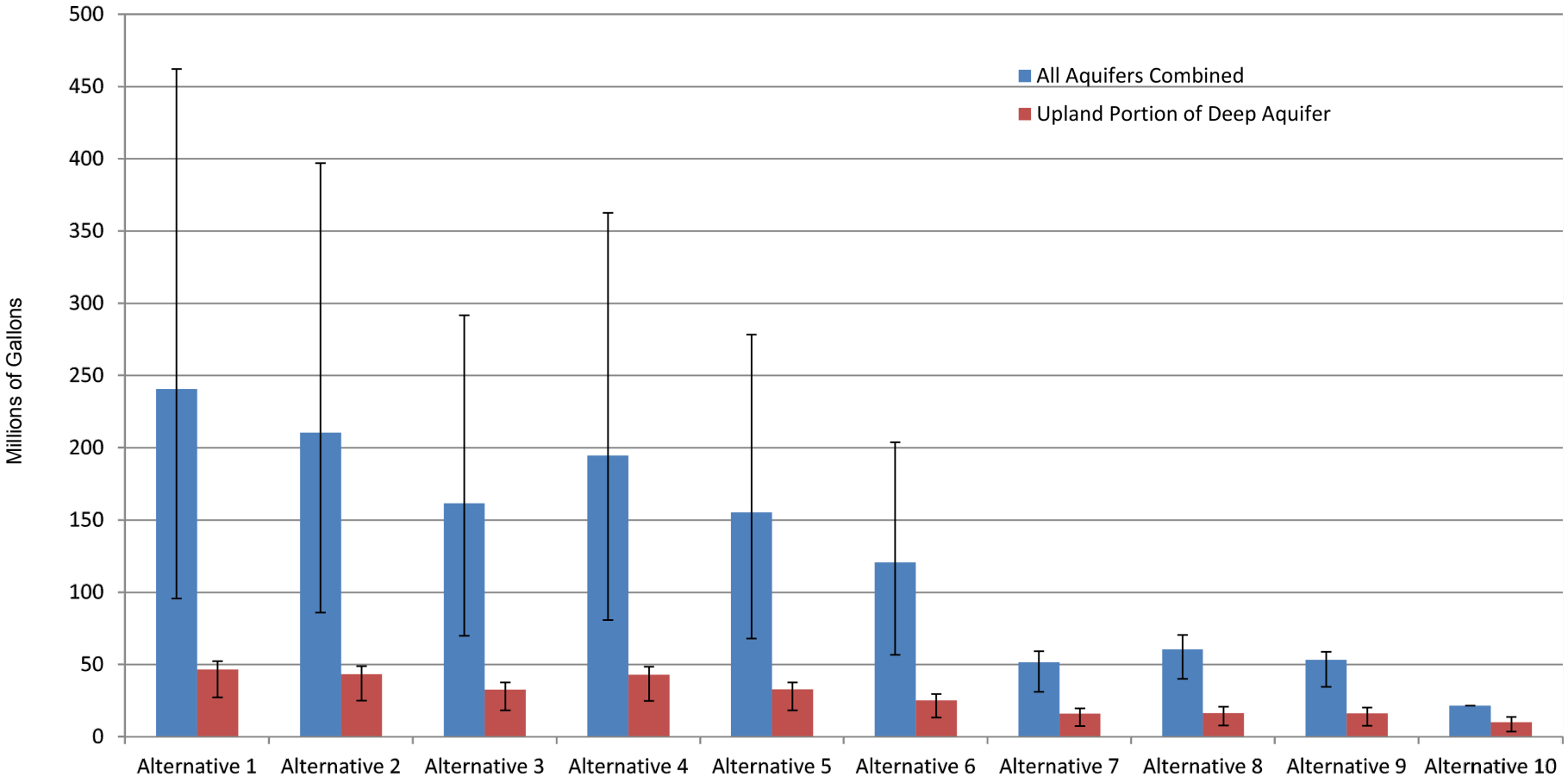
DRAFT FINAL
October 14, 2013

Estimated Sensitivity Analysis Results
Aggregate Plume Volume
Exceeding Drinking Water PRGs

Quendall Terminals Feasibility Study Report
Renton, Washington

Aspect CONSULTING / ARCADIS		FIRM: ASPECT DRAWN BY: JJP/SCC	FIGURE NO. A-24

CAD Path: Q:\Quendall\020027 Quendall Terminals\2013-06 FS Draft Final\020027-A-22 thru A-34.dwg A-24 | | Date Saved: Oct 10, 2013 12:28pm | | User: scudd



Notes:

1. Groundwater modeling results should be used as a relative tool for comparison and not considered a prediction of actual conditions. For example, model-estimated benzo[a]pyrene volumes for all alternatives are larger than anticipated based on current site data, due to simplifying modeling assumptions (see Appendix A, Section A3.2).
2. Modeling results do not include the potential contribution of residuals resulting from removal actions (i.e., excavation or dredging). It is expected, based on a model sensitivity analysis (see Appendix A, Section A5.1.2), that residuals will result in benzo[a]pyrene exceedances after 100 years for all alternatives, including Alternative 10.
3. Error bar represents range between best and worst cases.

DRAFT FINAL
October 14, 2013

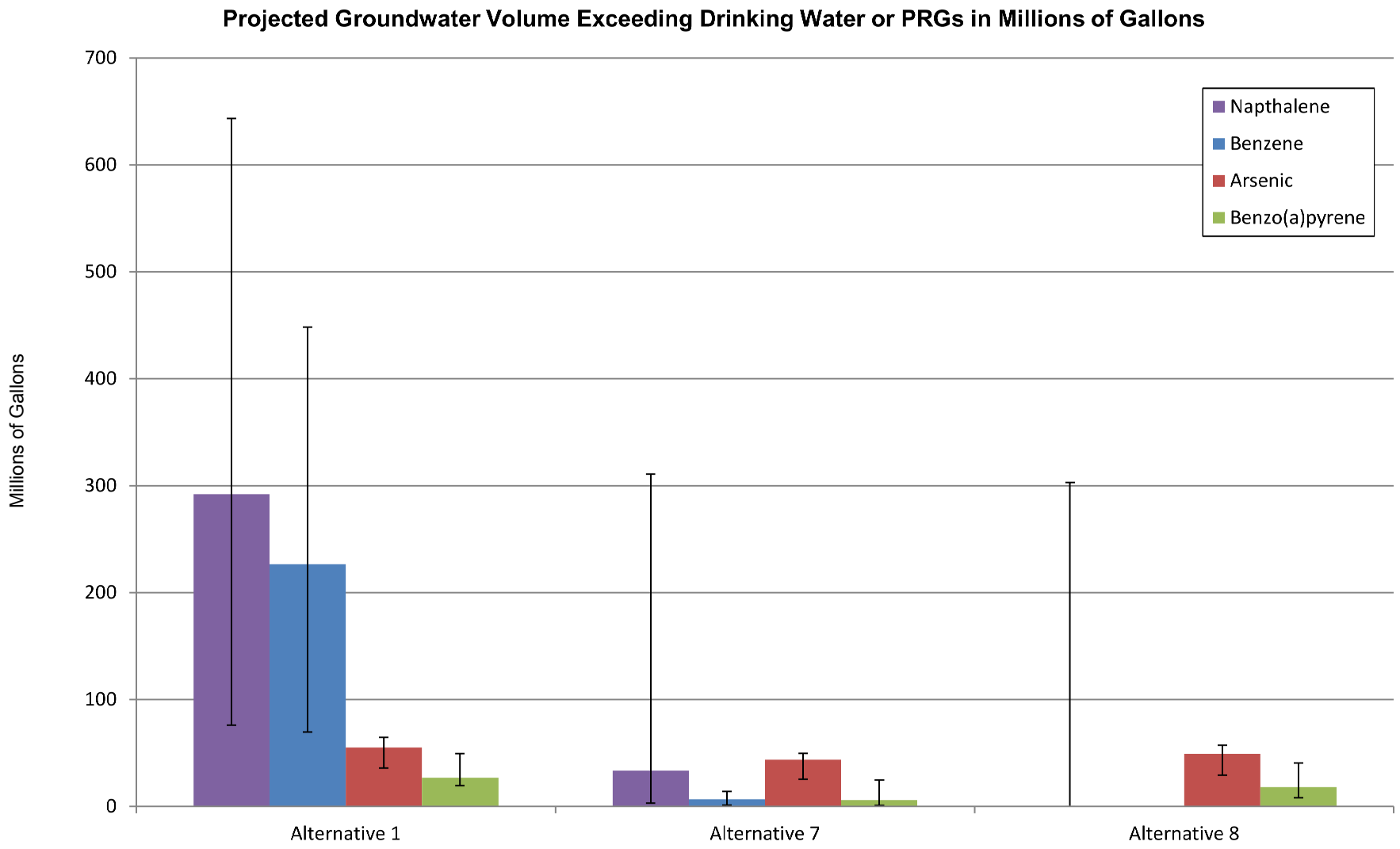
Estimated Sensitivity Analysis Results
Aggregate Plume Volume
Exceeding Drinking Water MCLs Only

Quendall Terminals Feasibility Study Report
Renton, Washington

Aspect CONSULTING / ARCADIS		FIRM: ASPECT DRAWN BY: JJP/SCC	FIGURE NO. A-25

CAD Path: Q:\Quendall\020027 Quendall Terminals\2013-06 FS Draft Final\020027-A-22 thru A-34.dwg A-25 || Date Saved: Oct 10, 2013 12:29pm || User: scudd

CAD Path: Q:\Quendall\020027 Quendall Terminals\2013-06 FS Draft Final\020027-A-22 thru A-34.dwg A-26 | | Date Saved: Oct 10, 2013 12:45pm | | User: scudd



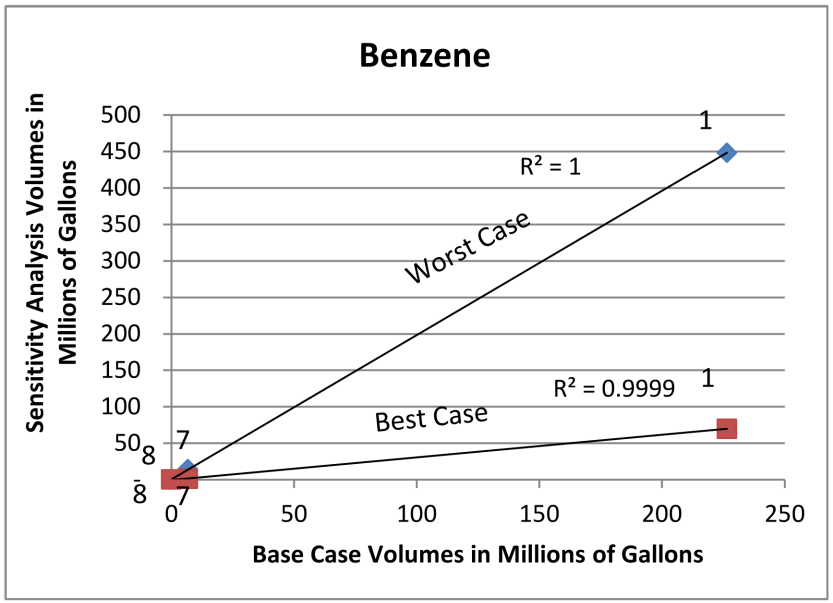
Note:
1. Error bar represents range between best and worst cases.

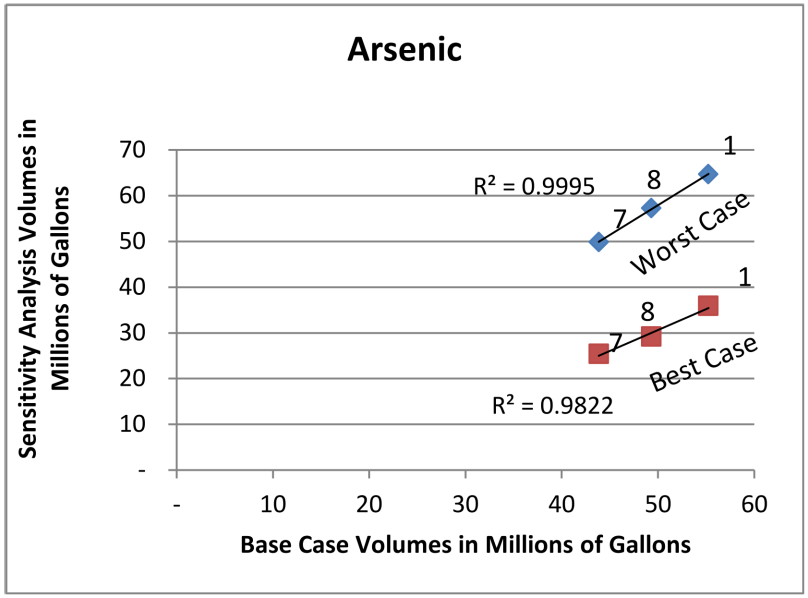
Sensitivity Analysis Results by COC
Plume Volume

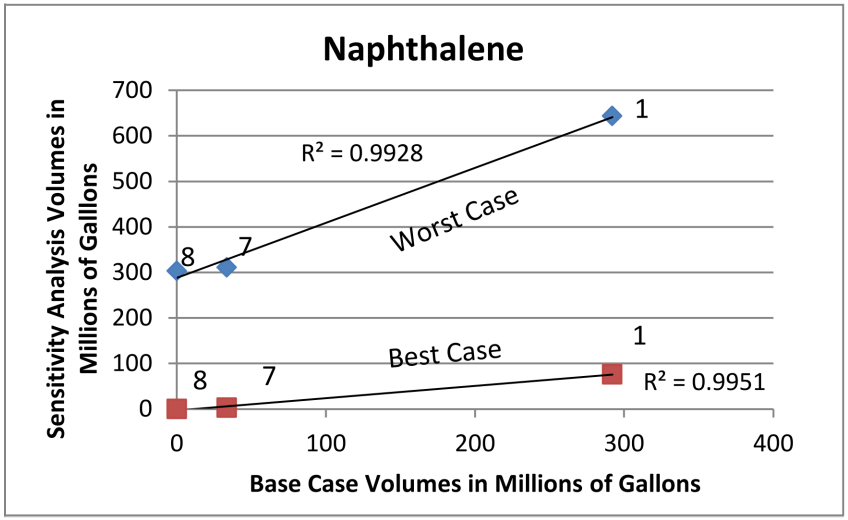
Quendall Terminals Feasibility Study Report
Renton, Washington

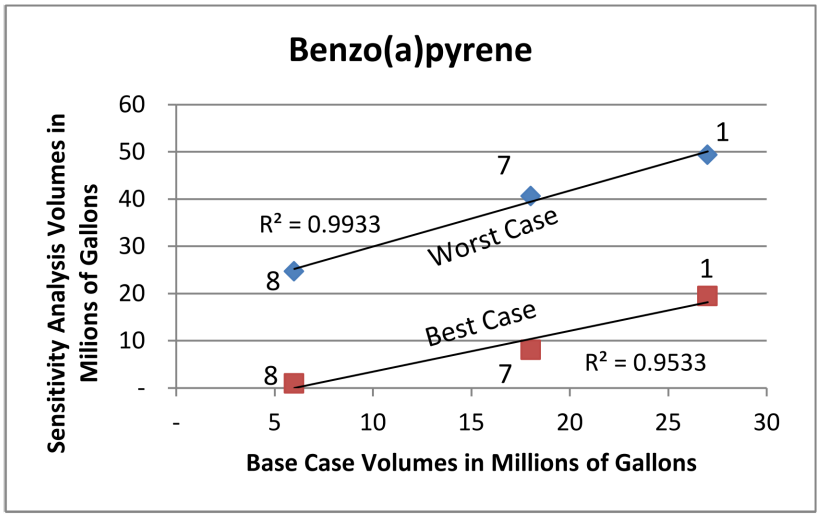
DRAFT FINAL
October 14, 2013

Aspect CONSULTING / ARCADIS	FIRM: ASPECT	DRAWN BY: JJP/SCC	FIGURE NO. A-26









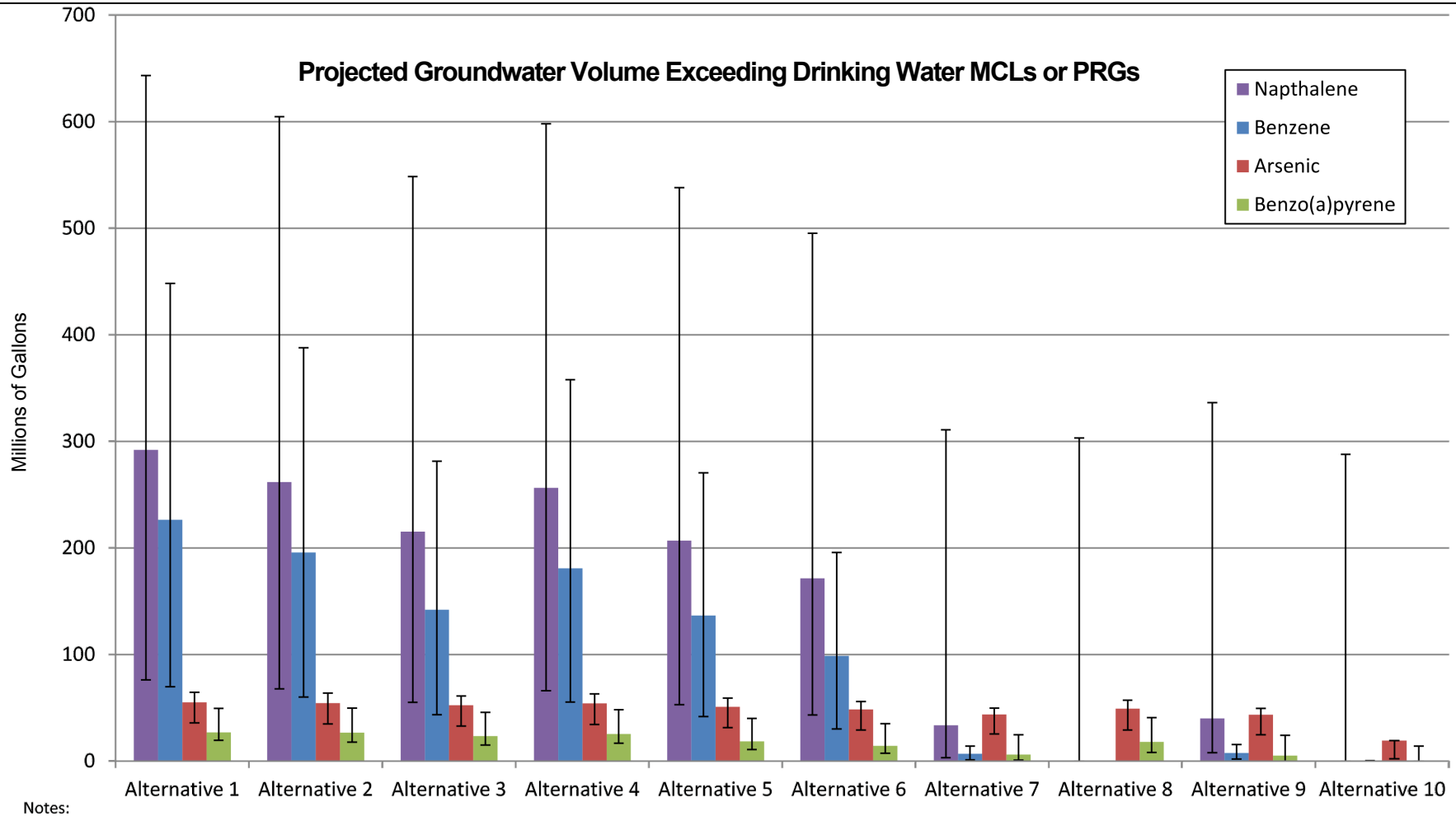
DRAFT FINAL
October 14, 2013

Linear Interpolation of Sensitivity Analysis Results by COC-Plume Volume

Quendall Terminals Feasibility Study Report
Renton, Washington

Aspect Consulting / ARCADIS	FIRM: ASPECT	DRAWN BY: JJP/SCC	FIGURE NO. A-27

CAD Path: Q:\Quendall\020027 Quendall Terminals\2013-06 FS Draft Final\020027-A-22 thru A-34.dwg A-27 || Date Saved: Oct 10, 2013 12:30pm || User: scudd



Notes:

1. Groundwater modeling results should be used as a relative tool for comparison and not considered a prediction of actual conditions. For example, model-estimated benzo[a]pyrene volumes for all alternatives are larger than anticipated based on current site data, due to simplifying modeling assumptions (see Appendix A, Section A3.2).
2. Modeling results do not include the potential contribution of residuals resulting from removal actions (i.e., excavation or dredging). It is expected, based on a model sensitivity analysis (see Appendix A, Section A5.1.2), that residuals will result in benzo[a]pyrene exceedances after 100 years for all alternatives, including Alternative 10.
3. Benzo[a]pyrene error bar for Alternative 10 is based on volume of plume estimated under residuals sensitivity analysis (see Appendix A, Section A5.1.2).
4. Error bar represents range between best and worst cases.

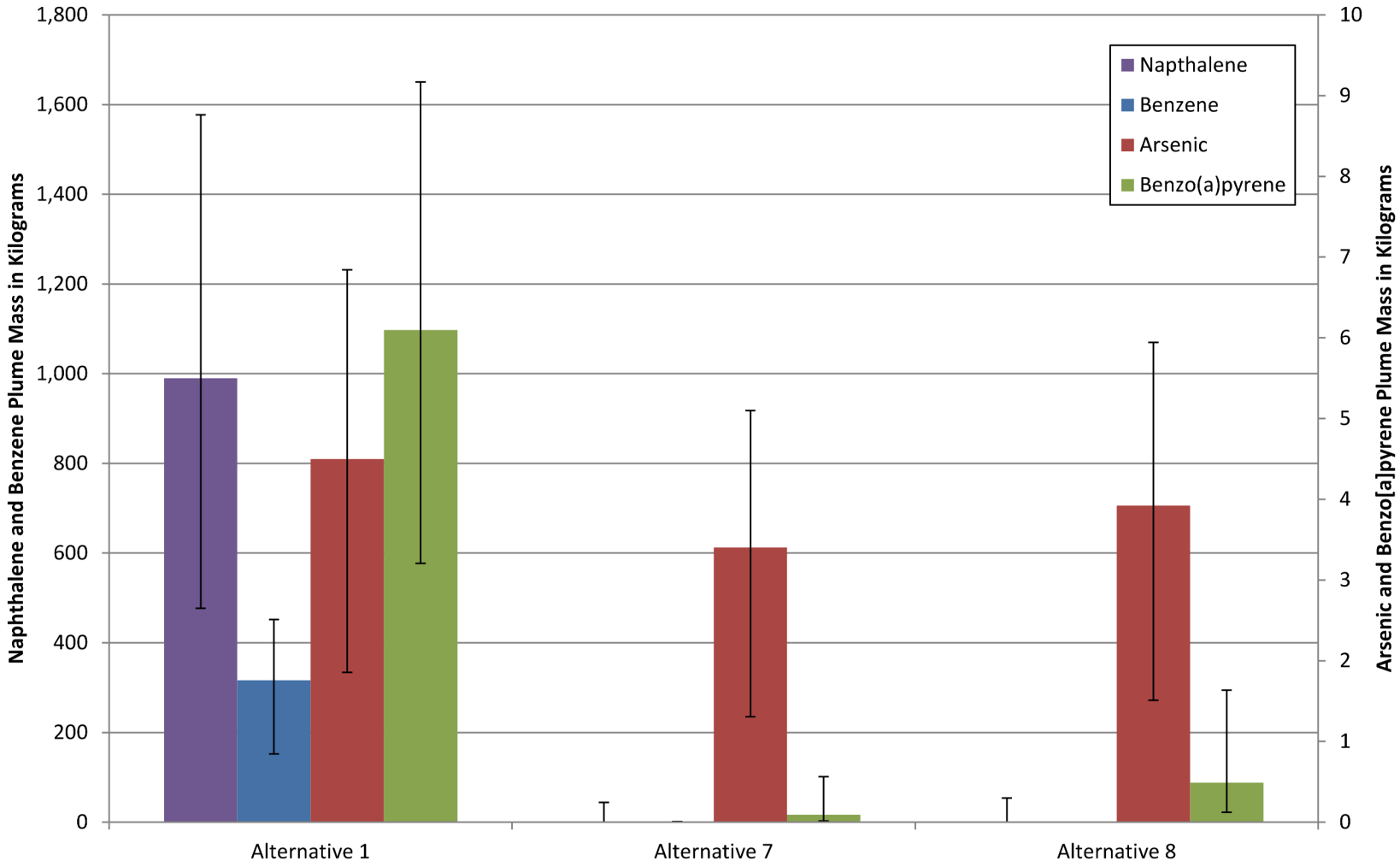
Estimated Sensitivity Analysis Results by COC-Plume Volume

Quendall Terminals Feasibility Study Report
Renton, Washington

DRAFT FINAL
October 14, 2013

Aspect CONSULTING / ARCADIS	FIRM: ASPECT	DRAWN BY: JJP/SCC	FIGURE NO. A-28

CAD Path: Q:\Quendall\020027 Quendall Terminals\2013-06 FS Draft Final\020027-A-22 thru A-34.dwg A-28 || Date Saved: Oct 10, 2013 12:31pm || User: scudd



Note:
1. Error bar represents range between best and worst cases.

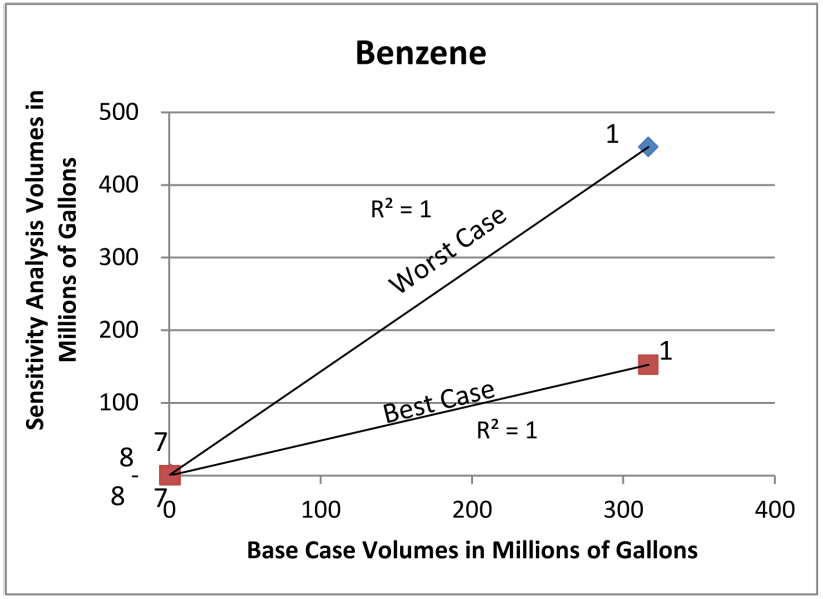
Sensitivity Analysis Results by COC Plume Mass

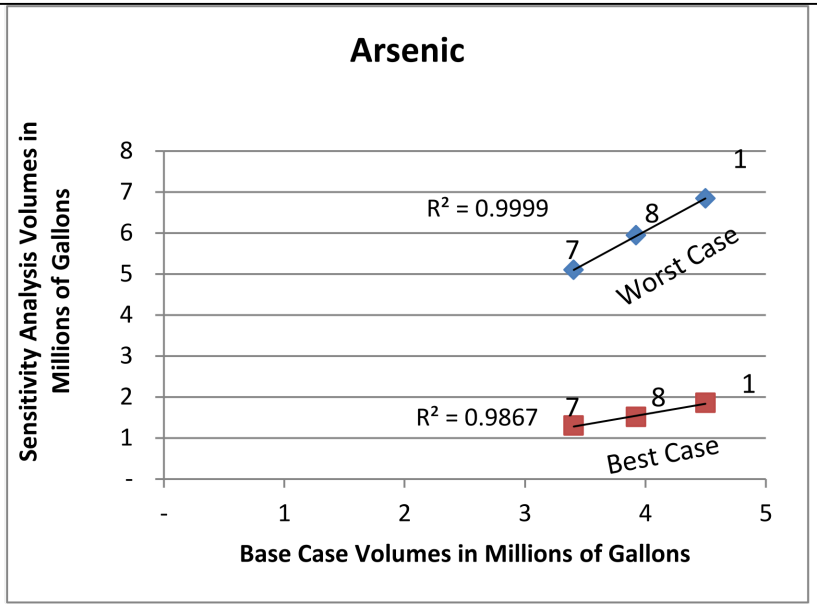
Quendall Terminals Feasibility Study Report
Renton, Washington

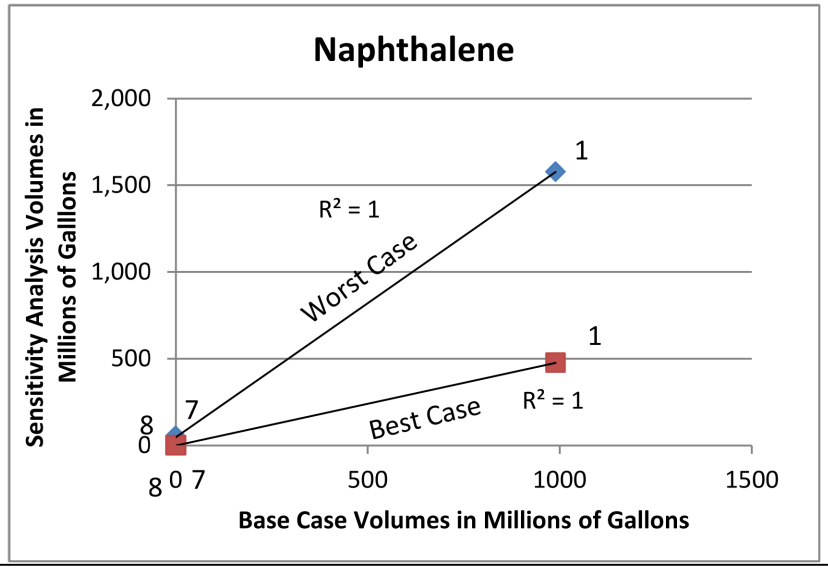
DRAFT FINAL
October 14, 2013

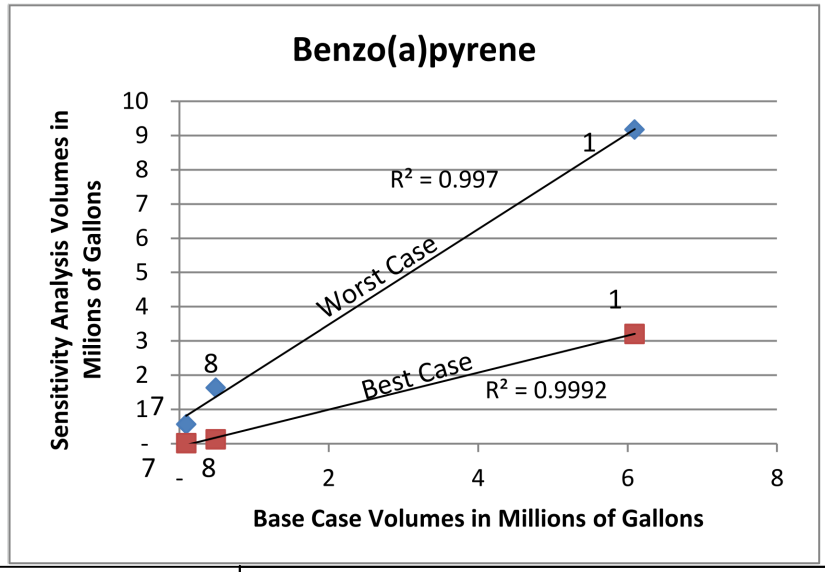
Aspect CONSULTING / ARCADIS	FIRM: ASPECT	DRAWN BY: JJP/SCC	FIGURE NO. A-29

CAD Path: Q:\Quendall\020027 Quendall Terminals\2013-06 FS Draft Final\020027-A-22 thru A-34.dwg A-29 | | Date Saved: Oct 10, 2013 12:46pm | | User: scudd









CAD Path: Q:\Quendall\020027 Quendall Terminals\2013-06 FS Draft Final\020027-A-22 thru A-34.dwg A-30 | | Date Saved: Oct 10, 2013 12:33pm | | User: scudd

DRAFT FINAL
October 14, 2013

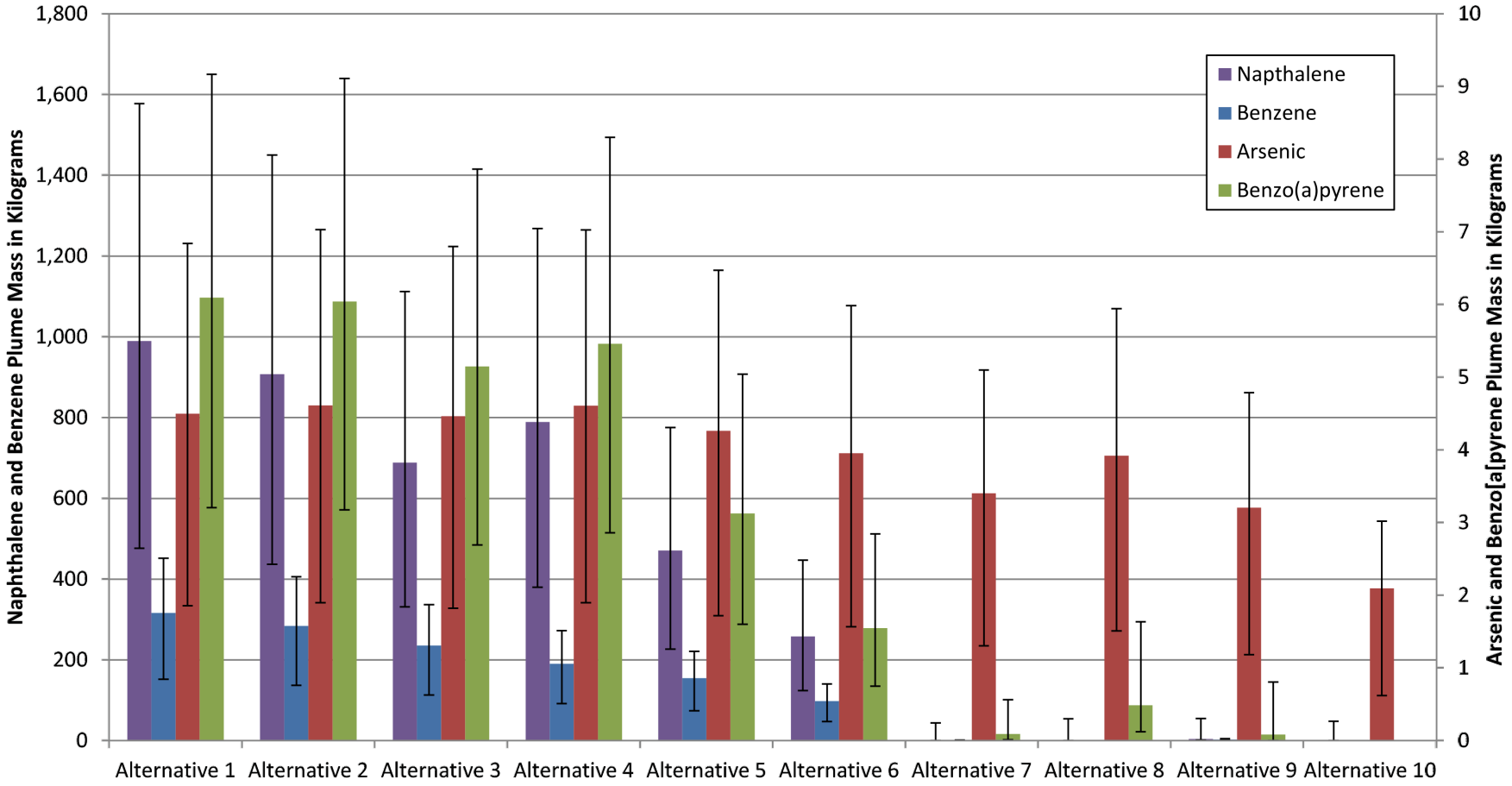
Linear Interpolation of Sensitivity Analysis Results by COC-Plume Mass

Quendall Terminals Feasibility Study Report
Renton, Washington

Aspect CONSULTING / ARCADIS	FIRM: ASPECT	DRAWN BY: JJP/SCC	FIGURE NO. A-30

CAD Path: Q:\Quendall\020027 Quendall Terminals\2013-06 FS Draft Final\020027-A-22 thru A-34.dwg A-31 || Date Saved: Oct 10, 2013 12:34pm || User: scudd

Projected Mass of Plume in Kilograms



Notes:

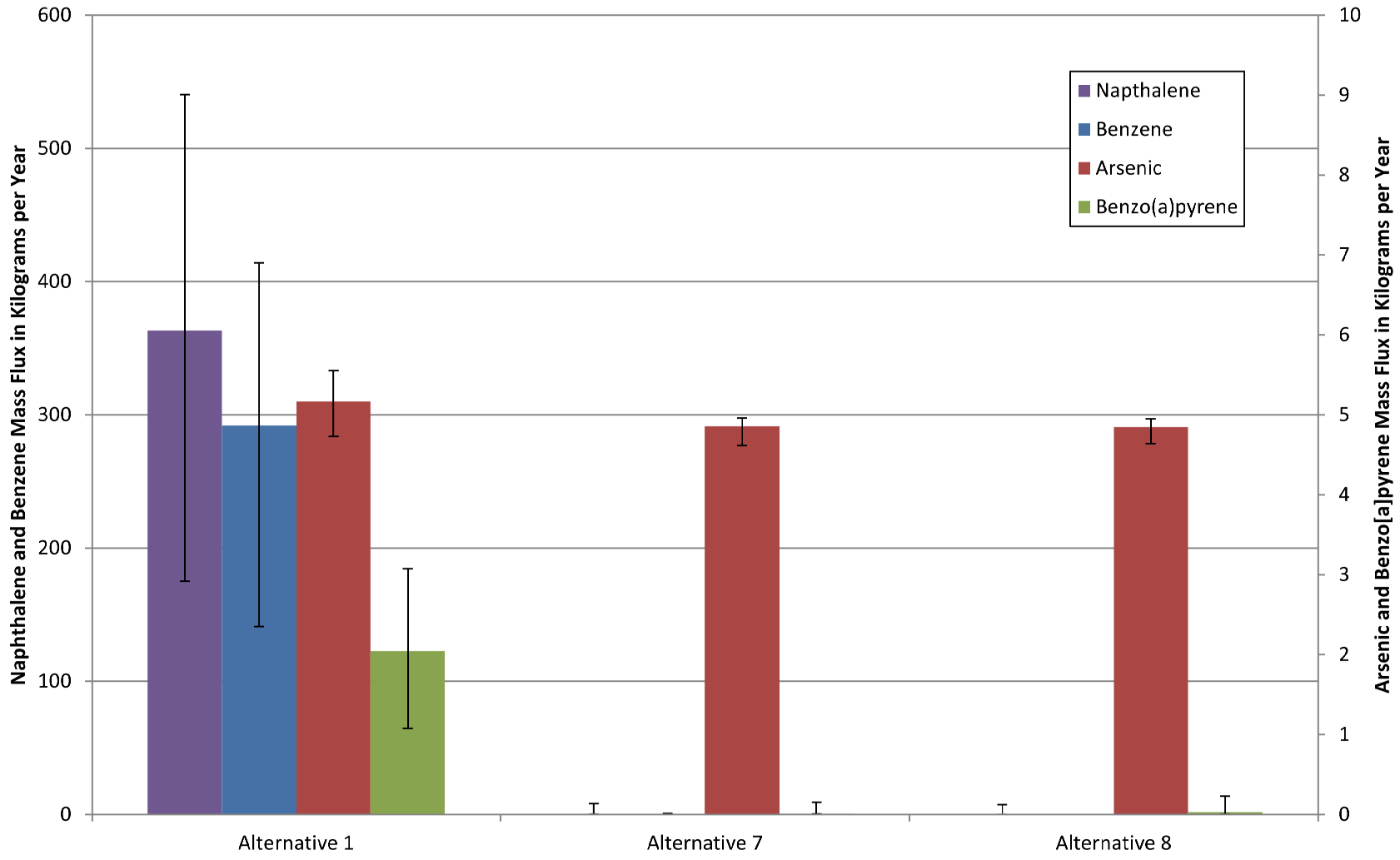
1. Groundwater modeling results should be used as a relative tool for comparison and not considered a prediction of actual conditions.
2. Modeling results do not include the potential contribution of residuals resulting from removal actions (i.e., excavation or dredging). It is expected, based on a model sensitivity analysis (see Appendix A, Section A5.1.2.2), that residuals will result in benzo[a]pyrene exceedances after 100 years for all alternatives, including Alternative 10.
3. Error bar represents range between best and worst cases.

DRAFT FINAL
October 14, 2013

Estimated Sensitivity Analysis Results by COC-Plume Mass

Quendall Terminals Feasibility Study Report
Renton, Washington

Aspect CONSULTING / ARCADIS	FIRM: ASPECT	DRAWN BY: JJP/SCC	FIGURE NO. A-31



Note:
1. Error bar represents range between best and worst cases.

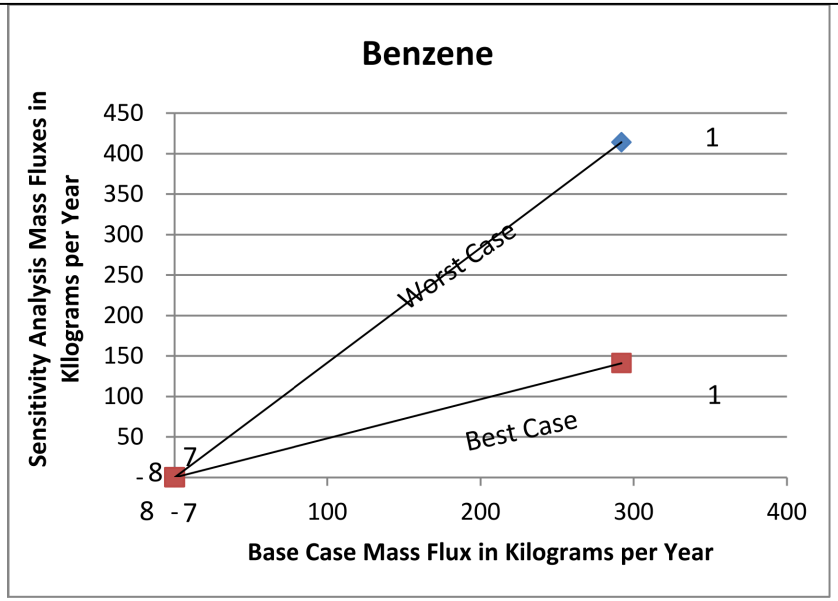
Sensitivity Analysis Results by COC Mass Flux

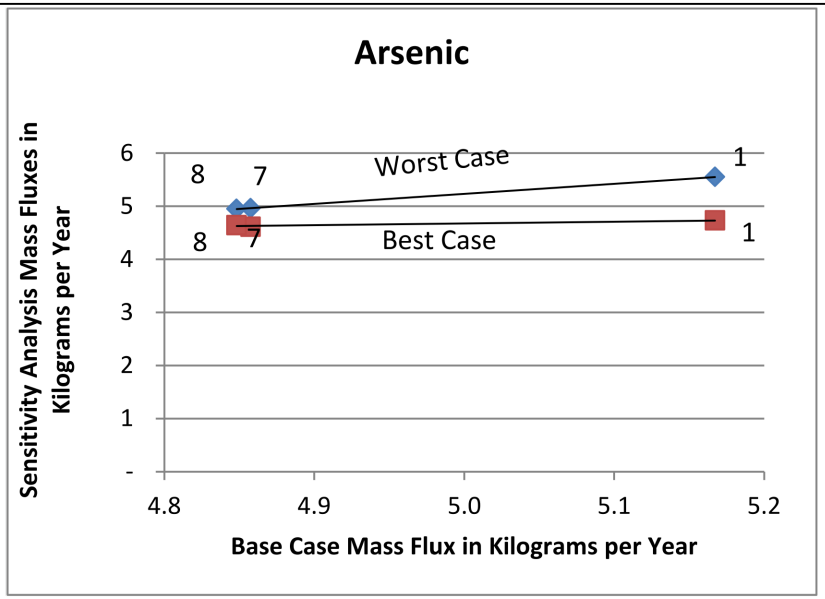
Quendall Terminals Feasibility Study Report
Renton, Washington

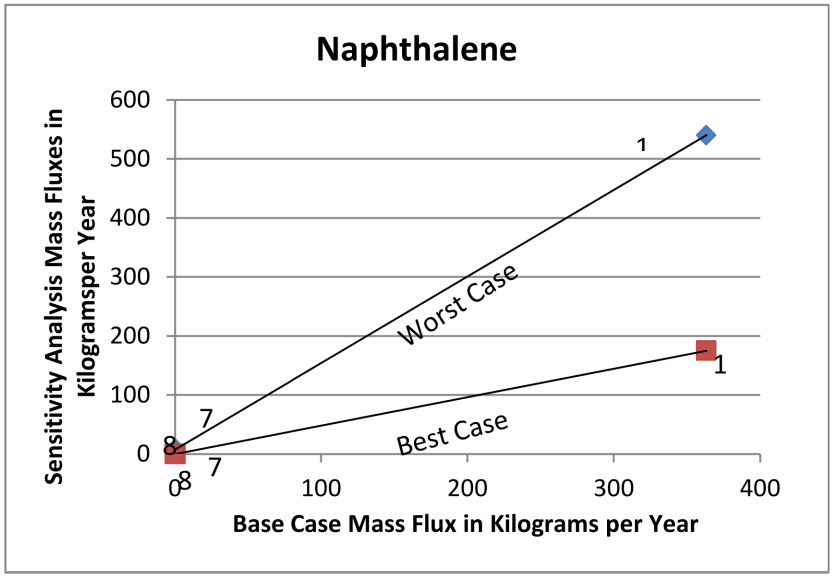
DRAFT FINAL
October 14, 2013

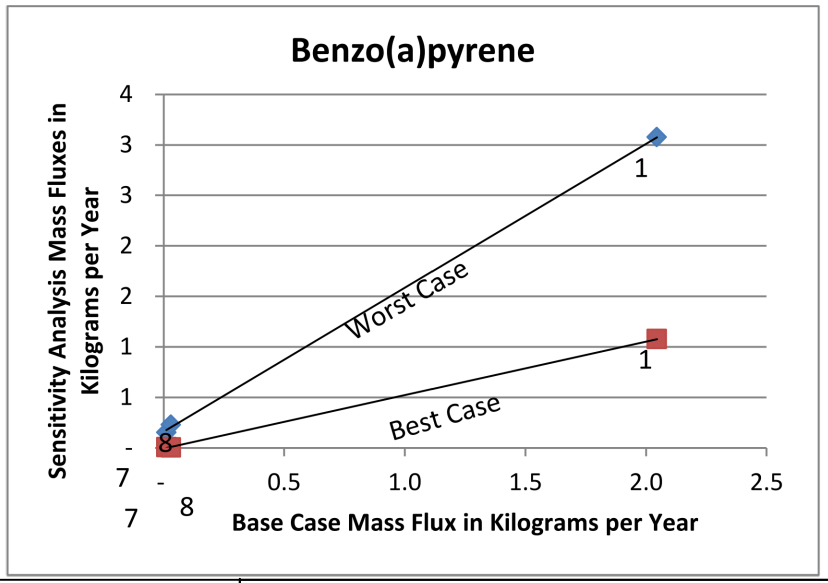
Aspect CONSULTING / ARCADIS		FIRM: ASPECT DRAWN BY: JJP/SCC	FIGURE NO. A-32

CAD Path: Q:\Quendall\020027 Quendall Terminals\2013-06 FS Draft Final\020027-A-22 thru A-34.dwg A-32 | | Date Saved: Oct 10, 2013 12:48pm | | User: scudd









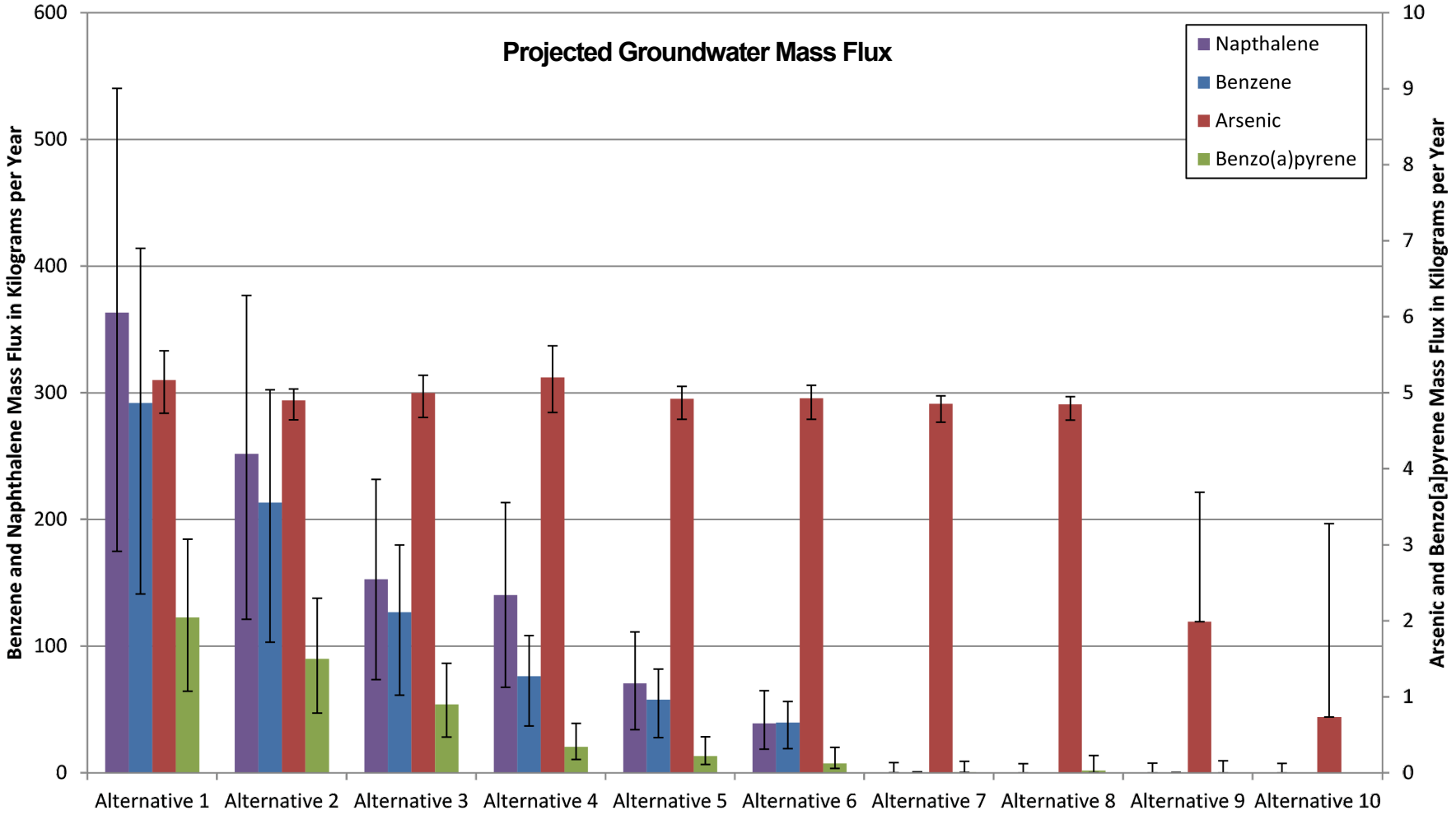
CAD Path: Q:\Quendall\020027 Quendall Terminals\2013-06 FS Draft Final\020027-A-22 thru A-34.dwg A-33 | | Date Saved: Oct 10, 2013 12:37pm | | User: scudd

DRAFT FINAL
October 14, 2013

Linear Interpolation of Sensitivity Analysis Results by COC-Mass Flux

Quendall Terminals Feasibility Study Report
Renton, Washington

Aspect CONSULTING / ARCADIS	FIRM: ASPECT	DRAWN BY: JJP/SCC	FIGURE NO. A-33



Notes:

1. Groundwater modeling results should be used as a relative tool for comparison and not considered a prediction of actual conditions.
2. Modeling results do not include the potential contribution of residuals resulting from removal actions (i.e., excavation or dredging). It is expected, based on a model sensitivity analysis (see Appendix A, Section A5.1.2.2), that residuals will result in benzo[a]pyrene exceedances after 100 years for all alternatives, including Alternative 10.
3. Error bar represents range between best and worst cases.

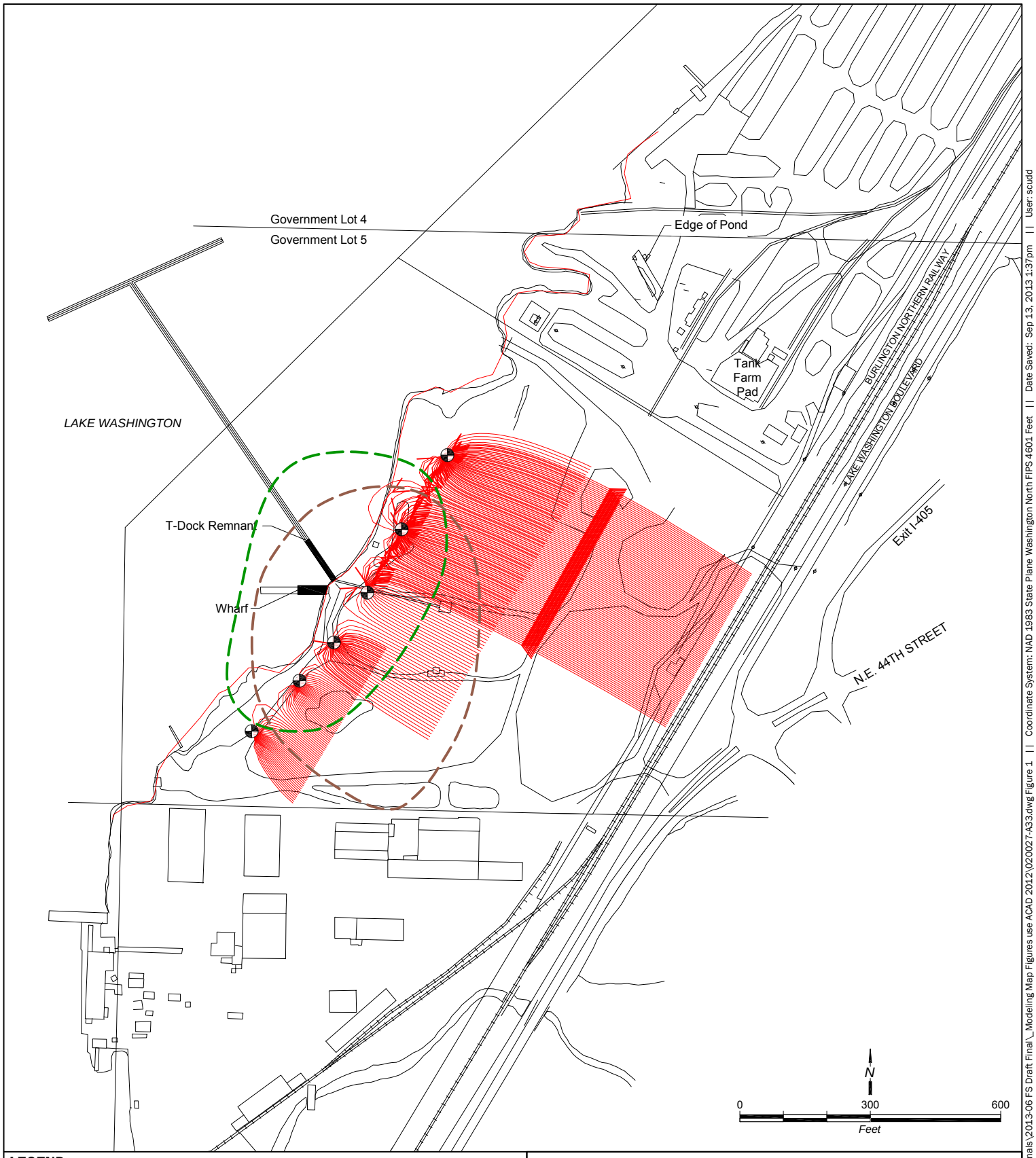
Estimated Sensitivity Analysis Results by COC-Mass Flux

Quendall Terminals Feasibility Study Report
Renton, Washington

DRAFT FINAL
October 14, 2013

Aspect CONSULTING / ARCADIS		FIRM: ASPECT DRAWN BY: JJP/SCC	FIGURE NO. A-34

CAD Path: Q:\Quendall\020027 Quendall Terminals\2013-06 FS Draft Final\020027-A-22 thru A-34.dwg A-34 | | Date Saved: Oct 10, 2013 12:40pm | | User: scudd



LEGEND

- Pumping Well
- MODPATH Particle Trace
- Estimated extent of benzene exceeding MCL in groundwater (5 µg/L) - Deeper Alluvium
- Estimated extent of arsenic exceeding MCL in groundwater (10 µg/L) - Deeper Alluvium

DRAFT FINAL
October 14, 2013

Pump and Treat Capture Analysis
Plan View

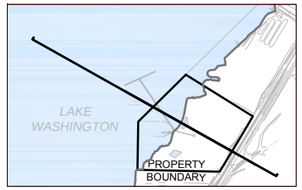
Quendall Terminals Feasibility Study Report
Renton, Washington

Aspect CONSULTING | ARCADIS | FIRM: ASPECT | DRAWN BY: SM/SCC | FIGURE NO. A-35

CAD Path: Q:\Quendall\020027 Quendall Terminals\2013-06 FS Draft Final_Modeling Map Figures use ACAD 2012\020027-A33.dwg Figure 1 || Coordinate System: NAD 1983 State Plane Washington North FIPS 4601 Feet || Date Saved: Sep 13, 2013 1:37pm || User: scudd

West

East



Cross Section Location

Elevation in Feet (NAVD 88)

200
180
160
140
120
100
80
60
40
20
0
-20
-40
-60
-80
-100

Lake Washington

16.7'

Quendall Property

I-405

Vertical Exaggeration x5

120
60
0
Feet

0
300
600
Feet

All elevations are in feet NAVD 88.

Legend

- Fill
- Shallow Alluvium
- Deeper Alluvium
- Lake Washington Sediments
- Quendall Property Boundary
- MODPATH Particle Trace

DRAFT FINAL
October 14, 2013

Pump and Treat Capture Analysis
Cross Section View

Quendall Terminals Feasibility Study Report
Renton, Washington

Aspect CONSULTING | ARCADIS

FIRM: ASPECT
DRAWN BY: SM/SCC

FIGURE NO.
A-36

CAD Path: Q:\Quendall\020027 Quendall Terminals\2013-06 FS Draft Final_Modeling Map Figures use ACAD 2012\020027-A34.dwg Section E Figure 3-2 || Coordinate System: NAD 1983 State Plane Washington North FIPS 4601 Feet || Date Saved: Sep 13, 2013 1:39pm || User: scudd

APPENDIX B

Engineering Evaluations in Support of Sediment Remedial Alternatives

- B1 – cPAH Background Threshold Value and Replacement Value Calculation Memo
- B2 – Engineered Sand Cap – Chemical Isolation Layer Modeling
- B3 – Cap Armor Layer Evaluation
- B4 – Cap Geotechnical Considerations
- B5 – Sheet Pile Enclosure Calculations

APPENDIX B1

cPAH Background Threshold Value and Replacement Value Calculation Memo

ARCADIS U.S., Inc.
1100 Olive Way
Suite 800
Seattle
Washington 98101
Tel 206 325 5254
Fax 206 325 8218

MEMO

To:
Barbara Orchard
Barry Kellems

Copies:

From:
Alison Skwarski
Ryan Shatt

Date:
August 13, 2013

ARCADIS Project No.:
WA000907.0000 00003

Subject:
cPAH Background Threshold Value and Replacement Value Calculation -- Quendall Terminals Draft Final Feasibility Study

---

This memorandum summarizes the reasoning and methodology for EPA's background threshold value (BTV) of 17.5 mg/kg organic carbon (OC) for the Quendall Terminals Site (Site) and provides ARCADIS's calculations that confirm EPA's replacement value range of 15.96 to 16.3 mg/kg OC.

In the August 6, 2012 *Agency Review Draft Feasibility Study* (Draft FS) prepared for the Site by Aspect Consulting and Anchor QEA, a site-specific replacement threshold value of 27 mg/kg OC was calculated for carcinogenic polynuclear aromatic hydrocarbons (cPAHs) to determine the sediment footprint requiring remedial action. This replacement value calculation consecutively replaced the highest Site sample with a randomly generated background concentration. A t-test was used to compare the remaining Site and background datasets. A Monte Carlo simulation of the t-test was run to evaluate the probable range of the background variable to determine the mean t-test p-value and lower confidence limit and upper confidence limit on the p-value.

In EPA's April 12, 2013 comments on the Draft FS, EPA did not support the Site-specific replacement threshold of 27 mg/kg OC for cPAHs and requested that a BTV be calculated instead, based on the 95% gamma Upper Tolerance Limit (UTL) with 95% coverage of the background sample dataset. For purposes of the Remedial Investigation, background surface sediment was functionally represented by sampling data collected approximately 1 mile from the Site along the eastern Lake Washington shoreline.

Background samples were collected at similar depths and in similar depositional sediment environments to those at the Site. EPA calculated a BTV of 17.5 mg/kg OC cPAH using ProUCL 4.1, a statistical software package, and the 95% Hawkins Wixley approach.

Additionally, for comparison purposes, EPA also completed a replacement value exercise that differed from the approach used in the Draft FS. The mean background cPAH concentration of 4.62 mg/kg OC was substituted instead of a randomly generated variable. Instead of using the t-test, the Wilcoxon Rank Sum test (a non-parametric test) was used. EPA's replacement value exercise resulted in a value between 15.96 and 16.3 mg/kg OC, which was slightly lower than EPA's calculated BTV of 17.5 mg/kg OC cPAH.

EPA required that the sediment footprint requiring remedial action be based on the revised BTV of 17.5 mg/kg OC cPAH.

To confirm EPA's calculations, ARCADIS conducted the calculation using EPA's methodology and confirmed the BTV of 17.5 mg/kg OC. ARCADIS' calculation also resulted in a replacement value between 15.96 and 16.3 mg/kg OC. Attachment 1 provides the calculations used to confirm EPA's replacement value results, and Attachment 2 summarizes the calculation results.

Attachments

Attachment 1 -- cPAH Background Threshold Value and Replacement Value Calculations

Attachment 2 – cPAH Background Threshold Value and Replacement Value Results

Gamma Background Statistics for Full Data Sets

User Selected Options

From File	WorkSheet_a.wst
Full Precision	OFF
Confidence Coefficient	95%
Coverage	95%
Number of Bootstrap Operations	2000

Background ug/kg OC

Raw Statistics

Number of Valid Observations	10
Number of Distinct Observations	10
Minimum	1709
Maximum	13022
Second Largest	5808
Mean	4620
Geometric Mean	3912
First Quartile	2631
Median	3870
Third Quartile	5144
SD	3250

Gamma Distribution Test

k hat (MLE)	3.162
k star (bias corrected MLE)	2.28
Theta Hat (MLE)	1461
Theta star (bias corrected MLE)	2026
nu hat (MLE)	63.25
nu star (based upon bias corrected estimates)	45.61
MLE Mean (based upon bias corrected estimates)	4620
MLE Sd (based upon bias corrected estimates)	3059
95% Percentile of Chisquare (2k)	10.38
A-D Test Statistic	0.404
5% A-D Critical Value	0.732
K-S Test Statistic	0.172
5% K-S Critical Value	0.268

Data appear Gamma Distributed at 5% Significance Level

Background Statistics Assuming Gamma Distribution

90% Percentile	8715
95% Percentile	10519
99% Percentile	14489
95% Wilson Hilferty (WH) Approx. Gamma UPL	11160
95% Hawkins Wixley (HW) Approx. Gamma UPL	11286
Tolerance Factor K	2.911
95% Wilson Hilferty (WH) Approx. Gamma UTL with 95% Coverage	16764
95% Hawkins Wixley (HW) Approx. Gamma UTL with 95% Coverage	17494

Nonparametic Background Statistics

95% Chebyshev UPL	19477
95% BCA Bootstrap UTL with 95% Coverage	13022
95% Bootstrap (%) UTL with 95% Coverage	13022

Attachment 2 of Appendix B1 - cPAH Background Threshold Value and Replacement Value Results

Quendall Terminals
Renton, Washington

Iteration	Number of Background Replacements	Sample ID	Concentration (mg/kg-OC)	Untransformed Data Wilcoxon p-value	Log-Transformed Data Wilcoxon t-test p-value	Mean (mg/kg-OC)	Standard Deviation
1	0	TD-15-BS	2,370	3.11E-05	2.71E-05	186	532
2	1	TD-08-BS	1,771	5.32E-05	4.66E-05	104	326
3	2	NS-12-BS	278	8.95E-05	7.87E-05	43.4	60.9
4	3	NS-11-BS	176	1.48E-04	1.31E-04	34.0	41.4
5	4	TD-14-BS	130	2.42E-04	2.14E-04	28.1	31.4
6	5	SS-05-BS	98.3	3.88E-04	3.45E-04	23.8	24.8
7	6	SS-06-BS	81.8	6.14E-04	5.48E-04	20.5	20.4
8	7	SS-04-BS	66.2	9.55E-04	8.57E-04	17.9	16.9
9	8	TD-09-BS	61.8	0.00146	0.00132	15.8	14.3
10	9	TD-11-BS	38.2	0.00221	0.002	13.8	11.3
11	10	NS-07-BS	38.1	0.00329	0.00298	12.6	10.4
12	11	NS-16-BS	38.1	0.00481	0.00438	11.5	9.30
13	12	TD-SO-03-SS-090930	30.9	0.00694	0.00634	10.3	7.84
14	13	TD-13-BS	27.8	0.00985	0.00904	9.41	6.83
15	14	TD-SO-02-SS-090930	22.9	0.0138	0.0127	8.61	5.89
16	15	SS-03-BS	20.8	0.019	0.0176	7.98	5.25
17	16	TD-12-BS	18.7	0.0258	0.024	7.42	4.67
18	17	TD-CT-02-SS-090930	16.5	0.0346	0.0322	6.93	4.16
19	18	TD-SO-01-SS-090930	16.3	***0.0457***	***0.0426***	6.53	3.74
20	19	TD-CT-01-SS-090930	16.0	***0.0594***	***0.0557***	6.12	3.25
21	20	TD-10-BS	13.1	0.0762	0.0717	5.73	2.65
22	21	TD-SO-04-SS-090930	11.2	0.0964	0.091	5.44	2.25
23	22	TD-07-BS	10.7	0.114	0.108	5.21	1.97
24	23	TD-SO-05-SS-090930	10.3	0.134	0.127	5.01	1.66
25	24	NS-03-BS	10.0	0.155	0.148	4.81	1.31
26	25	TD-SO-09-SS-090930	6.94	0.18	0.171	4.62	0.84
27	26	TD-SO-07-SS-090930	5.44	0.206	0.197	4.54	0.71
28	27	TD-SO-08-SS-090930	5.15	0.225	0.215	4.51	0.69
29	28	TD-SO-06-SS-090930	0.98	0.235	0.235	4.49	0.68

Background Sample	Concentration cPAH (mg/kg-OC)	Concentration Log cPAH
BG-03-BS	13.0	1.11
BG-13-BS	5.81	0.76
BG-04-BS	5.16	0.71
BG-06-BS	5.09	0.71
BG-19-BS	3.89	0.59
BG-09-BS	3.85	0.59
BG-12-BS	2.83	0.45
BG-17-BS	2.57	0.41
BG-15-BS	2.27	0.36
BG-02-BS	1.71	0.23
Average Background	4.62	0.59

Notes:
1. The first iteration used all data; no samples were replaced. The second iteration replaced the highest sample concentration with average background value. The third iteration replaced the two (2) highest sample concentrations with the average background value and so on for all the data.
2. Each iteration of sample concentrations was statistically compared against the background concentrations in ProUCL 4.1 using the Wilcoxon-Mann-Whitney test (95% confidence and a null hypothesis of area of concern [AOC] ≤ Background).
3. Log transformed p-values used the same dataset iterations but the concentrations used are the log values.
4. The highlighted cells indicate the results that bracket a Wilcoxon Rank Sum Test p-value of 0.05.

cPAH = carcinogenic polynuclear aromatic hydrocarbon
mg/kg-OC = milligram(s) per kilogram organic carbon

APPENDIX B2

Engineered Sand Cap – Chemical Isolation Layer Modeling

Table of Contents

B2-1 Introduction B2-1

B2-2 Methodology B2-1

B2-2.1 Model Framework B2-1

B2-2.2 Approach B2-2

B2-3 Initial Modeling B2-3

B2-3.1 Approach B2-3

B2-3.2 Model Inputs B2-4

B2-3.2.1 Input Parameters Based on Site Data and Literature B2-4

B2-3.2.2 Partitioning Coefficients B2-6

B2-3.2.3 COC Calibration B2-7

B2-3.2.4 Model Input Summary B2-7

B2-3.3 Results of Initial Modeling B2-10

B2-2 Capping Evaluation B2-11

B2-4.1 Model Application Approach B2-11

B2-4.2 Model Setup and Inputs B2-11

B2-4.2.1 Model Domain and Layers B2-11

B2-4.2.2 Model Input Parameters B2-11

B2-4.3 Results of Cap Modeling Evaluation B2-14

B2-4.4 Sensitivity Analyses B2-14

B2-5 References for Appendix B2 ..... B2-17

List of Tables

B2-1 Cation Porewater Concentrations B2-5

B2-2 Benzene and Naphthalene Porewater Concentrations B2-5

B2-3 UT Model Input Parameters Used in Cation, Benzene, and Naphthalene Calibrations B2-8

B2-4 Cap Modeling Input Parameters Used in the Capping Evaluation B2-13

B2-5 Model-Predicted Vertical Average Concentrations for Cap Evaluation B2-14

B2-6 Sensitivity Analyses Input Parameters and Results B2-15

B2-7 Sensitivity for Paired Calibration of Seepage Velocity and Degradation Rate B2-16

List of Figures

B2-1 Schematic of Model Configuration and Processes

B2-2 Cation Normalized Concentration Profile in Current Sediment Conditions

B2-3 Naphthalene Concentration Calibration to Current Sediment Conditions

B2-4 Naphthalene Calibration – Relationship of Degradation Half-life to Seepage Velocity

B2-5 Simulated Naphthalene Concentration Profile in Cap

Attachments

B2-1 Sediment Porewater Analytical Data

B2-1 Introduction

In support of the Quendall Terminals Site (Site) feasibility study (FS), one-dimensional chemical mass transport modeling was performed to develop a conceptual-level chemical isolation layer design for an engineered sand cap included in remedial alternatives evaluated in the FS. The engineered sand cap modeling was performed using analytical model tools and assumptions following guidance for designing sediment caps developed by both the U.S. Army Corps of Engineers (USACE; Palermo et al. 1998) and the U.S. Environmental Protection Agency (EPA 2005).

The chemical isolation layer modeling was initially applied to measured sediment porewater cation profiles at the Site, using validated Site characterization data presented in the Remedial Investigation (RI) Report (Anchor QEA and Aspect 2012). The model in this application provides a useful analytical framework to help differentiate the combined effects of a range of physical processes (e.g., advection and dispersion) from chemical and biological degradation processes for Site chemicals of concern (COCs).

Following simulation with best-estimate values for the range of physical parameters and calibration of degradation parameters to existing Site conditions, the analytical model was subsequently applied to simulate the effectiveness of an engineered sand cap in reducing long-term flux of COCs into surface sediments and achieving the surface water/porewater and surface sediment preliminary remediation goals (PRGs) summarized in Tables 4-6 through 4-7 in the main body of this FS. To provide a conservative assessment of long-term cap effectiveness consistent with the USACE and EPA guidance, long-term cap protectiveness was defined in this FS evaluation at steady-state conditions (i.e., infinite timeframe), also conservatively assuming that the current soil and groundwater "source" concentrations to Site sediments do not diminish over time. Thus, cap designs developed using these and other conservative assumptions as described in this appendix are projected to achieve PRGs under steady-state conditions. The cap isolation layer modeling evaluation was performed for the shallow nearshore sediment area at the Site as depicted on Figure 6-1 of the main FS report.

B2-2 Methodology

B2-2.1 Model Framework

The one-dimensional analytical steady-state model of chemical transport within sediment caps developed by Dr. Danny Reible from the University of Texas (as described in Lampert and Reible 2009, and Reible 2012) was used for this evaluation (hereafter referred to as the UT model). Although this model was originally developed to simulate sediment caps, it can also be applied to represent uncapped conditions. Predictions calculated using the steady-state model provide a useful means of assessing long-term COC profiles within a subaqueous sediment/cap system, although the time to reach the steady-state concentrations predicted by the model will vary, depending on the chemical

characteristics of the COCs, sediment geochemical conditions, and subsurface hydrogeology.

As shown on Figure B2-1, the UT model consists of two layers: a chemical isolation layer and a bioturbation zone. The UT model conservatively assumes that soil and groundwater COC concentrations underlying the sediments remain constant over time (i.e., infinite source); therefore, detailed simulation of transport within the underlying soils and groundwater is not necessary in this application. COC concentrations in surface water overlying the sediments are treated as a boundary condition in the UT model (it is typically assumed to be zero, which is usually appropriate in the case of sorptive contaminants, but that assumption was refined for this FS analysis in certain cases, as discussed below). The groundwater transport mechanisms of advection, diffusion, dispersion, partitioning between the aqueous and sorbed (sediment or cap material) phases, and first-order reaction (to represent degradation processes) are all incorporated into the model. In addition, the model incorporates mass transfer processes at the sediment-water interface, including biological mixing and exchange through the benthic boundary layer with the overlying water column.

The UT model calculates steady-state porewater and sorbed phase COC concentrations vertically throughout the cap (or existing sediment when the model is used to represent current uncapped conditions), including the surficial (bioturbation) zone. As dissolved COCs move upward through the cap through advection and diffusion, they can undergo degradation while at the same time partitioning onto the solid phase. Bioturbation mixes the surface layer, further reducing surface concentrations. The UT model calculates COC concentrations in the bioturbation zone as a balance between the flux from the underlying chemical isolation layer, the flux associated with bioturbation processes, and the flux leaving the benthic boundary layer and entering the overlying water column.

Details on the UT model structure, its underlying theory, and the governing equations, including the analytical steady-state solution, are provided in Lampert and Reible (2009). Additional details on other similar one-dimensional models of sediment caps are provided in Go et al. (2009) and the USACE/EPA capping technical guidance document (refer to Appendix B of Palermo et al. 1998).

B2-2.2 Approach

The UT model was used to predict steady-state COC concentrations at the surface of the cap for assessing preliminary engineered sand cap design options and long-term cap effectiveness in nearshore areas. The general approach used to perform the modeling is outlined below:

- Initial modeling was performed looking at current Site conditions to assess the appropriateness of the best-estimate literature values for the parameters that describe the various physical processes occurring at the Site (based on observed porewater cation concentration profiles). The model was then calibrated to develop estimates of the parameters that describe the various chemical and biological processes occurring at the Site (based on observed porewater COC concentration profiles. The details of the approach and results from this modeling are provided in Section B2-3.3.

- To evaluate the long-term effectiveness of the engineered sand cap, the calibrated model was configured to represent preliminary cap design and projected changes in groundwater flux in the sediment areas that would occur following construction of the remedy. Steady-state sediment porewater COC concentrations modeled within the upper zone of the cap were then compared to PRGs for the two most mobile Site COCs—naphthalene and benzene. The details of the approach and results from this component of the chemical isolation layer modeling are provided in Section B2-4.3.

B2-3 Initial Modeling

B2-3.1 Approach

The UT model was used in this FS evaluation to help quantify the combined effects of a range of physical processes that occur in the Site sediments. This was accomplished by configuring the model to simulate measured concentration profiles of cations, which behave largely as non-reactive tracers at the Site.

The model coefficients were specified based on Site-specific data, where available, or literature values for similar conditions. Since many of the parameters were not readily available for the Site-specific conditions, the best available literature value or typical modeling value was used but there remains a degree of uncertainty. Some of these parameters are fairly well established and exhibited little variability or result in minimal variability of model output (e.g., diffusion coefficients). Other parameters related to particle dynamics may be significant to organic compounds which sorb to sediments, but will not appreciably influence dissolved cations.

Once the parameters were specified, the model simulations were run for cations. Model output was compared to the cation porewater data collected from the nearshore area of the Site (Anchor QEA and Aspect 2012) to see if the model predictions matched the measured vertical profiles of the porewater cation data. The cation simulation has the advantage of being able to exclude degradation reactions (and for the most part partitioning) which impact the COCs, allowing the cation model simulations to focus on applicability of the physical parameters. Given the number of unknown or uncertain parameters, the input parameters in the cation model were not calibrated, but rather the model was used to determine if the best estimates for the unmeasured parameters yield a reasonable match. If so those values would then be carried on to simulations of the COCs.

Based on the acceptability of the cation model prediction, the model was then used to simulate porewater benzene and naphthalene concentrations. Chemical-specific coefficients (diffusivity in water and organic carbon partition coefficients) were changed when the physical/ chemical model was converted from simulating cations to simulating benzene and naphthalene. The UT model was then calibrated to fit the measured porewater benzene and naphthalene profile data (Anchor QEA and Aspect 2012) by increasing degradation rates for these COCs.

B2-3.2 Model Inputs

Specification of input parameters for the current conditions model was based on Site-specific data, such as groundwater flow velocities and porewater benzene and naphthalene concentration profiles, along with information from the literature and experience with modeling other similar sites. Physical parameter model inputs were checked by their use in the cation model and results compared with the Site-specific cation data. Similarly, degradation rates for benzene and naphthalene were determined through calibration of the UT model against measured existing conditions. Details on the development of the various model input parameters are provided in the following sections.

B2-3.2.1 Input Parameters Based on Site Data and Literature

B2-3.2.1.1 Thickness of Model Domain

The sediment thickness evaluated in the current conditions modeling was 40 centimeters (cm; 1.3 feet), which represents the average depth of the greatest COC concentrations observed in the samples collected during the RI in the nearshore area from which cation, benzene, and naphthalene porewater data were collected. The top 8 cm of the modeled thickness was represented as the bioturbation zone. This thickness is typical of the median depth in estuarine systems (Thomas et al. 1995)

B2-3.2.1.2 Initial Porewater Concentrations

The UT model works under the assumption that the overlying surface water constituent concentrations are negligible. While this assumption is appropriate for benzene and naphthalene (given their volatility and low surface water concentrations), the cation data exhibit non-zero concentrations in Site surface water (Table B2-1). To allow for simulation of the porewater cation concentration profiles in the sediment, the concentrations measured within the porewater were corrected to be relative to the surface water concentration (to satisfy the model-assumed zero surface water concentration) and normalized to the concentration at depth using the following equation:

$$C_{N(i)} = \frac{C_{PW(i)} - C_{SW}}{C_{PW(\max)} - C_{SW}}$$

Where:

i = index for depth interval

C_N = the normalized concentration in mg/L

C_{PW} = the concentration in porewater in mg/L

C_{SW} = the concentration in the surface water in mg/L

$C_{PW(max)}$ = the cation concentration collected from the depth of maximum concentration (40 cm average) in mg/L

Table B2-1 – Cation Porewater Concentrations

Depth in cm	Potassium in mg/L	Sodium in mg/L	Calcium in mg/L	Magnesium in mg/L	Average Cation Concentration in mg/L
Original Data					
Surface water	0.9+/-0.0	4.2+/-0.06	9.0+/-0.09	3.4+/-0.04	
0-10	2.2+/-0.41	8.2+/-1.4	21.6+/-3.6	8.2+/-2.2	
40	3.1+/-0.32	15.7+/-1.3	26.4+/-3.5	11.3+/-1.8	
Normalized Data (unitless)					
0-10	0.59+/-0.118	0.35+/-0.12	0.72+/-0.20	0.61+/-0.27	0.57+/-0.19
40	1.00+/-0.14	1.00+/-0.12	1.00+/-0.20	1.00+/-0.23	1.00+/-0.13

Note:
Porewater concentrations are based on nearshore data; average values +/- standard error are shown.

The measured Site porewater cation concentration profiles, including the normalized concentrations used in the UT model, are summarized in Table B2-1. The model input (boundary condition) was set to the normalized concentration at the 40 cm depth, which was equal to 1. The normalized concentrations for the 0 to 10 cm depth interval was averaged across the four individual cations (Table B2-1) were used to calibrate the Site-specific coefficients.

The measured benzene and naphthalene porewater concentrations in each sampled depth interval are summarized in Table B2-2. These data are summarized as the average measured (i.e., not normalized) concentrations at three sampled depths. Table B2-2 was generated using benzene and naphthalene data from near shore surface grab samples (e.g. NS-04-SS) for depth of 0-10 cm and data from nearshore vibracore samples for depths 40 cm and 125 cm. Only the vibracore sample locations with available collocated surface grab sample locations were used in generating Table B2-2. The greatest concentrations are generally observed at 40 cm depth. The average concentrations from the 40 cm sampling depth were used to specify the initial porewater concentration used for the current conditions simulations of these COCs.

Table B2-2 – Benzene and Naphthalene Porewater Concentrations

Depth in cm	Benzene in µg/L	Naphthalene in µg/L
0-10	0.46+/-0.22	1.19+/-0.49
40	200+/-199.9	106.6+/-105.3
125	134.4+/-123.8	3.4+/-1.4

Notes:
Porewater concentrations are based on nearshore data; average values +/- standard error are shown.
For non detects, half of the reporting limit values was used for averaging.
Samples from the depth range of 8 – 12 inches were used for 40 cm depth.
Samples from the depth ranges of 20 – 24 inches and 36 -40 inches were used for 125 cm depth.

B2-3.2.1.3 Groundwater Seepage Velocity

The numerical groundwater flow model developed for the Site was used to calculate groundwater seepage velocities through Site sediments under existing conditions (Table

A-8, in Appendix A). The flow model calculated an average groundwater seepage velocity of 176 centimeters per year (cm/yr) in nearshore areas of the Site, which was used as a base case. These flow calculations were corroborated with Site-specific measurements of lake bed seepage (Table 3.1-3; Anchor QEA and Aspect 2012). Due to the suspicion that an overestimation of groundwater seepage flux may in turn be resulting in an overestimation of COC degradations rates, the current conditions modeling was also conducted using groundwater seepage velocities ranging from 66 to 176 cm/yr. The paired seepage and resultant degradation rates were evaluated as sensitivity cases.

B2-3.2.1.4 Physical Parameters

The selection of various physical parameter values such as boundary layer mass transfer coefficient (K_{bl}) , dispersivity (alpha), particle biodiffusion coefficient (D_{bio}^{p}) and porewater biodiffusion coefficient (D_{bio}^{pw}) in the model is outlined below.

The mechanical dispersion of a chemical through the cap is modeled as a Fickian Diffusion-like process. The dispersion coefficient is related to the product of the groundwater velocity through the cap and a length scale related to the size of the domain considered (Neuman 1990) A value of 4 cm was selected for alpha, the dispersivity coefficient, based on the 40 cm sampling depth, and an estimated 10 percent factor consistent with values from Neuman (1990) for a domain of approximately 1 meter.

The boundary layer mass transfer coefficient dictates the transport at the cap-water interface. Boudreau and Jorgensen (2001), Thidodeaux (1996) and Thibodeaux et al. (2001) present empirical values to estimate this parameter. A common value of 1 centimeter per hour (cm/hr) is frequently used for capping simulations of highly hydrophobic compounds. However, the literature indicates that the mass transfer coefficient is a function of a chemical's hydrophobicity, exhibiting a positive relationship with the partition coefficient (Thibodeaux et al. 2001); therefore, smaller values would be expected for benzene and naphthalene. The input value of 0.33 cm/hr used for the model was selected as a value typical of a compound with partitioning coefficient on the order of 10^3 (Thibodaux et al. 2001).

The process of bioturbation serves to increase the effective diffusion/dispersion coefficient for mass transport. Thomas et al. (1995) and Thibodeaux (1996) provided an extensive review of measured particle biodiffusion coefficient (D_{bio}^{p}) and porewater biodiffusion coefficient (D_{bio}^{pw}) at different locations in the United States. The value of 9 cm^2/yr used in the model for D_{bio}^{pw} is the median value observed in estuarine conditions (Thomas et al. 1995) and consistent with the range of value for marine conditions presented in Thibedeaux (1996). There is less guidance regarding the value of D_{bio}^{p} which was selected to be 100 times D_{bio}^{pw} as suggested by Lampert and Reible (2009, resulting in a value of 900 cm^2/yr. Again this value is consistent with the range of values for marine conditions presented in Thibodeaux (1996).

B2-3.2.2 Partitioning Coefficients

Partitioning of chemicals between the dissolved and sorbed phases is described in the UT model by the chemical-specific equilibrium partition coefficient (K_d) based on the customary $K_d = f_{OC}*K_{OC}$ approach (e.g., Karickhoff 1984), where K_{OC} is the compound's organic carbon partition coefficient and f_{OC} is the organic carbon content of the solid

phase material (i.e., sediment). The log K_{OC} value used in the model for simulation of cations was set to a nominally low value because these species, as tracers, do not readily associate with the particulate phase. In the model, the octanol-water partition coefficient (log K_{OW}) is used to estimate log K_{OC} (log K_{OC} = 0.903*log K_{OW} + 0.094). The partition coefficients (log K_{OW}) used in the current conditions simulations of benzene and naphthalene were 2.13 and 3.29, respectively.

B2-3.2.3 COC Calibration

Benzene and the naphthalene degradation half-lives in surface and near-surface sediments at the Site under existing conditions were estimated by increasing the degradation rate from the base value of zero until the model-predicted concentrations matched the measured Site COC concentration profiles.

B2-3.2.4 Model Input Summary

A full listing of the model input parameters used for simulation of both cations and COCs (benzene and naphthalene) is presented in Table B2-3. This table is divided into sections containing input parameters that are general to each chemical modeled and those that are chemical-specific.

Table B2-3 – UT Model Input Parameters Used in Cation, Benzene, and Naphthalene Calibrations **Sheet 1 of 2**

Model Input Parameters	Value	Notes
Porosity, e	0.4	Typical value for surface and subsurface sediments.
Bioturbation Layer Thickness, h_{bio} in cm	8	Typical value used in cap modeling for marine environments.
Cap Material Type	C	Based on observations of sediment type, the sediment was specified as consolidated (silt or clay) material (C), which causes the model to calculate the effective molecular diffusion coefficient as a function of porosity based on the formulation of Boudreau (1997).
Depositional Velocity, Vdep in cm/yr	0.5	Average depositional velocity based on radionuclide-dated cores (Table 4-3 in Anchor Environmental and Aspect 2004).
Darcy Velocity, Vdar (positive is upwelling) in cm/yr	Base value: 176 Sensitivity Range: 66 - 176	Darcy velocities representative of nearshore conditions. Values are based on results of the calibrated groundwater model combined with local variations in material type (Table A-8, in Appendix A).
Particle Density, ρ_P in g/cm^3	2.5	Typical value for sediment particles (e.g., Domenico and Schwartz 1990).
Biological Active Zone fraction organic carbon, $(f_{oc})_{bio}$	8%	Average value from top 8 cm of the sediments at the Site.
Fraction organic carbon, $(f_{oc})_{eff}$	4%	Average values from sediment depths between 10 and 100 cm at the Site.
Dispersivity, α in cm	Base value: 4	Values were determined through calibration to cation data (10% of modeled depth).
Boundary Layer Mass Transfer Coefficient, Kbl in cm/hr	Base value:0.33	Values were determined through calibration to cation data.

Table B2-3 – UT Model Input Parameters Used in Cation, Benzene, and Naphthalene Calibrations **Sheet 2 of 2**

Model Input Parameters	Value			Notes
Porewater Biodiffusion Coefficient, D_{biopw} in cm^2/yr	900			Parameter represents bioturbation rate applied to dissolved phase. Typical value used for capping design of marine environments based on Thibodeaux (1996).
Particle Biodiffusion Coefficient, D_{biop} in cm^2/yr	9			Parameter represents bioturbation rate applied to particulate phase. Typical value used for capping design as 1% of Porewater Biodiffusion Coefficient.
Modeled depth in cm	40			Based on average depth of greatest porewater concentrations observed.
Chemical-Specific Parameters	**Cations**	**Naphthalene**	**Benzene**	**Notes**
Contaminant Initial Porewater Concentration, C_0 in µg/L	1	106	200	Cation model results are simulated in normalized space relative to the surface water concentration; therefore, the initial C_0 value was set to 1 (see Section B2-3.2). Porewater values for naphthalene and benzene are nearshore averages reported for deeper subsurface sediments (40 cm).
Organic Carbon Partition Coefficient, log K_{OW}	-1	3.29	2.13	Typical values from literature.
Colloidal Organic Carbon Partition Coefficient, log K_{DOC} in log L/kg	NA	NA	NA	Partitioning to dissolved organic carbon (DOC) was not considered as it is generally not important for cations or the relatively less sorptive contaminants (i.e., naphthalene and benzene) evaluated in the model.
Colloidal Organic Carbon Concentration, r_{DOC} in mg/L	NA	NA	NA	
Water Diffusivity, D_w in cm^2/sec	2.5E-05	4.7E-06	6.0E-06	Cation values estimated using correlation identified from Schwarzenbach et al. (1993), relating diffusivity to a compound's molecular weight. Benzene and naphthalene values from Lyman et al. (1990).
Undifferentiated chemical and biological degradation half life, λ_1 in days	0	Base value: 7 Sensitivity range: 7 - 28	Base value: 5	Cation half-life set to 0 to represent no degradation. Values for benzene and naphthalene determined through calibration.

Note: NA = not applicable

B2-3.3 Results of Initial Modeling

The model-predicted cation concentration is in general agreement with the average measured cation depth profile (Figure B2-2). The model results generally reproduce the pattern of decreasing cation concentration as the porewater nears the surface, but slightly underestimates the cation concentration in the 0 to 10 cm depth. The target normalized cation concentration for this depth is 0.57 +/- 0.15, while the model results predict an average concentration of 0.42; this would indicate that the effect of physical processes related to dispersive mixing (including bioturbation) and exchange with the surface water have been overestimated. Reducing some of the mixing related coefficients can produce a better match, for example reducing the porewater biodiffusion coefficient to a range more appropriate for a less dynamic setting, such as a freshwater lake (approximately 100 cm^2/yr), produces an average concentration of 0.58; however, using physical mixing parameter values that overestimate the reduction of cation concentration in the sediment column will allow for conservative values of the degradation rates to be generated in the subsequent benzene and naphthalene calibration.

The best-estimate values for surface exchange coefficient , dispersivity, and biodiffusion were retained in the cation model and then used in the model calibration for benzene and naphthalene. For the naphthalene calibration a range of groundwater seepage velocities were used, in addition to the base value of 176 cm/yr for nearshore areas. To reproduce the measured porewater benzene and naphthalene concentration profiles, use of non-zero degradation rates in the model was required; this was achieved by using the previous values for dispersive mixing and surface exchange from the cation model, modifying fixed chemical-specific coefficients and adjusting the degradation rates for benzene and naphthalene to calibrate.

Degradation rates for benzene and naphthalene estimated through the calibration process are represented by half-life values of 5 days and 7 days (range of 7 to 36 days for sensitivity cases), respectively. As shown on Figure B2-3, the modeled concentration profiles of naphthalene generally fit the measured values, although porewater concentration are slightly overestimated (a target of 1.19 µg/L in the 0 to 10 cm layer, and model prediction of 1.89 µg/L). Recognizing that these values are on the low-end (higher degradation rate) of literature-based (Chung and King, 1991 and Heitkamp, et. al., 1987) values for half-lives (but are not out of the range of what has been observed), the decision was made not to further decrease the half-lives to force a better fit. Due to suspicion that possible overestimation of the groundwater seepage lead to overestimation of degradation rates, a range of calibrated degradation rates corresponding to a range of input groundwater seepage (range 66 to 176 cm/yr) were computed (shown in Figure B2.4). All the seepage rate/degradation rate combinations resulted in an average porewater naphthalene concentration in the 0 to 10 cm layer of approximately 1.9 µg/L.

Even with a slight overestimation of the physical mixing related reduction in concentration, as noted in the cation simulation, without degradation, the benzene and naphthalene models would substantially over-predict (by a factor of 20) the benzene and naphthalene concentrations measured in the porewater near the sediment surface. The difference in the magnitude of cation (approximately a 50 percent reduction) and COC concentrations (approximately a 99 percent reduction) decline as they approach the

surface provides strong evidence that reduction in contaminant concentration is much more than simple mixing and dilution with surface water, and that contaminant degradation must be occurring in the sediment.

B2-2 Capping Evaluation

B2-4.1 Model Application Approach

Following the calibration process described in Section B2-3, the UT model was used to assess the performance of the chemical isolation component of the engineered sand cap included in the remedial alternatives (Figure 6-1 of main FS report), taking into account the conditions expected in this area (i.e., cap thicknesses and groundwater seepage velocities). Long-term cap performance was assessed by its ability to meet the following PRGs developed for the Site:

- **1.1 µg/L naphthalene**, based on the conservative ecological screening value developed by EPA Regions 3 and 5. As discussed in Sections 4.3.4 and 7 of the main FS text, the polycyclic aromatic hydrocarbon (PAH) equilibrium screening-level benchmark quotient (ESBQ) applied per EPA guidance, builds on the results of the baseline risk assessment and provides a more accurate determination of the protectiveness of alternative sediment cleanup actions.
- **22 µg/L benzene**, based on the National Water Quality Criteria for human health (water + organisms).

These model evaluations accounted for the effects of upland hydraulic controls and constructed caps under the wide range of remedial alternatives evaluated in this FS. To simplify the assessment, the model input parameters were selected by using conservative values to represent the range of FS alternatives.

B2-4.2 Model Setup and Inputs

B2-4.2.1 Model Domain and Layers

The preliminary engineered sand cap design evaluated for the nearshore sediment area consists of a bioturbation layer (8 cm) over a chemical isolation layer (approximately 1.25 feet sand), which would be placed over native sediment. An erosion protection layer would be required in the nearshore and bank sediment areas. Any added benefit provided by the erosion protection layer in reducing COC migration from the cap is not included in this evaluation. Only the bioturbation and chemical isolation layers were modeled for this FS. Therefore, the cap profile simulated in the model for the nearshore area of the Site consists of a total 1.5-feet (45.7 cm.) sand layer.

B2-4.2.2 Model Input Parameters

Most of the input parameters used for the capping simulations were the same as those developed from the current conditions modeling, as described in Section B2-3.2 and listed on Table B2-3. The only inputs that differed were the initial porewater concentration (boundary condition) at the base of the cap, and those necessary to simulate

the remedial alternatives, which included the thickness and properties of the cap and the groundwater seepage velocity achieved following upland hydraulic controls. These inputs are described in detail in the sections that follow.

B2-4.2.2.1 Initial Porewater Concentrations

The measured surface sediment (0 to 10 cm) porewater concentrations from Table B2.2 were used for model inputs representing the porewater concentration entering the bottom boundary of the cap. The values are 0.46 µg/L for benzene and 1.19 µg/L for naphthalene.

B2-4.2.2.2 Groundwater Seepage Velocity

As discussed previously, results from the groundwater flow model were used to calculate the average groundwater seepage velocities in the nearshore and offshore areas (Table A-8, in Appendix A). The magnitude of the estimated groundwater velocities was dependent on the distance from shore and the remedial alternative selected for the modeling evaluation. In the nearshore area, the average predicted groundwater velocity is 147 cm/yr when upland caps are considered[1].

B2-4.2.2.3 Type of Material

Sand is used for cap material; therefore, for the cap material type in the model "G", indicating granular, was used. Even though the model was calibrated on native sediments composed of silts and clay, the model can be readily used to simulate granular cap material performance since the only term in the model that is affected by the material type is the effective diffusion coefficient. As observed by the differences between cation calibration and COC (benzene and naphthalene) calibration, for COCs the bigger driver for contaminant reduction is not diffusion but degradation. All the other parameters are same as calibrated values.

B2-4.2.2.4 Model Input Summary

The complete set of input values used in the capping evaluations, including those described above, is provided in Table B2-4. The inputs are divided into the following two categories based on the processes they characterize:

- Cap properties, which include physical properties of the evaluated capping material; and
- Chemical-specific properties.

[1] Predicted Darcy discharge velocities for the groundwater model runs representative of an upland capping alternative were used in offshore and nearshore sediment cap modeling; therefore, additional flux reductions provided by funnel and gate system hydraulic controls were not included in the model.

Table B2-4 – Cap Modeling Input Parameters Used in the Capping Evaluation

Model Input Parameters	Value		Notes
Porosity, e	0.4		Porosity of coarse sand (0.4).
Cap Materials - Granular (G)	G		Based on anticipated cap material type, this input was specified as "Granular material (G)", which causes the model to calculate the effective molecular diffusion coefficient as a function of porosity based on the formulation of Millington and Quirk (1961).
Darcy Velocity, Vdar (positive is upwelling) in cm/yr	Nearshore: 147.1		Average groundwater seepage velocities representative of simulated conditions for each area and alternative based on the Site groundwater flow model (Table A-8, in Appendix A).
Particle Density, ρ_P in g/cm^3	2.5		Typical value for sand particles (e.g., Domenico and Schwartz 1990).
Biological Active Zone fraction organic carbon, $(f_{oc})_{bio}$	8%		Average value from top 10 cm of the sediments at the Site.
Fraction organic carbon, $(foc)_{eff}$	0.1%		Nominal value for sand cap.
Dispersivity, α in cm	4.57		Percent value determined through calibration to average near-shore cation concentrations (10% of model domain length).
Cap thickness in cm	45.7		Sand cap thickness
Chemical-Specific Parameters	**Naphthalene**	**Benzene**	**Notes**
Contaminant Initial Porewater Concentration, C_0 in μg/L	Nearshore: 1.19	0.46	Porewater concentrations represent average values from top 10 cm.

B2-4.3 Results of Cap Modeling Evaluation

The results of the cap chemical transport modeling indicate that the cap evaluated for the nearshore area of the Site, as described previously in Section B2-4.2.1 (i.e., 1.5 feet of sand), is predicted to achieve the PRGs at steady-state. This is not surprising given that the current average porewater concentration in the sampled 0 to 10 cm layer is already near or below the respective PRGs for naphthalene and benzene. The model simulated concentration profile of naphthalene in the cap is presented in Figure B2-5. The model computed concentrations in the upper-portion of the cap (expressed as the concentration of porewater entering the bottom of the bioturbation layer [8 cm] and the vertical averages over the top 10 cm [representing the sampled depth]) were compared to current surface concentrations and PRGs in Table B2-5, and are summarized below.

In the nearshore area, benzene and naphthalene concentrations in the top 10 cm of the cap are predicted to be nearly 100 times less than the current porewater concentrations in the surface sediment. The average porewater concentrations at the base of the bioturbation layer (8 cm depth) are predicted to be for naphthalene more than 50 times less and for benzene more than 100 times less than the current porewater concentrations in the surface sediment. For both depths, the predicted concentrations are well below the PRGs, by factors of an order of magnitude or more.

Table B2-5 – Model-Predicted Vertical Average Concentrations for Cap Evaluation

Modeled Area	Chemical	PRG in µg/L[1]	Current Surface (0-10 cm) Porewater Concentration in µg /L	Model-Predicted Average Concentration in µg /L	
				at 8 cm	0-10 cm
Nearshore (1.5-foot sand cap)	Naphthalene	1.1	1.19	0.017	0.012
	Benzene	22	0.46	0.0032	0.0026

Note:
[1] PRG for naphthalene is based on ecological risk criteria. PRG for benzene is based on a human health standard.

B2-4.4 Sensitivity Analyses

Several of the model input parameters have uncertainty/variability associated with them, such as initial COC concentrations, groundwater seepage velocity, degradation rate, and the physical attenuation parameters that were calibrated (i.e., dispersion and Kbl).

The porewater concentrations computed at various depths are linearly a function of the initial concentration specified; doubling the initial concentration doubles the computed concentration at all depths. Given the reduction in relative porewater concentration determined by the model, initial porewater concentrations at the sediment/cap interface could be 106 µg/L for naphthalene and 3,900 µg/L for benzene, and the concentrations in the 0 to 10 cm layer would still meet the respective PRG.

Given the very low initial concentration of benzene in porewater compared to the PRG, only naphthalene was used in the sensitivity analyses. The model input parameter sets used in these sensitivity analyses and the results of the sensitivity analyses are listed in Table B2-6.

Table B2-6 – Sensitivity Analyses Input Parameters and Results

	Naphthalene Concentration (µg/L)	
	avg. 0 -10 cm	**at 8 cm**
Base Model	0.0124	0.0171
Seepage Velocity		
147 cm/yr (base)	0.0124	0.0171
100 cm/yr	0.0036	0.0048
200 cm/yr	0.0288	0.0397
300 cm/yr	0.0707	0.0981
Boundary Layer Mass Transfer Coefficient, Kbl		
0.33 cm/hr (base)	0.0124	0.0171
0.2 cm/hr	0.0131	0.0176
0.5 cm/hr	0.0119	0.0169
1 cm/hr	0.0114	0.0164
Dispersivity, α		
4.57 cm (base; 10%)	0.0124	0.0171
2.28 cm (5%)	0.0071	0.0093
6.85 cm (15%)	0.0169	0.0252
9.14 cm (20%)	0.0236	0.0336
Degradation Half-life		
7 days (base)	0.0124	0.0171
14 days	0.0514	0.0709
21 days	0.0888	0.1223
28 days	0.1197	0.1649
Cap Thickness		
45.7 cm (base; 1.5 ft)	0.0124	0.0171
40 cm	0.0193	0.0257
30 cm	0.0445	0.0600
Bioturbation depth		
8 cm (base)	0.0124	0.0171
4 cm	0.0155	0.0267
12 cm	0.0131	0.0195
Porosity		
40% (base)	0.0124	0.0171
30%	0.0233	0.0319
50%	0.0071	0.0098
Porewater Biodiffusion (and particle biodiff *100)		
900 cm^2/yr (base)	0.0124	0.0171
100 cm^2/yr	0.0183	0.0271
300 cm^2/yr	0.0162	0.0236
1,800 cm^2/yr	0.0100	0.0129

Compared to current surface naphthalene porewater concentrations, the model results for sensitivity cases are still at least 10 times lower in all instances. Similarly, compared to the PRGs, the results from the sensitivity simulations based on alternate parameter sets are generally 10 times lower than the PRGs.

Most of the parameters used in the sensitivity analysis exhibited relative low influence, especially the results in comparison to the PRG. This may be due to the concentration reductions observed being more a factor of degradation rather than sorption reactions with the cap material. The three input parameters which exhibited the most influence were the cap thickness, the seepage velocity, and the degradation half-life. These parameters are related in that they determine how many half-lives the COCs will remain within the cap. The cap thickness and seepage velocity are fundamental in the determination of the residence time of the chemical within the cap, while the degradation half-life determines the rate at which the chemical breaks down.

As noted earlier in the COC calibration, there is an interdependency of groundwater seepage flux with degradation. In the calibration, as one increases the other follows. Various combinations of groundwater seepage and degradation yielding acceptable calibrations were developed and these were then used in capping scenarios. When considered together the individual effects of groundwater seepage velocity and degradation rates are significantly reduced, indicating that these two parameters each may have uncertainty, and calibrating them together to a Site-specific concentration profile reduces the overall modeling generated variability (Table B2-7).

Table B2-7 – Sensitivity for Paired Calibration of Seepage Velocity and Degradation Rate

Darcy Velocity (cm/yr)	Degradation Half-Live (days)	Napthphalene Concentration (µg/L)	
		at 8 cm	0-10 cm average
55	36	0.038	0.03
73	21	0.027	0.021
92	14	0.024	0.017
110	10.5	0.02	0.015
125	8.8	0.019	0.014
147	7	0.017	0.012

B2-5 References for Appendix B2

Anchor Environmental and Aspect, 2004, Draft Final, Risk Assessment/Feasibility Study, Port Quendall Terminals Site, October 2004.

Anchor QEA and Aspect, 2012, Remedial Investigation Report, Quendall Terminals Site, Renton, Washington, Prepared for U.S. Environmental Protection Agency, Region 10, on behalf of Altino Properties, Inc and J.H Baxter & Company, March 2012.

Boudreau, B., 1997, Diagenetic Models and Their Implementation: Modeling Transport Reactions in Aquatic Sediments, Springer-Verlag, New York.

Boudreau, B., and Jorgensen, B., 2001, The Benthic Boundary Layer, Oxford University Press, New York.

Chung, W.K. and King, G.M., 1999, Biogeochemical transformations and potential polyaromatic hydrocarbon degradation in macrofaunal burrow sediments, Aquatic Microbial Ecology, Vol 19, p. 285

Domenico, P.A. and F.W. Schwartz, 1990, Physical and Chemical Hydrogeology, John Wiley & Sons, New York.

EPA, 2005, Contaminated Sediment Remediation Guidance for Hazardous Waste Sites, OSWER Publication 9355.0-85, EPA, Office of Solid Waste and Emergency Response, http://www.epa.gov/superfund/resources/sediment/guidance.htm.

Go, J., D.J. Lampert, J.A. Stegemann, and D.D. Reible, 2009, Predicting contaminant fate and transport in sediment caps: Mathematical modeling approaches, Applied Geochemistry 24(7):1347-1353.

Heitkamp, M.A., Freeman, J.P., and Cerniglia, C.E., 1987, Naphthalene Biodegradation in environmental Microcosms: Estimates of Degradation rates and Characterization of Metabolites, Applied and Environmental Microbiology, Vol 53, p 129

Karickhoff, S.W, 1984, Organic pollutant sorption in aquatic system, J. Hydr. Eng. 110:707-735.

Lampert, D. J. and D. Reible, 2009, An Analytical Modeling Approach for Evaluation of Capping of Contaminated Sediments. Soil and Sediment Contamination: An International Journal, 18:4, 470-488.

Lyman, W.J, W.F. Reehl, and D.H. Rosenblatt, 1990, Handbook of Chemical Property Estimation Methods. American Chemical Society, Washington, D.C.

Millington, R.J., and J.M. Quirk, 1961, Permeability of porous solids, Trans. Far. Soc. 57, 1200–1207.

Neuman, S.P., 1990, Universal Scaling in Geologic Media", Water Resources Research, 26:8, 1749-1758.

Palermo, M., S. Maynord, J. Miller, and D. Reible, 1998, Guidance for In-Situ Subaqueous Capping of Contaminated Sediments, EPA 905-B96-004, Great Lakes National Program Office, Chicago, Illinois.

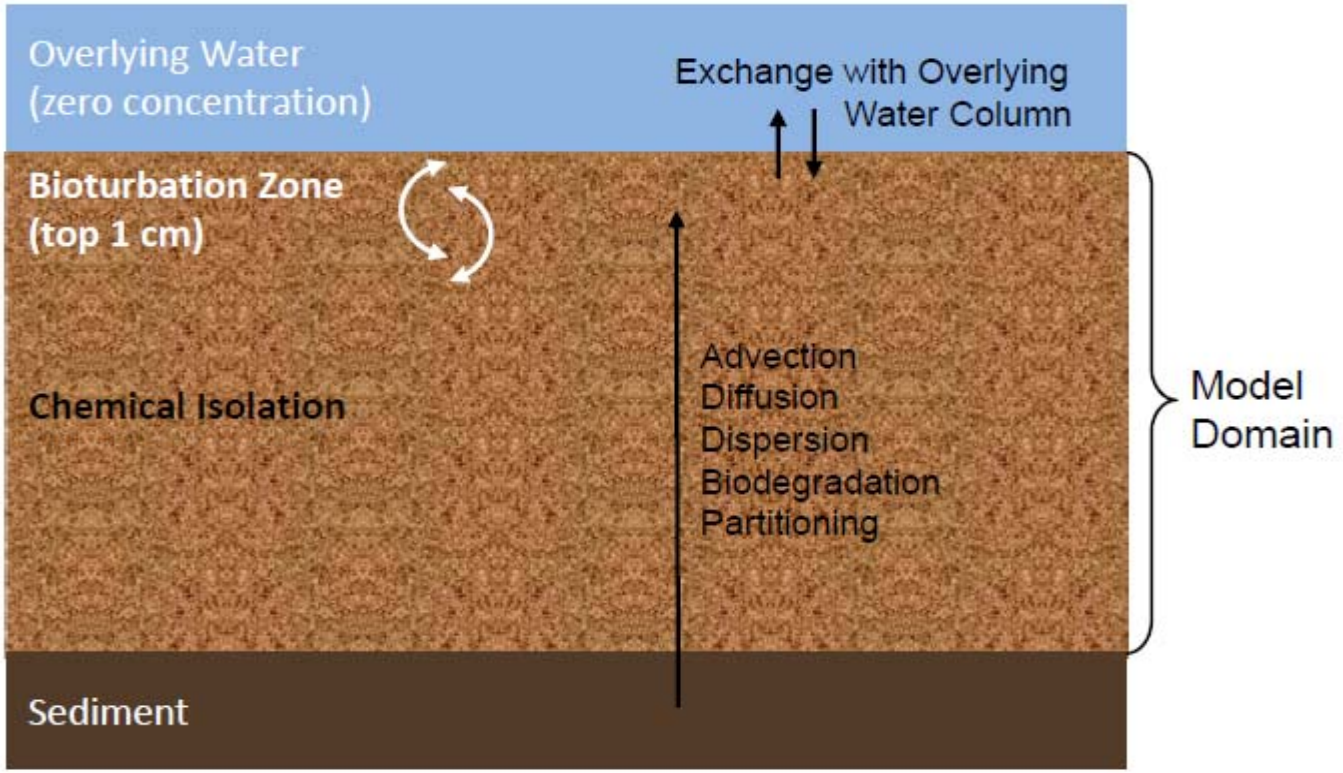
Reible, D., 2012, Model of 2 Layer Sediment Cap, Description And Parameters for Active Cap Layer Model v 4.1, Accessed online at: http://remediation.cetco.com/LeftSideNavigation/TechnicalInfo/TechnicalReferences/tabid/1381/Default.aspx - download TR-843b

Schwarzenbach, R.P., P.M. Gschwend, and D.M. Imboden, 1993, Environmental Organic Chemistry, John Wiley & Sons, Inc.

Thibodeaux, L.J., K.T. Valsaraj, and D.D. Reible, 2001, Bioturbation-Driven Transport of Hydrophobic Organic Contaminants from Bed Sediment, Environmental Engineering Science 18(4):215-223.

Thibodeaux, L.J., 1996, Environmental Chemodynamics: Movement of chemicals in air, water and soil, John Wiley & Sons, New York, New York.

Thomas, S.R., Matisoff, G, McCall, P.L. and Wang, X., 1995. Models for Alteration of Sediments by Benthic Organisms, Project 92-NPS-2, Water Environment Research Foundation, Alexandria, Virginia.



Not to scale.

Figure B2-1
Schematic of Model Configuration and Processes
Quendall Terminals Feasibility Study Report
Renton, Washington

ARCADIS

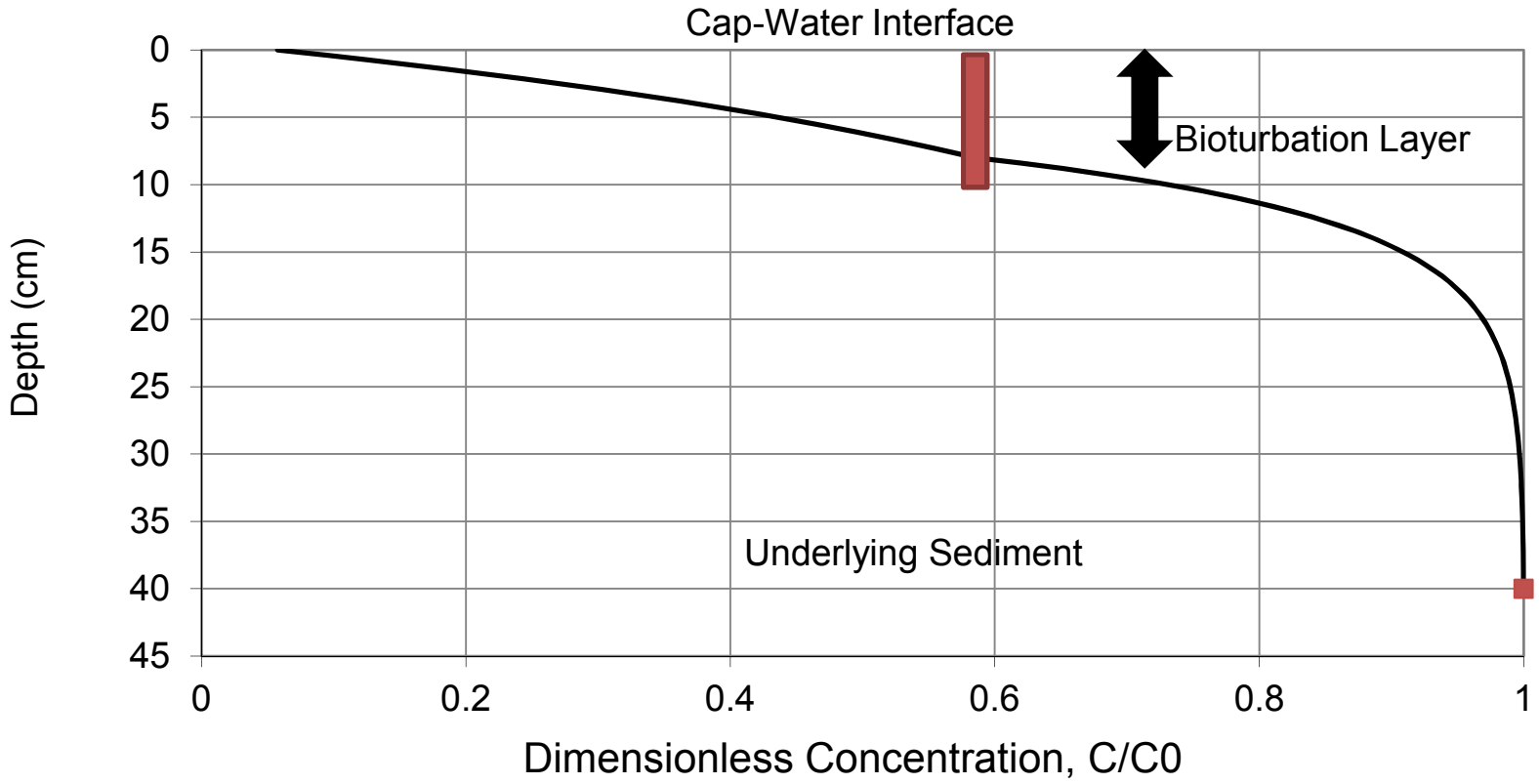


Figure B2-2
Cation Normalized Concentration Profile in Current Sediment Conditions
Quendall Terminals Feasibility Study Report
Renton, Washington

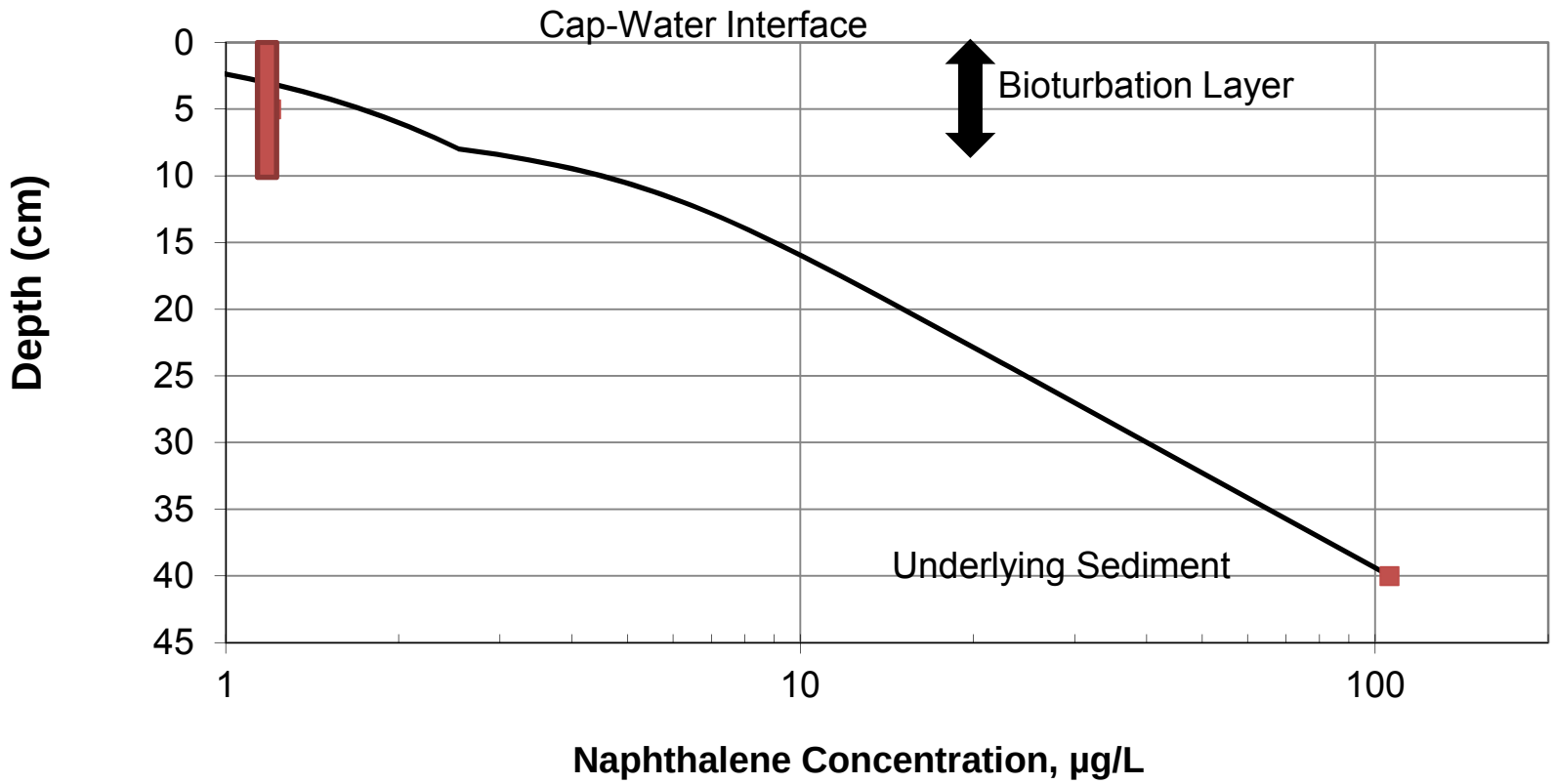


Figure B2-3
Naphthalene Concentration Calibration to Current Sediment Conditions
Quendall Terminals Feasibility Study Report
Renton, Washington

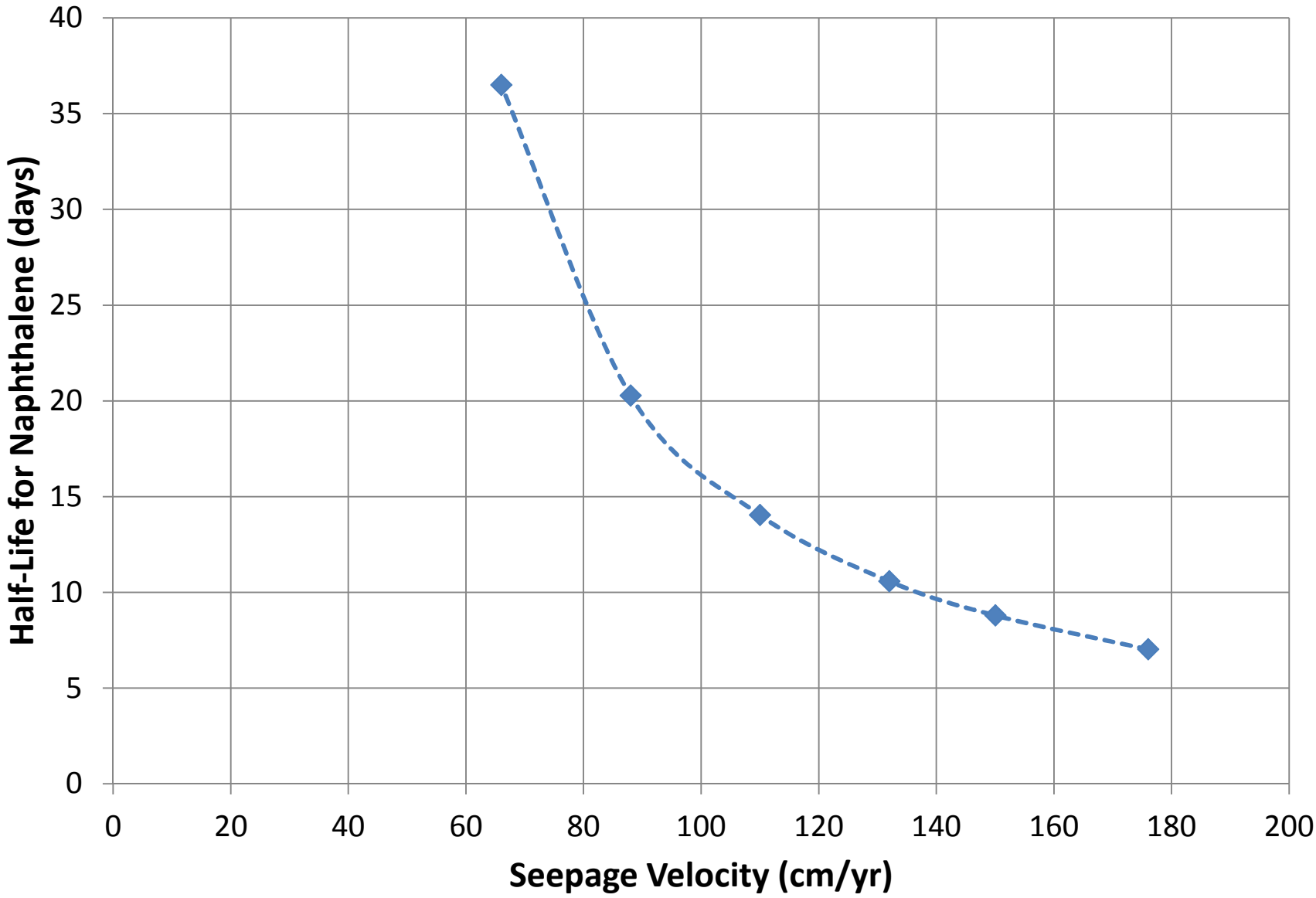


Figure B2-4

Naphthalene Calibration - Relationship of Degradation Half-life to Seepage Velocity

Quendall Terminals Feasibility Study Report

Renton, Washington

ARCADIS

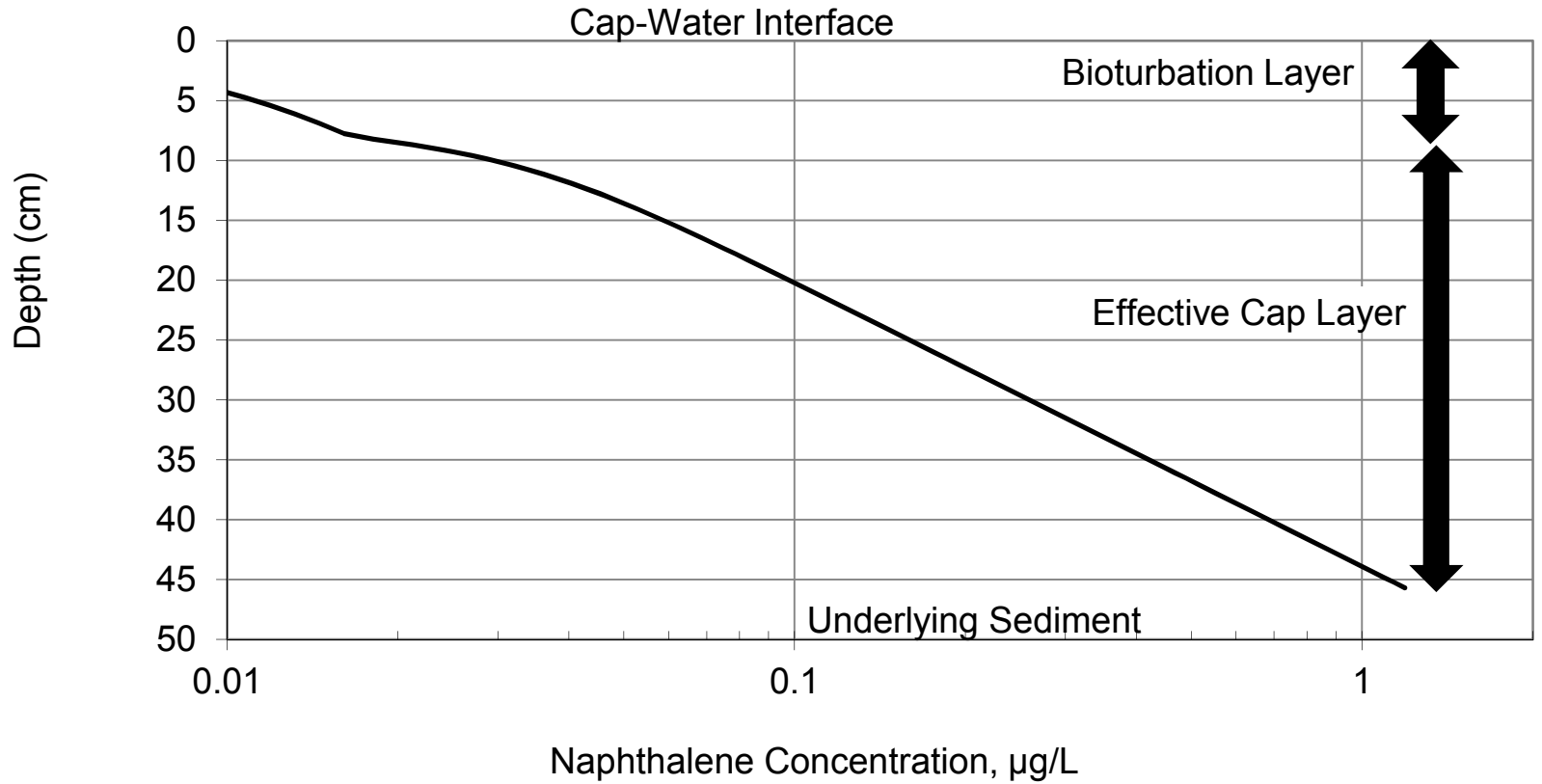


Figure B2-5
Simulated Naphthalene Concentration Profile in Cap
Quendall Terminals Feasibility Study Report
Renton, Washington

Attachment 1 of Appendix B2 - Sediment Porewater Analytical Data

Quendall Terminals
Renton, Washington

Sample Location	Sample Name	Date	Magnesium µg/l	Sodium µg/l	Calcium µg/l	Potassium µg/l	Benzene µg/l	Naphthalene µg/l
NS-04-SS	NS-04-PW	6/16/2009	--	--	--	--	< 0.2 U	< 0.83 U
NS-04-SS	NS-04-PW-0-4	6/16/2009	5650	7625	16250	2875	--	--
NS-04-SS	NS-04-PW-8-12	6/16/2009	7645	15730	26950	4950	--	--
NS-04-VC	NS-04-VC-0-4	6/25/2009	--	--	--	--	< 1 U	< 0.83 U
NS-04-VC	NS-04-VC-12-16	6/25/2009	--	--	--	--	--	--
NS-04-VC	NS-04-VC-20-24	6/25/2009	--	--	--	--	4	2.23
NS-04-VC	NS-04-VC-28-32	6/25/2009	10509	20340	18758	2260	--	--
NS-04-VC	NS-04-VC-36-40	6/25/2009	--	--	--	--	2.6	0.844
NS-04-VC	NS-04-VC-44-48	6/25/2009	15504	23712	27360	3078	--	--
NS-04-VC	NS-04-VC-8-12	6/25/2009	--	--	--	--	< 1 U	< 0.83 U
NS-05-SS	NS-05-PW	6/16/2009	--	--	--	--	< 1 U	0.974
NS-05-SS	NS-05-PW-0-4	6/16/2009	6815.9	6741	23326	4280	--	--
NS-05-SS	NS-05-PW-8-12	6/16/2009	9590.4	10692	38664	5292	--	--
NS-05-VC	NS-05-VC-0-4	6/25/2009	--	--	--	--	1.5	332 J
NS-05-VC	NS-05-VC-20-24	6/25/2009	--	--	--	--	19	17.6
NS-05-VC	NS-05-VC-28-32	6/25/2009	5702.8	14734	10918	2226	--	--
NS-05-VC	NS-05-VC-36-40	6/25/2009	--	--	--	--	< 1 U	7.01
NS-05-VC	NS-05-VC-44-48	6/25/2009	6741	15836	11984	2461	--	--
NS-05-VC	NS-05-VC-48-60	6/25/2009	--	--	--	--	< 1 U	0.568 J
NS-05-VC	NS-05-VC-8-12	6/25/2009	--	--	--	--	--	844 J
NS-05-VC	NS-55-VC-48-60	6/25/2009	--	--	--	--	0.6 J	2.53
NS-06-SS	NS-06-PW	6/17/2009	--	--	--	--	< 0.2 U	< 0.83 U
NS-06-VC	NS-06-VC-0-4	6/30/2009	--	--	--	--	< 1 U	< 0.83 U
NS-06-VC	NS-06-VC-20-24	6/30/2009	--	--	--	--	< 1 UJ	< 0.83 U
NS-06-VC	NS-06-VC-8-12	6/30/2009	--	--	--	--	< 1 UJ	< 0.83 U
NS-07-SS	NS-07-PW	6/16/2009	--	--	--	--	< 0.2 U	< 0.83 U
NS-07-SS	NS-07-PW-0-4	6/16/2009	6684.7	7004	19982	1339	--	--
NS-07-SS	NS-07-PW-8-12	6/16/2009	8137	11639	21630	1751	--	--
NS-07-VC	NS-07-VC-0-4	6/30/2009	--	--	--	--	< 1 U	< 0.83 U
NS-07-VC	NS-07-VC-20-24	6/30/2009	--	--	--	--	--	< 0.83 U
NS-07-VC	NS-07-VC-28-32	6/30/2009	19470	26070	42460	4070	--	--
NS-07-VC	NS-07-VC-36-40	6/30/2009	--	--	--	--	--	< 0.83 U
NS-07-VC	NS-07-VC-44-48	6/30/2009	22230	24570	46917	4680	--	--
NS-07-VC	NS-07-VC-8-12	6/30/2009	--	--	--	--	< 1 U	< 0.83 U
NS-08-SS	NS-08-PW	6/17/2009	--	--	--	--	2.1	4.2
NS-08-SS	NS-08-PW-0-4	6/17/2009	21527	16789	41715	2060	--	--
NS-08-SS	NS-08-PW-8-12	6/17/2009	21726	17748	42738	2244	--	--
NS-08-VC	NS-08-VC-0-4	6/29/2009	--	--	--	--	5.7	2.5
NS-08-VC	NS-08-VC-20-24	6/29/2009	--	--	--	--	1000	5.73
NS-08-VC	NS-08-VC-28-32	6/29/2009	28200	24000	53280	3600	--	--
NS-08-VC	NS-08-VC-36-40	6/29/2009	--	--	--	--	--	8.36
NS-08-VC	NS-08-VC-44-48	6/29/2009	22815	24219	43524	3744	--	--
NS-08-VC	NS-08-VC-8-12	6/29/2009	--	--	--	--	1200	6.34
NS-09-SS	NS-09-PW	6/17/2009	--	--	--	--	< 0.2 U	2.26
NS-09-SS	NS-09-PW-0-4	6/17/2009	6252.1	6386	20394	2369	--	--
NS-09-SS	NS-09-PW-8-12	6/17/2009	5050.2	9120	12996	2850	--	--
NS-09-SS	NS-59-PW	6/17/2009	--	--	--	--	--	< 0.83 U
NS-09-VC	NS-09-VC-0-4	6/24/2009	--	--	--	--	140	2.6
NS-09-VC	NS-59-VC-0-4	6/24/2009	--	--	--	--	--	830 J
NS-12-SS	NS-12-PW	6/15/2009	--	--	--	--	< 0.2 U	< 0.83 U
NS-12-SS	NS-12-PW-0-4	6/15/2009	4091.6	5936	12084	1272	--	--
NS-12-SS	NS-12-PW-8-12	6/15/2009	5200.2	10593	15408	1605	--	--
NS-12-VC	NS-12-VC-0-4	6/29/2009	--	--	--	--	< 1 U	1.45
NS-12-VC	NS-12-VC-20-24	6/29/2009	--	--	--	--	--	< 0.83 U
NS-12-VC	NS-12-VC-36-40	6/29/2009	--	--	--	--	--	< 0.83 U
NS-12-VC	NS-12-VC-44-48	6/29/2009	9711	18252	17784	3276	--	--
NS-12-VC	NS-12-VC-8-12	6/29/2009	--	--	--	--	< 1 U	0.719 J
NS-13-SS	NS-13-PW	6/16/2009	--	--	--	--	< 0.2 U	< 0.83 U
NS-13-SS	NS-13-PW-0-4	6/16/2009	6386	6798	17407	1339	--	--
NS-13-SS	NS-13-PW-8-12	6/16/2009	9548.1	11948	21836	1854	--	--
NS-13-VC	NS-13-VC-0-4	6/25/2009	--	--	--	--	< 1 U	< 0.83 U
NS-13-VC	NS-13-VC-20-24	6/25/2009	--	--	--	--	48	< 0.83 U
NS-13-VC	NS-13-VC-28-32	6/25/2009	13589	17655	27499	2889	--	--
NS-13-VC	NS-13-VC-36-40	6/25/2009	--	--	--	--	< 1 U	< 0.83 U
NS-13-VC	NS-13-VC-44-48	6/25/2009	15260	20056	29103	3706	--	--
NS-13-VC	NS-13-VC-8-12	6/25/2009	--	--	--	--	2.2	< 0.83 U
NS-14-SS	NS-14-PW	6/17/2009	--	--	--	--	< 1 U	
NS-14-SS	NS-14-PW-8-12	6/17/2009	3619	4290	16940	1650	--	--
NS-14-VC	NS-14-VC-8-12	6/24/2009	--	--	--	--	--	< 0.83 U

Notes:
1. These are the sediment samples between the inner harborline and the shoreline and outside the DNAPL areas.
2. Only the subsurface sample which have corresponding surface sample data are presented here and used in model inputs.

APPENDIX B3

Cap Armor Layer Evaluation

Table of Contents

B3-1 Introduction B3-1

B3-2 Methodology B3-1

B3-3 Analysis of Wave Action and Propeller Wash B3-1

B3-3.1 Water Levels B3-1

B3-3.2 Evaluation of Wind-Induced Waves B3-1

B3-3.3 Evaluation of Vessel-Induced Waves B3-5

B3-3.4 Evaluation of Propeller-Wash Velocities B3-5

B3-4 Armor Size Evaluation B3-7

B3-4.1 Cap Armor Size – Breaking-Wave Zone B3-7

B3-4.2 Cap Armor Extent – Breaking-Wave Zone B3-7

B3-4.3 Cap Armor Size – Non-Breaking-Wave Zone B3-7

B3-4.4 Cap Armor Size – Propeller-Wash Zone B3-8

B3-5 Conclusions B3-8

B3-6 References B3-9

List of Tables

B3-1 Wind Speeds and Fetch B3-3

B3-2 Predicted Wave Height and Period B3-4

B3-3 Maximum Predicted Bed Velocities from Propeller Wash for Various Water Depths B3-6

B3-4 Stable Armor Rock Size and Runup for a 10H:1V Slope within the Breaking-Wave Zone B3-7

B3-5 Stable Sediment Size Below the Breaking-Wave Zone for Propeller-Wash Velocities B3-8

B3-6 Recommended Armor D_{50} Values as Function of Water Depth (based on low water level of 16.7 feet NAVD88) B3-9

List of Figures

B3-1 Sea-Tac Wind Speed Distribution (January 1990–September 2011) ... B3-2

B3-1 Introduction

This appendix summarizes the engineering evaluations conducted to develop a preliminary armor layer design that would promote long-term stability of a sediment isolation cap constructed at the Quendall Terminals Site (Site). The armor layer is intended to protect the chemical isolation layer and underlying contaminated sediments from erosional processes such as waves and propeller wash.

B3-2 Methodology

Screening-level analyses were performed to determine the required particle size and thickness for the sediment cap armor layer to resist erosive forces. Long-term wind data from a nearby wind gage was used to estimate various storm event return periods for the area from a variety of wind directions. These extreme wind speeds, fetch lengths, and average depths were then used to estimate the wave action that will influence the Site. Vessel-induced waves and propeller-wash forces were also evaluated. Predicted wave heights were used to estimate stable rock sizes for the potential cap areas as a function of water depth.

Engineering evaluations were conducted in accordance with guidance developed by the U.S. Army Corps of Engineers (USACE). In addition, the U.S. Environmental Protection Agency's (EPA) Contaminated Sediment Remediation Guidance for Hazardous Waste Sites (EPA 2005) states that, *"[t]he design of the erosion protection features of an in-situ cap (i.e., armor layers) should be based on the magnitude and probability of occurrence of relatively extreme erosive forces estimated at the capping site. Generally, in-situ caps should be designed to withstand forces with a probability of 0.01 per year, for example, the 100-year storm."*

B3-3 Analysis of Wave Action and Propeller Wash

B3-3.1 Water Levels

The elevation of Lake Washington is controlled by the Lake Washington Ship Canal, which connects Lake Washington to Lake Union and Puget Sound. As a result, ordinary low and ordinary high water lake elevations are 16.67 and 18.67 feet NAVD88, respectively, for this portion of Lake Washington.

B3-3.2 Evaluation of Wind-Induced Waves

The wave conditions near the Site were estimated by applying wind wave growth formulas to wind data from Sea-Tac International Airport (Sea-Tac) in Seattle,

Washington (NOAA, WBAN #24233). Data were obtained through the National Climatic Data Center (http://www.ncdc.noaa.gov/oa/ncdc.html) for the time period of interest. The wind data encompassed hourly wind speeds (2-minute averages) between the years of 1990 and 2011. Figure B3-1 illustrates a wind rose (frequency of occurrence based on wind speed and wind direction) for the wind data over the period of record. The wind data were used to predict extreme wind speed values for 2-, 10-, 20-, 50-, and 100-year return period storm events. The extreme wind speeds were evaluated for 10-degree and 30-degree wind direction bins from true north (e.g., 0 to 10 degrees, 211 to 240 degrees, etc.) that impact the area. The Raleigh distribution was used to develop the extreme wind speeds with R^2 values equal to or greater than 0.87 for all direction bins.

Fetch lengths were measured for each wind directional zone that has the potential for wind waves to develop and impact the shoreline. Fetch measurements were completed based on methodology outlined in the CEM (USACE 2002). These fetch lengths and associated directions are summarized in Table B3-1.

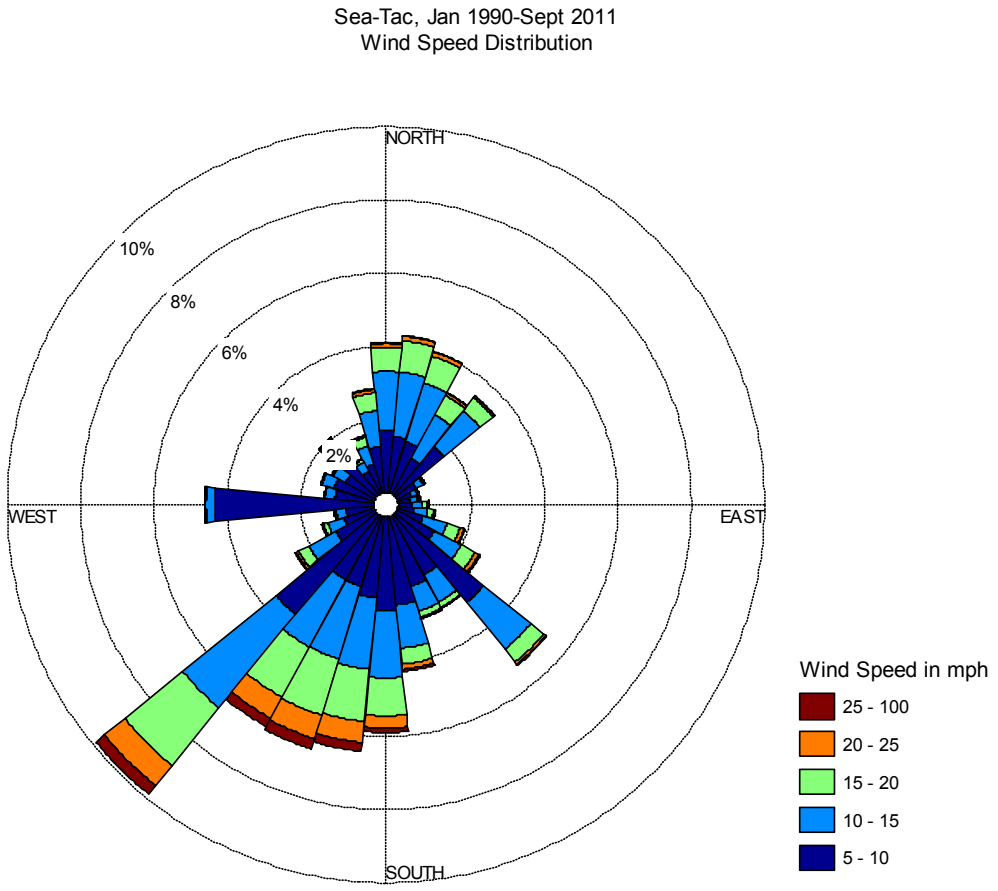


Figure B3-1 – Sea-Tac Wind Speed Distribution (January 1990–September 2011)

Predicted values of wind speed for a range of return periods were used as input into the Automated Coastal Engineering System (ACES) using the Windspeed Adjustment and Wave Growth module (fetch limited) to predict significant wave heights and peak wave periods generated by the extreme winds (USACE 1992). Results of the wave growth analysis are shown in Table B3-2. The highest winds and waves are from the southwest (as shown on Figure B3-1 and in Table B3-1). During a 100-year storm from the southwest, waves are estimated to be 3.5 feet high. Waves from the north (331 to 10 degrees) are also high based on high winds and long fetches. During a 100-year storm from 331 to 360 degrees waves heights are estimated to be 2 feet and from 0 to 10 degrees they are expected to be approximately 1.7 feet.

Table B3-1 – Wind Speeds and Fetch

Wind Direction Zone	Fetch Length in Miles	Water Depth in Feet[1]	Wind Speed as a Function of Return Period in mph				
			2-year	10-year	20-year	50-year	100-year
0 to 10 deg	3.1	60	25	29	31	32	34
11 to 20 deg	1.1	70	25	29	31	33	35
21 to 30 deg	0.7	50	23	28	30	32	33
211 to 240 deg	2.3	90	37	48	52	58	60
241 to 270 deg	0.8	60	25	32	35	38	40
271 to 300 deg	0.5	70	17	22	24	25	27
301 to 330 deg	0.5	60	20	30	32	36	38
331 to 360 deg	1.5	60	28	37	40	44	46

Notes:
1. Average water depth at location where wave is generated (i.e., over the fetch length).

Table B3-2 – Predicted Wave Height and Period

Wind Direction Zone	Return Period									
	2-year		10-year		20-year		50-year		100-year	
	Wave Height in Feet	Wave Period in Seconds	Wave Height in Feet	Wave Period in Seconds	Wave Height in Feet	Wave Period in Seconds	Wave Height in Feet	Wave Period in Seconds	Wave Height in Feet	Wave Period in Seconds
0 to 10 deg	1.1	2.0	1.3	2.2	1.4	2.3	1.5	2.3	1.6	2.4
11 to 20 deg	0.6	1.5	0.8	1.6	0.8	1.7	0.9	1.8	1.0	1.8
21 to 30 deg	0.4	1.3	0.6	1.4	0.6	1.5	0.7	1.5	0.7	1.6
211 to 240 deg	1.8	2.5	2.4	2.9	2.7	3.0	3.3	3.3	3.5	3.4
241 to 270 deg	0.6	1.5	0.9	1.7	1.0	1.8	1.1	1.9	1.2	2.0
271 to 300 deg	0.3	1.1	0.4	1.2	0.5	1.3	0.5	1.3	0.5	1.4
301 to 330 deg	0.4	1.2	0.6	1.5	0.7	1.5	0.8	1.6	0.9	1.7
331 to 360 deg	1.0	1.9	1.5	2.2	1.6	2.	1.8	2.5	2.0	2.5

B3-3.3 Evaluation of Vessel-Induced Waves

A systematic vessel study has not been completed for this evaluation. However, based on Site knowledge it is anticipated that the project aquatic and shoreline areas will be impacted by wakes from passing recreational boats operating offshore in Lake Washington adjacent to the Site.

Design wave heights resulting from wind waves (Section B3-3.2) are expected to be higher than wakes for the Site. To verify this assumption, wake heights were calculated for a representative high performance recreational boat for various vessel speeds at various distances from the project shoreline. Characteristics of this representative vessel are summarized below:

Type of Vessel: Baja Outlaw 23

Propeller Shaft Depth: 2.75 feet

Number of Engines: 1

Engine Horsepower: 375

Propeller Dimensions: 17 inches

This vessel represents a reasonable worst case scenario within Lake Washington for both wake and propeller-wash velocities at the Site, and has been used for similar evaluations at other sites (Parsons and Anchor QEA 2012). If capping is selected as a final remedy at the Site, a more robust vessel survey would be conducted for the project area during remedial design to refine this evaluation in the design phase for this project.

Wake heights were calculated using an analytical method developed by Bhowmik et al. (1991). This method is based on empirical data from 12 different recreational type vessels and is applicable for recreational vessels operating at a speed of between 8 and 45 miles per hour (Bhowmik et al. 1991, Parsons and Anchor QEA 2012). Wake heights were estimated for the representative design vessel over a range of operating speeds and offshore passing distances. Computed wake heights ranged from 0.5 foot to a maximum of 2.2 feet (for a vessel passing 10 feet offshore of the Site). As anticipated, these wake heights are less than the maximum wave height estimated for wind-induced waves (Table B3-2). Therefore, the wind-induced waves were used in the analysis.

B3-3.4 Evaluation of Propeller-Wash Velocities

Proposed caps in deeper water away from the shoreline (water depths greater than 5 feet) may be subject to propeller-induced velocities that will be greater than those created by wind- and vessel-induced waves. Therefore, propeller-wash velocities in these capping areas may be the dominant factor in sizing stable cap material.

To estimate the bed velocity resulting from propeller wash, the Blaauw and van de Kaa (1978) method was used with the characteristics of the design vessel (described in Section B3-3.3).

$$V_b(max) = C_1 U_o D_p / H_p$$

Where:

$V_b(max)$	=	maximum bottom velocity in ft/sec
C_1	=	0.22 for non-ducted propeller
	=	0.30 for ducted propeller
U_o	=	jet velocity exiting propeller in ft/sec
D_p	=	propeller diameter in feet
H_p	=	distance from propeller shaft to channel bottom in feet

The jet velocity exiting a propeller is given by Blaauw and van de Kaa (1978) as

$$U_o = C_2\left(\frac{P_d}{D_p^2}\right)^{1/3}$$

Where:

U_o	=	jet velocity exiting propeller in ft/sec
P_d	=	applied engine power/propeller in Hp
D_p	=	propeller diameter in ft
C_2	=	9.72 for non-ducted propellers
C_2	=	0.68 for ducted propellers

Propeller-wash velocities at the bed for various water depths associated with the proposed capping areas were calculated using the equations above and are summarized in Table B3-3.

Table B3-3 – Maximum Predicted Bed Velocities from Propeller Wash for Various Water Depths

	Applied Engine Power from Design Vessel (Section B3-2.2)			
Water Depth based on Low Lake Level in Feet	**85%**	**75%**	**50%**	**25%**
	Maximum Predicted Bed Velocity in ft/sec			
5.5	4.1	3.9	3.4	2.7
14.5	1.1	1.1	1.0	0.8
16.5	1.0	0.9	0.8	0.7
21.5	0.7	0.7	0.6	0.5
25.5	0.6	0.6	0.5	0.4

B3-4 Armor Size Evaluation

B3-4.1 Cap Armor Size – Breaking-Wave Zone

The ACES Rubble Mound Revetment Design module was used to estimate revetment armor and bedding layer stone sizes, thicknesses, and gradation characteristics required; as well as runup estimates (USACE 1992). Table B3-4 provides the median (D_{50}) rock size that would be stable (limited to no damage) for the given waves in Table B3-2 for a slope of 10H:1V. Table B3-4 also provides the vertical runup height. The vertical runup represents the expected maximum runup using the Ahrens and Heimbaugh method (USACE 1992). The worst case is from direction 211 to 240 degrees with a 5.3-inch armor stone required for caps located within the breaking-wave zone defined in the next section.

Table B3-4 –Stable Armor Rock Size and Runup for a 10H:1V Slope within the Breaking-Wave Zone

Wind Direction Zone	Armor Size D_{50} in Inches	Runup Distance in Feet
0 to 10 deg	2.5	0.8
11 to 20 deg	1.6	0.5
21 to 30 deg	1.2	0.4
211 to 240 deg	5.3	1.6
241 to 270 deg	1.8	0.6
271 to 300 deg	0.8	0.3
301 to 330 deg	1.3	0.4
331 to 360 deg	3.0	0.9

B3-4.2 Cap Armor Extent – Breaking-Wave Zone

The cap armor along the shoreline should extend up slope to the vertical extent of wave runup based on the water level elevation at high water and down slope to a depth that is no longer impacted by the breaking waves at low water (i.e., the breaking-wave zone). The highest runup elevation is estimated by adding the runup height (shown in Table B3-4) to the elevation of ordinary high water at the Site (18.7 feet NAVD88). The lower bound of the armor is estimated by multiplying the significant wave height by 1.5 and subtracting that number for the low water elevation (approximately 16.7 feet NAVD88) (USACE 2002). The upper bound of the intertidal cap armor should be 19.3 feet NAVD88 and the lower bound of the armor should be 11 feet NAVD88 (16.7 feet low water minus 1.5 times the largest wave of 3.52 feet). This would correspond to a water depth of approximately 5.5 feet (based on the low water level).

B3-4.3 Cap Armor Size – Non-Breaking-Wave Zone

Armor stone blanket stability design (USACE 2002) was used to estimate the D_{50} required for the areas below the influence of breaking waves (i.e., approximately elevation 11 feet NAVD88). Gradation was calculated using HQUSACE 1994 method described in the Coastal Engineering Manual (USACE 2002). The proposed armor size is based on the worst case 100-year return period wind direction, which is 211 to 240 degrees (significant wave height is 3.5 feet).

Below the breaking-wave zone (11 feet NAVD88; approximately 5-foot water depth based on low water level) down to an elevation of approximately 1 foot NAVD88 (approximately 15-foot water depth based on low water level), the stable rock size is 0.6 inch. At elevations below 1 foot NAVD88, stable rock sizes are reduced to 0.06 inch (sand).

B3-4.4 Cap Armor Size – Propeller-Wash Zone

Methods presented in the USEPA guidance (Maynord 1998) to evaluate stable sediment size for propeller-wash velocities at the bed (Blaauw and van de Kaa 1978) are based on large ocean-going vessels operating at very slow speeds. Therefore, these methods are not applicable for use with smaller, fast-moving recreational vessels. A more robust analysis to evaluate stable sediment sizes for propeller wash from recreational vessels was conducted to inform capping design for the Fox River (Shaw and Anchor 2007) and Onondaga Lake (Parsons and Anchor QEA 2012) projects. Results from these previous studies were used to estimate stable sediment sizes for the range of bed velocities induced by propeller wash summarized in Table B3-3. Based on characteristics of the design vessel (Section B3-3.3), stable particle sizes for a range of water depths and applied horsepower is summarized in Table B3-5.

Table B3-5 – Stable Sediment Size below the Breaking-Wave Zone for Propeller-Wash Velocities

Water Depth in Feet (based on low water level)	Applied Horsepower in Percent	Median Particle Size (D_{50}) in Inches / Sediment Type
≤ 6	25	0.2 / coarse sand
	50	0.3 / fine gravel
	75	0.4 / fine gravel
	100	0.5 / fine gravel
≥10	25	0.01 / fine sand
	50	0.01 / fine sand
	75	0.01 / fine sand
	100	0.02 / medium sand

B3-5 Conclusions

The proposed capping areas extend from relatively deep water (> 15 feet) to shoreline areas at the Site. These areas are impacted by both wind- and vessel-induced waves and propeller-wash forces. The process that dominated the stable armor/sediment size evaluation is dependent on water depth (i.e., a D_{50} value from the breaking-wave evaluation will influence the stable particle size to a greater degree than propeller-wash forces in shallow water and vice versa in deeper water). Table B3-6 summarizes the recommended median (D_{50}) stable armor/sediment sizes at each water depth based on the above evaluations.

Table B3-6 – Recommended Armor D_{50} Values as Function of Water Depth (based on low water level of 16.7 feet NAVD88)

Water Depth in Feet (based on low water level)	Armor Size D_{50} in Inches	Dominant Process
≤ 5	6.0	Breaking Waves (Sections B3-3.1 and B3-3.2)
≤ 5 and ≥15	0.6	Non-Breaking Waves (Section B3-3.3)
≥15	0.01	Propeller Wash – 75% applied power (Section B3-3.4)

B3-6 References

Bhowmik, N., T. Soong, W. Reichelt, and N. Seddik, 1991, Waves Generated by Recreational Traffic on the Upper Mississippi River System, Illinois State Water Survey, Department of Energy and Natural Resources.

Blaauw, H.G., and E.J. van de Kaa, 1978, Erosion of Bottom and Sloping Banks Caused by the Screw Race of Maneuvering Ships. Paper presented at the 7th International Harbour Congress, Antwerp, Belgium. May 22-26, 1978

EPA, 2005, Contaminated Sediment Remediation Guidance for Hazardous Waste Sites, OSWER Publication 9355.0-85, EPA, Office of Solid Waste and Emergency Response, http://www.epa.gov/superfund/resources/sediment/guidance.htm.

Maynord, S., 1998, Appendix A: Armor Layer Design for the Guidance for In-Situ Subaqueous Capping of Contaminated Sediment. Prepared for the U.S. Environmental Protection Agency (EPA).

Parsons and Anchor QEA, 2012, Onondaga Lake Capping, Dredging, Habitat and Profundal Zone (Sediment Management Unit 8) Final Design. Prepared for Honeywell. March 2012.

Shaw and Anchor, 2007, Lower Fox River 30 Percent Design. Prepared for Fort James Operating Company and NCR Corporation for Submittal to Wisconsin Department of Natural Resources and the U.S. Environmental Protection Agency. November 30.

USACE (U.S. Army Corps of Engineers), 1992, Automated Coastal Engineering System. 1992.

USACE, 2002, Coastal Engineering Manual, Engineer Manual 1110-2-1100, U.S. Army Corps of Engineers, Washington, D.C. (in 6 volumes).

APPENDIX B4

Cap Geotechnical Considerations

Contents

B4-1 Introduction B4-1

B4-2 Subsurface Conditions B4-1

B4-3 Settlement Analyses B4-2

B4-3.1 Conceptual Cap Design Sections B4-2

B4-3.2 Cap-Induced Load B4-2

B4-3.3 Sediment Properties and Layer Thicknesses B4-2

B4-3.4 Settlement Magnitude B4-3

B4-4 Bearing Capacity B4-4

B4-4.1 Method of Analysis B4-4

B4-4.2 Assumptions B4-5

B4-4.3 Bearing Capacity Assessment Results and Conclusions B4-5

B4-5 Seismic Considerations B4-6

B4-6 Considerations for Amended Sand Cap B4-7

B4-7 Conclusions B4-7

B4-8 References B4-8

List of Tables

B4-1 Compressibility Assumptions for Settlement Calculations B4-3

B4-2 Estimated Cap-Induced Total and Differential Settlement B4-4

B4-1 Introduction

This appendix presents a preliminary feasibility-level evaluation of geotechnical considerations in conjunction with remedial alternatives for the Quendall Terminals Site (Site) that include subaqueous capping. These alternatives are discussed in Section 6 of the main text. This appendix provides discussions in regards to cap settlement, bearing capacity during cap construction, and seismic considerations. Conclusions regarding the overall feasibility of subaqueous capping at the Site, and design and construction considerations are provided at the end of this appendix.

B4-2 Subsurface Conditions

Subsurface conditions used for this analysis were based in part on a review of existing geotechnical engineering reports for the Site (Aspect 2009). Geotechnical borings logs and sediment core logs collected as part of the Remedial Investigation (RI) (Anchor QEA and Aspect 2012), as well as laboratory data, and historical geotechnical borings by others (Twelker and Associates 1973, Shannon and Wilson 1997) were also used in assessing subsurface conditions and properties. Figures 3-4, 4-2, 4-3, 4-4, and 4-5 of the main text show cross-sections of soil and sediment lithology. The following major geologic units were encountered at the Site, from the ground surface, or mudline, downward:

- **Soft Sediments.** The uppermost geologic unit consists of soft, dark brown, highly plastic sediments with varying proportions of clay, silt, and peat. Explorations indicate that this layer is 5 to 15 feet thick. Blow counts in this layer were generally 0 to 2 blows per foot. For cap-induced settlement evaluations, the majority of the settlement is expected to occur in this layer.
- **Shallow Alluvium.** This layer is characterized as a loose to medium dense sand with interbedded clay and silt, and has been interpreted to be a Shallow Alluvium layer. The thickness of the Shallow Alluvium appears to be greatest toward shore, approximately 10 to 20 feet, and thins offshore to approximately 5 feet thick. The Shallow alluvium is typically loose to medium dense with density increasing with depth. Significant amounts of organic sediments were generally not observed in this layer, but layers of silt encountered in this layer would be compressible in the event of cap placement.
- **Deeper Alluvium.** The Deeper Alluvium consists of medium dense to dense, coarse sand and gravel. For the purposes of cap stability, this layer is generally below the depth of interest. For cap-induced settlement evaluations, this layer is generally assumed to be incompressible.

Based on visual observations of the nearshore surface sediment, there is some coarse-grained material (silty sand) present along the shoreline. Although some of the

explorations indicate relatively thick sand deposits in some of the nearshore areas, the coarse-grained material may not exist consistently along the shoreline or extend into the offshore area. For the purpose of this evaluation, the soft sediment layer was used for the analysis of the 1.5-foot thick sand cap—this is a conservative approach.

B4-3 Settlement Analyses

This section describes the preliminary analyses that were performed to estimate cap-induced primary consolidation settlement.

B4-3.1 Conceptual Cap Design Sections

The calculations presented herein were performed for two scenarios:

- **"No Prior Dredging":** 1.5-foot-thick sand cap placed directly over soft sediment; and
- **"With Prior Dredging":** 1.5-foot-thick sand cap placed after dredging of 1.5 feet of soft sediment.

An additional evaluation will be conducted for a third scenario: the Alternative 2 Amended reactive cap (no-prior dredging 4.5-feet-thick cap).

B4-3.2 Cap-Induced Load

The buoyant unit weight of the cap was assumed to be 70 pounds per cubic foot (pcf). For a 1.5-foot-thick cap, this assumption results in a stress increase of 105 pounds per square foot (psf) in the subsurface sediments and soils. For the scenario in which dredging is performed prior to cap placement, the overall stress increase is smaller and is based on the difference between the unit weight of the cap material and the unit weight of the sediment. For the dredging scenario, the stress increase was estimated to be 71 psf.

B4-3.3 Sediment Properties and Layer Thicknesses

The geotechnical properties of the sediments used in this analysis were based on the results of relevant RI sampling available to date, and laboratory and field testing data collected from the geotechnical reports by others. At this conceptual level of analysis, soil parameters, including compressibility and shear strength parameters, were largely estimated based on index properties and field observations in conjunction with engineering judgment. A single one-dimensional consolidation test (Shannon and Wilson 1997) on a sample of organic clay and silt was available for this analysis. The consolidation test results were used to estimate the compressibility parameters of the soft sediment. For the Shallow Alluvium, the compressibility parameters were estimated based on correlations with Atterberg limits. To assess the variability in settlement estimates for a particular geologic layer, a range of compressibility parameters was calculated based on the given range of Atterberg limits and consolidation test data.

Based on field investigations and subsequent laboratory testing conducted by others as part of early Site investigations, some of the geologic units are best characterized by a

range of thicknesses and/or a range of physical properties. To assess the potential range of settlement resulting from these observed variations, three cases (termed "very high", "high", and "moderate" compressibility) were evaluated to reflect varying compressibility and geologic layer thickness. Each case used a unique set of input parameters and a settlement estimate was developed for each case. The intent of this evaluation is to bracket the potential range of settlement that may occur as a result of cap construction and to estimate the potential range of differential settlements that may occur given the heterogeneity at the Site.

The soil parameters that were assumed for the consolidation settlement analysis are provided in Table B4-1.

Table B4-1 – Compressibility Assumptions for Settlement Calculations

Analysis Layer	Parameter	Settlement Evaluation Scenarios		
		Lower-End Assumptions	Intermediate Assumptions	Higher-End Assumptions
1	Description	Soft Sediment	Soft Sediment	Soft Sediment
	Layer Thickness in ft	10	10	15
	Buoyant Unit Weight in pcf	22.6	22.6	22.6
	Overconsolidation Ratio (OCR)	1.3	1.3	1.3
	$C_r/(1+e_o)$	0.028	0.030	0.034
	$C_{c/}(1+e_o)$	0.35	0.40	0.45
2	Description	Shallow Alluvium	Shallow Alluvium	Shallow Alluvium
	Layer Thickness in ft	10	10	15
	Buoyant Unit Weight in pcf	42.6	42.6	42.6
	Overconsolidation Ratio (OCR)	1.3	1.3	1.3
	$C_r/(1+e_o)$	0.012	0.012	0.012
	$C_{c/}(1+e_o)$	0.15	0.15	0.15

Note:
Deeper Alluvium assumed to be incompressible for the purpose of this analysis.

B4-3.4 Settlement Magnitude

Spreadsheet calculations were performed to calculate primary consolidation settlement using the assumed subsurface profiles described in previous sections. The geologic units were divided into sub-layers. For each layer, settlement was calculated using the estimated modified compression index and stresses in the sediment and soils as described in many geotechnical engineering text books (e.g., Das 2010). The sediments and soils were assumed to be slightly overconsolidated-consolidated (overconsolidation ratio [OCR] = 1.3). Differential settlement may occur between areas "With Prior Dredging" and areas with "No Prior Dredging". Differential settlements were calculated as the

difference in primary consolidation of "No Prior Dredging" and "With Prior Dredging". At the interface between these two areas, differential settlement is generally expected to be gradual, not abrupt. The edges of the dredge area can be sloped to create a more gradual transition between the two areas. The results of the settlement calculations are summarized in Table B4-2.

Table B4-2 – Estimated Cap-Induced Total and Differential Settlement

Scenario	Cap Thickness in Feet	Dredge Depth in Feet	Estimated Total Settlement from Primary Consolidation in Inches	Estimated Worst Case Differential Settlement in Inches[1]
Lower-End Estimates				
With Prior Dredging	1.5	1.5	4	8
No Prior Dredging	1.5	0	12	
Intermediate Estimates				
With Prior Dredging	1.5	1.5	5	9
No Prior Dredging	1.5	0	14	
Higher-End Estimates				
With Prior Dredging	1.5	1.5	6	10
No Prior Dredging	1.5	0	16	

Notes:
General – The assumptions for the settlement calculations are summarized in Table B4-1.
1. Differential settlements were calculated as the difference in primary consolidation of "No Prior Dredging" and "With Prior Dredging".

B4-4 Bearing Capacity

A traditional bearing capacity analysis was performed to estimate the maximum lift thickness that could be placed during construction.

B4-4.1 Method of Analysis

Appendix C of the Assessment and Remediation of Contaminated Sediments (ARCS) Program cap design guidance manual Guidance for In-Situ Subaqueous Capping of Contaminated Sediments (Palermo et al. 1998) describes a method of assessing stability of a cap placed on soft sediment. Refinements to this methodology are presented in a U.S. Army Engineer Research and Development Center Technical Note (Rollings 2000). The method is based on the bearing capacity theory applied to a shallow foundation on a subgrade, whereby the cap is considered a footing acting over a large area. In this case, the footing contact pressure is calculated as the submerged unit weight of the cap multiplied by its thickness:

$$q = \gamma' h \qquad \text{(EQ 1)}$$

Where:

q = "footing" contact pressure in psf

γ' = submerged unit weight of cap in pcf

h = cap lift thickness in ft

Due to the soft nature of the sediments to be capped, the undrained soil shear strength is appropriate. After placement of the initial cap lift, the pore pressures will dissipate as part of the consolidation process and the shear strength of the underlying sediment will improve. The ultimate bearing capacity is calculated as follows:

$$q_{ult} = s_u N_c \qquad \text{(EQ 2)}$$

Where:

q_{ult} = ultimate bearing capacity in psf

s_u = undrained shear strength of sediment in psf

N_c = bearing capacity factor (N_c = 5.7 for undrained conditions ($\phi = 0$))

The allowable bearing capacity (q_{allow}) is calculated as follows:

$$q_{allow} = q_{ult} / FS \qquad \text{(EQ 3)}$$

Where:

FS = factor of safety for bearing capacity under short-term conditions (FS = 1.5 was used)

By combining equations EQ 1, EQ 2, and EQ 3, the maximum lift thickness is calculated as follows:

$$h_{max} = (s_u N_c) / (FS \gamma')$$

B4-4.2 Assumptions

For this preliminary bearing capacity assessment, relatively conservative assumptions were made in terms of the undrained shear strength of the sediments to be capped. It was assumed that the sediments to be capped are very soft. The following average undrained strengths were assumed:

- For "No Prior Dredging": s_u = 15 psf;
- For "With Prior Dredging": s_u = 25 psf.

The cap was estimated to have a submerged unit weight of 70 pcf.

B4-4.3 Bearing Capacity Assessment Results and Conclusions

For this preliminary assessment, the following maximum lift thicknesses were calculated:

- For "No Prior Dredging": h_{max} = 9 inches
- For "With Prior Dredging": h_{max} = 16 inches

These results are based on relatively conservative assumptions in terms of the undrained strength of the underlying sediment. There are no existing strength data for the sediments; therefore, the estimates of bearing capacity have significant uncertainty. Prior to design, design-level geotechnical data should be collected to refine the analysis. Should the shear strength of the underlying sediment actually be as low as assumed for this assessment, the cap will need to be placed in two lifts. The thicknesses provided above are the maximum lift thicknesses for the initial lift. Following placement of the initial lift thickness, the underlying sediment will need to be allowed to consolidate and gain strength before additional cap material is placed. The time between placement of the initial lift and second lift will be estimated during design based on design-level data. If the sediment is stronger than estimated herein, it may be possible to place the cap in one lift. Generally, the cap will need to be built up gradually to the maximum lift thickness before construction is stopped to allow consolidation to occur. If the sediment is very soft, it may be advisable to first place a geotextile fabric to provide additional support.

B4-5 Seismic Considerations

The seismic hazard at the Site, particularly in the upland setting, has been analyzed and discussed by others (Aspect 2009). The conclusions of the upland studies are based on current building codes. Building codes are generally not directly applicable to earthen structures. No guidance currently exists for seismic considerations for environmental cleanup projects and sediment capping projects in particular. However, for some Comprehensive Environmental Response, Compensation, and Liability Act (CERLCA) projects, a design seismic event with a 10% probability of exceedance in 50 years (475-year return period) has been used. This level of event seems appropriate and originated from port facility design where it was referred to as the Contingency Level Event (CLE). Per the 2008 U.S. Geological Survey seismic hazard maps (Kramer 2008), the peak ground acceleration for rock outcrop associated with the 475-year event is 0.3 g (g = acceleration of gravity). Some amplification is to be expected due to the soft soils at the Site. Under this event, some liquefaction of the sand cap and some of the underlying soils is possible. The consequences of seismic shaking will need to be evaluated during design. Generally, the in-water slopes to be capped are fairly gentle (approximately 10H:1V). Seismic stability of an *in situ* sediment cap was assessed for the Palos Verdes Shelf off the coast of Los Angeles, California (USACE 1999). For the Palos Verdes site, it was concluded that a sand cap would be reasonably stable on slopes of 5 degrees or less; this is generally similar to the conditions at the Site. Analyses to be performed during design may indicate that some form of stabilization will be required. Stabilization may consist of a terraced configuration with "rock ribs" between sediment cap terraces. The rock ribs would reduce lateral movement of the cap and reduce the need for repairs after a significant seismic event. Some settlement may also occur as a result of seismic liquefaction. Generally, sediment caps should be inspected after significant seismic events and repairs performed as necessary.

B4-6 Considerations for Amended Sand Cap

Alternative 2 includes a 4.5-foot-thick amended sand reactive cap that would be placed in dredge area DA-6. This cap consists of the following layers (from top to bottom):

- 0.5 feet of aquatic habitat friendly material
- 2 feet of clean sand
- 2 feet of sand (90%) and organoclay (10%) mix

The individual layer and overall thicknesses are nominal for FS purposes. The final thicknesses would be defined during design.

The amended sand cap covers a nearshore area that is approximately 240 feet long by 140 feet wide. Based on existing subsurface exploration data presented in the Remedial Investigation report (Appendix E; Anchor QEA and Aspect 2012), the area closest to the shoreline is underlain predominantly by sand. The assumption that sandy subsurface conditions exist under the amended sand cap is different from the subsurface conditions assumed for the 1.5-foot sand cap provided in Section B4-3.3. Explorations advanced outside of dredge area DA-6 indicate the existence of soft sediments that would likely settle significantly under the weight of the cap. Thus, the assumptions for the 1.5-foot cap may be valid further offshore.

For the 4.5-foot cap, the sand along the shoreline is expected to provide sufficient bearing capacity and will not compress significantly. The transition from sandy subsurface conditions to softer conditions will need to be delineated further during design based on additional subsurface explorations. The 4.5-foot cap will need to be properly engineered during design to account for the actual subsurface conditions. If the 4.5-foot cap is to be placed on soft sediments, it may be necessary to use high-strength geotextile to improve bearing capacity. Settlement may also occur over time and the 4.5-foot cap thickness may need to be replenished over time. However, in general, cap material placed on sand in the area along the shoreline is not expected to settle significantly. Therefore, the creation of shallow-water habitat in these areas is anticipated to be feasible and not expected to be affected by settlement.

B4-7 Conclusions

A series of geotechnical evaluations were performed to assess the constructability and stability of caps that may be constructed at the Site. Evaluations were also performed to estimate the amount of primary consolidation settlement that may be expected following placement of a subaqueous cap. Based on these evaluations, a subaqueous cap is generally considered feasible under the conditions that were evaluated herein. Caps constructed over soft sediments generally need to be placed in thin lifts; this will require the use of special construction techniques (e.g., the use of a spreader box). For cap design, it will be necessary to collect additional geotechnical data to better characterize the sediments and soils in the capping areas, in terms of shear strength, stress history, and compressibility. Additional geotechnical design analyses will need to be performed,

particularly to assess the seismic stability of the cap. It may be necessary to install stabilizing measures such as rock ribs to improve seismic performance. Lastly, it should be noted that caps generally need to be monitored to assess their performance. If deficiencies are discovered during monitoring events, repairs may be needed. An inspection should be performed following a significant seismic event and repairs performed as necessary. Costs associated with monitoring and repairs need to be included in cost estimates, and funds for monitoring and repairs set aside if capping is selected.

Additionally, some alternatives include thinner physical isolation caps (e.g., 6 inches of sand) and a reactive cap consisting of an organoclay reactive core mat (RCM) overlain by approximately 6 inches of sand cap. Although, these caps were not specifically addressed in the evaluations above, settlement is expected to be less than the calculated settlement estimates presented above; therefore, they are generally considered feasible. RCMs also typically include the use of geosynthetic materials that can improve cap performance in terms of stability and differential settlement. Geosynthetic materials such as geotextiles may be added to sand caps to improve stability, provide separation between contaminated sediment and the cap, and provide demarcation to allow easier cap monitoring.

B4-8 References

Anchor QEA and Aspect, 2012, Remedial Investigation Report, Quendall Terminals Site, Renton, Washington, Prepared for U.S. Environmental Protection Agency, Region 10, on behalf of Altino Properties, Inc and J.H Baxter & Company, March 2012.

Aspect, 2009, Preliminary Geotechnical Study, Quendall Terminals, Renton, Washington. Prepared for Altino Properties, Inc. and J.H. Baxter & Company, November 2009.

Das, B.M., 2010, Principles of Foundation Engineering, Seventh Edition, CENGAGE Learning. 816 pages.

Kramer, S., 2008, Evaluation of Liquefaction Hazards in Washington State, prepared for the Washington State Transportation Commission.

Palermo, M., S. Maynord, J. Miller, and D. Reible, 1998, “Guidance for In-Situ Subaqueous Capping of Contaminated Sediments,” EPA 905-B96-004. Great Lakes National Program Office, Chicago, Illinois.

Rollings, M. P., 2000, Geotechnical Considerations in Contained Aquatic Disposal Design, DOER Technical Notes Collection (ERDC TN-DOER-N5), U.S. Army Engineer Research and Development Center, Vicksburg, MS. www.wes.army.mil/el/dots/doer/

Shannon & Wilson, 1997, Geotechnical Report, Conceptual Design Phase, JAG, Development, Renton, Washington. Prepared for CNA Architecture Group, Inc., Bellevue, Washington. February 1997.

Twelker & Associates, 1973, Control of Oil Contamination at Quendall Terminal Project Area, Renton, Washington. October 11, 1973.

U.S. Army Corps of Engineers (USACE), 1999, Options for In Situ Capping of Palos Verdes Shelf Contaminated Sediments. U.S. Army Corps of Engineers, Waterways Experiment Station. Technical Report EL-99-2. March 1999.

APPENDIX B5

Sheet Pile Enclosure Calculations

Contents

B5-1 Introduction and Background B5-1

B5-2 General Conditions B5-1

B5-2.1 Lake Water Levels B5-1

B5-2.2 Generalized Subsurface Conditions B5-1

B5-3 Methodologies B5-2

B5-3.1 Method of Analysis B5-2

B5-3.2 Earth Pressure Calculations B5-2

B5-3.3 Calculation of Design Soil Shear Strength for Passive Earth Pressures B5-3

B5-3.4 Factors of Safety B5-3

B5-3.5 Forces and Moments for Structural Design B5-4

B5-3.6 Allowable Stresses for Steel Sheet Piling B5-4

B5-3.7 Wall Deflection Limitations B5-4

B5-4 Assumptions B5-5

B5-4.1 Top-of-Wall Elevation B5-5

B5-4.2 Design Sections B5-5

B5-4.3 Soil Parameters B5-6

B5-4.4 Design Loads B5-6

B5-4.5 Steel Grade B5-7

B5-5 Analysis Results B5-7

B5-6 Conclusions B5-8

B5-7 References B5-8

List of Tables

B5-1 Factors of Safety B5-3

B5-2 Design Sections B5-6

B5-3 Soil Parameters B5-6

B5-4 Wave Force Calculations for Enclosure Wall (attached)

B5-5 Load Combinations and Analysis Results for Enclosure Wall (attached)

B5-6 Sheet Pile Length and Section B5-7

B5-1 Introduction and Background

Several of the remedial alternatives presented in this Feasibility Study (FS) for the Quendall Terminals Site (Site) include the use of a temporary sheet pile enclosure. As part of this FS, preliminary analyses were performed to select appropriate sheet pile sections and lengths for the various alternatives.

Dredging of nearshore sediments to various depths is included in 7 of the 10 alternatives presented in the FS. The various wall alignments are shown on the figures in the main text. For each of these 7 alternatives, a temporary sheet pile wall would isolate the nearshore dredge area from the open water of Lake Washington. Dredging within the enclosure would be performed with barge-mounted equipment and potentially land-based equipment along the shoreline where there may not be adequate draft for a barge.

B5-2 General Conditions

B5-2.1 Lake Water Levels

Lake Washington water levels are controlled by the Ship Canal Locks and do not vary significantly, generally only by 2 feet over the year. The lake is raised up to a targeted high water elevation of 18.67 feet NAVD88 in the summer months and low water elevation of 16.67 feet NAVD88 in the winter. A water level of elevation 18.67 feet NAVD88 was assumed for analysis purposes.

B5-2.2 Generalized Subsurface Conditions

Subsurface conditions used for this analysis were based in part on a review of existing geotechnical engineering reports for the Site (Aspect 2009). Geotechnical borings logs and sediment core logs collected as part of the Remedial Investigation (RI) (Anchor QEA and Aspect 2012), as well as laboratory data, and historical geotechnical borings by others (Twelker and Associates 1973, Shannon and Wilson 1997) were also used in assessing subsurface conditions and properties.

The following major geologic units were encountered at the Site, from the ground surface, or mudline, downward:

- **Soft Sediments.** The uppermost geologic unit consists of soft, dark brown, highly plastic sediments with varying proportions of clay, silt, and peat. Explorations indicate that this layer is 5 to 15 feet thick. Blow counts in this layer were generally 0 to 2 blows per foot.
- **Shallow Alluvium.** This layer is characterized as a loose to medium dense sand with interbedded clay and silt, and has been interpreted to be a Shallow Alluvium layer. The thickness of the Shallow Alluvium appears to be greatest toward shore,

approximately 10 to 20 feet, and thins offshore to approximately 5 feet thick. The Shallow Alluvium is typically loose to medium dense with density increasing with depth. Significant amounts of organic sediments were generally not observed in this layer.

- **Deeper Alluvium.** The Deeper Alluvium consists of medium dense to dense, coarse sand and gravel. For the purposes of cap stability, this layer is generally below the depth of interest.

Based on visual observations of the nearshore surface sediment, there is some coarse-grained material (silty sand) present along the shoreline. However, the coarse-grained material may not extend beyond the surface or into the offshore area. For the purpose of this evaluation the soft sediment layer was used for the analysis—this is a conservative approach.

B5-3 Methodologies

B5-3.1 Method of Analysis

The public domain computer program ProSheet (developed by Arbed) was used to perform the sheet pile wall analyses. ProSheet uses the Blum theory to calculate embedment depths, wall deflections, forces, and bending moments.

B5-3.2 Earth Pressure Calculations

Active and passive earth pressures were used for the geotechnical design of the enclosure walls. Earth pressures were calculated using Coulomb earth pressure theory (ASCE 1996).

Earth pressures for drained (long-term loading) analyses were calculated by multiplying the effective vertical stress of the soil by the appropriate earth pressure coefficient. Earth pressure coefficients were calculated using Coulomb earth pressure theory for active and passive pressures. For drained analyses, the soil's angle of internal friction and an appropriate wall friction angle were used to calculate the earth pressure coefficients. Soil parameters used for design are provided in subsequent sections of this memorandum.

Earth pressures for undrained (short-term loading) analyses were calculated as follows:

Active: $\sigma_a = \sigma'_v - 2s_u$

Passive: $\sigma_p = \sigma'_v + 2s_u$

Where:

σ_a = active lateral earth pressure

σ'_v = effective vertical stress

s_u = undrained shear strength

σ_p = passive lateral earth pressure

Using the above equation for calculation of the active earth pressure, the active pressure could become negative at low effective vertical stresses. Where the calculated active pressure was negative, the active pressure was assumed to be equal to zero. Undrained shear strength and unit weights that were used for the soils are provided in subsequent sections of this memorandum.

B5-3.3 Calculation of Design Soil Shear Strength for Passive Earth Pressures

Wall stability calculations were performed using both drained and undrained analyses. Soil parameters assumed for the analyses are provided later in this appendix. For calculation of embedment depths required for wall stability, factors of safety were applied to the soil strength used for calculation of passive earth pressures. No factors of safety were applied to active earth pressures.

Design shear strength parameters used for calculation of passive earth pressures were calculated as follows:

- Undrained Strength: $s_{u,design} = s_u / FS_p$
- Drained Strength: $\tan(\varphi_{design}) = \tan(\varphi) / FS_p$

Where:

s_u = undrained shear strength

ϕ = angle of internal friction (drained strength parameter)

FS_p = factor of safety applied to soil strength prior to calculation of passive earth pressures

B5-3.4 Factors of Safety

Using guidelines provided in the Design of Sheet Pile Walls (ASCE 1996), factors of safety for calculation of wall embedment depths were selected based on the loading case, type of loading, and type of soil. The walls were designed using usual, unusual, and extreme loading cases per USACE design procedures (ASCE 1996). These loading cases correlate with the likeliness for the load to occur. More severe and less likely loading cases are generally assigned smaller factors of safety than less severe loading cases that occur regularly under normal operating conditions. Table B5-1 lists the factors of safety used for passive earth pressure calculations.

Table B5-1 – Factors of Safety

Loading Case	FS_p
Usual	1.5
Unusual	1.25
Extreme	1.1

Note: FS_p = factor of safety applied to soil strength prior to calculation of passive earth pressures

B5-3.5 Forces and Moments for Structural Design

To avoid compounding of factors of safety, the structural components were designed using a factor of safety of 1 on the soil side to calculate the forces and moments. To calculate required embedment depths, the analyses were then repeated applying the appropriate factor of safety on the passive earth pressure side for each of the loading conditions (i.e., usual, unusual, and extreme loading conditions). Allowable stresses for structural design were calculated taking into account the various loading conditions, as described in the following sections.

B5-3.6 Allowable Stresses for Steel Sheet Piling

Allowable stresses for steel for usual loading conditions were calculated per the U.S. Army Corps of Engineers (USACE) design procedures (ASCE 1996) as follows:

$f_b = 0.5\ f_y$ (combined bending and axial load)

$f_v = 0.33\ f_y$ (shear)

For the unusual loading conditions, the allowable stress equations were increased 33 percent above that for usual loading conditions:

$f_b = 1.33\ (0.5\ fy) = 0.67\ fy$

For the extreme loading conditions, the allowable stress equations were increased 75 percent above that for usual loading conditions:

$f_b = 1.75\ (0.5\ f_y) = 0.875\ f_y$

Where:

f_b = combined bending and axial load

f_v = shear stress

f_y = yield stress of the steel

The increases in allowable stress are appropriate given the infrequent, short-term loading conditions on structural elements that can be subjected to greater load.

B5-3.7 Wall Deflection Limitations

Sheet pile sections were selected based on both bending moments and deflections. Deflections were calculated for conditions with and without wave loads. Wave loads are transient loads that only occur for brief moments. The dynamic nature of these loads cannot be modeled in any available sheet pile analysis software. The wave loads were modeled as static loads and it is assumed that this results in overestimation of the deflections that include wave loads. As part of the selection of the sheet pile sections, top-of-wall deflections were limited as follows:

- Maximum deflection for deflection calculations without wave load: 5 inches
- Maximum deflection for deflection calculations with wave load: 10 inches

B5-4 Assumptions

B5-4.1 Top-of-Wall Elevation

A top-of-wall elevation of 23 feet NAVD88 was selected. This elevation was selected such that overtopping would not occur from high water levels and most wave actions.

B5-4.2 Design Sections

Due to the similarities in enclosure alignments and dredge depths, alternatives were grouped for analysis as follows:

- Group 1: Alternatives 4, 5, and 6
- Group 2: Alternatives 7 and 8
- Group 3: Alternatives 9 and 10

Differences between the Groups are summarized as follows:

- **Group 1:** Alternatives 4, 5, and 6 are characterized by a relatively short sheet pile alignment with a length of approximately 700 feet. The mudline elevation on the lakeside wall does not vary significantly from the lowest elevation of approximately 6 feet to approximately 8 feet NAVD88. The generalized design section was based on the outer lakeside wall due to wave loads, largest water depth, and overall most severe loading conditions. A conservative dredge depth of 8 feet of excavation was analyzed.
- **Group 2:** Alternatives 7 and 8 include a longer sheet pile alignment with a length of approximately 1,260 feet. The mudline elevation of the longest bay side wall varies from the lowest elevation of approximately 3 feet to approximately 10.5 feet NAVD88. The wall was analyzed at the northeast portion due to the deepest water depth in this region, influence from wave loads, and deepest excavation near the wall. A dredge depth of 11.5 feet of excavation was analyzed.
- **Group 3:** Alternatives 9 and 10 include the longest sheet pile alignment with a length of approximately 1,530 feet and the deepest excavation with material being removed down to the Shallow Alluvium layer. The mudline elevation varies significantly across the alignment with elevations of approximately 0.5 feet to 11 feet NAVD88. Due to the much larger excavation depths, two wall sections were analyzed, one on the lake side wall and another for the return wall towards the shoreline with excavation depths of 24 feet and 28 feet, respectively.

Table B5-2 shows the design sections used for the preliminary analyses.

Table B5-2 – Design Sections

Description	Group 1	Group 2	Group 3 Section A	Group 3 Section B
Sediment Surface Elevation	6	3	11	8
Thickness of Soft Sediment (feet)	5	5	7	5
Thickness of Shallow Alluvium[1] (feet)	14	14	20	19

Note:
[1] Shallow Alluvium is underlain by Deep Alluvium.

B5-4.3 Soil Parameters

Soil parameters were based on available subsurface information. Shear strength parameters were selected based on correlations with Standard Penetration Test (SPT) blow counts and soil plasticity data, in conjunction with engineering judgment. Table B5-3 shows the soil parameters used for this feasibility-level assessment.

Table B5-3 – Soil Parameters

Soil Parameter	Soft Sediment	Shallow Alluvium	Deeper Alluvium
Total Unit Weight, γ_T (pcf)	85	105	125
Submerged Unit Weight, γ' (pcf)	22.6	42.6	62.6
Angle of Internal Friction, ϕ' (degrees)	15	20	36
Wall Interface Friction Angle, δ (degrees)	7	10	18
Undrained Strength, S_u (psf)	75	500	NA

Notes:
NA = not applicable
pcf = pounds per cubic foot
psf = pounds per square foot

B5-4.4 Design Loads

For this feasibility-level assessment, design loads consisted of earth pressures, hydrostatic loads due to water level differentials, and wave action. The calculation of earth pressures is discussed above. Assumptions regarding hydrostatic loads and wave loading are discussed below.

Hydrostatic Loads

Some water level changes may occur during dredging on the outside and inside of the enclosure. Generally, the water level within the enclosure would need to be controlled by the contractor to keep water level differentials and associated hydrostatic loads on the wall relatively small. For analysis purposes, the water level inside the enclosure was assumed to be 1 foot below the lake level. The analyses were performed for the summer lake conditions with an elevation of 18.67 feet NAVD88 as this would result in the greatest hydrostatic load on the wall.

Wave Loads

Wave loads were taken into account for the various scenarios. Both wind-induced waves and vessel-induced waves were analyzed in Appendix B3 – Cap Armor Layer Evaluation It was determined that for the majority of the wall, non-breaking waves needed to be taken into account as the depths along the longer bay side portions of the enclosure are sufficient to be above the transitions zone to breaking waves. The occurrence of direct breaking waves against the enclosure is unlikely and forces resulting from such impacts would only last for short durations (on the order of hundredths of a second). Wall stability analyses were analyzed for 1-, 2.5-, and 3.5-foot wave heights for usual, unusual, and extreme loading conditions, respectively. Wave forces were calculated using the Shore Protection Manual (USACE 1984). The calculations are presented on Table B5-4.

B5-4.5 Steel Grade

The selected steel grade is ASTM A572 – Grade 50.

B5-5 Analysis Results

The load combinations and results for the feasibility-level analyses are provided in Table B5-5 (attached). Table B5-6 shows the sheet pile lengths and sections that would be required based on those results.

Table B5-6 – Sheet Pile Length and Section

Description	Sheet Pile Length (feet)	Sheet Pile Section[1]
Group 1: Alternatives 4, 5, & 6	47	AZ17-700
Group 2: Alternatives 7 & 8	50	AZ24-700
Group 3: Alternatives 9 & 10		
North wall	60	AZ50
Bay side wall	60	AZ50

Note:
[1]Section designations presented in this table are for sections made by ArcelorMittal (available through Skyline Steel). Similar sections with similar properties are also available through other suppliers.

B5-6 Conclusions

Based on the feasibility-level analyses presented herein, a sheet pile enclosure would be a generally feasible technology to accommodate dredging of the nearshore sediments. The results presented herein are preliminary in nature. Additional analyses would be required during design to refine the selection of the sheet piles.

B5-7 References

Anchor QEA and Aspect, 2012, Remedial Investigation Report, Quendall Terminals Site, Renton, Washington, Prepared for U.S. Environmental Protection Agency, Region 10, on behalf of Altino Properties, Inc and J.H Baxter & Company, March 2012.

Aspect, 2009, Preliminary Geotechnical Study, Quendall Terminals, Renton, Washington. Prepared for Altino Properties, Inc. and J.H. Baxter & Company, November 2009.

ASCE, 1996, Design of Sheet Pile Walls, Technical Engineering and Design Guides as Adapted from the U.S. Army Corps of Engineers, No. 15, Published by the American Society of Civil Engineers (ASCE).

Shannon & Wilson, 1997, Geotechnical Report, Conceptual Design Phase, JAG, Development, Renton, Washington. Prepared for CNA Architecture Group, Inc., Bellevue, Washington. February 1997.

Twelker & Associates, 1973, Control of Oil Contamination at Quendall Terminal Project Area, Renton, Washington. October 11, 1973.

USACE. 1984. Shore Protection Manual. Coastal Engineering Research Center, Department of the Army, Waterways Experiment Station, U.S. Army Corps of Engineers, Vicksburg, Mississippi, Volume II, 1984.

Table B5-4 of Appendix B5 - Wave Force Calculations for Enclosure Wall

Quendall Terminals
Renton, Washington

Assumptions / Input Parameters for Figures 7-90 through 7-92 (USACE 1984):

χ = 1.0 wave reflection coefficient

γ_w = 62.4 pcf unit weight of water

Water Level	Water Level Elevation (ft)	Mudline Elevation (ft)	d (ft)	H_i (ft)	T (s)	H_i/d [a]	$H_i/(gT^2)$ [b]	h_0/H_i [c]	y_c [d]	(y_c-d)	$F/(\gamma_w d^2)$ [e]	F [f] (lbs/ft)	h_F (ft)	Load Application Elevation (ft NGVD29)
Group 1: Alternatives 4, 5, & 6														
Usual Event	18.67	6	12.67	1	2	0.08	0.0078	0.15	13.82	1.15	0.02	200	8.9	14.9
Unusual Event	18.67	6	12.67	2.5	3	0.20	0.0086	0.200	15.67	3.00	0.09	902	8.9	14.9
Extreme Event	18.67	6	12.67	3.5	3.5	0.28	0.0089	0.255	17.06	4.39	0.16	1603	8.9	14.9
Group 2: Alternatives 7 & 8														
Usual Event	18.67	3	15.67	1	2	0.06	0.0078	0.15	16.82	1.15	0.02	306	11.0	14.0
Unusual Event	18.67	3	15.67	2.5	3	0.16	0.0086	0.195	18.66	2.99	0.05	766	11.0	14.0
Extreme Event	18.67	3	15.67	3.5	3.5	0.22	0.0089	0.215	19.92	4.25	0.1	1532	11.0	14.0
Group 3: Alternatives 9 & 10														
North wall														
Usual Event	18.67	11	7.67	1	2	0.13	0.0078	0.17	8.84	1.17	0.04	147	5.4	16.4
Unusual Event	18.67	11	7.67	2.5	3	0.33	0.0086	0.300	10.92	3.25	0.24	881	5.4	16.4
Extreme Event	18.67	11	7.67	3.5	3.5	0.46	0.0089	0.435	12.69	5.02	0.43	1578	5.4	16.4
Bay side wall														
Usual Event	18.67	8	10.67	1	2	0.09	0.0078	0.15	11.82	1.15	0.02	142	7.5	15.5
Unusual Event	18.67	8	10.67	2.5	3	0.23	0.0086	0.220	13.72	3.05	0.11	781	7.5	15.5
Extreme Event	18.67	8	10.67	3.5	3.5	0.33	0.0089	0.300	15.22	4.55	0.23	1634	7.5	15.5

Note:

Calculations are based on methods provided in the 4th edition of the Shore Protection Manual (U.S. Army Corps of Engineers (USACE) 1984).

Footnotes:

a. $H_i/d > 0.67$ --> Wave is likely a breaking wave.

b. Obtained values from Figure 7-92 (USACE 1984).

c. Obtained values from Figure 7-90 (USACE 1984). For $H_i/d < 0.10$, values obtained from 0.10 curve.

d. Value based on Equation 7-73 (USACE 1984).

e. Obtained values from Figure 7-91 (USACE 1984).

f. Hydrostatic force not included.

Acronyms and Abbreviations:

d = water depth
F = wave force (includes hydrostatic component)
ft = feet
g = acceleration of gravity (32.2 ft/s^2)
h_F = distance between mudline and force application point
H_i = wave height
h_0 = height of clapotis orbit above still water level
lbs = pounds
NGVD29 = National Geodetic Vertical Datum of 1929
pcf = pounds per cubic foot
s = seconds
T = wave period
y_c = distance between mudline and wave crest
γ_w = unit weight of water

Table B5-5 of Appendix B5 - Load Combinations and Analysis Results for Enclosure Wall

Quendall Terminals
Renton, Washington

Load Combinations				Results for Drained Analyses				Results for Undrained Analyses			
Description	Dredge Depth (ft)	Water Level Difference (ft)	Wave Height (ft)	Required Minimum Sheet Pile Length (ft)	Required Minimum Section Modulus (in^3/ft)[1)]	Deflection with wave load (in)[2)]	Deflection without wave load (in)[2)]	Required Minimum Sheet Pile Length (ft)	Required Minimum Section Modulus (in^3/ft)[1)]	Deflection with wave load (in)[2)]	Deflection without wave load (in)[2)]
Group 1: Alternatives 4, 5, & 6					*Selected Section AZ17-700* [3)]				*Selected Section AZ17-700* [3)]		
Usual Event	8	1	1	42.3	16.14	3.4	2.8	33.1	9.51	1.2	0.9
Unusual Event	8	1	2.5	46.7	18.71	5.8	2.8	34.2	11.78	2.2	0.9
Extreme Event	8	1	3.5	42.6	19.41	8.3	2.8	35.0	12.51	3.5	0.9
Group 2: Alternatives 7 & 8					*Selected Section AZ24-700* [3)]				*Selected Section AZ24-700* [3)]		
Usual Event	11.5	1	1	49.3	28.71	4.7	3.8	42.0	16.55	2.1	1.5
Unusual Event	11.5	1	2.5	48.7	26.64	6.2	3.8	42.1	16.41	3.0	1.5
Extreme Event	11.5	1	3.5	48.5	26.78	8.9	3.8	42.9	17.61	4.8	1.5
Group 3: Alternatives 9 & 10					*Selected Section AZ50* [3)]				*Selected Section AZ50* [3)]		
North wall											
Usual Event	28	1	1	59.6	62.03	6.2	5.8	53.6	25.61	2.4	2.1
Unusual Event	28	1	2.5	58.1	56.82	8.2	5.8	53.5	28.86	4.0	2.1
Extreme Event	28	1	3.5	57.0	50.67	10.3	5.8	53.3	29.01	5.7	2.1
Bay side wall											
Usual Event	24	1	1	58.4	52.90	5.1	4.7	53.4	25.53	2.4	2.1
Unusual Event	24	1	2.5	57.2	50.43	7.1	4.7	53.4	28.80	4.0	2.1
Extreme Event	24	1	3.5	56.2	45.40	9.0	4.7	53.2	28.94	5.7	2.1

Notes:

[1)] Based on bending moments.

[2)] Used both bending moments and deflections for selection of section. Deflections calculated with selected section properties for two scenarios: with calculated wave force from Table B5-2 and without wave force.

[3)] Assumed steel grade is ASTM A572 - Grade 50.

Acronyms and Abbreviations:

ft = feet
in = inches

APPENDIX C

Description of Technologies and Process Options for DNAPL, Soil, Groundwater, and Sediment

Table of Contents

C1 Introduction C-1

C2 DNAPL Technologies and Process Options C-1

C2.1 DNAPL Institutional Controls C-1
C2.2 DNAPL *In Situ* Containment C-1
C2.3 DNAPL *In Situ* Treatment C-2
C2.3.1 *In Situ* Thermal Treatment C-2
C2.3.2 *In Situ* Chemical Treatment C-5
C2.3.3 *In Situ* Stabilization C-6
C2.4 DNAPL Removal Technologies C-6
C2.5 DNAPL *Ex Situ* Treatment Technologies C-8
C2.6 DNAPL Disposal Technologies C-8

C3 Soil Technologies and Process Options C-9

C3.1 Soil Institutional Controls C-9
C3.2 Soil *In Situ* Containment C-9
C3.3 Soil *In Situ* Treatment C-9
C3.3.1 Interstitial Media Removal and Treatment C-10
C3.3.2 *In Situ* Thermal Treatment C-10
C3.3.3 *In Situ* Stabilization C-11
C3.3.4 *In Situ* Chemical Treatment C-11
C3.3.5 Bioremediation C-12
C3.4 Soil Removal Technologies C-13
C3.5 Ex Situ Soil Treatment Technologies C-13
C3.5.1 *Ex Situ* Physical Treatment C-13
C3.5.2 *Ex Situ* Thermal Treatment C-14
C3.5.3 *Ex Situ* Chemical/Physical Treatment C-15
C3.5.4 *Ex Situ* Biological Treatment C-15
C3.6 Soil Disposal Technologies C-16
C3.6.1 On-Site Beneficial Use C-16
C3.6.2 On-Site Confined Disposal C-16
C3.6.3 Off-Site Landfill Disposal C-16

C4 Groundwater Technologies and Process Options C-18

C4.1 Groundwater Institutional Controls C-18
C4.2 Groundwater Monitored Natural Attenuation C-18
C4.3 Groundwater *In Situ* Containment C-18
C4.3.1 Impermeable Vertical Barriers C-19
C4.3.2 Groundwater Pumping C-19
C4.3.3 Stormwater Controls C-19
C4.4 Groundwater *In Situ* Treatment C-20
C4.4.1 Permeable Reactive Barrier C-20
C4.4.2 *In Situ* Chemical Treatment C-20

C4.4.3 Bioremediation C-20
C4.5 Groundwater Removal Technologies C-21
C4.6 Ex Situ Groundwater Treatment Technologies C-21
C4.6.1 Physical/Chemical Treatment C-21
C4.6.2 Biological Treatment C-22
C4.7 Groundwater Disposal Technologies C-22
C4.7.1 Off-Site Management C-22
C4.7.2 On-Site Management C-23

C5 Sediment Technologies and Process Options C-23
C5.1 Sediment Institutional Controls C-23
C5.2 Sediment Monitored Natural Recovery C-24
C5.2.1 Monitored Natural Recovery C-24
C5.2.2 Enhanced Natural Recovery C-24
C5.3 Sediment *In Situ* Containment C-25
C5.3.1 Engineered Sand Cap C-25
C5.3.2 Post-Dredge Residuals Cap C-25
C5.4 Sediment *In Situ* Treatment C-25
C5.4.1 Physical/Chemical Treatment C-25
C5.4.2 Bioremediation C-27
C5.5 Sediment Removal Technologies C-28
C5.5.1 Excavation C-28
C5.5.2 Dredging C-28
C5.6 Ex Situ Sediment Treatment Technologies C-29
C5.6.1 Physical Treatment C-29
C5.6.2 *Ex Situ* Thermal Treatment C-30
C5.6.3 *Ex Situ* Chemical/Physical Treatment C-30
C5.6.4 *Ex Situ* Biological Treatment C-31
C5.7 Sediment Disposal Technologies C-31
C5.7.1 On-Site Beneficial Use C-31
C5.7.2 On-Site Confined Disposal C-31
C5.7.3 Off-Site Landfill Disposal C-31

C6 References for Appendix C C-32

C1 Introduction

The information in this appendix provides additional detail on remedial technologies and process options presented in Section 5 of the Feasibility Study (FS) to address dense non-aqueous phase liquid (DNAPL), soil, groundwater, and sediment.

C2 DNAPL Technologies and Process Options

C2.1 DNAPL Institutional Controls

Potentially applicable institutional controls for DNAPL include the following:

- Fences and warning signs to control access to the Quendall Site (Site) or to specific areas of the Site such as the nearshore area in the vicinity of Quendall Pond.
- Deed restrictions, such as restricting land use, construction, and soil excavation without U.S. Environmental Protection Agency (EPA) approval.
- Use restrictions and monitoring requirements to prevent disturbance of caps or other engineered controls.

Each of the above institutional controls is potentially effective at preventing exposure to hazardous substances, is easy to implement, and can be implemented at relatively low cost. Institutional controls have commonly been implemented as part of a remedy at similar sites. Therefore, they have been retained as representative institutional control process options.

C2.2 DNAPL *In Situ* Containment

The lateral mobility of DNAPL can be controlled by installing impermeable vertical barriers across potential DNAPL flow paths. At the Site, vertical barriers can be keyed into low-permeability soil layers in the Shallow Alluvium to limit horizontal liquid-phase migration. Vertical barriers would not prevent vertical DNAPL migration through discontinuities in low-permeability soil layers.

Free-phase DNAPL is typically present at the Site in relatively thin layers; DNAPL mobility at the Site is already limited by low-permeability soils or sediments (see Section 3.5 of the FS). However, this technology could offer additional protection by limiting migration of free-phase DNAPL. Note that placing an impermeable vertical barrier may also require collecting and treating groundwater (discussed below in Section 4) to prevent spreading of the contaminated groundwater plume as well as downgradient monitoring wells to confirm that DNAPL is being retained behind the vertical barrier. Impermeable barriers to prevent DNAPL migration are considered applicable only to upland Site areas.

Process options for impermeable vertical barriers include the following:

- **Slurry Walls.** Can be constructed using a one-pass continuous trencher or by traditional trench excavation and backfilling.
  - **High-density polyethylene (HDPE) or soil-bentonite slurry walls constructed using a one-pass continuous trencher.** Shallow subsurface debris (pipes, rubble) may need to be cleared with an excavator prior to using the trencher. Maximum depth of trenching using this method is approximately 35 feet (DeWind 2010). Unit costs for this option are typically around $6/vertical square foot (VSF) for slurry walls and $20/VSF for HDPE walls (Banks et al. 2006).
  - **Slurry walls constructed by excavating a trench and backfilling with a bentonite, cement-bentonite, or soil-bentonite slurry.** Slurry walls can also be constructed by driving vertical plates and injecting grout as the plate is removed. Unit costs for this option typically range from $2 to $10/VSF (Navy Website 2010) for walls up to 80 feet deep.
- **Sheet Pile Wall.** Interlocking sheet pile sections constructed of steel or HDPE. Sheets are either driven or vibrated into the ground, and joints are sealed with grout to prevent leaking. Unit costs for this option typically range from $25 to $80/VSF (Navy Website 2010).
- **Grout Curtain.** Slurry walls constructed by injection of cement or bentonite grout into soil (jet grouting) to construct a grout curtain. This technology can be used to construct very deep barriers, although establishing a continuous wall of consistent thickness is more difficult, and the resulting permeability is often higher than walls constructed by other methods. Unit costs for this option range from $40 to $200/VSF (Navy Website 2010) for walls up to 400 feet deep.

The process options discussed above potentially are implementable at the Site and effective for DNAPL. Sheet pile and grout curtain walls are significantly more costly than slurry walls, and the greater depths obtainable with a grout curtain are not necessary for the Site because DNAPL is present at a maximum depth of 34 feet below ground surface. Both methods of slurry wall installation (trench excavation and one-pass continuous trencher) have similar costs, but the trench excavation method has been more conventionally used and would be able to more easily cope with subsurface debris, which is expected to be present in some Site locations. Therefore, slurry wall installation via trench excavation is retained as a representative process option for impermeable vertical barriers.

C2.3 DNAPL *In Situ* Treatment

Potentially applicable *in situ* DNAPL treatment technologies include *in situ* thermal treatment (low-temperature thermal treatment, mid-temperature thermal treatment, and high-temperature thermal treatment), chemical oxidation, and *in situ* stabilization. Each of these technologies is discussed below.

C2.3.1 In Situ Thermal Treatment

Subsurface heating can be used to destroy or volatilize organic chemicals present in soil, sediment, and groundwater. This technology typically includes a network of heating or injection wells to heat the subsurface, and a network of extraction wells to remove contaminated soil vapor, groundwater, and DNAPL from the subsurface. Contaminated

fluids are treated above ground, typically by a combination of physical separation (to remove DNAPL), adsorption (to remove dissolved contaminants), and thermal oxidation (to destroy contaminated vapors).

Process options for *in situ* thermal treatment include the following:

- **Hot Water Injection.** Hot water is injected into the subsurface, decreasing DNAPL viscosity and raising the solubility of organic compounds.
- Steam Injection. Steam is injected into the subsurface, volatilizing or destroying (by pyrolysis) organic compounds. This heating method is considered the most cost-effective method of heat transfer to permeable soils, but effectiveness is limited in low-permeability soils.
- **Electrical Resistance Heating (ERH).** A voltage is applied to subsurface electrodes installed in vertical boreholes. The electrical resistivity of site soils creates heat. The efficiency of this method depends on the subsurface electrical properties, including soil type and moisture content.
- **Thermal Conduction Heating (TCH).** Vertical wells are heated, typically using in-ground electrical heaters, and the heat is transferred to subsurface soils via the soil's thermal conductivity. This method of heating provides relatively consistent heating regardless of soil type.

These heating methods are developing technologies and may require bench, pilot, or treatability testing prior to design and implementation.

Thermal treatment methods are considered applicable only to Site upland areas. Thermal treatment of Lake Washington sediments would be highly inefficient because of heat loss to the lake and would mobilize contaminants[1] that could not be reliably captured, resulting in aquatic habitat degradation.

Operating temperatures can be varied depending on remedial action objectives (RAOs), with three general technology types based on the level of heating:

- **Low-Temperature Heating.** The subsurface is heated to a temperature below the boiling point of water.
- **Mid-Temperature Heating.** The subsurface is heated to the boiling point of water.
- **High-Temperature Heating.** Also called *in situ* thermal desorption, the subsurface is heated above the boiling point of water.

Each of these technologies is discussed below.

Low-Temperature Heating. Heating the subsurface to temperature less than the boiling point of water would reduce the DNAPL viscosity and increase the solubility of DNAPL constituents for enhanced physical recovery. It would also volatilize the most volatile compounds. A portion of residual DNAPL would remain coated to soil after treatment.

Low-temperature heating is a developing technology for treatment of creosote and coal tar and has been used to enhance physical recovery of non-aqueous phase liquid (NAPL). The only full-scale applications of low-temperature heating to creosote or coal tar sites

[1] Mobilizing contaminants including decreasing the density of creosote and coal tar to below the density of water, creating a floating product (LNAPL).

have been applied as the first phase of a higher temperature heating method. Low temperature heating has most often been applied to sites containing chlorinated solvents where water-solvent mixtures have azeotrope boiling points less than 100 degrees C (EPA 2004). Based on case studies for these sites, unit costs are expected to range between $60 and $250/cy depending on the size of the area treated.

Process options to achieve low-temperature heating include hot water injection, ERH, and TCH. These technologies are likely applicable to the Site, although the resistivity of Site soils would have to be tested to verify the effectiveness of ERH. Hot water injection would have limited effectiveness based on the prevalence of low-permeability soil layers in the Shallow Alluvium where DNAPL is located. Because Site soils are heterogeneous, the technology would require substantial groundwater controls, such as barrier walls and/or a DNAPL recovery system, to prevent contaminant mobilization to Lake Washington. Site subsurface conditions[2] would require a relatively dense network of extraction and heating wells.

This technology has had limited full-scale application and is not likely to be cost-effective when compared to other technologies for addressing DNAPL for the following reasons:

- Mid-temperature heating (described below), is slightly more expensive but would remove much more contaminant mass.
- The cost of low-temperature heating is comparable or higher than for *in situ* stabilization, which would be more effective in addressing both free-phase and residual DNAPL in heterogeneous soil conditions.

Therefore, this technology has not been carried forward for remedial alternative assembly.

Mid-Temperature Heating. Heating the subsurface to the boiling point of water would improve contaminant removal, when compared to low-temperature heating, by further reducing the DNAPL viscosity and increasing contaminant solubility. Many of the Site chemicals of concern (COCs), including benzene and naphthalene, would be volatilized and removed, but a significant fraction of semivolatile compounds, such as carcinogenic polycyclic aromatic hydrocarbons (cPAHs), would remain in soil. Residual material treated by this technology would be relatively immobile and contain compounds of lower solubility, significantly reducing the amount of contaminant leaching (Baker and Herron 2010).

Mid-temperature heating is a developing technology for treatment of creosote and coal tar. Full-scale applications of mid-temperature heating to creosote or coal tar sites include the Visalia Pole Site in California, where creosote-containing soil was treated using steam. The unit cost of treatment at Visalia was approximately $100/cy (USACE 2009) to treat 115,000 cy of soil.

[2] Including a high water table; contamination distributed over a broad, shallow area; presence of high-organic soils such as peat and organic silt, which reduces removal efficiency of contaminants; and the presence of highly heterogeneous soils.

Similar to low-temperature heating, mid-temperature heating has most often been applied to sites containing chlorinated solvents; based on case studies for these sites, unit costs are expected to range between $100 and $450/cy depending on the size of the area treated and subsurface conditions (NAVFAC 2007). As previously stated, Site subsurface conditions would require a relatively dense network of extraction and heating wells for this option.

Process options to achieve mid-temperature heating include steam, ERH, and TCH. These technologies may be applicable to different portions of the Site, although the use of steam in the Shallow Alluvium may be inefficient based on the presence of low-permeability silts and peat. In some cases, a combination of steam, ERH, and TCH may be used to realize the benefits of each technology. Mid-temperature heating was not retained in the Draft Evaluation of Groundwater Restoration Potential Technical Memorandum (Aspect and Anchor QEA 2011) since it is unlikely to achieve MCLs.

High-Temperature Heating. In high-temperature heating, also called *in situ* thermal desorption, most DNAPL constituents, including semivolatile compounds, such as cPAHs, would be removed or destroyed *in situ*. Variation in the degree of contaminant reduction has been observed in samples from different manufactured gas plant (MGP) sites where this process option has been implemented. This technology is typically not implemented in saturated conditions because groundwater limits the maximum temperature to the boiling point of water; as water is boiled off, more groundwater flows in. Because the Site has a high water table and the majority of DNAPL is in the saturated zone, extensive dewatering would be required for the duration of treatment to achieve target temperatures.

High-temperature heating is a developing technology for treatment of creosote and coal tar. Full-scale applications of high-temperature heating to creosote or coal tar sites include the Alhambra Site in California, where creosote was treated by heating soil to approximately 650°F using TCH. Treatment reduced the average benzo[a]pyrene concentrations in soil by more than 99 percent. Based on the data collected at the Alhambra Site, the thermal vendor estimated that application of the technology to similarly sized sites (approximately 16,000 cy of treated soil) would cost approximately $380/cy (Baker et al. 2007). High-temperature heating costs at the Quendall Site would likely be higher based on the heterogeneity of subsurface soils (also described under mid-temperature heating) and the significant dewatering that would be required. The cost of implementing this technology, therefore, would be much higher than for *ex situ* treatment options (discussed below) but provide no greater effectiveness. Therefore, this technology has not been carried forward for remedial alternative development.

C2.3.2 In Situ Chemical Treatment

In this technology, chemical oxidants in solution are injected into the subsurface to react with and destroy organic contaminants. Common oxidants include hydrogen peroxide, potassium permanganate, ozone, and sodium persulfate. These chemicals have been shown to destroy a wide range of contaminants, including PAHs, benzene, and other COCs, in soil and groundwater. Full-scale *in situ* chemical oxidation using hydrogen peroxide has been used to treat coal tar DNAPL at MGP sites in New Jersey, New York, Georgia, Michigan, and Wisconsin. Full-scale ozone treatment of coal tar DNAPL has been implemented at two MGP sites in New York. Pilot studies to treat creosote using the oxidant potassium permanganate have reduced mass transfer of creosote constituents to

groundwater in the short term, because manganese precipitates form in the vicinity of DNAPL, but they have not shown significant mass reduction or long-term improvements in groundwater quality (Thomson et al. 2008).

This technology's effectiveness is generally limited in heterogeneous and low-permeability soils because of poor distribution of the oxidants, which must contact contaminants directly to be effective. Additionally, high organic matter concentrations in the subsurface consume oxidants and decrease treatment efficiency. The majority of the COC mass at the Site is located within heterogeneous soils containing peat and organic silt layers that would consume oxidants and make the process inefficient. Bench- or field-scale treatability testing would be required prior to design and implementation of this technology.

A review of 13 DNAPL sites where chemical oxidation was applied (primarily chlorinated solvent DNAPL sites, for which chemical oxidation has been applied more frequently than for creosote DNAPL sites) identified an average chemical oxidation treatment cost of $130/cy, which is greater than the cost for thermal treatment. Because it has not been demonstrated to be effective for creosote DNAPL and because potential treatment costs are higher than thermal treatment, this technology was not carried forward for remedial alternative assembly.

C2.3.3 In Situ Stabilization

In this technology, organic and inorganic COCs in soil are physically bound within a stabilized mass (solidification) while chemical reactions between the stabilizing agent and the contaminants reduces contaminant mobility. Potential amendments include bentonite, activated carbon, and cement. Bench testing may be needed to determine an amendment or blend of amendments to achieve performance criteria. Amendments can be mixed with soil *in situ* using large-diameter augers or jet-grouting equipment. Through this process, free-phase DNAPL is reduced to below its residual saturation level by mixing with amendments, which reduce soil permeability and contaminant leachability.

Geotechnical soil properties, such as compressive strength, are often improved by *in situ* stabilization, although solidified soil may complicate installation of future utilities or other subsurface structures. This treatment method does not destroy contaminants and increases the volume of contaminated material. *In situ* stabilization potentially can be applied deeper than excavation at sites with high water tables, such as this Site, and was used at the adjoining JH Baxter site immediately to the north to immobilize similar contaminants. It has frequently been used for source control at Superfund sites, and unit costs typically range from $40 to $60/cy for the depth range of DNAPL at the Site (EPA 2009). Therefore, this technology has been retained for remedial alternative assembly.

C2.4 DNAPL Removal Technologies

DNAPL can either be removed directly as a free-phase product by pumping fluids from wells or trenches or by removing soil or sediment containing DNAPL. Removal and treatment methods for soil and sediment containing DNAPL are discussed in the soil and sediment sections below. This section discusses methods of removing free-phase DNAPL from groundwater. Process options are as follows:

- **Vertical Wells.** Vertical wells can be installed with carefully placed screen sections to maximize DNAPL removal from targeted zones. Wells can include sumps for collecting DNAPL if the underlying confining layer is adequately thick. The main disadvantage of vertical wells is the potential for incomplete fluids capture in heterogeneous soils, as well as limited radius of influence in low-permeability soils. In some cases, this can be overcome by installing vertical wells at multiple levels and spaced closely together. Because vertical wells are a proven technology, they have been retained as a potential DNAPL removal technology.
- **Horizontal or Angled Wells.** Horizontal drilling techniques have been used at some cleanup sites to install non-vertical wells that provide access to areas where the surface is inaccessible to drilling rigs or trench installation. This technology could be applied in the nearshore Quendall Pond area to recover DNAPL; however, angled wells targeted to relatively shallow contamination (as observed in this area) would provide for only minimal additional lateral DNAPL capture compared to vertical wells. Construction of horizontal DNAPL recovery wells is not a proven technology. Therefore, horizontal and angled wells have not been retained.
- **Trenches.** Trenches generally allow more effective capture of groundwater and DNAPL than individual vertical wells by providing an expanded zone of influence (capture). Trenches are typically the preferred method for groundwater collection at sites with heterogeneous subsurface soils and shallow DNAPL occurrences (such as this Site), but constructing DNAPL collection trenches may require significant dewatering, particularly when working adjacent to the lake. Additionally, in areas of stratified DNAPL occurrences (as observed in the Quendall Pond area), trenching could increase DNAPL vertical mobility. Future Site use may limit the use of trenches for DNAPL recovery. Because trenches may be effective and less costly, trenches have been retained as a potential DNAPL removal technology in areas with suitable subsurface stratigraphy.

DNAPL pumped from wells or trenches can either be recovered by itself or with groundwater (total-fluids recovery). Site DNAPL is more viscous than water, flows into wells relatively slowly, and would be most efficiently recovered separately by low-flow or intermittent pumping, likely from a sump constructed in a well or trench, which allows DNAPL in the surrounding soil to drain by gravity and collect in the well. When combined with groundwater pumping, oil-wet soil surrounding the well can become water-wet, limiting DNAPL flow toward the well. A variety of pumping options are available for DNAPL and groundwater under both low-flow and high-flow pumping applications, including above-ground pumps (e.g., peristaltic pumps) and down-well pumps (e.g., electric submersible pumps).

Removal by pumping from wells or trenches can remove DNAPL that is present above residual saturation only. DNAPL present in oil-coated soil would not flow into wells or trenches[3] and would not be treated by this technology. Residual DNAPL can be mobilized for removal and treatment using thermal techniques, as described above.

[3] A small portion of additional DNAPL could be mobilized under a strong hydraulic gradient induced by total-fluids pumping; however, as described above, passive DNAPL collection is anticipated to be the more efficient method of DNAPL recovery at the Site.

The majority of Site DNAPL is present in thin layers and/or below residual saturation. A DNAPL recovery pilot test was successful at removing approximately 100 gallons of DNAPL from three recovery wells during a 2-year period; however, this is a small fraction (0.2 percent) of the total Site DNAPL mass (estimated to be nearly 500,000 gallons; see Section 4.4.1 of the FS). Therefore, this technology would be potentially effective for supplementing a containment strategy but not for source reduction. Given this application and the heterogeneous Site soils, recovery trenches would be the preferred collection method because they would be less sensitive to heterogeneous soil conditions. Therefore, DNAPL recovery using passive collection and pumping from trenches was retained as a representative process option for this FS.

C2.5 DNAPL *Ex Situ* Treatment Technologies

DNAPL collected from liquid pumping or separated from other waste materials would likely be classified as a hazardous waste based on the high concentrations of PAHs (Washington State persistent dangerous waste WP01) and, in some areas, high concentrations of benzene (Resource Conservation and Recovery Act [RCRA] characteristic hazardous waste D018). The process options for *ex situ* treatment of recovered DNAPL include incineration. If DNAPL is classified as a hazardous waste and recycling/reuse is impractical, it would likely need to be shipped to a hazardous waste treatment facility and incinerated. This is typically a very expensive disposal technology, but the high energy content of DNAPL may reduce the cost. This technology has been carried forward for remedial alternative assembly.

C2.6 DNAPL Disposal Technologies

Recovered DNAPL disposal process options include:

- Recycling of recovered DNAPL; and
- Disposal of recovered DNAPL via off-site incineration (refer also to the previous section).

If available, DNAPL recycling is the preferred and lowest cost method of disposal but may not be practicable because of the potential for hazardous waste classification and the low demand for this product. This technology has been retained for this FS.

In incineration, contaminated material is heated to temperatures above 1,400°F, directly oxidizing and converting volatile organic compounds (VOCs) and semivolatile organic compounds (SVOCs) to carbon dioxide and water. Metals are not treated, though they may be volatilized and the offgas may require treatment. This technology is an EPA presumptive remedy at wood treatment sites and can achieve treatment efficiencies between 90 and 99 percent (EPA 1995). This technology has been retained for this FS.

C3 Soil Technologies and Process Options

C3.1 Soil Institutional Controls

See Section 2.1 (of this appendix) for a description of institutional control technologies and process options effective at preventing exposure to hazardous substances in soil, which are the same as those for DNAPL.

C3.2 Soil *In Situ* Containment

A common method of controlling exposure to contaminated soils is to place an engineered cap over the materials. The long-term cap integrity can be maintained through implementation of appropriate institutional controls. In many cases, the clean cap may be separated from underlying potentially contaminated materials with a marker (e.g., geotextile fabric) indicating the cap boundary.

Process options for soil capping include the following:

- **Permeable Soil Capping.** Placing clean soil on the surface provides a barrier that prevents exposure to underlying soil but allows stormwater to infiltrate. Permeable soil caps implemented without additional measures (e.g., hydraulic controls to limit stormwater infiltration) may not address the soil to groundwater migration pathway in identified source areas. Cap thicknesses of 2 feet are typical in this application, potentially varying based on specific land uses and the presence of existing clean cover materials.
- **Low-Permeability Capping.** A low-permeability cap, constructed of clay or an engineered material, such as asphalt or concrete, would not only prevent exposure to underlying soils, but would also minimize stormwater infiltration through potentially contaminated materials, thereby reducing mobility of contaminants located in the unsaturated soil zone. Engineered materials could also be used in areas requiring a durable surface, such as high-traffic areas.
- **Impervious Capping.** An impervious cap, constructed of clay overlain by a synthetic liner, provides an additional impermeable layer, preventing infiltration to underlying soils and direct exposure, and also controls erosion. A slurry wall may be constructed along the perimeter of the cap to fully contain contaminated material.

Permeable, low-permeability, and impervious caps are proven, effective, and easily implemented, and can be designed to address the Site COCs. Engineered low-permeability and impervious caps are significantly more costly and require more maintenance, but may provide further groundwater mobility controls and may also be compatible with future land uses. Therefore, these three process options have been retained for remedial alternative assembly.

C3.3 Soil *In Situ* Treatment

In situ treatment technologies for soil include the following:

- Interstitial media removal and treatment;
- Thermal treatment;
- Stabilization;

- Chemical treatment; and
- Bioremediation.

These technologies, and available process options, are described below.

C3.3.1 Interstitial Media Removal and Treatment

Interstitial media removal and treatment options include passive soil venting, soil vapor extraction, and soil flushing as discussed below.

Passive Soil Venting. Passive soil venting is a less aggressive version of soil vapor extraction that is usually applied to prevent contaminated soil vapors from migrating into buildings or crawl spaces. In passive venting, soil vapors beneath a building foundation are vented to the atmosphere either through atmospheric pressure changes or by applying a low vacuum with a ventilation fan. Vented vapors can be passed through activated carbon for treatment, if necessary. There are no existing on-Site buildings that are occupied and would require sub-foundation venting, so this has not been retained for the development of remediation alternatives. However, use of this technology may be appropriate under future development scenarios that may include permanent, heated buildings. This potential application may be included as an institutional control for future Site uses.

Soil Vapor Extraction. In soil vapor extraction, a vacuum is applied to subsurface soil to remove soil vapor. Volatile constituents in soil are removed in the vapor stream and are treated above ground. This technology works best on VOCs in homogeneous, permeable soils. It is not effective for SVOCs or metals, and is not applicable to soils below the groundwater table. At the Site, the groundwater table is very shallow, unsaturated soils are highly heterogeneous and often have a low permeability, and much of the contamination identified in the unsaturated zone consists of heavier SVOCs. Therefore, this technology has not been retained for this FS.

Soil Flushing. Soil flushing is an enhancement to groundwater extraction and treatment in which a solution that enhances the solubility of organic constituents is injected into groundwater, passed through contaminated soil to remove contaminants, and then extracted for treatment. Soil flushing is a developing technology that would require bench and field testing prior to design and implementation. It would be potentially applicable to VOCs and SVOCs but not to metals. Surfactants and alcohols are examples of flushing solutions. Field applications of this technology have had mixed results. The effectiveness of soil flushing is limited when applied to heterogeneous soils (such as those at the Site) that cause poor subsurface distribution of the flushing solution and make complete capture of the mobilized contaminants difficult. Incomplete capture of mobilized contaminants at the Site could result in discharge of hazardous substances to Lake Washington. A review of six sites where this technology has been implemented identified an average cost of treatment to be $385/cy, much higher than thermal, chemical, or biological treatment methods (McDade, et. al 2005). Therefore, this technology was not retained for this FS.

C3.3.2 In Situ Thermal Treatment

In situ thermal treatment options include low-, mid-, and high-temperature heating and vitrification as discussed below.

Low-, Mid-, and High-Temperature Heating. *In situ* thermal treatment technologies (as described in Section 2.3.1 of this appendix) are not effective for metals, but potentially are applicable to other COCs in soil as follows:

- Low-temperature heating is low to moderately effective for VOCs and of low effectiveness for SVOCs.
- Mid-temperature heating is highly effective for VOCs and low to moderately effective for SVOCs.
- High-temperature heating is highly effective for both VOCs and SVOCs.

Screening of these technologies for *in situ* DNAPL, including benefits, limitations, and typical costs, is described above and may be applicable for soil. Based on this screening, low-temperature heating is not retained because of its low potential effectiveness, and mid- and high-temperature heating are not retained because of their high cost and difficult implementability compared to other options.

Vitrification. Vitrification involves applying a strong electrical current to the subsurface, heating soil to temperatures above 2,400°F to fuse it into a glassy solid. Organic compounds are destroyed or volatilized by the heating process; volatilized compounds are collected in the offgas and treated. Inorganic compounds are immobilized within the glass. This process would be effective for the Site COCs. Because of the very high energy requirement, particularly in water-saturated soils, this technology is extremely expensive when compared to other soil treatment methods. Although vitrification is equally effective when compared to other high-temperature thermal treatment options (thermal desorption), it is much more expensive than thermal desorption because vitrification operating temperatures are up to three times higher than those required by thermal desorption. This technology was originally designed for handling radioactive waste and has only been implemented at one Superfund site because costs have precluded it as a viable treatment option in other cases (EPA 2009). Therefore, this technology was not retained for remedial alternative assembly.

C3.3.3 In Situ Stabilization

In situ solidification/stabilization for DNAPL is described above and may be applicable for soil. This technology was used at the adjoining JH Baxter Site immediately to the north to immobilize similar contaminants and has frequently been used for source control at Superfund sites. Therefore, this technology has been retained for this FS.

C3.3.4 In Situ Chemical Treatment

In situ chemical treatment technologies include chemical oxidation and electrochemical remediation as discussed below.

Chemical Oxidation. The chemical oxidation process is described in Section 2.3.2 of this appendix and may be applicable for soil. Chemical oxidation is not effective for metals, but potentially is applicable to other COCs in Site soils.

The effectiveness of this technology is generally limited in heterogeneous soils because of poor distribution of the oxidants, which must contact contaminants directly to be effective. Additionally, high organic matter concentrations in the subsurface consume oxidants and decrease treatment efficiency. Because the Shallow Alluvium (which contains the majority of the soil COC mass) contains layers of low-permeability peat and

organic silt, which are relatively impermeable and high in organic carbon, applying chemical oxidation to this zone would be costly and inefficient.

A review of 13 sites containing DNAPL at which chemical oxidation was applied identified an average treatment cost of $130/cy, greater than costs for thermal treatment or bioremediation (McDade et al. 2005). Because both bioremediation and thermal treatment potentially are more cost-effective options, chemical oxidation was not retained for this FS.

ElectroChemical Remediation. ElectroChemical Remediation Technology (ECRT) is an innovative technology for destroying organic contaminants *in situ* by applying an alternating current across electrodes placed in the subsurface (EPA 2007). In theory, the applied voltage creates redox reactions that destroy constituents through oxidation-reduction mechanisms. The primary advantage of this technology is that it can treat soil within the unsaturated and saturated zone. The disadvantages are that it has produced mixed results at the field level, and studies indicate that treatment is less effective in soils with high organic carbon content such as those at the Site. Therefore, this technology has not been retained for this FS.

C3.3.5 Bioremediation

Many of the Site COCs, including benzene and naphthalene, can be degraded by native microbial populations. Contaminant biodegradation under natural conditions is one element of natural attenuation. Bioremediation involves adding amendments to the subsurface to enhance *in situ* biological degradation of contaminants. This technology is most effective for VOCs, but is also effective (at a slower rate) for some SVOCs. Bioremediation is least effective for high-molecular weight (5- or 6-ring) PAHs (including benzo[a]pyrene). Bioremediation is not effective for metals; however, changes in groundwater chemistry, such as redox conditions, may cause some metals to form less toxic complexes or become insoluble, precipitating out of solution.

Site VOCs and SVOCs would degrade most efficiently using electron acceptors such as oxygen, nitrate, and sulfate. Oxygen is typically the preferred amendment, but delivery of other electron acceptors is easier under some conditions.

Process options include the following:

- **Amendment Injection.** This process option delivers amendments to the saturated zone. Amendments are typically injected into groundwater and can be used to promote bioremediation of groundwater and saturated-zone soil. Biosparging (adding oxygen to groundwater by injecting air) is typically the most cost-effective bioremediation method for VOC and SVOC contamination.
- **Bioventing.** This process option increases oxygen in the unsaturated zone by extracting soil vapor, similar to soil vapor extraction (SVE). This process draws in atmospheric oxygen, which stimulates microbial growth.

Bioventing is only applicable to the unsaturated zone. Similar to SVE, it would have low effectiveness because of the shallow water table and the fact that most contaminants in unsaturated soils are SVOCs and are not efficiently treated by this process. Therefore, bioventing was not retained.

Similar to other treatment technologies that rely on subsurface distribution of chemicals, bioventing would be inefficient when applied to heterogeneous soils of various permeabilities; however, unlike chemical oxidation, in which oxidants are consumed relatively quickly in the subsurface[4], amendments may diffuse from high-permeability zones into low-permeability zones over time and can stimulate growth beyond the injection zones.

A review of 11 sites containing DNAPL where bioremediation was applied determined that costs for bioremediation range widely, from $2 to $225/cy, but that the average treatment cost was $29/cy, cheaper than chemical oxidation, surfactant flushing, or thermal treatment (McDade et al. 2005)[5]. *In situ* bioremediation is an EPA presumptive remedy for wood treatment sites (EPA 1995). Biodegradation is ongoing at the Site, has been widely demonstrated, and could be implemented as a polishing technology for other more effective technologies. Therefore, bioremediation via amendment injection was retained for remedial alternative assembly.

C3.4 Soil Removal Technologies

Contaminated soils can be effectively removed by excavation. Excavators, backhoes, and other conventional earth moving equipment are the most common equipment used to remove contaminated soil from upland areas. Below the water table, dewatering may be required to use soil excavation equipment. Alternatively, dredging equipment (see Section 5, Sediment Technologies and Process Options, of this appendix) could be used to remove soil 'in the wet.' Contaminated soil excavation is a commonly implemented technology and has been retained for remedial alternative assembly.

C3.5 Ex Situ Soil Treatment Technologies

Soil may be treated using physical, thermal, or biological technologies. These technologies and process options are described below.

C3.5.1 Ex Situ Physical Treatment

Ex Situ physical treatment options include physical separation and solidification/ stabilization as discussed below.

Physical Separation. The volume of excavated contaminated materials can be reduced by physically separating the materials into two or more fractions that can be handled separately. For example, cobbles can be screened from contaminated soil and beneficially used. However, large gravels or cobbles are not prevalent in the upland area of the Site. Therefore, there is little or no benefit from applying physical separation; therefore, this technology has not been retained for this FS.

Solidification/Stabilization. Similar to *in situ* solidification/stabilization for DNAPL described above, *ex situ* solidification/ stabilization is performed *ex situ* to excavated soils using a pug mill or similar equipment to blend soil with amendments. Depending on the amount of amending agent used and/or the type of amending agents, the end product

[4] Some oxidants, such as permanganate, can persist at some sites for a long period of time. However, natural oxidant demand at the Quendall Site is expected to rapidly consume injected oxidants.

[5] This study reviewed primarily sites with chlorinated solvent DNAPL.

may take on the form of a quasi-soil/concrete material that could later be used as bulk fill or a solid mass that could be used as building blocks or tiles (FRTR Website 2012).

Solidification/stabilization is a presumptive remedy at wood treatment sites, but only for inorganic constituents (EPA 1995). This technology would have similar effectiveness to *in situ* stabilization (which is retained) but is more expensive, with costs typically ranging from $70 to $145/cy (EPA 2009). Therefore, this technology was not retained for this FS.

C3.5.2 Ex Situ Thermal Treatment

Ex situ thermal treatment options include thermal desorption, vitrification, and incineration as discussed below.

Thermal Desorption. Low-temperature thermal desorption involves heating soils to temperatures between 200°F and 600°F until VOCs and SVOCs, such as benzene and naphthalene, evaporate. Exhaust gases produced by the process are typically combusted. This technology is effective for VOCs and SVOCs, achieving 90 to 99.7 percent destruction efficiencies for PAHs (EPA 1999), but is not effective for metals. It is a presumptive remedy for wood treatment sites (EPA 1995).

Thermal desorption systems can be designed to operate without producing liquid or solid secondary wastes, to meet clean air standards, and to achieve very low concentrations of residual constituents in soil. Limitations include high energy requirements for treating wet soils, difficulty in completely treating soils containing high levels of organics (such as the peaty Site soils), and the need to obtain permits for treatment of offgas (typically via incineration) generated from the on-site thermal desorption system. Thermal desorption may be accomplished on site with a mobile treatment unit or off site at a permanent treatment facility. Treatment costs (including excavation, backfilling, and sampling) typically range between $78 and $110/ton for on-site treatment and approximately $100 to $200/ton for off-site treatment (EPA 1999).

Compared to off-site landfill disposal, thermal desorption is typically more expensive than disposal at a Subtitle D (non-hazardous waste) landfill, but has the advantage of providing contaminant treatment and destruction rather than containment. This technology is typically less expensive than disposal at a hazardous waste landfill (for medium to large quantities of soil) and less expensive and/or more effective than other *ex situ* treatment options. Therefore, this technology has been retained in the FS as a representative process option for *ex situ* treatment of contaminated soils.

Vitrification. Vitrification involves the application of a strong electrical current to heat sediment to temperatures above 2,400°F, fusing it into a glassy solid. Organic compounds are destroyed or volatilized by the heating process; volatilized compounds are collected in the offgas and treated. Inorganic compounds are immobilized within the glass. Because of the very high energy requirement, particularly in water-saturated sediments, this technology is extremely expensive when compared to other treatment methods. Although vitrification is equally effective in remediating organic compounds as other high-temperature thermal treatment options (thermal desorption), it is much more expensive than thermal desorption because vitrification operating temperatures are up to three times higher than those required by thermal desorption. Therefore, vitrification has not been retained for soil in this FS.

Incineration. In incineration, contaminated soil is heated to temperatures above 1,400°F, directly oxidizing and converting VOCs and SVOCs to carbon dioxide and water. Metals are not treated, though they may be volatilized and the offgas may require treatment. This technology is an EPA presumptive remedy at wood treatment sites and can achieve treatment efficiencies between 90 and 99 percent (EPA 1995). However, this technology is relatively expensive, with typical costs up to $400/ton (EPA 1999) for on-site treatment and up to $900/ton for transport[6] and off-site treatment. Permitting on-site units can be costly and implementation can be difficult because of public opposition. This technology was not retained based on its high cost and the availability of other effective and cheaper treatment options such as thermal desorption.

C3.5.3 Ex Situ Chemical/Physical Treatment

Ex Situ chemical/physical treatment options include soil washing and solvent extraction as discussed below.

Soil Washing. In soil washing, soil is put in contact with an aqueous solution to remove contaminants from the soil particles. The suspension is often also used to separate fine particles from coarser particles, allowing beneficial use of the coarser fraction (if sufficiently clean). The aqueous solution can contain surfactants or other additives to promote contaminant dissolution. Soil washing has rarely been implemented in the United States and is typically more expensive than thermal desorption, with an average cost of approximately $170/ton (EPA 1999). It has limited effectiveness for removing strongly hydrophobic chemicals such as PAHs, particularly from soils with a high organic content, and is not typically effective when soil is composed of large percentages of silt or clay (EPA 1999), as are Site soils. Therefore, this technology was not retained for this FS.

Solvent Extraction. Solvent extraction is a variant of soil washing in which an organic solvent (rather than an aqueous solution) is put in contact with the soil to remove contaminants. This technology is more effective than soil washing at removing hydrophobic organic compounds such as PAHs, but is more expensive to implement because the solvent must be carefully controlled, collected, treated, and recycled. This technology has many of the same limitations as soil washing and would not be cost competitive or offer better treatment than thermal desorption. Therefore, this technology was not retained for this FS.

C3.5.4 Ex Situ Biological Treatment

Contaminant biodegradation by indigenous soil microbes can be enhanced by amending excavated soil with nutrients, moisture, and oxygen (typically provided by mixing). Process options for biological treatment include the following:

- **Landfarming/Composting.** Contaminated soil is spread out in a lined area and regularly tilled and amended with moisture and nutrients. Unit costs for treatment by this method are approximately $75/cy (EPA 1999).
- **Biopiles.** Contaminated soil is amended with nutrients and stockpiled. Unit costs for treatment by this method are approximately $100 and $200/cy (EPA 1999).

[6] Limited off-site incineration options exist, with no off-site incineration facilities in the Pacific Northwest.

- **Bioreactor.** Contaminated soil is mixed in a vessel with nutrients and water to make a slurry. Unit costs for treatment by this method are approximately $216/cy (EPA 1999).

Ex situ biological treatment methods have limited effectiveness for high molecular weight PAHs, are slower than other treatment technologies, and require significant space to implement (EPA 1999). These technologies have lower effectiveness with similar or higher costs than other treatment options. Therefore, *ex situ* bioremediation of Site soils was not retained for this FS.

C3.6 Soil Disposal Technologies

Excavated soils may be either disposed of directly or treated, using one or more of the technologies retained in the analysis above, and then disposed of. At a minimum, saturated soils would likely require dewatering before disposal. Soil disposal options are described below.

C3.6.1 On-Site Beneficial Use

Excavated soils exceeding applicable cleanup standards may potentially be used on Site if they meet or can be treated to meet applicable cleanup standards. Process options for on-Site beneficial use consist of:

- **Sand/Aggregate Reclamation.** Particle separation of excavated material with high sand content for use as concrete aggregate or general upland fill.
- **Topsoil Feedstock.** Blending of excavated material with organics for use as non-organic topsoil feedstock.

On-Site reuse may be appropriate for excavated soils, depending on COC concentrations and future Site use, and is of moderate relative cost. Both sand/aggregate reclamation and topsoil feedstock process options have been retained as representative on-Site beneficial use process options.

C3.6.2 On-Site Confined Disposal

Excavated soils exceeding applicable cleanup standards can be disposed of on Site within a specially designed upland confined disposal facility (CDF). On-Site confined disposal can be less costly than off-Site confined disposal but requires long-term on-Site management of contaminated materials.

An upland on-Site CDF may be appropriate for disposal of excavated soils, depending on COC concentrations and future Site use, and is of moderate relative cost. The on-Site upland confined disposal process option has been retained as the representative on-Site confined disposal process option.

C3.6.3 Off-Site Landfill Disposal

Contaminated soils may be transported to an off-Site, permitted disposal facility. The proper disposal facility will depend on whether the soil is classified as a non-hazardous or hazardous waste. No listed RCRA wastes have been identified on the Site (Ecology 2002). Potentially hazardous waste classifications based on soil characteristics include the following:

- **Washington State Persistent Dangerous Waste (WP01).** Soil is classified as WP01 if total PAH concentrations exceed 1 percent. Based on analytical data collected during the RI, most DNAPL-containing soil contains less than 1 percent total PAHs (see Table 4.2-1 of the RI Report). Furthermore, soil or sediment containing DNAPL that is removed is likely to be blended with cleaner soils during removal and processing, further lowering the total PAH concentration. Therefore, most soil generated during a remedial action at the Site is not expected to be classified as WP01.
- **RCRA Hazardous Waste (D018).** Soil is classified as D018 if benzene toxicity characteristic leaching procedure (TCLP) concentrations exceed 0.5 milligrams per liter (mg/L; which is approximate, if benzene is leached during the TCLP test, to a soil concentration of 10 milligrams per kilogram [mg/kg]). Based on analytical data collected during the RI, soil containing DNAPL in the Quendall Pond area potentially exceeds this value, and could exceed even if blended with a reasonable volume of clean soil during excavation.

Other potentially hazardous constituents detected at the Site (including cresol, arsenic, and lead) have not been detected at concentrations potentially exhibiting a hazardous waste characteristic.

Most contaminated Site soils will likely be characterized as non-hazardous solid wastes. However, some wastes (including highly concentrated DNAPL-containing soil, or DNAPL-containing soils in the vicinity of Quendall Pond) could be classified as hazardous wastes.

Non-hazardous solid wastes would be shipped via truck and/or railcar to a Subtitle D facility, such as the Klickitat County Landfill in Roosevelt, Washington. This disposal method provides for secure, long-term containment of non-hazardous solid wastes. Disposal costs at this facility can vary with quantity and season but currently average approximately $45/ton.

Some Site soils could be characterized as an RCRA hazardous waste or state-only dangerous waste based on either the presence of benzene (in coal tar-contaminated soil) or high PAH concentrations. Soils characterized as hazardous waste, but at concentrations less than ten times the Universal Treatment Standards, could be shipped via truck and railcar to a Subtitle C facility, such as the Waste Management Landfill in Arlington, Oregon. Disposal costs at this facility typically range from approximately $100 to $190/ton. Because off-Site disposal effectively removes contaminants from the property and places them in a secure containment facility, and because it is cost competitive when compared to on-Site treatment technologies (particularly for relatively small quantities of materials), these disposal options have been retained for remedial alternative assembly.

C4 Groundwater Technologies and Process Options

C4.1 Groundwater Institutional Controls

Institutional controls limit access to contaminated groundwater and may consist of legal restrictions such as use limitations recorded on the property deed. Process options for institutional controls include:

- Deed restrictions restricting use of groundwater for drinking; and
- Deed restrictions restricting use of groundwater wells.

These institutional controls can be effective and implementable under a wide range of conditions and generally apply to the entire Site. Consequently, these institutional control process options were retained as a representative institutional control process options.

C4.2 Groundwater Monitored Natural Attenuation

Natural attenuation is the reduction of COC groundwater concentrations through a combination of naturally occurring physical, chemical, and/or biological processes. Some natural processes (e.g., sorption of hydrophobic organic contaminants to organic carbon in soil) act as containment mechanisms and others (e.g., biodegradation of contaminants by native bacteria) act as *in situ* treatment mechanisms.

Natural attenuation of Site COCs (primarily coal tar/creosote constituents) has been widely documented at similar sites, and biodegradation of key COCs such as benzene and naphthalene has been documented at the Site (see Section 6 of the RI Report). The consistency of Site-specific biodegradation rates across the Site, as well as their similarity to literature information, provides support that natural attenuation of dissolved-phase groundwater contaminants is an important process to consider during development of remedial alternatives.

As a general response action, monitored natural attenuation would include monitoring to document the presence and effectiveness of natural processes in removing or containing Site COCs. Measures to enhance natural processes are considered under the *in situ* treatment options. Potential technologies applied under monitored natural attenuation include further characterization and predictive modeling of natural attenuation processes, and performance monitoring to verify model predictions.

Natural attenuation will likely be an important mechanism affecting contaminant fate and transport under any general response action. While monitored natural attenuation may not be effective at achieving the RAOs as a stand-alone technology, this technology is highly implementable at the Site. Therefore, this technology was retained as a possible supplemental polishing technology to be combined with other groundwater remediation technologies.

C4.3 Groundwater *In Situ* Containment

Methods of groundwater containment include impermeable vertical barriers, groundwater pumping, and stormwater controls. These technologies and process options are described

above for DNAPL and their specific applications to groundwater are further discussed below.

C4.3.1 Impermeable Vertical Barriers

Vertical barrier technologies and process options, described in Section 2.2 of this appendix, may be applicable for controlling the material movement on contaminated groundwater. To prevent groundwater mounding behind the barrier, which would result in flow of contaminated groundwater beneath or around the barrier, a groundwater pumping system would likely need to be implemented. To reduce the amount of pumping required, the vertical barrier could be installed to completely encircle the area being treated. Process options include sheet pile walls, slurry walls, and grout curtains, which are described above for *in situ* treatment of DNAPL.

Vertical barriers are commonly implemented as part of containment remedies at Superfund sites. They can also be used to facilitate construction of treatment remedies, such as excavation, that require dewatering. As described for DNAPL above, slurry walls constructed by excavating trenches are likely the most reliable and cost-effective process option and have been retained as the representative process option for impermeable vertical barriers.

C4.3.2 Groundwater Pumping

Migration of dissolved groundwater contaminants can be controlled by pumping groundwater from vertical wells or trenches, creating a capture zone within which groundwater flows toward the capture point. This technology can be applied for the groundwater COCs. The effectiveness of this technology to completely capture contaminated groundwater is often limited at sites with heterogeneous soils (such as the Site). It would not be effective at capturing groundwater beneath the lake. Because of subsurface heterogeneities and the close proximity of Lake Washington, groundwater pumping would likely need to be implemented with vertical barriers to contain the contamination plume. Short-term groundwater pumping may be a component of another technology, such as dewatering to support soil excavation. Because of its common application to other sites and its potential short-term applications, groundwater pumping was retained for remedial alternative assembly.

C4.3.3 Stormwater Controls

Migration of groundwater contaminants can be controlled by modifying hydraulic gradients influenced by stormwater infiltration. Process options for stormwater controls include:

- **Targeted Infiltration.** Creation of a hydraulic barrier by collecting and infiltrating stormwater and forming a local groundwater ‘mound.’
- **Reduced Infiltration.** Reduce localized infiltration and seepage of stormwater in impacted areas along the shoreline by implementing hydraulic controls, such as an impermeable shoreline cap.

Implementation of targeted infiltration may be limited because seasonal variability of Site groundwater elevations. Reduced infiltration through impermeable capping is moderately effective and implementable under a variety of future Site uses; therefore, reduced infiltration has been retained as the representative stormwater control process option.

C4.4 Groundwater *In Situ* Treatment

In situ groundwater treatment technologies include permeable reactive barriers, chemical treatment, and bioremediation, which are described below.

C4.4.1 Permeable Reactive Barrier

A permeable reactive barrier can be used to limit the migration of dissolved groundwater contaminants by passively treating groundwater as it flows through the barrier. The process option for permeable reactive barriers consists of a sorptive/reactive wall. A sorptive/reactive wall consists of a trench excavated in the upland and backfilled with permeable reactive materials. As groundwater flows through the barrier, permeable materials within the barrier sorb dissolved-phase constituents and can promote biodegradation. Sorptive/reactive walls materials applicable to coal tar/creosote Site COCs include activated carbon, organoclay, and materials with a high organic content, such as wood debris. Amendments to increase biodegradation may include calcium nitrate or other electron acceptors.

A permeable treatment wall to treat arsenic in groundwater using granular iron was installed, using excavation and bioslurry displacement, to a depth of 22 feet along the shoreline on the adjacent Conner Homes property. Installation of deeper treatment walls is possible but would likely require different techniques depending on the amendment. Permeable treatment walls potentially are effective at preventing upland groundwater contamination from discharging to Lake Washington; however, this technology would not address contaminants that have already migrated beneath the lake. Because of its potential effectiveness to treat upland groundwater and its proven implementability, this technology has been retained for remedial alternative assembly.

C4.4.2 In Situ Chemical Treatment

In situ chemical treatment technologies and process options are described in FS Section 5.4.3.4 and in Section 2.3.2 of this appendix.

C4.4.3 Bioremediation

The two process options for bioremediation of groundwater include the following:

- **Amendment Injection.** Described in Section 3.3.5 above.
- **Biosparging.** During biosparging air is bubbled into groundwater. This technology is generally the most cost-effective method of delivering oxygen to the subsurface, but its effectiveness can be limited in heterogeneous soils that are not conducive to air distribution.

Bioremediation is generally not effective for metals, but is potentially applicable to other Site groundwater COCs. Biodegradation is most effective for VOCs and least effective for high-molecular weight (5- or 6-ring) PAHs. Changes in groundwater chemistry associated with bioremediation may cause metals to form less toxic metal complexes or become insoluble by precipitating out of solution. Bioremediation is less costly than other *in situ* technologies, such as chemical oxidation.

Biodegradation of Site COCs, which has been demonstrated at other similar sites, could be implemented as a polishing technology when combined with other technologies. Either of these process options may be appropriate depending on where the technology is

applied. For example, biosparging is best suited to applications in the Deeper Alluvium. Therefore, both process options for bioremediation were retained for remedial alternative development.

C4.5 Groundwater Removal Technologies

Groundwater can be removed from the subsurface by pumping fluids from wells or trenches. A variety of pumping options are available for groundwater but down-well pumps (e.g., electric submersible pumps) are most commonly used. Groundwater may be pumped from vertical wells, horizontal or angled wells, or trenches.

Groundwater removal for treatment has been implemented and is ongoing at many Superfund sites. While it would not be expected to adequately reduce source area concentrations for many Site COCs that have low solubility (particularly cPAHs), it could be used as a polishing technology when combined with other technologies. Because of their common use and potential application to the Site, groundwater pumping vertical wells and trenches are retained for remedial alternative development.

C4.6 Ex Situ Groundwater Treatment Technologies

Potentially applicable treatment technologies for extracted groundwater are described and evaluated below. Groundwater would not need treatment if it meets discharge requirements (e.g., if minimally impacted groundwater is extracted as a containment measure).

C4.6.1 Physical/Chemical Treatment

Physical/chemical treatments include adsorption, air stripping, and advanced oxidation processes, which are described below:

- **Adsorption.** Adsorption of dissolved organic contaminants is one of the most widely used water treatment technologies. In this technology, contaminated groundwater is passed through a bed of granulated media where contaminants sorb to the surface of the sorbent, reducing the concentration of COCs in the bulk liquid phase. Activated carbon adsorption is effective and widely used for VOCs and SVOCs. Arsenic is often treated using activated alumina, iron oxides, or greensand. Arsenic treatment using sorption is typically less expensive than other methods if the volume to be treated is less than roughly 1 million gallons per day (EPA 2002). Disadvantages of adsorption include the need to periodically replace and regenerate or dispose of the used media. Adsorption is typically the most cost-effective means of treatment for VOCs, SVOCs, and metals. Because of its proven effectiveness, this treatment technology has been retained as a representative process option in combination with groundwater removal technologies.
- **Air Stripping.** In air stripping, contaminated groundwater and air typically are passed counter-currently through a tower, and volatile contaminants (such as benzene and, to a lesser extent, naphthalene) are transferred from the water to the air. The contaminant-laden air is usually treated by activated carbon and then discharged to the atmosphere. Air stripping can be cost-effective for volatile compounds such as benzene, but it is typically not effective for less volatile compounds such as PAHs. Air stripping is not effective for arsenic. Treatment efficiencies for air stripping are generally less than those for activated carbon, and

air stripping may require water polishing by activated carbon for some discharge options. For treatment of water with high VOC concentrations, this technology may be a cost-effective step in a treatment train. Therefore, this technology has been retained as a representative process option in combination with groundwater removal technologies.

- **Advanced Oxidation Processes.** A number of technologies exist that involve adding chemicals that directly oxidize organic groundwater contaminants. Process options include ozonation, hydrogen peroxide (with or without catalysts such as Fenton's Reagent or ultraviolet light), and permanganate. These technologies can effectively destroy organic chemicals, but capital and operation and maintenance costs are significantly higher than treatment by activated carbon or air stripping. They are not effective to treat arsenic. Therefore, this technology has not been retained for this FS.

C4.6.2 Biological Treatment

Biological treatment consists of contaminant destruction by passing contaminated groundwater through a biological reactor in which a contaminant-degrading microbial culture is maintained, generally by adding nutrients and oxygen, and controlling temperature, pH, and other parameters. Types of biological reactors include bioslurry reactors, fixed-film bioreactors, and constructed wetlands.

Biological treatment is potentially highly effective for treatment of Site groundwater containing VOCs; however, the treatability of recalcitrant COCs (particularly cPAHs) would have to be demonstrated in bench-scale and/or pilot tests. Because biological treatment is likely to be effective for treating Site groundwater and is technically implementable, it has been retained as an *ex situ* representative process option.

C4.7 Groundwater Disposal Technologies

Potential groundwater disposal methods are described and evaluated below. Some disposal methods may require pre-treatment depending on the quality of the extracted groundwater. Inclusion of these technologies in remedial alternatives could occur if short-term dewatering is required as part of construction.

C4.7.1 Off-Site Management

Off-site groundwater disposal process options include discharge to sanitary sewer and discharge to surface water as discussed below.

Discharge to Sanitary Sewer. In this disposal option, recovered groundwater would be discharged to the local sanitary sewer system. Groundwater pre-treatment may not be required if COC concentrations meet discharge criteria. Water containing high solids concentrations (e.g., from construction dewatering) would likely need to be passed through a settling tank or filter to meet discharge requirements. Fees for groundwater disposal to the sanitary sewer are based on the volume discharged, and periodic chemical and physical discharge monitoring is typically required. Allowable discharge volumes may be limited, particularly in the wet season, by the sewer system's capacity. Because this option may allow groundwater discharge without substantial on-Site treatment, it has been retained.

Discharge to Surface Water. In this disposal option, recovered groundwater would be discharged to Lake Washington surface waters. A National Pollutant Discharge Elimination System (NPDES) permit would likely be required for discharges. Water discharged to surface water would have to meet strict water quality requirements and would likely require treatment before discharge; however, no discharge fee (besides permitting fees) would be incurred. This technology has been retained.

C4.7.2 On-Site Management

Extracted groundwater may be discharged on Site via reintroduction to groundwater. Process options for reintroduction to groundwater include infiltration galleries or injection wells. On-Site reintroduction to groundwater is often the preferred disposal method for water generated during construction at large sites, such as the Quendall Site, when practicable. Reintroduction to groundwater as a disposal method is potentially effective, implementable, and cost-effective; therefore, it has been retained as the representative on-Site management process option.

C5 Sediment Technologies and Process Options

C5.1 Sediment Institutional Controls

Institutional controls limit access to contaminated material and may consist of physical restrictions, such as public advisories on fish consumption, or legal restrictions, such as use limitations recorded on the property deed. Process options for institutional controls include:

- Advisories on harvesting fish or shellfish typically implemented and enforced by the local health department.
- Monitoring and notification of waterway users to restrict specific activities to protect the remedy (e.g., restrictions on anchorage within the areas that are capped; restrictions on grounding of small vessels on the shoreline and on vessel draft, horsepower, speed, and time in area; and restrictions on piling placement or removal through cap, or other potential in-water construction/structures). Easements or restrictive covenants to limit activities that may damage the remedy or increase the potential for exposure. These easements or restrictive covenants can be placed on privately-owned aquatic lands or on state-owned aquatic lands through a long-term agreement with the Washington Department of Natural Resources (DNR).

These institutional controls are potentially effective at preventing exposure to hazardous substances and could be implemented under a wide range of conditions. However, institutional controls would not meet RAOs alone. Consequently, these institutional control process options were retained as a representative institutional control process options for combination with active remedial technologies and to protect the selected remedy. These institutional controls are considered applicable to the alternatives with a cap remedy. In addition, for alternatives with a dredging component, short-term fish consumption advisories may be required due to the potential for short-term water quality and fish-tissue impacts during dredging. A remedy including sediment institutional controls will need to be designed to reduce conflicts or restrictions on Tribal treaty

fishing rights or other treaty protected rights such as anchorage of Tribal fishing vessels or access to aquatic resources. The combination of monitoring, maintenance, and institutional controls; formal 5-year reviews; and contingency actions (if required) are considered adequate for ensuring remedy integrity.

C5.2 Sediment Monitored Natural Recovery

Natural recovery is the reduction in sediment COC concentrations through a combination of naturally occurring physical, chemical, and/or biological processes. Some natural processes (e.g., sedimentation or sorption of hydrophobic organic contaminants to organic carbon in soil) act as containment mechanisms, while others (e.g., biodegradation of contaminants by native bacteria) act as *in situ* treatment mechanisms.

C5.2.1 Monitored Natural Recovery

As a general response action, monitored natural recovery (MNR) provides monitoring to document the presence and effectiveness of natural processes in removing, reducing the risk, or containing Site COCs. The key difference between monitored natural attenuation (MNA) for groundwater and MNR for sediment is in the type of processes being relied upon to reduce risk. Transformation of contaminants, including biodegradation, is usually the major attenuating process for contaminated groundwater. However, often these processes are too slow for the persistent contaminants in sediment for remediation in a reasonable timeframe. Natural sedimentation is the process most frequently relied upon for MNR (EPA, 2005).

Potential activities completed under MNR include the following:

- Further characterization and predictive modeling of natural recovery processes, including isolation and mixing through natural sedimentation.
- Ongoing monitoring of sediment concentrations and toxicity of surface sediments.

MNR may not be effective at achieving the RAOs as a stand-alone technology, but this technology is highly implementable at the Site. Therefore, this technology was retained as a possible supplemental polishing technology to be combined with other sediment remediation technologies.

C5.2.2 Enhanced Natural Recovery

Deposition of clean sediment plays a role in the natural recovery of contaminated sediments. Enhanced Natural Recovery (ENR) is a remedial approach that enhances MNR by adding a thin layer of clean sediment layer over impacted sediment (i.e., thin-layer placement). The acceleration can occur through several processes, including increased dilution through bioturbation of clean sediment mixed with underlying contaminants. Thin-layer placement is typically different than *in situ* isolation caps because it is not designed to provide long-term isolation of contaminants from benthic organisms. ENR has been implemented as part of a remedy at similar sites. For instance, ENR has been implemented successfully as a component of the larger remedial effort at the creosote contaminated Wyckoff/Eagle Harbor Site on Bainbridge Island (ENVIRON and SPAWAR, 2009). Specifically, the thin layer cap has remained stable during 10 years of monitoring. Therefore, ENR has been retained for remediation of contaminated sediment.

C5.3 Sediment *In Situ* Containment

Engineered caps as an *in situ* containment technology, described for soil above, may be effective for isolating COCs in sediment. Cap monitoring results at other Puget Sound region sites have shown that capping can provide an opportunity for effective and economical sediment remediation without the risks involved in removing contaminants by dredging (Sumeri 1996). Sediment capping has been applied as a component of site remediation at a significant number of contaminated sediment sites (USEPA 2005). Recent demonstrations of reactive capping techniques have also been effective in providing additional protection through enhanced adsorption of contaminants. Capping process options are described below.

C5.3.1 Engineered Sand Cap

An engineered sand cap (typically up to 3 feet thick) can be designed to effectively contain and isolate contaminated sediments from the biologically active surface zone. The cap can be designed to be thick enough and of sufficient grain size to maintain its integrity under reasonable worst-case environmental and land use conditions. A sediment cap system's surface layers would likely be constructed of clean sand and could be placed by a number of mechanical and hydraulic methods. Engineered caps may also include erosion protection or stability layers such as geosynthetics or armoring materials. Armored caps (e.g., with a gravel surface) may be potentially appropriate for consideration in sediment areas with high potential for disturbance (e.g., areas likely to experience propeller wash).

Sediment capping is a proven technology to prevent exposure to contaminated sediments and could be implemented at the Site. Engineered sand caps are relatively cost-effective remediation technologies. Therefore, this process option has been retained for containment of contaminated sediment.

C5.3.2 Post-Dredge Residuals Cap

Recent research focused on evaluating contaminant concentrations of the post-dredge sediment surface indicates that approximately 2 to 11 percent of the mass of solids dredged during the last dredge production cut accumulates as a post-dredge residual layer (Bridges et al. 2010). The research further indicates that additional "cleanup" passes are inefficient in dealing with the generated residuals layer and other management approaches are required. One increasingly common and successful approach is the placement of a post-dredge residuals cap. The purpose of the cap is to provide a reduction in exposure to the residual contamination layer. Because post-dredge residuals caps are effective management solutions, this process option has been retained for containment of contaminated sediment.

C5.4 Sediment *In Situ* Treatment

In situ treatment methods applicable to sediment remediation generally rely on physical, chemical, or biological processes to destroy or immobilize contaminants or reduce toxicity.

C5.4.1 Physical/Chemical Treatment

Physical/chemical treatment options include permeable reactive capping, electrochemical remediation technology (ECRT), and stabilization as discussed below.

Permeable Reactive Capping. This technology could be used in targeted areas where DNAPL or sheens are an issue. In permeable reactive capping, a permeable cap is placed above contaminated sediments, and a material (organoclay or activated carbon) is placed within the sediment cap to sorb NAPL and/or dissolved-phase constituents, limiting migration into overlying sediment porewater and surface water. In certain applications, reactive caps may lose their effectiveness when the reactive material becomes saturated. Therefore, for continued effectiveness, a reactive cap should be designed such that one or more of the following design goals are achieved:

- A sufficient volume of reactive material is added such that its operating lifetime is longer than the projected restoration timeframe; or
- A mechanism to allow for reactive layer replacement is incorporated into the design.

Typical reactive capping media include granular activated carbon (GAC), organoclay, or apatite. The type of reactive media depends on the site COCs. GAC or lower cost coal or coke products are typically used to control dissolved-phase organic compounds. Apatite is used for metals. organoclay is manufactured by replacing cations in layered clays, such as bentonite, with cationic organic compounds, such as quaternary ammonium compounds (QACs), to create an organic phase along the surface of each layer in the molecular lattice. Organoclay effectively controls NAPL and has been installed to control NAPL at several sediment sites.

The Reactive Core Mat® (RCM) developed by CETCO™ uses a reactive material (e.g., organoclay, GAC, or apatite) within a geotextile envelope to provide capacity for contaminant sequestration (e.g., NAPL, organics, or metals) in a thin, rolled product that is readily transported and deployable. RCMs are appropriate for a cap of less thickness than a traditional bulk cap and have a significantly lower weight than bulk caps. Additional benefits of RCMs are their ease of installation, stability, and physical isolation.

Over the last ten years, reactive caps have been installed as full-scale remedies at numerous contaminated sediment sites in the United States, including:

- McCormick and Baxter Creosoting Co. Superfund Site, Portland, Oregon: Bulk organoclay Cap and organoclay RCM;
- Zidell Marine Corporation Sediment Cap, Portland, Oregon: RCM with GAC and apatite;
- Port of Portland Nearshore Cap, Portland, Oregon: Bulk Organoclay;
- Pine Street Canal Superfund Site, Burlington, Vermont: Organoclay RCM;
- Harbor Point Former MGP, Utica, New York: Organoclay RCM;
- Former Salem Massachusetts Manufactured Gas Plant (MGP), Salem, Massachusetts: Organoclay RCM;
- Former MGP, Everett, Massachusetts: Organoclay RCM;
- Bridgeport Rental and Oil Services (BROS) Superfund site, Logan Township, New Jersey: Organoclay RCM;
- Former Gautier Oil Company (CSX) Site, Gautier, Mississippi: Organoclay RCM;
- Stryker Bay St. Louis River/Interlake/Duluth Tar Superfund Site, Duluth, Minnesota: GAC RCM;

- Former Cresote Wood Treating Site, Escanaba, Michigan: Organoclay RCM and Bulk organoclay in a permeable reactive barrier; and
- Grand Calumet River - West Branch, Reach #3, Hammond, IN: GAC RCM.

Reactive caps or RCMs are designed to allow flow of groundwater or porewater through the cap. In addition, organoclay RCMs have been shown to be effective for control of NAPL or sheen at sites with ebullition, including the Pine Street Canal Superfund Site and the McCormick and Baxter Creosoting Co. Superfund Site. The organoclay sorbs/strips NAPL from NAPL-coated gas bubbles so that the bubbles do not transport NAPL beyond the reactive cap layer. For instance, at the McCormick and Baxter Superfund Site in Portland, Oregon, gas bubbles were associated with sheen prior to capping. After installation of the RCM, gas bubbles were still observed; however, there was no longer a sheen associated with the bubbles (Bullock 2007).

Although not applicable for this Site, an innovative application of reactive materials is to physically mix the reactive material with sediments to allow treatment of a thickness of sediment (EPA, 2013). Reactive materials have also been applied for upland sites or on shorelines in both bulk and as RCMs to line DNAPL collection trenches or in permeable reactive barriers. Reactive cap technology has been retained as a process option for *in situ* sediment treatment.

ElectroChemical Remediation Technology (ECRT). The ECRT process option is described in Section 5.3.2.3 of the FS and Section 3.3.4 of this appendix. This technology has been field-scale demonstrated by Weiss Associates Electrochemical Remediation Technologies and Lynntech, Inc., at three sites in the United States: the Duluth/Superior Harbor Superfund Site in Minnesota; the Georgia Pacific Remediation Site in Bellingham, Washington; and the Naval Air Weapons Station in Point Magu, California. In spite of several successful demonstrations in Europe, the projects in the United States were unable to yield favorable results. ECRT was not retained as a process option for *in situ* sediment treatment.

Stabilization. This technology is generally described in Section 2.3.3 above. In the aquatic environment, this process option is applicable to relatively coarse-grained, homogeneous sediment with lower concentrations of contamination and minimal free product present. The Site sediments are typically fine and in heterogeneous deposits. In addition, stabilization of aquatic sediments *in situ* has not been demonstrated to be effective in the long term. Therefore, this process option has not been retained for *in situ* sediment treatment.

C5.4.2 Bioremediation

Described in Section 3.3.5 of this appendix, bioremediation may be effective for reducing COC concentrations in sediment. The bioremediation process option for sediment is amendment injection.

Bioremediation of sediments *in situ* (e.g., via amendment injection) is an innovative technology and may not meet RAOs when implemented alone, but may be effective when combined with other technologies and can potentially be implemented under a variety of Site conditions. Therefore, amendment injection was retained for sediment for future consideration as a potential polishing technology, but not as a stand-alone application.

C5.5 Sediment Removal Technologies

C5.5.1 Excavation

Long-reaching excavators positioned from upland staging areas could be used to remove contaminated sediment. Dry excavation of nearshore sediments may also be facilitated through the installation of temporary cofferdams and the subsequent lowering of the groundwater table. Shoreline sediment excavation (at or just below the water line) is a proven method; however, costs associated with dewatering are relatively high and dewatered fluids would require disposal or treatment prior to discharge into Lake Washington. The technical feasibility of dewatering and dry excavation declines rapidly with increasing excavation depth. Site-specific evaluations estimate that dry excavations cannot be maintained in water depths greater than approximately 12 to 15 feet of water (refer to Appendix D of this FS), and due to this low implementability cofferdam containment was not retained as a representative excavation process option. Upland-based excavation was retained as a representative excavation process option.

C5.5.2 Dredging

Dredging is a method of excavation that allows removal of sediments without the necessary dry conditions required of traditional methods. Dredging is generally accomplished with two main technologies:

- **Hydraulic.** Removal using a cutterhead or auger, which dislodges the sediment, or using plain suction. The dredged material is conveyed along with water using a suction pipe and slurry pumps. The resulting sediment slurry is pumped to a barge or upland location for processing.
- **Mechanical.** Removal using an articulated fixed arm (e.g., backhoe) dredge, enclosed (environmental) bucket, or clamshell bucket on a barge. The mechanical dredge removes the sediment and transfers it into a separate barge for transport to the primary staging area.

Dredging effectiveness may be limited by resuspension, release of COCs (i.e., dissolved, particles, and sheens) to water, volatilization to air during dredging, and residual COCs remaining after dredging (USACE 2008). These effects may be reduced by use of containment (e.g., sheet piles, silt curtains, booms), best management practices (BMPs) (e.g., production rates, bucket control, etc.), and/or by equipment selection.

Mechanical dredging has been used to effectively remove contaminated sediment at many dredging sites. Mechanical dredging can use environmental buckets and operational controls to minimize resuspension. Mechanical dredges are more effective at removing debris than hydraulic dredges. Mechanical dredges are capable of removing most types of small debris without compromising the effectiveness of the dredge to remove sediment. As the size of the debris increases, the effectiveness of the dredge to remove sediment may decrease. Although large debris may cause resuspension, mechanical dredges are still capable of removing the debris (Palermo et al. 2004). Mechanical dredging generally requires handling the dredged material multiple times (e.g., placement on a barge, barge offloading, and transfer to upland staging area).

Hydraulic dredging has also been used successfully to remove contaminated sediments and is advantageous due to the production rate it can achieve under ideal conditions.

Hydraulic dredging is effective for removal of soft sediment, and may cause less resuspension than mechanical sediment removal. In addition, plain suction and specialty hydraulic dredges designed for environmental dredging (e.g., SedVac® by Terra Contracting or the VicVac™ by Brennan) have the potential for greater control of resuspension and releases than navigational hydraulic dredges (USACE 2008). Hydraulic dredges are less effective at handling debris than mechanical dredges and may require debris removal prior to dredging. (Palermo et al. 2004, USACE 2008). Hydraulic dredges can convey the dredged slurry directly to an upland staging area in a pipeline. Because hydraulically dredged sediment has higher water content than mechanical dredging, hydraulically dredged material would require significantly more dewatering than mechanically dredged sediment and would also generate significant amounts of water requiring treatment. Hydraulic dredging would require a greater dewatering and handling area than mechanical dredging.

Real-time positioning systems on both mechanical and hydraulic dredges allow control of position accuracy, inventory control, and real-time tracking.

Both mechanical and hydraulic dredging may be applicable for sediment removal and were retained as representative dredging process options. Containment of dredge areas using sheet piles or silt curtains is also retained for consideration.

C5.6 Ex Situ Sediment Treatment Technologies

Potentially applicable treatment technologies for sediment are described and evaluated below.

C5.6.1 Physical Treatment

Physical treatment options include physical separation and solidification/stabilization as discussed below:

Physical Separation. Physical separation is described in Section 3.5.1 above. Excess water can be removed from sediments using process options such as gravity dewatering, filter press, or geotextile tubes, allowing separate treatment and/or disposal of the liquid and solid fractions. Processing may be further performed on the solid fraction to separate coarse- and fine-grained material, as contaminants are generally bound to fine-grained particles and not coarser sands and gravels. Physical separation typically can be accomplished at relatively high to moderate cost and depending on the project may reduce overall treatment/disposal costs by reducing contaminant volume. Therefore, physical separation has been retained as a representative physical treatment process option for sediment.

Solidification/Stabilization. *Ex situ* solidification/stabilization is generally described in Section 3.5.1 above. While stabilization has been successful using relatively coarse sediments and soil, the generally fine-grained nature of Site materials would require the addition of sand and/or gravel to achieve typical structural requirements. Further, the presence of organic materials in Site soils and sediments are of significant concern when applying this process. High organics content can substantially affect stabilization performance and increase costs (which range from $40 to 100/cy; also dependent on water content). Because the stabilization process does not permanently destroy chemical contaminants, the permanence (e.g., long-term durability) of the stabilized material would need to be addressed in bench-scale testing.

Solidification/stabilization as a means of dewatering dredged sediments prior to transport for off-Site disposal is commonly implemented, effective, and relatively low in cost (EPA 2005). Therefore, solidification/stabilization was retained as a potential process option for treating and disposing of dredged sediment.

C5.6.2 Ex Situ Thermal Treatment

Ex situ thermal treatment options included thermal desorption, vitrification, and incinerations as discussed below:

Thermal Desorption. Thermal treatment is described in Section 3.5.2 above. Limitations of thermal desorption for treatment of sediment include high energy requirements for treating wet soils, difficulty in completely treating soils containing high organic content (such as the wood and peaty soils at the Site), and the extensive permitting requirements for on-Site thermal desorption systems. Thermal desorption may be accomplished on Site with a mobile treatment unit or off Site at a permanent treatment facility. Compared to off-Site landfill disposal, thermal desorption is typically more expensive (ranging from $60 to $120/cy), but has the advantage of providing contaminant treatment and destruction rather than containment. Therefore, this process option has been retained for *ex situ* thermal treatment.

Vitrification. Vitrification is described in Section 3.5.2 above. Costs for treating sediment via vitrification are approximately equivalent to those for saturated soil treatment. Therefore, this process option was not retained for this FS.

Incineration. Incineration is described in Section 3.5.2 above. Costs for treating sediment via incineration are approximately equivalent to those for saturated soil treatment. Therefore, this process option was not retained for this FS.

C5.6.3 Ex Situ Chemical/Physical Treatment

Ex situ chemical/physical treatment options include dehalogenation, sediment washing, and solvent extraction as discussed below;

Dehalogenation. Dehalogenation is the process of removing the halogen molecules (e.g., chlorine) from a contaminant in the sediment. In this process, dewatered contaminated sediment is screened, pulverized, and mixed with reagents prior to being heated in a reactor. Reagents used in the process consist of sodium bicarbonate (BCD) or potassium polyethylene glycol (APEG). The dehalogenation process is achieved by either the replacement of the halogen molecules or the decomposition and partial volatilization of the contaminants. The technology targets a relatively small range of contaminants (i.e., PCBs, dioxins, furans, and other halogenated compounds).

Because dehalogenation does not target Site COCs, this process option was not retained for this FS.

Sediment Washing. In sediment washing, sediment is put in contact with an aqueous solution to remove contaminants from the soil particles. The suspension is often also used to separate fine particles from coarser particles, allowing beneficial use of the coarser fraction (if sufficiently clean). The aqueous solution can contain surfactants or other additives to promote contaminant dissolution. Sediment washing is typically more expensive than thermal desorption and has limited effectiveness for removing strongly

hydrophobic chemicals such as PAHs, particularly from sediments with a high organic content. Therefore, this process option was not retained.

Solvent Extraction. See Section 3.5.3 above for a description of the solvent extraction process option and its applicability to Site COCs. As discussed, these options were not retained.

C5.6.4 Ex Situ Biological Treatment

See Section 3.5.4 above for a description of biological treatment technology and process options and the applicability to Site COCs. As discussed, these options were not retained.

C5.7 Sediment Disposal Technologies

C5.7.1 On-Site Beneficial Use

Dredged sediments may potentially be beneficially used on the Site if they meet or can be treated to meet applicable cleanup standards. Examples of potential beneficial uses of Site sediments that may be excavated include upland use of wood debris or clean sediments removed as part of habitat restoration or mitigation. Depending on the application (e.g., topsoil or landscaping materials), wood debris dredged for habitat restoration may require amendment through blending (with sand or other granular material) prior to on-Site beneficial use. On-Site beneficial use is the most preferred and likely the least costly method of sediment disposal (ranging between $15 to $30/cy depending on moisture content of the material and whether temporary stockpiling is required). Therefore, on-Site beneficial use has been retained as a technology for this FS.

C5.7.2 On-Site Confined Disposal

Dredged sediments exceeding applicable cleanup standards could potentially be placed on Site in a specially designed upland CDF. Depending on the leachability of confined materials, the CDF could potentially include a liner and a liquid collection system to prevent leachate from contaminating groundwater. On-Site confined disposal can be cheaper than off-Site confined disposal, but requires long-term on-Site management of contaminated materials. Costs for on-Site confined disposal would include those for beneficial use and the cost for developing the facility, which could result in total costs of approximately $35 to $50/cy. This disposal technology has been retained for this FS.

C5.7.3 Off-Site Landfill Disposal

Off-Site landfill disposal process options are described in Section 3.6.3 above. Contaminated Site sediments will likely be characterized as non-hazardous solid wastes and could be shipped via truck and railcar to facilities such as the Klickitat County Landfill in Roosevelt, Washington. This disposal method provides for secure, long-term containment of non-hazardous solid wastes. Costs for dewatering, transport, and disposal may range from approximately $50 to $200/cy. This disposal technology has been retained for this FS.

C6 References for Appendix C

Aspect and Anchor QEA, 2011, Evaluation of Groundwater Restoration Potential Technical Memorandum, Quendall Terminals Site, Prepared for U.S. Environmental Protection Agency, Region 10, on behalf of Altino Properties, Inc and J.H Baxter & Company, May 13, 2011 DRAFT.

Baker, Ralph S., Devon Tarmasiewicz, John M. Bierschenk, Jennie King, Tony Landler, and Doug Sheppard, 2007, Completion of *In-Situ* Thermal Remediation of PAHs, PCP and Dioxins at a Former Wood Treatment Facility, IT3'07 Conference, May 14-18, 2007, Phoenix, Arizona.

Baker, Ralph, and Gorm Herron, (TerraTherm Inc.) 2010, *In Situ* Thermal Remediation (ISTR) of MGP and Creosote Sites in Context of Wyckoff/Eagle Harbor Superfund Site Generational Remedy Evaluation.

Banks, John A., Robert L. Westly, Robert A. Hauser Jr., 2006, The Relocation of Subsurface Cutoff Wall for a Major Urban MSW Disposal Facility.

Bridges, T.S., K.E. Gustavson, P. Schroeder, S.J. Ells, D. Hayes, S.C. Nadeau, M.R. Palermo, and C.R. Patmont, 2010, Dredging Processes and Remedy Effectiveness: Relationship to the 4 Rs of Environmental Dredging, Integrated Environmental Assessment and Management, October 2010.

Bullock, A. M. 2007. Innovative Uses of Organophilic Clays for Remediation of Soils, Sediments, and Groundwater. In WM Symposia, *Waste Management 2007 Symposium: Global Accomplishments in Environmental and Radioactive Waste Management*. Tuscon, AZ. February 25 to March 1, 2007. http://www.wmsym.org/archives/2007/pdfs/7032.pdf

DeWind, 2010, http://dewinddewatering.com/enviro.htm.

Ecology, 2002, Letter to Lori Herman (Hart Crowser) from Brian Sato (Washington Department of Ecology), Waste Designation and Disposal of Quendall Terminals IDW Drums, February 26, 2002.

ENVIRON and SPAWAR, 2009. Merritt, K. A., J.M. Conder, V.S Magar, V.J Kirtay, D.B. Chadwick. Enhanced Monitored Natural Recovery (EMNR) Case Studies Review. July 2009.

EPA, 1995, Presumptive Remedies for Soils, Sediments, and Sludges at Wood Treater Sites. U. S. Environmental Protection Agency, Office of Emergency and Remedial Response, 1995.

EPA, 1999, A Resource for MGP Site Characterization and Remediation. U. S. Environmental Protection Agency, Office of Solid Waste and Emergency Response, 1999.

EPA, 2002, Role of Background in the CERCLA Cleanup Program, OSWER 9285.6-07P, US Environmental Protection Agency, Office of Solid Waste and Emergency Response, Office of Emergency and Remedial Response, Washington, DC. April 26, 2002.

EPA, 2004, *In Situ* Thermal Treatment of Chlorinated Solvents – Fundamentals and Field Applications, EPA 542-R-04-010, March 2001.

EPA, 2005, Contaminated Sediment Remediation Guidance for Hazardous Waste Sites. OSWER Publication 9355.0-85, United States Environmental Protection Agency, Office of Solid Waste and Emergency Response, Website: http://www.epa.gov/superfund/resources/sediment/guidance.htm.

EPA, 2007, Innovative Technology Evaluation Report: Electrochemical Remediation Technologies (ECRTs) – *In situ* Remediation of Contaminated Marine Sediments, U.S. Environmental Protection Agency, Office of Research and Development.

EPA, 2009, Technology Performance Review: Selecting and Using Solidification/Stabilization Treatment for Site Remediation, U. S. Environmental Protection Agency, Office of Research and Development, 2009.

EPA, 2013. Use of Amendments for In Situ Remediation at Superfund Sediment Sites. U. S. Environmental Protection Agency, Office of Superfund Remediation and Technology Innovation. OSWER Directive 9200.2-128FS. April 2013.

Federal Remediation Technologies Roundtable (FRTR), Website, 2012, Remediation Technologies Screening Matrix and Reference Guide, Version 4.0, http://www.frtr.gov/matrix2/section4/4-21.html.

McDade, James M., Travis M. McGuire, and Charles J. Newell, 2005, Analysis of DNAPL Source-Depletion Costs at 36 Field Sites.

NAVFAC (Naval Facilities Engineering Command), 2007, Final Report – Cost and Performance Review of Electrical Resistance Heating (ERH) for Source Treatment, Prepared by: Arun Gavaskar, Battelle, Mohit Bhargava, Battelle, Wendy Condit, Battelle, Technical Report TR-2279-ENV. 2007.

Navy Website, 2010, Vertical Cutoff Wall, https://portal.navfac.navy.mil/portal/page/portal/NAVFAC/NAVFAC_WW_PP/NAVFAC_NFESC_PP/ERB/VERTCUTOFF.

Palermo, M. R., N. R. Francingues, and D. E. Averett, 2004. Operational Characteristics and Equipment Selection Factors for Environmental Dredging. Journal of Dredging Engineering, Volume 6, No. 3, December.

Sumeri, 1996, Dredged Material is Not Spoil: A Report on the Use of Dredged Material in Puget Sound to Isolate Contaminated Sediments, Western Dredging Association Seventeenth Annual Meeting, June 11-14, 1996.

Thomson, N. R., M.J. Fraser, C. Lamarche, J. F. Barker, and S. P. Forsey, 2008, Rebound of a Coal Tar Creosote Plume Following Partial Source Zone Treatment with Permanganate.

USACE, 2008, Technical Guidelines for Environmental Dredging of Contaminated Sediments, ERDC/EL TR-08-29, September 2008.

USACE (U. S. Army Corps of Engineers, Engineering and Design), 2009, Design: *In Situ* Thermal Remediation.

V:\020027 Quendall Terminals\FS Report\Draft Final Deliverable\DRAFT FINAL FS OCT 14\Appendices\Appendix C\Draft Final FS_Appendix C.docx

APPENDIX D

Remedial Alternatives Cost Estimates

Table of Contents: List of Tables

D-1 Summary of Cost Estimates for EPA-Specified Alternatives

D-2 Alternative 2 Cost Estimates –Containment

D-3 Alternative 3 Cost Estimates – Containment with Targeted PTM Solidification (RR and MC DNAPL Areas)

D-4 Alternative 4 Cost Estimates – Containment with Targeted PTM Removal (TD, QP-S, and QP-U DNAPL Areas)

D-5 Alternative 5 Cost Estimates – Containment with Targeted PTM Solidification (RR, MC, and QP-U DNAPL Areas and ≥ 4-Foot-Thickness) and Removal (TD and QP-S DNAPL Areas)

D-6 Alternative 6 Cost Estimates – Containment with Targeted PTM Solidification (RR and MC DNAPL Areas and ≥ 2-Foot-Thickness) and Removal (TD, QP-S, and QP-U DNAPL Areas)

D-7 Alternative 7 Cost Estimates – Containment with PTM Solidification (Upland) and Removal (Sediment)

D-8 Alternative 8 Cost Estimates – Containment with PTM Removal (Upland and Sediment)

D-9 Alternative 9 Cost Estimates – Containment with Solidification and Removal of Contaminated Soil and Removal of Contaminated Sediment

D-10 Alternative 10 Cost Estimates – Containment with Removal of Contaminated Soil and Removal of Contaminated Sediment

D1 Introduction

This appendix provides detailed cost estimates for Alternatives 2 through 10. Cost estimates were developed in accordance with EPA cost estimating guidance (*A Guide to Developing and Documenting Cost Estimates During the Feasibility Study,* U.S. Environmental Protection Agency, Office of Emergency and Remedial Response, OSWER Directive 9355.0-75, July 2000) and are FS-level (+50/-30%). Costs are inclusive of contractor overhead and profit. Costs are based on a variety of sources including project experience, vendor and contractor quotes, and available cost databases as noted in each table. Costs are in 2013 dollars. Two total costs were calculated for each alternative: one using Net Present Value (NPV) analysis assuming a discount rate of 1.6 percent, and one with no discount rate for future costs. The discount rate was based on the values published in the Office of Management and Budget (OMB) Circular A-94, Appendix C. For the purposes of these estimates, remedial construction costs were not discounted for alternatives in which construction extends past Year 0. As indicated in Table D-1, these cost estimates range from $33,500,000 (NPV $26,000,000) to $439,000,000 (NPV $409,000,000) for the proposed alternatives.

Table D-1 - Summary of Cost Estimates for EPA-Specified Alternatives

Quendall Terminals
Renton, Washington

Alternative	Total Estimated Cost			
	Without NPV Analysis	With NPV Analysis[2]	FS-Level Accuracy Range (with NPV Analysis[2])	
			Minus 30%	Plus 50%
Alternative 1 - No Action	$ 0	$ 0	$ 0	$ 0
Alternative 2 - Containment	$ 33,500,000	$ 26,000,000	$ 18,200,000	$ 39,000,000
Alternative 3 - Containment with Targeted PTM Solidification (RR and MC DNAPL Areas) (RR and MC DNAPL Areas)	$ 40,100,000	$ 30,700,000	$ 21,500,000	$ 46,100,000
Alternative 4 - Containment with Targeted PTM Removal (TD, QP-S, and QP-U DNAPL Areas)	$ 49,100,000	$ 44,300,000	$ 31,000,000	$ 66,500,000
Alternative 5 - Containment with Targeted PTM Solidification (RR and MC DNAPL Areas and ≥ 4-Foot-Thickness) and Removal (TD and QP-S DNAPL Areas)	$ 50,700,000	$ 46,500,000	$ 32,600,000	$ 69,800,000
Alternative 6 - Containment with Targeted PTM Solidification (RR and MC DNAPL Areas and ≥ 2-Foot-Thickness) and Removal (TD, QP-S, and QP-U DNAPL Areas)	$ 64,800,000	$ 60,600,000	$ 42,400,000	$ 90,900,000
Alternative 7 - Containment with PTM Solidification (Upland) and Removal (Sediment)	$ 82,800,000	$ 80,400,000	$ 56,300,000	$ 121,000,000
Alternative 8 - Containment with PTM Removal (Upland and Sediment)	$ 142,000,000	$ 140,000,000	$ 98,000,000	$ 210,000,000
Alternative 9 - Containment with Solidification and Removal of Contaminated Soil and Removal of Contaminated Sediment	$ 264,000,000	$ 262,000,000	$ 183,000,000	$ 393,000,000
Alternative 10 - Containment with Removal of Contaminated Soil and Sediment	$ 439,000,000	$ 409,000,000	$ 286,000,000	$ 614,000,000

NPV - Net Present Value

Notes:
1. Estimated costs are rounded to three significant figures.
2. A 1.6% discount rate was used in the net present value analysis.

Table D-2 - Alternative 2 Cost Estimates

Quendall Terminals
Renton, Washington

Site:	Quendall Terminals					
Remedial Action Description:	Alternative 2 Containment					
Cost Estimate Accuracy:	FS Screening Level (+50/-30 percent)					
Key Assumptions and Quantities:	Capping of Upland Soil					
(see Appendix E for calculations)	21.6	acre	total area			
	940,896	SF	total area			
	133,521	SF	permeable area along shoreline			
	14,836	BCY	habitat excavation overlap			
	104,544	BCY	total volume	based on 3' cap thickness		
	Enhanced Natural Recovery - Sand Material					
	14,300	BCY	total volume			
	Engineered Sand Cap					
	15,300	BCY	total sand volume			
	2,150	BCY	removal volume for offsetting sand cap			
	40,000	SF	area for offsetting sand cap			
	3.2	acre	DNR lease area			
	RCM Reactive Capping materials					
	214,800	SF	area of RCM			
	4,100	BCY	total sand volume			
	581	BCY	removal volume for offsetting reactive cap			
	Amended Sand Capping Materials					
	429	BCY	Bulk Organoclay Material - (PM-199)			
	5,727	BCY	Sand			
	Soil/Sediment Density					
	1.6	tons/BCY	soil density			
	1.3	tons/BCY	sediment density			
	0.7	tons/CY	organoclay density			
	Volume of sediment removal					
	2,800	BCY	sediment removal			
	2,800	BCY	total sediment removal volume (including for offsetting cap)			

Item	Quantity	Unit	Unit Cost	Total Cost	Source	Notes
CAPITAL CONSTRUCTION COSTS						
Upland Soil Cap						
Mobilization/Demobilization	1	LS	$ 424,940	$ 424,940	percentage of construction costs	includes temporary facilities for duration of construction
Site Preparation	22	acre	$ 6,900	$ 149,040	Costworks	clearing, grubbing brush and stumps
Geotextile marker layer	104,544	SY	$ 2	$ 158,907	Costworks	non-woven, 120lb tensile strength
Import Fill - Permeable Cap	104,544	BCY	$ 30	$ 3,136,320	project experience	
Compaction	104,544	BCY	$ 5	$ 522,720	project experience	
Habitat Area - excavation	14,836	BCY	$ 6	$ 89,014		
Habitat Area - non-hazardous transport and disposal	23,737	ton	$ 50	$ 1,186,853		
Hydroseeding	14,836	SY	$ 1	$ 8,901	Costworks	includes seed and fertilizer for wetland area
Stormwater collection and detention system	1,500	LF	$ 40	$ 60,000	project experience	media filter drain
Subtotal				*$ 5,736,696*		
Tax	9.5%		$ 5,736,696	$ 544,986		Sales Tax
Contingency	25%		$ 6,281,682	$ 1,570,421		
Total Upland Soil Cap Cost				$ 7,852,103		
Enhanced Natural Recovery						
Mobilization/Demobilization	1	LS	$ 65,664	$ 65,664		
Sand Material	22,880	ton	$ 20	$ 457,600	vendor quote	
Sand Placement	22,880	ton	$ 15	$ 343,200	project experience	ENR placed as one lift
Confirmation of Placement	1	LS	$ 20,000	$ 20,000		
Subtotal				*$ 886,464*		
Tax	9.5%		$ 886,464	$ 84,214		Sales Tax
Contingency	25%		$ 970,678	$ 242,669.52		
Total Enhanced Natural Recovery Cost				$ 1,213,348		
Engineered Sand Cap						
Mobilization/Demobilization	1	LS	$ 81,536	$ 81,536		
Sand Material	24,480	ton	$ 20	$ 489,600	vendor quote	
Sand Placement	24,480	ton	$ 20	$ 489,600	project experience	Sand Cap placed in multiple lifts
Geotextile Separation Layer	40,000	SF	$ 1	$ 20,000	Vendor quote	Only in nearshore area
Confirmation of Placement	1	LS	$ 20,000	$ 20,000		
Subtotal				*$ 1,100,736*		
Tax	9.5%		$ 1,100,736	$ 104,570		Sales Tax
Contingency	25%		$ 1,205,306	$ 301,326		
Total Engineered Sand Cap Cost				$ 1,506,632		
RCM Reactive Capping						
Mobilization/Demobilization	1	LS	$ 99,014	$ 99,014		
Organoclay RCM Material + Transportation	214,800	SF	$ 3	$ 558,480	Quote from Cetco	
Organoclay RCM Placement	214,800	SF	$ 2	$ 429,600	Project experience	
Sand Material	6,560	ton	$ 20	$ 131,200	vendor quote	
Sand Placement	6,560	ton	$ 15	$ 98,400	project experience	Sand over RCM placed in one lift
Confirmation of Placement	1	LS	$ 20,000	$ 20,000		
Subtotal				*$ 1,336,694*		
Tax	9.5%		$ 1,336,694	$ 126,986		Sales Tax
Contingency	25%		$ 1,463,680	$ 365,920		
Total RCM Reactive Capping Cost				$ 1,829,600		
Amended Sand Capping						
Mobilization/Demobilization	1	LS	$ 108,177	$ 108,177		
Bulk Organoclay Material - (PM-199)	300	ton	$ 3,250	$ 975,687	Quote from Cetco	
Sand	9,163	ton	$ 20	$ 183,265	vendor quote	
Material Placement	9,163	ton	$ 20	$ 183,265	project experience	
Confirmation of Placement	1	LS	$ 10,000	$ 10,000		
Subtotal				*$ 1,460,395*		
Tax	9.5%		$ 1,460,395	$ 138,737		Sales Tax
Contingency	25%		$ 1,599,132	$ 399,783		
Total Ameded Sand Capping Cost				$ 1,998,915		
Sediment Removal						
Mobilization/Demobilization	1	LS	$ 32,688	$ 32,688		
Mechanical Dredging	2,800	BCY	$ 35	$ 98,000		Mechanical dredging in nearshore and for offsetting nearshore cap
Transloading/Material Handling	2,800	BCY	$ 15	$ 42,000		
Dewatering	2,800	BCY	$ 10	$ 26,600	vendor quote	Assumes 5% amendment by weight
Water Treatment	1	LS	$ 50,000	$ 50,000	Project experience	
Transportation and Disposal - Non-Hazardous	3,640	ton	$ 50	$ 182,000		Subtitle D landfill disposal
Dredging Confirmation	1	LS	$ 10,000	$ 10,000		
Subtotal				*$ 441,288*		
Tax	9.5%		$ 441,288	$ 41,922		Sales Tax
Contingency	25%		$ 483,210	$ 120,803		
Total Sediment Removal Cost				$ 604,013		
Sediment Environmental Controls and Monitoring						
Water Quality Monitoring	100	day	$ 2,000	$ 200,000		
Water Quality Controls and BMPs (Absorbent Booms, Silt Curtains, Oil Bo	1	LS	$ 25,000	$ 25,000		
Odor Control	10	day	$ 2,500	$ 25,000		
Erosion Protection for Shoreline Area	1	LS	$ 250,000	$ 250,000		
Subtotal				*$ 500,000*		
Tax	9.5%		$ 500,000	$ 47,500		Sales Tax
Contingency	25%		$ 547,500	$ 136,875		
Total Sediment Environmental Controls and Monitoring Cost				$ 684,375		
Subtotal Construction Costs				**$ 15,688,986**		
Professional Services (as percent of construction and contingency costs)						
Project management	5%		$ 15,688,986	$ 784,449		
Remedial design	6%		$ 15,688,986	$ 941,339		Includes treatability studies for remedy components as necessary
Construction management	6%		$ 15,688,986	$ 941,339		
Subtotal				*$ 2,667,128*		
Total Estimated Capital Cost				**$ 18,400,000**		

Table D-2 - Alternative 2 Cost Estimates

Quendall Terminals
Renton, Washington

O&M COSTS						
1st Year O&M						
GW Monitoring	1	LS	$ 80,000	$ 80,000	Project experience	
Sediment Sand Cap and ENR Sampling	1	LS	$ 25,000	$ 25,000	Project experience	
Sediment Cap Inspection	1	LS	$ 15,000	$ 15,000	Project experience	Visual and In-Water (Bathymetric/ Sediment Profile Image)
DNR Lease	3.2	acre	$ 20,000	$ 64,000		Offshore cap area off property
Subtotal				*$ 184,000*		
Tax	9.5%		$ 184,000	$ 17,480		Sales Tax
Contingency	25%		$ 201,480	$ 50,370		
Total 1st Year O&M Cost				$ 251,850		
Annual O&M						
Groundwater Monitoring	1	LS	$ 25,000	$ 25,000	Project experience	20 wells annually
Upland Cap inspection	6	hour	$ 80	$ 480	labor estimate	
DNR Lease	3.2	acre	$ 20,000	$ 64,000		Offshore cap area off property
Subtotal				*$ 89,480*		
Tax	9.5%		$ 89,480	$ 8,501		Sales Tax
Contingency	25%		$ 97,981	$ 24,495		
Total Annual O&M Cost				$ 122,476		
Professional Services (as percent of Annual O&M costs)						
Project management/Reporting	10%		$ 122,476	$ 12,248		
Total, Annual O&M:				**$ 134,723**		
Total Estimated O&M, 100 Years, No NPV Analysis:				**$ 13,700,000**		
Periodic Costs						
Reactive Cap						
Replace 25% of RC at 22 yrs				$ 300,000		
Replace 25% of RC at 44 yrs				$ 300,000		
Replace 25% of RC at 66 yrs				$ 300,000		
Replace 25% of RC at 88 yrs				$ 300,000		
Sand Cap and ENR						
Sediment Sand Cap and ENR Sampling at 2 years				$ 25,000		
Sediment Sand Cap and ENR Sampling at 5 years				$ 25,000		
Sediment Sand Cap and ENR Sampling at 10 years				$ 25,000		
Sediment Cap Inspection at 2 years				$ 15,000		
Sediment Cap Inspection at 5 years				$ 15,000		
Sediment Cap Inspection at 10 years				$ 15,000		
Sand Cap Shoreline Maintenance at 30 years				$ 25,000		
Sand Cap Shoreline Maintenance at 60 years				$ 25,000		
Sand Cap Shoreline Maintenance at 90 years				$ 25,000		
Subtotal				*$ 1,395,000*		
TOTAL ESTIMATED COST, NO NPV ANALSYS				**$ 33,495,000**		
Net Present Value Analysis						
Annual O&M	100	year	$ 134,723	$ 6,698,529		
1st year O&M	1	LS	$ 251,850	$ 251,850		
Replace 25% of RC at 22 yrs	1	LS	$ 300,000	$ 211,573		
Replace 25% of RC at 44 yrs	1	LS	$ 300,000	$ 149,210		
Replace 25% of RC at 66 yrs	1	LS	$ 300,000	$ 105,229		
Replace 25% of RC at 88 yrs	1	LS	$ 300,000	$ 74,212		
Sediment Sand Cap and ENR Sampling at 2 years	1	LS	$ 25,000	$ 24,219		
Sediment Sand Cap and ENR Sampling at 5 years	1	LS	$ 25,000	$ 23,093		
Sediment Sand Cap and ENR Sampling at 10 years	1	LS	$ 25,000	$ 21,331		
Sediment Cap Inspection at 2 years	1	LS	$ 15,000	$ 14,531		
Sediment Cap Inspection at 5 years	1	LS	$ 15,000	$ 13,856		
Sediment Cap Inspection at 10 years	1	LS	$ 15,000	$ 12,798		
Sand Cap Shoreline Maintenance at 30 years	1	LS	$ 25,000	$ 15,528		
Sand Cap Shoreline Maintenance at 60 years	1	LS	$ 25,000	$ 9,645		
Sand Cap Shoreline Maintenance at 90 years	1	LS	$ 25,000	$ 5,991		
2013 discount rate for NPV	1.6%					
Total Estimated O&M and Periodic NPV				**$ 7,631,596**		
TOTAL ESTIMATED COST				**$ 26,031,596**		

Notes:
1. Mobilization/Demobilization costs are assumed to include equipment transport and setup, temporary erosion and sedimentation control (TESC) measures, bonds, and insurance.
2. Contingency costs include miscellaneous costs not currently itemized due to the current (preliminary) stage of design development, as well as costs to address unanticipated conditions encountered during construction.

Table D-3 Alternative 3 Cost Estimates

Quendall Terminals
Renton, Washington

Site: Quendall Terminals
Remedial Action Description: Alternative 3 Containment with Targeted PTM Solidification (RR and MC DNAPL Areas)
Cost Estimate Accuracy: FS Screening Level (+50/-30 percent)

Key Assumptions and Quantities:
(see Appendix E for calculations)

Capping of Upland Soil
21.6 acre total area
940,896 SF total area
133,521 SF permeable area along shoreline
14,836 BCY habitat excavation overlap
104,544 BCY total volume based on 3' cap thickness
Enhanced Natural Recovery - Sand Material
14,300 BCY total volume
Engineered Sand Cap
15,300 BCY total sand volume
2,150 BCY removal volume for offsetting sand cap
40,000 SF area for offsetting sand cap
3.2 acre DNR lease area
RCM Reactive Capping materials
247,000 SF area of RCM
4,700 BCY total sand volume
958 BCY removal volume for offsetting reactive cap
Soil/Sediment Density
1.6 tons/BCY soil density
1.3 tons/BCY sediment density
Solidification of Upland Source Area Soil
17,542 BCY volume of soil to be solidified
8,066 BCY volume of soil at shallow depths to be solidified
9,476 BCY volume of deeper soil to be solidified
Volume of sediment removal
3,200 BCY sediment removal
3,200 BCY total sediment removal volume (including for offsetting cap)
Volumes for DNAPL collection trench installation
167 BCY volume classified as hazardous
759 BCY volume classified as non-hazardous
Volumes for PRB installation
367 BCY volume classified as hazardous
1,670 BCY volume classified as non-hazardous
163 ton amount of PRB media
44 BCY cover material
820 LF slurry wall length

Item	Quantity	Unit	Unit Cost	Total Cost	Source	Notes
CAPITAL CONSTRUCTION COSTS						
Upland Soil Cap						
Mobilization/Demobilization	1	LS	$ 424,940	$ 424,940	percentage of construction costs	includes temporary facilities for duration of construction
Site Preparation	22	acre	$ 6,900	$ 149,040	Costworks	clearing, grubbing brush and stumps
Geotextile marker layer	104,544	SY	$ 2	$ 158,907	Costworks	non-woven, 120lb tensile strength
Import Fill - Permeable Cap	104,544	BCY	$ 30	$ 3,136,320	project experience	
Compaction	104,544	BCY	$ 5	$ 522,720	project experience	
Habitat Area - excavation	14,836	BCY	$ 6	$ 89,014		
Habitat Area - non-hazardous transport and disposal	23,737	ton	$ 50	$ 1,186,853		
Hydroseeding	14,836	SY	$ 1	$ 8,901	Costworks	includes seed and fertilizer for wetland area
Stormwater collection and detention system	1,500	LF	$ 40	$ 60,000	project experience	media filter drain
Subtotal				*$ 5,736,696*		
Tax	9.5%		$ 5,736,696	$ 544,986		Sales Tax
Contingency	25%		$ 6,281,682	$ 1,570,421		
Total Upland Soil Cap Cost				$ 7,852,103		
Enhanced Natural Recovery						
Mobilization/Demobilization	1	LS	$ 65,664	$ 65,664		
Sand Material	22,880	ton	$ 20	$ 457,600	vendor quote	
Sand Placement	22,880	ton	$ 15	$ 343,200	project experience	ENR placed as one lift
Confirmation of Placement	1	LS	$ 20,000	$ 20,000		
Subtotal				*$ 886,464*		
Tax	9.5%		$ 886,464	$ 84,214		Sales Tax
Contingency	25%		$ 970,678	$ 242,669.52		
Total Enhanced Natural Recovery Cost				$ 1,213,348		
Engineered Sand Cap						
Mobilization/Demobilization	1	LS	$ 81,536	$ 81,536		
Sand Material	24,480	ton	$ 20	$ 489,600	vendor quote	
Sand Placement	24,480	ton	$ 20	$ 489,600	project experience	Sand Cap placed in multiple lifts
Geotextile Separation Layer	40,000	SF	$ 1	$ 20,000	Vendor quote	Only in nearshore area
Confirmation of Placement	1	LS	$ 20,000	$ 20,000		
Subtotal				*$ 1,100,736*		
Tax	9.5%		$ 1,100,736	$ 104,570		Sales Tax
Contingency	25%		$ 1,205,306	$ 301,326		
Total Engineered Sand Cap Cost				$ 1,506,632		
RCM Reactive Capping						
Mobilization/Demobilization	1	LS	$ 113,552	$ 113,552		
Organoclay RCM Material + Transportation	247,000	SF	$ 3	$ 642,200	Quote from Cetco	
Organoclay RCM Placement	247,000	SF	$ 2	$ 494,000	Project experience	
Sand Material	7,520	ton	$ 20	$ 150,400	vendor quote	
Sand Placement	7,520	ton	$ 15	$ 112,800	project experience	Sand over RCM placed in one lift
Confirmation of Placement	1	LS	$ 20,000	$ 20,000		
Subtotal				*$ 1,532,952*		
Tax	9.5%		$ 1,532,952	$ 145,630		Sales Tax
Contingency	25%		$ 1,678,582	$ 419,646		
Total RCM Reactive Capping Cost				$ 2,098,228		
Upland Soil Solidification						
Mobilization/Demobilization	1	LS	$ 113,395	$ 113,395	percentage of construction costs	includes temporary facilities for duration of construction
Solidification - 8-ft diameter auger	8,066	BCY	$ 70	$ 564,588	project experience	8-ft auger used to cost-effectively treat shallower soils
Solidification - 4-ft diameter auger	9,476	BCY	$ 90	$ 852,847	project experience	4-ft auger used to treat deeper soils, below 8-ft auger limit
Subtotal				*$ 1,530,829*		
Tax	9.5%		$ 1,530,829	$ 145,429		Sales Tax
Contingency	30%		$ 1,676,258	$ 502,877		
Total Upland Soil Solidification Cost				$ 2,179,135		
Sediment Removal						
Mobilization/Demobilization	1	LS	$ 36,672	$ 36,672		
Mechanical Dredging	3,200	BCY	$ 35	$ 112,000		Mechanical dredging in nearshore and for offsetting nearshore cap
Transloading/Material Handling	3,200	BCY	$ 15	$ 48,000		
Dewatering	3,200	BCY	$ 10	$ 30,400	vendor quote	Assumes 5% amendment by weight
Water Treatment	1	LS	$ 50,000	$ 50,000	Project experience	
Transportation and Disposal - Non-Hazardous	4,160	ton	$ 50	$ 208,000		Subtitle D landfill disposal
Dredging Confirmation	1	LS	$ 10,000	$ 10,000		
Subtotal				*$ 495,072*		
Tax	9.5%		$ 495,072	$ 47,032		Sales Tax
Contingency	25%		$ 542,104	$ 135,526		
Total Sediment Removal Cost				$ 677,630		
Sediment Environmental Controls and Monitoring						
Water Quality Monitoring	100	day	$ 2,000	$ 200,000		
Water Quality Controls and BMPs (Absorbent Booms, Silt Curtains, Oil Bo	1	LS	$ 25,000	$ 25,000		
Odor Control	10	day	$ 2,500	$ 25,000		
Noise Monitoring	-	LS	$ -	$ -		
Erosion Protection for Shoreline Area	1	LS	$ 250,000	$ 250,000		
Subtotal				*$ 500,000*		
Tax	9.5%		$ 500,000	$ 47,500		Sales Tax
Contingency	25%		$ 547,500	$ 136,875		
Total Sediment Environmental Controls and Monitoring Cost				$ 684,375		
DNAPL Collection Trenches						
Mobilization/Demobilization	1	LS	$ 51,705	$ 51,705		
Installation	12,500	VSF	$ 40	$ 500,000	Vendor quote	one-pass excavation and backfill including piping and sump
Backfill	1,389	ton	$ 20	$ 27,778	Costworks	pea gravel to 5' bgs, material only
Adsorbent liner	5,000	VSF	$ 4	$ 17,800	Vendor quote	organoclay liner on downgradient wall adjacent PRB - 4 1500ft2 rolls
Transport and Disposal - Non-Hazardous Waste	1,215	ton	$ 50	$ 60,741	project experience	Subtitle D landfill disposal
Transport and Disposal - Hazardous Waste	267	ton	$ 150	$ 40,000	project experience	Subtitle C landfill disposal, assuming no treatment required
Subtotal				*$ 698,024*		
Tax	9.5%		$ 698,024	$ 66,312		Sales Tax
Contingency	25%		$ 764,336	$ 191,084		
Total DNAPL Collection Trenches Cost				$ 955,420		

Table D-3 Alternative 3 Cost Estimates

Quendall Terminals
Renton, Washington

Permeable Treatment Wall						
Mobilization/Demobilization	1	LS	$ 63,731	$ 63,731	Vendor quote	One Pass trencher transport, assembly and disassembly
Excavation and media installation	1	LS	$ 250,000	$ 250,000	Vendor quote	excavate and place GAC
Treatment media	163	ton	$ 920	$ 149,926	Vendor quote	GAC: see Appendix E
Import fill	44	BCY	$ 30	$ 1,333	Project experience	cap for PRB
Monitoring well installation	5	well	$ 4,000	$ 20,000	Project experience	
Transport and Disposal - Non-Hazardous Waste	2,673	ton	$ 50	$ 133,630	project experience	Subtitle D landfill disposal
Transport and Disposal - Hazardous Waste	587	ton	$ 150	$ 88,000	project experience	Subtitle C landfill disposal, assuming no treatment required
Slurry Wall installation	820	LF	$ 188	$ 153,750	Vendor quote	slurry to 25' depth
Subtotal				*$ 860,370*		
Tax	9.5%		$ 860,370	$ 81,735		Sales Tax
Contingency	25%		$ 942,105	$ 235,526		
Total Permeable Treatment Wall Cost				$ 1,177,631		
Subtotal Construction Costs				**$ 18,344,503**		
Professional Services (as percent of construction and contingency costs)						
Project management	5%		$ 18,344,503	$ 917,225		
Remedial design	6%		$ 18,344,503	$ 1,100,670		Includes treatability studies for remedy components as necessary
Construction management	6%		$ 18,344,503	$ 1,100,670		
Subtotal				*$ 3,118,565*		
Total Estimated Capital Cost				**$ 21,500,000**		
O&M COSTS						
1st Year O&M						
GW Monitoring	1	LS	$ 80,000	$ 80,000	Project experience	
Sediment Sand Cap and ENR Sampling	1	LS	$ 25,000	$ 25,000	Project experience	
Sediment Cap Inspection	1	LS	$ 15,000	$ 15,000	Project experience	Visual and In-Water (Bathymetric/ Sediment Profile Image)
DNR Lease	3.2	acre	$ 20,000	$ 64,000		Offshore cap area off property
Subtotal				*$ 184,000*		
Tax	9.5%		$ 184,000	$ 17,480		Sales Tax
Contingency	25%		$ 201,480	$ 50,370		
Total 1st Year O&M Cost				$ 251,850		
Annual O&M						
Groundwater Monitoring	1	LS	$ 25,000	$ 25,000	Project experience	20 wells annually
Upland Cap inspection	6	hour	$ 80	$ 480	labor estimate	
DNR Lease	3.2	acre	$ 20,000	$ 64,000		Offshore cap area off property
Sump Collection and Waste Management	96	hour	$ 80	$ 7,680		monthly
DNAPL Disposal	200	gal	$ 6	$ 1,200		
Subtotal				*$ 98,360*		
Tax	9.5%		$ 98,360	$ 9,344		Sales Tax
Contingency	25%		$ 107,704	$ 26,926		
Total Annual O&M Cost				$ 134,630		
Professional Services (as percent of Annual O&M costs)						
Project management/Reporting	10%		$ 134,630	$ 13,463		
Total, Annual O&M:				**$ 148,093**		
Total Estimated O&M, 100 Years, No NPV Analysis:				**$ 15,100,000**		
Periodic Costs						
Reactive Cap						
Replace 25% of RC at 22 yrs				$ 300,000		
Replace 25% of RC at 44 yrs				$ 300,000		
Replace 25% of RC at 66 yrs				$ 300,000		
Replace 25% of RC at 88 yrs				$ 300,000		
Sand Cap and ENR						
Sediment Sand Cap and ENR Sampling at 2 years				$ 25,000		
Sediment Sand Cap and ENR Sampling at 5 years				$ 25,000		
Sediment Sand Cap and ENR Sampling at 10 years				$ 25,000		
Sediment Cap Inspection at 2 years				$ 15,000		
Sediment Cap Inspection at 5 years				$ 15,000		
Sediment Cap Inspection at 10 years				$ 15,000		
Sand Cap Shoreline Maintenance at 30 years				$ 25,000		
Sand Cap Shoreline Maintenance at 60 years				$ 25,000		
Sand Cap Shoreline Maintenance at 90 years				$ 25,000		
Permeable treatment wall						
Replace Media at 22 yrs				$ 528,842		includes mob/demob, excavation, media, and $400 per ton disposal fee
Replace Media at 44 yrs				$ 528,842		includes mob/demob, excavation, media, and $400 per ton disposal fee
Replace Media at 66 yrs				$ 528,842		includes mob/demob, excavation, media, and $400 per ton disposal fee
Replace Media at 88 yrs				$ 528,842		includes mob/demob, excavation, media, and $400 per ton disposal fee
Subtotal				*$ 3,510,369*		
TOTAL ESTIMATED COST, NO NPV ANALSYS				**$ 40,110,369**		
Net Present Value Analysis						
Annual O&M	100	year	$ 148,093	$ 7,363,292		
1st year O&M	1	LS	$ 251,850	$ 251,850		
Replace 25% of RC at 22 yrs	1	LS	$ 300,000	$ 211,573		
Replace 25% of RC at 44 yrs	1	LS	$ 300,000	$ 149,210		
Replace 25% of RC at 66 yrs	1	LS	$ 300,000	$ 105,229		
Replace 25% of RC at 88 yrs	1	LS	$ 300,000	$ 74,212		
Sediment Sand Cap and ENR Sampling at 2 years	1	LS	$ 25,000	$ 24,219		
Sediment Sand Cap and ENR Sampling at 5 years	1	LS	$ 25,000	$ 23,093		
Sediment Sand Cap and ENR Sampling at 10 years	1	LS	$ 25,000	$ 21,331		
Sediment Cap Inspection at 2 years	1	LS	$ 15,000	$ 14,531		
Sediment Cap Inspection at 5 years	1	LS	$ 15,000	$ 13,856		
Sediment Cap Inspection at 10 years	1	LS	$ 15,000	$ 12,798		
Sand Cap Shoreline Maintenance at 30 years	1	LS	$ 25,000	$ 15,528		
Sand Cap Shoreline Maintenance at 60 years	1	LS	$ 25,000	$ 9,645		
Sand Cap Shoreline Maintenance at 90 years	1	LS	$ 25,000	$ 5,991		
Replace PRB Media at 22 yrs	1	LS	$ 528,842	$ 372,962		
Replace PRB Media at 44 yrs	1	LS	$ 528,842	$ 263,029		
Replace PRB Media at 66 yrs	1	LS	$ 528,842	$ 185,499		
Replace PRB Media at 88 yrs	1	LS	$ 528,842	$ 130,822		
2013 discount rate for NPV	1.6%					
Total Estimated O&M and Periodic NPV				**$ 9,248,669**		
TOTAL ESTIMATED COST				**$ 30,748,669**		

Notes:
1. Mobilization/Demobilization costs are assumed to include equipment transport and setup, temporary erosion and sedimentation control (TESC) measures, bonds, and insurance.
2. Contingency costs include miscellaneous costs not currently itemized due to the current (preliminary) stage of design development, as well as costs to address unanticipated conditions encountered during construction.

Table D-4 - Alternative 4 Cost Estimate

Quendall Terminals
Renton, Washington

Site: Quendall Terminals
Remedial Action Description: Alternative 4 Containment with Targeted PTM Removal (TD, QP-S, and QP-U DNAPL Areas)

Cost Estimate Accuracy: FS Screening Level (+50/-30 percent)

Key Assumptions and Quantities:
(see Appendix E for calculations)

Capping of Upland Soil
21.6 acre total area
940,896 SF total area
133,521 SF permeable area along shoreline
12,441 BCY habitat excavation overlap
104,544 BCY total volume based on 3' cap thickness
Enhanced Natural Recovery - Sand Material
14,300 BCY total volume
Engineered Sand Cap
15,800 BCY total sand volume
2,150 BCY removal volume for offsetting sand cap
40,000 SF area for offsetting sand cap
0.5 acre DNR lease area
RCM Reactive Capping materials
85,600 SF area of RCM
1,700 BCY total sand volume
570 BCY removal volume for offsetting reactive cap
Soil/Sediment Density
1.6 tons/BCY soil density
1.3 tons/BCY sediment density
0.7 tons/CY organoclay density
Removal of Upland Source Area Soil
12,700 BCY total volume
0.5 acre total area
2,286 BCY volume classified as hazardous
10,414 BCY volume classified as non-hazardous
Volume of sediment removal
23,200 BCY sediment removal
25,900 BCY total sediment removal volume (including for offsetting cap)
11,000 BCY mechanical dredging
12,200 BCY hydraulic dredging
510 BCY residual cover - organoclay
2,300 BCY residual cover - sand
20,400 BCY backfill
35,000 SF sheet pile area
Volumes for DNAPL collection trench installation
167 BCY volume classified as hazardous
759 BCY volume classified as non-hazardous
Volumes for PRB installation
367 BCY volume classified as hazardous
1,670 BCY volume classified as non-hazardous
163 ton amount of PRB media
44 BCY cover material
820 LF slurry wall length
Dewatering to maintain wet removal for upland soil
120 gpm maximum upland dewatering rate
120 gpm average upland dewatering rate
6 each deep aquifer depressurization wells
0.12 year upland soil removal time
16 feet average excavation depth
35 feet min.embed. depth
10,109 SF shoring wall area

Item	Quantity	Unit	Unit Cost	Total Cost	Source	Notes
CAPITAL CONSTRUCTION COSTS						
Upland Soil Cap						
Mobilization/Demobilization	1	LS	$ 357,404	$ 357,404	percentage of construction costs	includes temporary facilities for duration of construction
Site Preparation	22	acre	$ 6,900	$ 149,040	Costworks	clearing, grubbing brush and stumps
Geotextile marker layer	104,544	SY	$ 2	$ 158,907	Costworks	non-woven, 120lb tensile strength
Import Fill - Permeable Cap	104,544	BCY	$ 30	$ 3,136,320	project experience	
Compaction	104,544	BCY	$ 5	$ 522,720	project experience	
Habitat Area - excavation	12,441	BCY	$ 6	$ 74,643		
Habitat Area - non-hazardous transport and disposal	19,905	ton	$ 50	$ 995,244		
Hydroseeding	14,836	SY	$ 1	$ 8,901	Costworks	includes seed and fertilizer for wetland area
Stormwater collection and detention system	1,500	LF	$ 40	$ 60,000	project experience	media filter drain
Subtotal				*$ 5,463,180*		
Tax	9.5%		$ 5,463,180	$ 519,002		Sales Tax
Contingency	25%		$ 5,982,183	$ 1,495,546		
Total Upland Soil Cap Cost				$ 7,477,728		
Enhanced Natural Recovery						
Mobilization/Demobilization	1	LS	$ 57,456	$ 57,456		
Sand Material	22,880	ton	$ 20	$ 457,600	vendor quote	
Sand Placement	22,880	ton	$ 15	$ 343,200	project experience	ENR placed as one lift
Confirmation of Placement	1	LS	$ 20,000	$ 20,000		
Subtotal				*$ 878,256*		
Tax	9.5%		$ 878,256	$ 83,434		Sales Tax
Contingency	25%		$ 961,690	$ 240,422.58		
Total Enhanced Natural Recovery Cost				$ 1,202,113		
Engineered Sand Cap						
Mobilization/Demobilization	1	LS	$ 73,584	$ 73,584		
Sand Material	25,280	ton	$ 20	$ 505,600	vendor quote	
Sand Placement	25,280	ton	$ 20	$ 505,600	project experience	Sand Cap placed in multiple lifts
Geotextile Separation Layer	40,000	SF	$ 1	$ 20,000	Vendor quote	Only in nearshore area
Confirmation of Placement	1	LS	$ 20,000	$ 20,000		
Subtotal				*$ 1,124,784*		
Tax	9.5%		$ 1,124,784	$ 106,854		Sales Tax
Contingency	25%		$ 1,231,638	$ 307,910		
Total Engineered Sand Cap Cost				$ 1,539,548		
RCM Reactive Capping						
Mobilization/Demobilization	1	LS	$ 35,627	$ 35,627		
Organoclay RCM Material + Transportation	85,600	SF	$ 3	$ 222,560	Quote from Cetco	
Organoclay RCM Placement	85,600	SF	$ 2	$ 171,200	Project experience	
Sand Material	2,720	ton	$ 20	$ 54,400	vendor quote	
Sand Placement	2,720	ton	$ 15	$ 40,800	project experience	Sand over RCM placed in one lift
Confirmation of Placement	1	LS	$ 20,000	$ 20,000		
Subtotal				*$ 544,587*		
Tax	9.5%		$ 544,587	$ 51,736		Sales Tax
Contingency	25%		$ 596,323	$ 149,081		
Total RCM Reactive Capping Cost				$ 745,404		
Upland Soil Removal						
Mobilization/Demobilization	1	LS	$ 245,881	$ 245,881	percentage of construction costs	includes temporary facilities for duration of construction
Excavation	12,700	BCY	$ 6	$ 76,200	project experience	
Import Fill	12,700	BCY	$ 30	$ 381,000	project experience	
Soil Handling and Stockpiling	12,700	BCY	$ 5	$ 63,500	project experience	segregation into hazardous/non-hazardous
Analytical Sampling	200	ea	$ 500	$ 100,000	project experience	VOCs and SVOCs
Compaction	12,700	BCY	$ 5	$ 63,500	project experience	
Transport and Disposal - Non-Hazardous Waste	16,662	ton	$ 50	$ 833,120	project experience	Subtitle D landfill disposal
Transport and Disposal - Hazardous Waste	3,658	ton	$ 150	$ 548,640	project experience	Subtitle C landfill disposal, assuming no treatment required
Shoring	10,109	SF	$ 92	$ 930,055	project experience	sheet pile - stiffened to allow excavation in the wet (see Appendix F)
Dewatering - Deep Aquifer Depressurization Wells and Pumps	6	ea	$ 40,000	$ 240,000	project experience	
Dewatering - Equalization Tank	2	month	$ 980	$ 1,960	project experience	Rental - 20,000 gallon tank
Dewatering - Treatment system	2	month	$ 8,066	$ 16,132	Vendor quote	rental system: DNAPL separation, air stripping, filtration, GAC vessels
Dewatering - Carbon Replacement	45	day	$ 72	$ 3,198	Vendor quote	based on usage rate of 65 lb/day @ 50gpm - $0.46/lb
Dewatering - Carbon Disposal	3	ton	$ 400	$ 1,391	Vendor quote	
Dewatering - Coagulant	64	lb	$ 2	$ 145	Vendor quote	$2.25 per lb, 1mg/L concentration, average flow rate
Dewatering - Miscellaneous Equipment	20%		$ 363,804	$ 72,761	percentage of dewatering capital cos	
Dewatering - Equipment Operation and Maintenance	45	day	$ 700	$ 31,200	labor estimate	1 full-time operator, $70/hr, 10hr/day
Dewatering - Discharge Fee	7,702,062	gal	$ 0	$ 64,697	project experience	$0.0084/gal discharge rate for city of Renton sewer at adjacent site
Dewatering - Power	2	month	$ 2,540	$ 5,080	project experience	$0.0996/KWH estimated power rate
Monitoring Well Installation	20	ea	$ 4,000	$ 80,000	project experience	confirmation monitoring program
Subtotal				*$ 3,758,460*		
Tax	9.5%		$ 3,758,460	$ 357,054		Sales Tax
Contingency	35%		$ 4,115,514	$ 1,440,430		
Total Upland Soil Removal Cost				$ 5,555,943		

Table D-4 - Alternative 4 Cost Estimate

Quendall Terminals
Renton, Washington

Sediment Removal						
Mobilization/Demobilization	1	LS	$ 439,800	$ 439,800		
Mechanical Dredging	13,720	BCY	$ 35	$ 480,194		Mechanical dredging in nearshore and for offsetting nearshore cap
Hydraulic Dredging	12,200	BCY	$ 60	$ 732,000	Project experience	Assumes specialty hydraulic for T-Dock/Offshore
Debris Removal and Disposal	1	LS	$ 50,000	$ 50,000		Removal of piling
Transloading/Material Handling	25,900	BCY	$ 15	$ 388,500		
Dewatering	25,900	BCY	$ 10	$ 246,050	vendor quote	Assumes 5% amendment by weight
Water Treatment	1	LS	$ 200,000	$ 200,000	Project experience	
Residuals Cover Bulk Organoclay Material - (PM-199)	365	ton	$ 3,250	$ 1,185,941	Quote from Cetco	
Residuals Cover Sand Material	3,680	ton	$ 20	$ 73,600	vendor quote	
Residuals Cover Material Placement	4,045	ton	$ 15	$ 60,674	project experience	
Backfill Material	32,640	ton	$ 20	$ 652,800	vendor quote	
Backfill Material Placement	32,640	ton	$ 15	$ 489,600	project experience	Backfill placed in bulk
Transportation and Disposal - Non-Hazardous	33,670	ton	$ 50	$ 1,683,500		Subtitle D landfill disposal
Dredging Confirmation	1	LS	$ 40,000	$ 40,000		
Subtotal				*$ 6,722,659*		
Tax	9.5%		$ 6,722,659	$ 638,653		Sales Tax
Contingency	25%		$ 7,361,312	$ 1,840,328		
Total Sediment Removal Cost				$ 9,201,640		
Sheet Pile Enclosure						
Mobilization/Demobilization	1	LS	$ 220,500	$ 220,500	Project experience	
Steel Unit Cost	35,000	SF	$ 35	$ 1,225,000	Project experience	
Installation Unit Cost	35,000	SF	$ 45	$ 1,575,000	Project experience	
Removal Unit Cost	35,000	SF	$ 15	$ 525,000	Project experience	
Salvage Unit Value	1,750,000	lb	$ (0.1)	$ (175,000)	Project experience	50 pounds per sf
Subtotal				*$ 3,370,500*		
Tax	9.5%		$ 3,370,500	$ 320,198		Sales Tax
Contingency	25%		$ 3,690,698	$ 922,674		
Total Sheet Pile Enclosure Cost				$ 4,613,372		
Sediment Environmental Controls and Monitoring						
Water Quality Monitoring	175	day	$ 2,500	$ 437,500		
Water Quality Controls and BMPs (Absorbent Booms, Silt Curtains, Oil Boor	1	LS	$ 75,000	$ 75,000		
Odor Control	60	day	$ 2,500	$ 150,000		
Noise Monitoring	1	LS	$ 15,000	$ 15,000		
Erosion Protection for Shoreline Area	1	LS	$ 250,000	$ 250,000		
Subtotal				*$ 927,500*		
Tax	9.5%		$ 927,500	$ 88,113		Sales Tax
Contingency	25%		$ 1,015,613	$ 253,903		
Total Sediment Environmental Controls and Monitoring Cost				$ 1,269,516		
DNAPL Collection Trenches						
Mobilization/Demobilization	1	LS	$ 45,242	$ 45,242		
Installation	12,500	VSF	$ 40	$ 500,000	Vendor quote	one-pass excavation and backfill including piping and sump
Backfill	1,389	ton	$ 20	$ 27,778	Costworks	pea gravel to 5' bgs, material only
Adsorbent liner	5,000	VSF	$ 4	$ 17,800	Vendor quote	organoclay liner on downgradient wall adjacent PRB - 4 1500ft2 rolls
Transport and Disposal - Non-Hazardous Waste	1,215	ton	$ 50	$ 60,741	project experience	Subtitle D landfill disposal
Transport and Disposal - Hazardous Waste	267	ton	$ 150	$ 40,000	project experience	Subtitle C landfill disposal, assuming no treatment required
Subtotal				*$ 691,561*		
Tax	9.5%		$ 691,561	$ 65,698		Sales Tax
Contingency	25%		$ 757,259	$ 189,315		
Total DNAPL Collection Trenches Cost				$ 946,574		
Permeable Treatment Wall						
Mobilization/Demobilization	1	LS	$ 55,765	$ 55,765	Vendor quote	One Pass trencher transport, assembly and disassembly
Excavation and media installation	1	LS	$ 250,000	$ 250,000	Vendor quote	excavate and place GAC
Treatment media	163	ton	$ 920	$ 149,926	Vendor quote	GAC: see Appendix E
Import fill	44	BCY	$ 30	$ 1,333	Project experience	cap for PRB
Monitoring well installation	5	well	$ 4,000	$ 20,000	Project experience	
Transport and Disposal - Non-Hazardous Waste	2,673	ton	$ 50	$ 133,630	project experience	Subtitle D landfill disposal
Transport and Disposal - Hazardous Waste	587	ton	$ 150	$ 88,000	project experience	Subtitle C landfill disposal, assuming no treatment required
Slurry Wall installation	820	LF	$ 188	$ 153,750	Vendor quote	slurry to 25' depth
Subtotal				*$ 852,404*		
Tax	9.5%		$ 852,404	$ 80,978		Sales Tax
Contingency	25%		$ 933,382	$ 233,345		
Total Permeable Treatment Wall Cost				$ 1,166,727		
Subtotal Construction Costs				**$ 33,718,565**		
Professional Services (as percent of construction and contingency costs)						
Project management	5%		$ 33,718,565	$ 1,685,928		
Remedial design	6%		$ 33,718,565	$ 2,023,114		Includes treatability studies for remedy components as necessary
Construction management	6%		$ 33,718,565	$ 2,023,114		
Subtotal				*$ 5,732,156*		
Total Estimated Capital Cost				**$ 39,500,000**		
O&M COSTS						
1st Year O&M						
GW Monitoring	1	LS	$ 80,000	$ 80,000	Project experience	
Sediment Sand Cap and ENR Sampling	1	LS	$ 25,000	$ 25,000	Project experience	
Sediment Cap Inspection	1	LS	$ 15,000	$ 15,000	Project experience	Visual and In-Water (Bathymetric/ Sediment Profile Image)
Backfilled Area Surface Sediment Monitoring	1	LS	$ 25,000	$ 25,000		
DNR Lease	0.5	acre	$ 20,000	$ 10,000		Offshore cap area off property
Subtotal				*$ 155,000*		
Tax	9.5%		$ 155,000	$ 14,725		Sales Tax
Contingency	25%		$ 169,725	$ 42,431		
Total 1st Year O&M Cost				$ 212,156		
Annual O&M						
Groundwater Monitoring	1	LS	$ 25,000	$ 25,000	Project experience	20 wells annually
Upland Cap inspection	6	hour	$ 80	$ 480	labor estimate	
DNR Lease	0.5	acre	$ 20,000	$ 10,000		Offshore cap area off property
Sump Collection and Waste Management	96	hour	$ 80	$ 7,680		monthly
DNAPL Disposal	200	gal	$ 6	$ 1,200		
Subtotal				*$ 44,360*		
Tax	9.5%		$ 44,360	$ 4,214		Sales Tax
Contingency	25%		$ 48,574	$ 12,144		
Total Annual O&M Cost				$ 60,718		
Professional Services (as percent of Annual O&M costs)						
Project management/Reporting	10%		$ 60,718	$ 6,072		
Total, Annual O&M:				**$ 66,790**		
Total Estimated O&M, 100 Years, No NPV Analysis:				**$ 6,900,000**		
Periodic Costs						
Reactive Cap						
Replace 25% of RC at 22 yrs				$ 110,000		
Replace 25% of RC at 44 yrs				$ 110,000		
Replace 25% of RC at 66 yrs				$ 110,000		
Replace 25% of RC at 88 yrs				$ 110,000		
Sand Cap and ENR						
Sediment Sand Cap and ENR Sampling at 2 years				$ 25,000		
Sediment Sand Cap and ENR Sampling at 5 years				$ 25,000		
Sediment Sand Cap and ENR Sampling at 10 years				$ 25,000		
Sediment Cap Inspection at 2 years				$ 15,000		
Sediment Cap Inspection at 5 years				$ 15,000		
Sediment Cap Inspection at 10 years				$ 15,000		
Sand Cap Shoreline Maintenance at 30 years				$ 25,000		
Sand Cap Shoreline Maintenance at 60 years				$ 25,000		
Sand Cap Shoreline Maintenance at 90 years				$ 25,000		
Permeable treatment wall						
Replace Media at 22 yrs				$ 520,876		includes mob/demob, excavation, media, and $400 per ton disposal fee
Replace Media at 44 yrs				$ 520,876		includes mob/demob, excavation, media, and $400 per ton disposal fee
Replace Media at 66 yrs				$ 520,876		includes mob/demob, excavation, media, and $400 per ton disposal fee
Replace Media at 88 yrs				$ 520,876		includes mob/demob, excavation, media, and $400 per ton disposal fee
Subtotal				*$ 2,718,503*		
TOTAL ESTIMATED COST, NO NPV ANALSYS				**$ 49,118,503**		
Net Present Value Analysis						
Annual O&M	100	year	$ 66,790	$ 3,320,818		
1st year O&M	1	LS	$ 212,156	$ 212,156		
Replace 25% of RC at 22 yrs	1	LS	$ 110,000	$ 77,577		
Replace 25% of RC at 44 yrs	1	LS	$ 110,000	$ 54,710		
Replace 25% of RC at 66 yrs	1	LS	$ 110,000	$ 38,584		
Replace 25% of RC at 88 yrs	1	LS	$ 110,000	$ 27,211		
Sediment Sand Cap and ENR Sampling at 2 years	1	LS	$ 25,000	$ 24,219		
Sediment Sand Cap and ENR Sampling at 5 years	1	LS	$ 25,000	$ 23,093		
Sediment Sand Cap and ENR Sampling at 10 years	1	LS	$ 25,000	$ 21,331		
Sediment Cap Inspection at 2 years	1	LS	$ 15,000	$ 14,531		
Sediment Cap Inspection at 5 years	1	LS	$ 15,000	$ 13,856		
Sediment Cap Inspection at 10 years	1	LS	$ 15,000	$ 12,798		
Sand Cap Shoreline Maintenance at 30 years	1	LS	$ 25,000	$ 15,528		
Sand Cap Shoreline Maintenance at 60 years	1	LS	$ 25,000	$ 9,645		
Sand Cap Shoreline Maintenance at 90 years	1	LS	$ 25,000	$ 5,991		
Replace PRB Media at 22 yrs	1	LS	$ 520,876	$ 367,344		
Replace PRB Media at 44 yrs	1	LS	$ 520,876	$ 259,066		
Replace PRB Media at 66 yrs	1	LS	$ 520,876	$ 182,705		
Replace PRB Media at 88 yrs	1	LS	$ 520,876	$ 128,851		
2013 discount rate for NPV	1.6%					
Total Estimated O&M and Periodic NPV				**$ 4,810,014**		
TOTAL ESTIMATED COST				**$ 44,310,014**		

Notes:
1. Mobilization/Demobilization costs are assumed to include equipment transport and setup, temporary erosion and sedimentation control (TESC) measures, bonds, and insurance.
2. Contingency costs include miscellaneous costs not currently itemized due to the current (preliminary) stage of design development, as well as costs to address unanticipated conditions encountered during construction.

Table D-5 - Alternative 5 Cost Estimate

Quendall Terminals
Renton, Washington

Site: Quendall Terminals
Remedial Action Description: Alternative 5 Containment with Targeted PTM Solidfication (RR, MC, and QP-U DNAPL Areas and ≥ 4-Foot-Thickness) and Removal (TD and QP-S DNAPL Areas)
Cost Estimate Accuracy: FS Screening Level (+50/-30 percent)

Key Assumptions and Quantities:
(see Appendix E for calculations)

Capping of Upland Soil
- 21.6 acre — total area
- 940,896 SF — total area
- 133,521 SF — permeable area along shoreline
- 14,836 BCY — habitat excavation overlap
- 104,544 BCY — total volume based on 3' cap thickness

Enhanced Natural Recovery - Sand Material
- 14,300 BCY — total volume

Engineered Sand Cap
- 15,800 BCY — total sand volume
- 2,150 BCY — removal volume for offsetting sand cap
- 40,000 SF — area for offsetting sand cap
- 0.5 acre — DNR lease area

RCM Reactive Capping materials
- 85,600 SF — area of RCM
- 1,700 BCY — total sand volume
- 570 BCY — removal volume for offsetting reactive cap

Soil/Sediment Density
- 1.6 tons/BCY — soil density
- 1.3 tons/BCY — sediment density
- 0.7 tons/CY — organoclay density

Solidification of Upland Source Area Soil
- 78,913 BCY — volume of soil to be solidified
- 69,437 BCY — volume of soil at shallow depths to be solidified
- 9,476 BCY — volume of deeper soil to be solidified

Volume of sediment removal
- 23,200 BCY — sediment removal
- 25,900 BCY — total sediment removal volume (including for offsetting cap)
- 11,000 BCY — mechanical dredging
- 12,200 BCY — hydraulic dredging
- 510 BCY — residual cover - organoclay
- 2,300 BCY — residual cover - sand
- 20,400 BCY — backfill
- 35,000 SF — sheet pile area

Volumes for PRB installation
- 367 BCY — volume classified as hazardous
- 1,670 BCY — volume classified as non-hazardous
- 163 ton — amount of PRB media
- 44 BCY — cover material
- 820 LF — slurry wall length

Item	Quantity	Unit	Unit Cost	Total Cost	Source	Notes
CAPITAL CONSTRUCTION COSTS						
Upland Soil Cap						
Mobilization/Demobilization	1	LS	$ 371,823	$ 371,823	percentage of construction costs	includes temporary facilities for duration of construction
Site Preparation	22	acre	$ 6,900	$ 149,040	Costworks	clearing, grubbing brush and stumps
Geotextile marker layer	104,544	SY	$ 2	$ 158,907	Costworks	non-woven, 120lb tensile strength
Import Fill - Permeable Cap	104,544	BCY	$ 30	$ 3,136,320	project experience	
Compaction	104,544	BCY	$ 5	$ 522,720	project experience	
Habitat Area - excavation	14,836	BCY	$ 6	$ 89,014		
Habitat Area - non-hazardous transport and disposal	23,737	ton	$ 50	$ 1,186,853		
Hydroseeding	14,836	SY	$ 1	$ 8,901	Costworks	includes seed and fertilizer for wetland area
Stormwater collection and detention system	1,500	LF	$ 40	$ 60,000	project experience	media filter drain
Subtotal				*$ 5,683,579*		
Tax	9.5%		$ 5,683,579	$ 539,940		Sales Tax
Contingency	25%		$ 6,223,518	$ 1,555,880		
Total Upland Soil Cap Cost				$ 7,779,398		
Enhanced Natural Recovery						
Mobilization/Demobilization	1	LS	$ 57,456	$ 57,456		
Sand Material	22,880	ton	$ 20	$ 457,600	vendor quote	
Sand Placement	22,880	ton	$ 15	$ 343,200	project experience	ENR placed as one lift
Confirmation of Placement	1	LS	$ 20,000	$ 20,000		
Subtotal				*$ 878,256*		
Tax	9.5%		$ 878,256	$ 83,434		Sales Tax
Contingency	25%		$ 961,690	$ 240,422.58		
Total Enhanced Natural Recovery Cost				$ 1,202,113		
Engineered Sand Cap						
Mobilization/Demobilization	1	LS	$ 73,584	$ 73,584		
Sand Material	25,280	ton	$ 20	$ 505,600	vendor quote	
Sand Placement	25,280	ton	$ 20	$ 505,600	project experience	Sand Cap placed in multiple lifts
Geotextile Separation Layer	40,000	SF	$ 1	$ 20,000	Vendor quote	Only in nearshore area
Confirmation of Placement	1	LS	$ 20,000	$ 20,000		
Subtotal				*$ 1,124,784*		
Tax	9.5%		$ 1,124,784	$ 106,854		Sales Tax
Contingency	25%		$ 1,231,638	$ 307,910		
Total Engineered Sand Cap Cost				$ 1,539,548		
RCM Reactive Capping						
Mobilization/Demobilization	1	LS	$ 35,627	$ 35,627		
Organoclay RCM Material + Transportation	85,600	SF	$ 3	$ 222,560	Quote from Cetco	
Organoclay RCM Placement	85,600	SF	$ 2	$ 171,200	Project experience	
Sand Material	2,720	ton	$ 20	$ 54,400	vendor quote	
Sand Placement	2,720	ton	$ 15	$ 40,800	project experience	Sand over RCM placed in one lift
Confirmation of Placement	1	LS	$ 20,000	$ 20,000		
Subtotal				*$ 544,587*		
Tax	9.5%		$ 544,587	$ 51,736		Sales Tax
Contingency	25%		$ 596,323	$ 149,081		
Total RCM Reactive Capping Cost				$ 745,404		
Upland Soil Solidification						
Mobilization/Demobilization	1	LS	$ 399,939	$ 399,939	percentage of construction costs	includes temporary facilities for duration of construction
Solidification - 8-ft diameter auger	69,437	BCY	$ 70	$ 4,860,566	project experience	8-ft auger used to cost-effectively treat shallower soils
Solidification - 4-ft diameter auger	9,476	BCY	$ 90	$ 852,847	project experience	4-ft auger used to treat deeper soils, below 8-ft auger limit
Subtotal				*$ 6,113,352*		
Tax	9.5%		$ 6,113,352	$ 580,768		Sales Tax
Contingency	30%		$ 6,694,120	$ 2,008,236		
Total Upland Soil Solidification Cost				$ 8,702,356		
Sediment Removal						
Mobilization/Demobilization	1	LS	$ 439,800	$ 439,800		
Mechanical Dredging	13,720	BCY	$ 35	$ 480,194		Mechanical dredging in nearshore and for offsetting nearshore cap
Hydraulic Dredging	12,200	BCY	$ 60	$ 732,000	Project experience	Assumes specialty hydraulic for T-Dock/Offshore
Debris Removal and Disposal	1	LS	$ 50,000	$ 50,000		Removal of piling
Transloading/Material Handling	25,900	BCY	$ 15	$ 388,500		
Dewatering	25,900	BCY	$ 10	$ 246,050	vendor quote	Assumes 5% amendment by weight
Water Treatment	1	LS	$ 200,000	$ 200,000	Project experience	
Residuals Cover Bulk Organoclay Material - (PM-199)	365	ton	$ 3,250	$ 1,185,941	Quote from Cetco	
Residuals Cover Sand Material	3,680	ton	$ 20	$ 73,600	vendor quote	
Residuals Cover Material Placement	4,045	ton	$ 15	$ 60,674	project experience	
Backfill Material	32,640	ton	$ 20	$ 652,800	vendor quote	
Backfill Material Placement	32,640	ton	$ 15	$ 489,600	project experience	Backfill placed in bulk
Transportation and Disposal - Non-Hazardous	33,670	ton	$ 50	$ 1,683,500		Subtitle D landfill disposal
Dredging Confirmation	1	LS	$ 40,000	$ 40,000		
Subtotal				*$ 6,722,659*		
Tax	9.5%		$ 6,722,659	$ 638,653		Sales Tax
Contingency	25%		$ 7,361,312	$ 1,840,328		
Total Sediment Removal Cost				$ 9,201,640		
Sheet Pile Enclosure						
Mobilization/Demobilization	1	LS	$ 220,500	$ 220,500	Project experience	
Steel Unit Cost	35,000	SF	$ 35	$ 1,225,000	Project experience	
Installation Unit Cost	35,000	SF	$ 45	$ 1,575,000	Project experience	
Removal Unit Cost	35,000	SF	$ 15	$ 525,000	Project experience	
Salvage Unit Value	1,750,000	lb	$ (0.1)	$ (175,000)	Project experience	50 pounds per sf
Subtotal				*$ 3,370,500*		
Tax	9.5%		$ 3,370,500	$ 320,198		Sales Tax
Contingency	25%		$ 3,690,698	$ 922,674		
Total Sheet Pile Enclosure Cost				$ 4,613,372		
Sediment Environmental Controls and Monitoring						
Water Quality Monitoring	175	day	$ 2,500	$ 437,500		
Water Quality Controls and BMPs (Absorbent Booms, Silt Curtains, Oil Bo	1	LS	$ 75,000	$ 75,000		
Odor Control	60	day	$ 2,500	$ 150,000		
Noise Monitoring	1	LS	$ 15,000	$ 15,000		
Erosion Protection for Shoreline Area	1	LS	$ 250,000	$ 250,000		
Subtotal				*$ 927,500*		
Tax	9.5%		$ 927,500	$ 88,113		Sales Tax
Contingency	25%		$ 1,015,613	$ 253,903		
Total Sediment Environmental Controls and Monitoring Cost				$ 1,269,516		

Table D-5 - Alternative 5 Cost Estimate

Quendall Terminals
Renton, Washington

Permeable Treatment Wall						
Mobilization/Demobilization	1	LS	$ 55,765	$ 55,765	Vendor quote	One Pass trencher transport, assembly and disassembly
Excavation and media installation	1	LS	$ 250,000	$ 250,000	Vendor quote	excavate and place GAC
Treatment media	163	ton	$ 920	$ 149,926	Vendor quote	GAC: see Appendix E
Import fill	44	BCY	$ 30	$ 1,333	Project experience	cap for PRB
Monitoring well installation	5	well	$ 4,000	$ 20,000	Project experience	
Transport and Disposal - Non-Hazardous Waste	2,673	ton	$ 50	$ 133,630	project experience	Subtitle D landfill disposal
Transport and Disposal - Hazardous Waste	587	ton	$ 150	$ 88,000	project experience	Subtitle C landfill disposal, assuming no treatment required
Slurry Wall installation	820	LF	$ 188	$ 153,750	Vendor quote	slurry to 25' depth
Subtotal				*$ 852,404*		
Tax	9.5%		$ 852,404	$ 80,978		Sales Tax
Contingency	25%		$ 933,382	$ 233,345		
Total Permeable Treatment Wall Cost				$ 1,166,727		
Subtotal Construction Costs				**$ 36,220,074**		
Professional Services (as percent of construction and contingency costs)						
Project management	5%		$ 36,220,074	$ 1,811,004		
Remedial design	6%		$ 36,220,074	$ 2,173,204		Includes treatability studies for remedy components as necessary
Construction management	6%		$ 36,220,074	$ 2,173,204		
Subtotal				*$ 6,157,413*		
Total Estimated Capital Cost				**$ 42,400,000**		
O&M COSTS						
1st Year O&M						
GW Monitoring	1	LS	$ 80,000	$ 80,000	Project experience	
Sediment Sand Cap and ENR Sampling	1	LS	$ 25,000	$ 25,000	Project experience	
Sediment Cap Inspection	1	LS	$ 15,000	$ 15,000	Project experience	Visual and In-Water (Bathymetric/ Sediment Profile Image)
Backfilled Area Surface Sediment Monitoring	1	LS	$ 25,000	$ 25,000		
DNR Lease	0.5	acre	$ 20,000	$ 10,000		Offshore cap area off property
Subtotal				*$ 155,000*		
Tax	9.5%		$ 155,000	$ 14,725		Sales Tax
Contingency	25%		$ 169,725	$ 42,431		
Total 1st Year O&M Cost				$ 212,156		
Annual O&M						
Groundwater Monitoring	1	LS	$ 25,000	$ 25,000	Project experience	20 wells annually
Upland Cap inspection	6	hour	$ 80	$ 480	labor estimate	
DNR Lease	0.5	acre	$ 20,000	$ 10,000		Offshore cap area off property
Subtotal				*$ 35,480*		
Tax	9.5%		$ 35,480	$ 3,371		Sales Tax
Contingency	25%		$ 38,851	$ 9,713		
Total Annual O&M Cost				$ 48,563		
Professional Services (as percent of Annual O&M costs)						
Project management/Reporting	10%		$ 48,563	$ 4,856		
Total, Annual O&M:				**$ 53,420**		
Total Estimated O&M, 100 Years, No NPV Analysis:				**$ 5,600,000**		
Periodic Costs						
Reactive Cap						
Replace 25% of RC at 22 yrs				$ 110,000		
Replace 25% of RC at 44 yrs				$ 110,000		
Replace 25% of RC at 66 yrs				$ 110,000		
Replace 25% of RC at 88 yrs				$ 110,000		
Sand Cap and ENR						
Sediment Sand Cap and ENR Sampling at 2 years				$ 25,000		
Sediment Sand Cap and ENR Sampling at 5 years				$ 25,000		
Sediment Sand Cap and ENR Sampling at 10 years				$ 25,000		
Sediment Cap Inspection at 2 years				$ 15,000		
Sediment Cap Inspection at 5 years				$ 15,000		
Sediment Cap Inspection at 10 years				$ 15,000		
Sand Cap Shoreline Maintenance at 30 years				$ 25,000		
Sand Cap Shoreline Maintenance at 60 years				$ 25,000		
Sand Cap Shoreline Maintenance at 90 years				$ 25,000		
Permeable treatment wall						
Replace Media at 22 yrs				$ 520,876		includes mob/demob, excavation, media, and $400 per ton disposal fee
Replace Media at 44 yrs				$ 520,876		includes mob/demob, excavation, media, and $400 per ton disposal fee
Replace Media at 66 yrs				$ 520,876		includes mob/demob, excavation, media, and $400 per ton disposal fee
Replace Media at 88 yrs				$ 520,876		includes mob/demob, excavation, media, and $400 per ton disposal fee
Subtotal				*$ 2,718,503*		
TOTAL ESTIMATED COST, NO NPV ANALSYS				**$ 50,718,503**		
Net Present Value Analysis						
Annual O&M	100	year	$ 53,420	$ 2,656,055		
1st year O&M	1	LS	$ 212,156	$ 212,156		
Replace 25% of RC at 22 yrs	1	LS	$ 110,000	$ 77,577		
Replace 25% of RC at 44 yrs	1	LS	$ 110,000	$ 54,710		
Replace 25% of RC at 66 yrs	1	LS	$ 110,000	$ 38,584		
Replace 25% of RC at 88 yrs	1	LS	$ 110,000	$ 27,211		
Sediment Sand Cap and ENR Sampling at 2 years	1	LS	$ 25,000	$ 24,219		
Sediment Sand Cap and ENR Sampling at 5 years	1	LS	$ 25,000	$ 23,093		
Sediment Sand Cap and ENR Sampling at 10 years	1	LS	$ 25,000	$ 21,331		
Sediment Cap Inspection at 2 years	1	LS	$ 15,000	$ 14,531		
Sediment Cap Inspection at 5 years	1	LS	$ 15,000	$ 13,856		
Sediment Cap Inspection at 10 years	1	LS	$ 15,000	$ 12,798		
Sand Cap Shoreline Maintenance at 30 years	1	LS	$ 25,000	$ 15,528		
Sand Cap Shoreline Maintenance at 60 years	1	LS	$ 25,000	$ 9,645		
Sand Cap Shoreline Maintenance at 90 years	1	LS	$ 25,000	$ 5,991		
Replace PRB Media at 22 yrs	1	LS	$ 520,876	$ 367,344		
Replace PRB Media at 44 yrs	1	LS	$ 520,876	$ 259,066		
Replace PRB Media at 66 yrs	1	LS	$ 520,876	$ 182,705		
Replace PRB Media at 88 yrs	1	LS	$ 520,876	$ 128,851		
2013 discount rate for NPV	1.6%					
Total Estimated O&M and Periodic NPV				**$ 4,145,251**		
TOTAL ESTIMATED COST				**$ 46,545,251**		

Notes:
1. Mobilization/Demobilization costs are assumed to include equipment transport and setup, temporary erosion and sedimentation control (TESC) measures, bonds, and insurance.
2. Contingency costs include miscellaneous costs not currently itemized due to the current (preliminary) stage of design development, as well as costs to address unanticipated conditions encountered during construction.

Table D-6 - Alternative 6 Cost Estimate

Quendall Terminals
Renton, Washington

Site:	Quendall Terminals	
Remedial Action Description:	Alternative 6	Containment with Targeted PTM Solidification (RR and MC DNAPL Areas and ≥ 2-Foot-Thickness) and Removal (TD, QP-S, and QP-U DNAPL Areas)
Cost Estimate Accuracy:	FS Screening Level (+50/-30 percent)	
Key Assumptions and Quantities:	Capping of Upland Soil	
(see Appendix E for calculations)	21.6 acre	total area
	940,896 SF	total area
	133,521 SF	permeable area along shoreline
	12,441 BCY	habitat excavation overlap
	104,544 BCY	total volume based on 3' cap thickness
	Enhanced Natural Recovery - Sand Material	
	14,300 BCY	total volume
	Engineered Sand Cap	
	15,800 BCY	total sand volume
	2,150 BCY	removal volume for offsetting sand cap
	40,000 SF	area for offsetting sand cap
	0.5 acre	DNR lease area
	RCM Reactive Capping materials	
	85,600 SF	area of RCM
	1,700 BCY	total sand volume
	570 BCY	removal volume for offsetting reactive cap
	Soil/Sediment Density	
	1.6 tons/BCY	soil density
	1.3 tons/BCY	sediment density
	0.7 tons/CY	organoclay density
	Solidification of Upland Source Area Soil	
	142,501 BCY	volume of soil to be solidified
	133,025 BCY	volume of soil at shallow depths to be solidified
	9,476 BCY	volume of deeper soil to be solidified
	Removal of Upland Source Area Soil	
	12,700 BCY	total volume
	0.5 acre	total area
	2,286 BCY	volume classified as hazardous
	10,414 BCY	volume classified as non-hazardous
	Volume of sediment removal	
	23,200 BCY	sediment removal
	25,900 BCY	total sediment removal volume (including for offsetting cap)
	11,000 BCY	mechanical dredging
	12,200 BCY	hydraulic dredging
	510 BCY	residual cover - organoclay
	2,300 BCY	residual cover - sand
	20,400 BCY	backfill
	35,000 SF	sheet pile area
	Volumes for PRB installation	
	367 BCY	volume classified as hazardous
	1,670 BCY	volume classified as non-hazardous
	163 ton	amount of PRB media
	44 BCY	cover material
	820 LF	slurry wall length
	Dewatering to maintain wet removal for upland soil	
	120 gpm	maximum upland dewatering rate
	120 gpm	average upland dewatering rate
	6 each	deep aquifer depressurization wells
	0.12 year	upland soil removal time
	0.91 year	upland soil solidification time
	16 feet	average excavation depth
	35 feet	min.embed. depth
	10,109 SF	shoring wall area

Item	Quantity	Unit	Unit Cost	Total Cost	Source	Notes
CAPITAL CONSTRUCTION COSTS						
Upland Soil Cap						
Mobilization/Demobilization	1	LS	$ 357,404	$ 357,404	percentage of construction costs	includes temporary facilities for duration of construction
Site Preparation	22	acre	$ 6,900	$ 149,040	Costworks	clearing, grubbing brush and stumps
Geotextile marker layer	104,544	SY	$ 2	$ 158,907	Costworks	non-woven, 120lb tensile strength
Import Fill - Permeable Cap	104,544	BCY	$ 30	$ 3,136,320	project experience	
Compaction	104,544	BCY	$ 5	$ 522,720	project experience	
Habitat Area - excavation	12,441	BCY	$ 6	$ 74,643		
Habitat Area - non-hazardous transport and disposal	19,905	ton	$ 50	$ 995,244		
Hydroseeding	14,836	SY	$ 1	$ 8,901	Costworks	includes seed and fertilizer for wetland area
Stormwater collection and detention system	1,500	LF	$ 40	$ 60,000	project experience	media filter drain
Subtotal				*$ 5,463,180*		
Tax	9.5%		$ 5,463,180	$ 519,002		Sales Tax
Contingency	25%		$ 5,982,183	$ 1,495,546		
Total Upland Soil Cap Cost				$ 7,477,728		
Enhanced Natural Recovery						
Mobilization/Demobilization	1	LS	$ 57,456	$ 57,456		
Sand Material	22,880	ton	$ 20	$ 457,600	vendor quote	
Sand Placement	22,880	ton	$ 15	$ 343,200	project experience	ENR placed as one lift
Confirmation of Placement	1	LS	$ 20,000	$ 20,000		
Subtotal				*$ 878,256*		
Tax	9.5%		$ 878,256	$ 83,434		Sales Tax
Contingency	25%		$ 961,690	$ 240,422.58		
Total Enhanced Natural Recovery Cost				$ 1,202,113		
Engineered Sand Cap						
Mobilization/Demobilization	1	LS	$ 73,584	$ 73,584		
Sand Material	25,280	ton	$ 20	$ 505,600	vendor quote	
Sand Placement	25,280	ton	$ 20	$ 505,600	project experience	Sand Cap placed in multiple lifts
Geotextile Separation Layer	40,000	SF	$ 1	$ 20,000	Vendor quote	Only in nearshore area
Confirmation of Placement	1	LS	$ 20,000	$ 20,000		
Subtotal				*$ 1,124,784*		
Tax	9.5%		$ 1,124,784	$ 106,854		Sales Tax
Contingency	25%		$ 1,231,638	$ 307,910		
Total Engineered Sand Cap Cost				$ 1,539,548		
RCM Reactive Capping						
Mobilization/Demobilization	1	LS	$ 35,627	$ 35,627		
Organoclay RCM Material + Transportation	85,600	SF	$ 3	$ 222,560	Quote from Cetco	
Organoclay RCM Placement	85,600	SF	$ 2	$ 171,200	Project experience	
Sand Material	2,720	ton	$ 20	$ 54,400	vendor quote	
Sand Placement	2,720	ton	$ 15	$ 40,800	project experience	Sand over RCM placed in one lift
Confirmation of Placement	1	LS	$ 20,000	$ 20,000		
Subtotal				*$ 544,587*		
Tax	9.5%		$ 544,587	$ 51,736		Sales Tax
Contingency	25%		$ 596,323	$ 149,081		
Total RCM Reactive Capping Cost				$ 745,404		
Upland Soil Solidification						
Mobilization/Demobilization	1	LS	$ 711,519	$ 711,519	percentage of construction costs	includes temporary facilities for duration of construction
Solidification - 8-ft diameter auger	133,025	BCY	$ 70	$ 9,311,717	project experience	8-ft auger used to cost-effectively treat shallower soils
Solidification - 4-ft diameter auger	9,476	BCY	$ 90	$ 852,847	project experience	4-ft auger used to treat deeper soils, below 8-ft auger limit
Subtotal				*$ 10,876,083*		
Tax	9.5%		$ 10,876,083	$ 1,033,228		Sales Tax
Contingency	30%		$ 11,909,311	$ 3,572,793		
Total Upland Soil Solidification Cost				$ 15,482,104		
Upland Soil Removal						
Mobilization/Demobilization	1	LS	$ 245,881	$ 245,881	percentage of construction costs	includes temporary facilities for duration of construction
Excavation	12,700	BCY	$ 6	$ 76,200	project experience	
Import Fill	12,700	BCY	$ 30	$ 381,000	project experience	
Soil Handling and Stockpiling	12,700	BCY	$ 5	$ 63,500	project experience	segregation into hazardous/non-hazardous
Analytical Sampling	200	ea	$ 500	$ 100,000	project experience	VOCs and SVOCs
Compaction	12,700	BCY	$ 5	$ 63,500	project experience	
Transport and Disposal - Non-Hazardous Waste	16,662	ton	$ 50	$ 833,120	project experience	Subtitle D landfill disposal
Transport and Disposal - Hazardous Waste	3,658	ton	$ 150	$ 548,640	project experience	Subtitle C landfill disposal, assuming no treatment required
Shoring	10,109	SF	$ 92	$ 930,055	project experience	sheet pile - stiffened to allow excavation in the wet (see Appendix F)
Dewatering - Deep Aquifer Depressurization Wells and Pumps	6	ea	$ 40,000	$ 240,000	project experience	
Dewatering - Equalization Tank	2	month	$ 980	$ 1,960	project experience	Rental - 20,000 gallon tank
Dewatering - Treatment system	2	month	$ 8,066	$ 16,132	Vendor quote	rental system: DNAPL separation, air stripping, filtration, GAC vessels
Dewatering - Carbon Replacement	45	day	$ 72	$ 3,198	Vendor quote	based on usage rate of 65 lb/day @ 50gpm - $0.46/lb
Dewatering - Carbon Disposal	3	ton	$ 400	$ 1,391	Vendor quote	
Dewatering - Coagulant	64	lb	$ 2	$ 145	Vendor quote	$2.25 per lb, 1mg/L concentration, average flow rate
Dewatering - Miscellaneous Equipment	20%		$ 363,804	$ 72,761	percentage of dewatering capital co	
Dewatering - Equipment Operation and Maintenance	45	day	$ 700	$ 31,200	labor estimate	1 full-time operator, $70/hr, 10hr/day
Dewatering - Discharge Fee	7,702,062	gal	$ 0	$ 64,697	project experience	$0.0084/gal discharge rate for city of Renton sewer at adjacent site
Dewatering - Power	2	month	$ 2,540	$ 5,080	project experience	$0.0996/KWH estimated power rate
Monitoring Well Installation	20	ea	$ 4,000	$ 80,000	project experience	confirmation monitoring program
Subtotal				*$ 3,758,460*		
Tax	9.5%		$ 3,758,460	$ 357,054		Sales Tax
Contingency	35%		$ 4,115,514	$ 1,440,430		
Total Upland Soil Removal Cost				$ 5,555,943		

Table D-6 - Alternative 6 Cost Estimate

Quendall Terminals
Renton, Washington

Sediment Removal						
Mobilization/Demobilization	1	LS	$ 439,800	$ 439,800		
Mechanical Dredging	13,720	BCY	$ 35	$ 480,194		Mechanical dredging in nearshore and for offsetting nearshore cap
Hydraulic Dredging	12,200	BCY	$ 60	$ 732,000	Project experience	Assumes specialty hydraulic for T-Dock/Offshore
Debris Removal and Disposal	1	LS	$ 50,000	$ 50,000		Removal of piling
Transloading/Material Handling	25,900	BCY	$ 15	$ 388,500		
Dewatering	25,900	BCY	$ 10	$ 246,050	vendor quote	Assumes 5% amendment by weight
Water Treatment	1	LS	$ 200,000	$ 200,000	Project experience	
Residuals Cover Bulk Organoclay Material - (PM-199)	365	ton	$ 3,250	$ 1,185,941	Quote from Cetco	
Residuals Cover Sand Material	3,680	ton	$ 20	$ 73,600	vendor quote	
Residuals Cover Material Placement	4,045	ton	$ 15	$ 60,674	project experience	
Backfill Material	32,640	ton	$ 20	$ 652,800	vendor quote	
Backfill Material Placement	32,640	ton	$ 15	$ 489,600	project experience	Backfill placed in bulk
Transportation and Disposal - Non-Hazardous	33,670	ton	$ 50	$ 1,683,500		Subtitle D landfill disposal
Dredging Confirmation	1	LS	$ 40,000	$ 40,000		
Subtotal				*$ 6,722,659*		
Tax	9.5%		$ 6,722,659	$ 638,653		Sales Tax
Contingency	25%		$ 7,361,312	$ 1,840,328		
Total Sediment Removal Cost				$ 9,201,640		
Sheet Pile Enclosure						
Mobilization/Demobilization	1	LS	$ 220,500	$ 220,500	Project experience	
Steel Unit Cost	35,000	SF	$ 35	$ 1,225,000	Project experience	
Installation Unit Cost	35,000	SF	$ 45	$ 1,575,000	Project experience	
Removal Unit Cost	35,000	SF	$ 15	$ 525,000	Project experience	
Salvage Unit Value	1,750,000	lb	$ (0.1)	$ (175,000)	Project experience	50 pounds per sf
Subtotal				*$ 3,370,500*		
Tax	9.5%		$ 3,370,500	$ 320,198		Sales Tax
Contingency	25%		$ 3,690,698	$ 922,674		
Total Sheet Pile Enclosure Cost				$ 4,613,372		
Sediment Environmental Controls and Monitoring						
Water Quality Monitoring	175	day	$ 2,500	$ 437,500		
Water Quality Controls and BMPs (Absorbent Booms, Silt Curtains, Oil Bo	1	LS	$ 75,000	$ 75,000		
Odor Control	60	day	$ 2,500	$ 150,000		
Noise Monitoring	1	LS	$ 15,000	$ 15,000		
Erosion Protection for Shoreline Area	1	LS	$ 250,000	$ 250,000		
Subtotal				*$ 927,500*		
Tax	9.5%		$ 927,500	$ 88,113		Sales Tax
Contingency	25%		$ 1,015,613	$ 253,903		
Total Sediment Environmental Controls and Monitoring Cost				$ 1,269,516		
Permeable Treatment Wall						
Mobilization/Demobilization	1	LS	$ 55,765	$ 55,765	Vendor quote	One Pass trencher transport, assembly and disassembly
Excavation and media installation	1	LS	$ 250,000	$ 250,000	Vendor quote	excavate and place GAC
Treatment media	163	ton	$ 920	$ 149,926	Vendor quote	GAC: see Appendix E
Import fill	44	BCY	$ 30	$ 1,333	Project experience	cap for PRB
Monitoring well installation	5	well	$ 4,000	$ 20,000	Project experience	
Transport and Disposal - Non-Hazardous Waste	2,673	ton	$ 50	$ 133,630	project experience	Subtitle D landfill disposal
Transport and Disposal - Hazardous Waste	587	ton	$ 150	$ 88,000	project experience	Subtitle C landfill disposal, assuming no treatment required
Slurry Wall installation	820	LF	$ 188	$ 153,750	Vendor quote	slurry to 25' depth
Subtotal				*$ 852,404*		
Tax	9.5%		$ 852,404	$ 80,978		Sales Tax
Contingency	25%		$ 933,382	$ 233,345		
Total Permeable Treatment Wall Cost				$ 1,166,727		
Subtotal Construction Costs				**$ 48,254,095**		
Professional Services (as percent of construction and contingency costs)						
Project management	5%		$ 48,254,095	$ 2,412,705		
Remedial design	6%		$ 48,254,095	$ 2,895,246		Includes treatability studies for remedy components as necessary
Construction management	6%		$ 48,254,095	$ 2,895,246		
Subtotal				*$ 8,203,196*		
Total Estimated Capital Cost				**$ 56,500,000**		
O&M COSTS						
1st Year O&M						
GW Monitoring	1	LS	$ 80,000	$ 80,000	Project experience	
Sediment Sand Cap and ENR Sampling	1	LS	$ 25,000	$ 25,000	Project experience	
Sediment Cap Inspection	1	LS	$ 15,000	$ 15,000	Project experience	Visual and In-Water (Bathymetric/ Sediment Profile Image)
Backfilled Area Surface Sediment Monitoring	1	LS	$ 25,000	$ 25,000		
DNR Lease	0.5	acre	$ 20,000	$ 10,000		Offshore cap area off property
Subtotal				*$ 155,000*		
Tax	9.5%		$ 155,000	$ 14,725		Sales Tax
Contingency	25%		$ 169,725	$ 42,431		
Total 1st Year O&M Cost				$ 212,156		
Annual O&M						
Groundwater Monitoring	1	LS	$ 25,000	$ 25,000	Project experience	20 wells annually
Upland Cap inspection	6	hour	$ 80	$ 480	labor estimate	
DNR Lease	0.5	acre	$ 20,000	$ 10,000		Offshore cap area off property
Subtotal				*$ 35,480*		
Tax	9.5%		$ 35,480	$ 3,371		Sales Tax
Contingency	25%		$ 38,851	$ 9,713		
Total Annual O&M Cost				$ 48,563		
Professional Services (as percent of Annual O&M costs)						
Project management/Reporting	10%		$ 48,563	$ 4,856		
Total, Annual O&M:				**$ 53,420**		
Total Estimated O&M, 100 Years, No NPV Analysis:				**$ 5,600,000**		
Periodic Costs						
Reactive Cap						
Replace 25% of RC at 22 yrs				$ 110,000		
Replace 25% of RC at 44 yrs				$ 110,000		
Replace 25% of RC at 66 yrs				$ 110,000		
Replace 25% of RC at 88 yrs				$ 110,000		
Sand Cap and ENR						
Sediment Sand Cap and ENR Sampling at 2 years				$ 25,000		
Sediment Sand Cap and ENR Sampling at 5 years				$ 25,000		
Sediment Sand Cap and ENR Sampling at 10 years				$ 25,000		
Sediment Cap Inspection at 2 years				$ 15,000		
Sediment Cap Inspection at 5 years				$ 15,000		
Sediment Cap Inspection at 10 years				$ 15,000		
Sand Cap Shoreline Maintenance at 30 years				$ 25,000		
Sand Cap Shoreline Maintenance at 60 years				$ 25,000		
Sand Cap Shoreline Maintenance at 90 years				$ 25,000		
Permeable treatment wall						
Replace Media at 22 yrs				$ 520,876		includes mob/demob, excavation, media, and $400 per ton disposal fee
Replace Media at 44 yrs				$ 520,876		includes mob/demob, excavation, media, and $400 per ton disposal fee
Replace Media at 66 yrs				$ 520,876		includes mob/demob, excavation, media, and $400 per ton disposal fee
Replace Media at 88 yrs				$ 520,876		includes mob/demob, excavation, media, and $400 per ton disposal fee
Subtotal				*$ 2,718,503*		
TOTAL ESTIMATED COST, NO NPV ANALSYS				**$ 64,818,503**		
Net Present Value Analysis						
Annual O&M	100	year	$ 53,420	$ 2,656,055		
1st year O&M	1	LS	$ 212,156	$ 212,156		
Replace 25% of RC at 22 yrs	1	LS	$ 110,000	$ 77,577		
Replace 25% of RC at 44 yrs	1	LS	$ 110,000	$ 54,710		
Replace 25% of RC at 66 yrs	1	LS	$ 110,000	$ 38,584		
Replace 25% of RC at 88 yrs	1	LS	$ 110,000	$ 27,211		
Sediment Sand Cap and ENR Sampling at 2 years	1	LS	$ 25,000	$ 24,219		
Sediment Sand Cap and ENR Sampling at 5 years	1	LS	$ 25,000	$ 23,093		
Sediment Sand Cap and ENR Sampling at 10 years	1	LS	$ 25,000	$ 21,331		
Sediment Cap Inspection at 2 years	1	LS	$ 15,000	$ 14,531		
Sediment Cap Inspection at 5 years	1	LS	$ 15,000	$ 13,856		
Sediment Cap Inspection at 10 years	1	LS	$ 15,000	$ 12,798		
Sand Cap Shoreline Maintenance at 30 years	1	LS	$ 25,000	$ 15,528		
Sand Cap Shoreline Maintenance at 60 years	1	LS	$ 25,000	$ 9,645		
Sand Cap Shoreline Maintenance at 90 years	1	LS	$ 25,000	$ 5,991		
Replace PRB Media at 22 yrs	1	LS	$ 520,876	$ 367,344		
Replace PRB Media at 44 yrs	1	LS	$ 520,876	$ 259,066		
Replace PRB Media at 66 yrs	1	LS	$ 520,876	$ 182,705		
Replace PRB Media at 88 yrs	1	LS	$ 520,876	$ 128,851		
2013 discount rate for NPV	1.6%					
Total Estimated O&M and Periodic NPV				**$ 4,145,251**		
TOTAL ESTIMATED COST				**$ 60,645,251**		

Notes:
1. Mobilization/Demobilization costs are assumed to include equipment transport and setup, temporary erosion and sedimentation control (TESC) measures, bonds, and insurance.
2. Contingency costs include miscellaneous costs not currently itemized due to the current (preliminary) stage of design development, as well as costs to address unanticipated conditions encountered during construction.

Table D-7 - Alternative 7 Cost Estimate

Quendall Terminals
Renton, Washington

Site:	Quendall Terminals							
Remedial Action Description:	Alternative	7	Containment with PTM Solidification (Upland) and Removal (Sediment)					
Cost Estimate Accuracy:	FS Screening Level (+50/-30 percent)							
Key Assumptions and Quantities:	Capping of Upland Soil							
(see Appendix E for calculations)	21.6	acre	total area					
	940,896	SF	total area					
	133,521	SF	permeable area along shoreline					
	14,836	BCY	habitat excavation overlap					
	104,544	BCY	total volume	based on 3' cap thickness				
	Enhanced Natural Recovery - Sand Material							
	14,300	BCY	total volume					
	Engineered Sand Cap							
	13,600	BCY	total sand volume					
	1,900	BCY	removal volume for offsetting sand cap					
	35,000	SF	area for offsetting sand cap					
	0.3	acre	DNR lease area					
	Soil/Sediment Density							
	1.6	tons/BCY	soil density					
	1.3	tons/BCY	sediment density					
	0.7	tons/CY	organoclay density					
	Solidification of Upland Source Area Soil							
	241,275	BCY	volume of soil to be solidified					
	231,799	BCY	volume of soil at shallow depths to be solidified					
	9,476	BCY	volume of deeper soil to be solidified					
	Volume of sediment removal							
	56,400	BCY	sediment removal					
	58,300	BCY	total sediment removal volume (including for offsetting cap)					
	41,200	BCY	mechanical dredging					
	15,200	BCY	hydraulic dredging					
	930	BCY	residual cover - organoclay					
	4,300	BCY	residual cover - sand					
	51,200	BCY	backfill					
	63,000	SF	sheet pile area					

Item	Quantity	Unit	Unit Cost	Total Cost	Source	Notes
CAPITAL CONSTRUCTION COSTS						
Upland Soil Cap						
Mobilization/Demobilization	1	LS	$ 371,823	$ 371,823	percentage of construction costs	includes temporary facilities for duration of construction
Site Preparation	22	acre	$ 6,900	$ 149,040	Costworks	clearing, grubbing brush and stumps
Geotextile marker layer	104,544	SY	$ 2	$ 158,907	Costworks	non-woven, 120lb tensile strength
Import Fill - Permeable Cap	104,544	BCY	$ 30	$ 3,136,320	project experience	
Compaction	104,544	BCY	$ 5	$ 522,720	project experience	
Habitat Area - excavation	14,836	BCY	$ 6	$ 89,014		
Habitat Area - non-hazardous transport and disposal	23,737	ton	$ 50	$ 1,186,853		
Hydroseeding	14,836	SY	$ 1	$ 8,901	Costworks	includes seed and fertilizer for wetland area
Stormwater collection and detention system	1,500	LF	$ 40	$ 60,000	project experience	media filter drain
Subtotal				*$ 5,683,579*		
Tax	9.5%		$ 5,683,579	$ 539,940		Sales Tax
Contingency	25%		$ 6,223,518	$ 1,555,880		
Total Upland Soil Cap Cost				$ 7,779,398		
Enhanced Natural Recovery						
Mobilization/Demobilization	1	LS	$ 57,456	$ 57,456		
Sand Material	22,880	ton	$ 20	$ 457,600	vendor quote	
Sand Placement	22,880	ton	$ 15	$ 343,200	project experience	ENR placed as one lift
Confirmation of Placement	1	LS	$ 20,000	$ 20,000		
Subtotal				*$ 878,256*		
Tax	9.5%		$ 878,256	$ 83,434		Sales Tax
Contingency	25%		$ 961,690	$ 240,422.58		
Total Enhanced Natural Recovery Cost				$ 1,202,113		
Engineered Sand Cap						
Mobilization/Demobilization	1	LS	$ 63,553	$ 63,553		
Sand Material	21,760	ton	$ 20	$ 435,200	vendor quote	
Sand Placement	21,760	ton	$ 20	$ 435,200	project experience	Sand Cap placed in multiple lifts
Geotextile Separation Layer	35,000	SF	$ 1	$ 17,500	Vendor quote	Only in nearshore area
Confirmation of Placement	1	LS	$ 20,000	$ 20,000		
Subtotal				*$ 971,453*		
Tax	9.5%		$ 971,453	$ 92,288		Sales Tax
Contingency	25%		$ 1,063,741	$ 265,935		
Total Engineered Sand Cap Cost				$ 1,329,676		
Upland Soil Solidification						
Mobilization/Demobilization	1	LS	$ 1,195,515	$ 1,195,515	percentage of construction costs	includes temporary facilities for duration of construction
Solidification - 8-ft diameter auger	231,799	BCY	$ 70	$ 16,225,938	project experience	8-ft auger used to cost-effectively treat shallower soils
Solidification - 4-ft diameter auger	9,476	BCY	$ 90	$ 852,847	project experience	4-ft auger used to treat deeper soils, below 8-ft auger limit
Subtotal				*$ 18,274,299*		
Tax	9.5%		$ 18,274,299	$ 1,736,058		Sales Tax
Contingency	30%		$ 20,010,358	$ 6,003,107		
Total Upland Soil Solidification Cost				$ 26,013,465		
Sediment Removal						
Mobilization/Demobilization	1	LS	$ 948,775	$ 948,775		
Mechanical Dredging	43,100	BCY	$ 35	$ 1,508,500		Mechanical dredging in nearshore and for offsetting nearshore cap
Hydraulic Dredging	15,200	BCY	$ 60	$ 912,000	Project experience	Assumes specialty hydraulic for T-Dock/Offshore
Debris Removal and Disposal	1	LS	$ 75,000	$ 75,000		Removal of piling
Transloading/Material Handling	58,300	BCY	$ 15	$ 874,500		
Dewatering	58,300	BCY	$ 10	$ 553,850	vendor quote	Assumes 5% amendment by weight
Water Treatment	1	LS	$ 500,000	$ 500,000	Project experience	
Residuals Cover Bulk Organoclay Material - (PM-199)	665	ton	$ 3,250	$ 2,162,599	Quote from Cetco	
Residuals Cover Sand Material	6,880	ton	$ 20	$ 137,600	vendor quote	
Residuals Cover Material Placement	7,545	ton	$ 15	$ 113,181	project experience	
Backfill Material	81,920	ton	$ 20	$ 1,638,400	vendor quote	
Backfill Material Placement	81,920	ton	$ 15	$ 1,228,800	project experience	Backfill placed in bulk
Transportation and Disposal - Non-Hazardous	75,790	ton	$ 50	$ 3,789,500		Subtitle D landfill disposal
Dredging Confirmation	1	LS	$ 60,000	$ 60,000		
Subtotal				*$ 14,502,705*		
Tax	9.5%		$ 14,502,705	$ 1,377,757		Sales Tax
Contingency	25%		$ 15,880,462	$ 3,970,116		
Total Sediment Removal Cost				$ 19,850,578		

Table D-7 - Alternative 7 Cost Estimate

Quendall Terminals
Renton, Washington

Sheet Pile Enclosure						
Mobilization/Demobilization	1	LS	$ 396,900	$ 396,900	Project experience	
Steel Unit Cost	63,000	SF	$ 35	$ 2,205,000	Project experience	
Installation Unit Cost	63,000	SF	$ 45	$ 2,835,000	Project experience	
Removal Unit Cost	63,000	SF	$ 15	$ 945,000	Project experience	
Salvage Unit Value	3,150,000	lb	$ (0.1)	$ (315,000)	Project experience	50 pounds per sf
Subtotal				*$ 6,066,900*		
Tax	9.5%		$ 6,066,900	$ 576,356		Sales Tax
Contingency	25%		$ 6,643,256	$ 1,660,814		
Total Sheet Pile Enclosure Cost				$ 8,304,069		
Sediment Environmental Controls and Monitoring						
Water Quality Monitoring	250	day	$ 2,500	$ 625,000		
Water Quality Controls and BMPs (Absorbent Booms, Silt Curtains, Oil Bo	1	LS	$ 150,000	$ 150,000		
Odor Control	150	day	$ 2,500	$ 375,000		
Noise Monitoring	1	LS	$ 30,000	$ 30,000		
Erosion Protection for Shoreline Area	1	LS	$ 250,000	$ 250,000		
Subtotal				*$ 1,430,000*		
Tax	9.5%		$ 1,430,000	$ 135,850		Sales Tax
Contingency	25%		$ 1,565,850	$ 391,463		
Total Sediment Environmental Controls and Monitoring Cost				$ 1,957,313		
Subtotal Construction Costs				**$ 66,436,612**		
Professional Services (as percent of construction and contingency costs)						
Project management	5%		$ 66,436,612	$ 3,321,831		
Remedial design	6%		$ 66,436,612	$ 3,986,197		Includes treatability studies for remedy components as necessary
Construction management	6%		$ 66,436,612	$ 3,986,197		
Subtotal				*$ 11,294,224*		
Total Estimated Capital Cost				**$ 77,700,000**		
O&M COSTS						
1st Year O&M						
GW Monitoring	1	LS	$ 80,000	$ 80,000	Project experience	
Sediment Sand Cap and ENR Sampling	1	LS	$ 25,000	$ 25,000	Project experience	
Sediment Cap Inspection	1	LS	$ 15,000	$ 15,000	Project experience	Visual and In-Water (Bathymetric/ Sediment Profile Image)
Backfilled Area Surface Sediment Monitoring	1	LS	$ 25,000	$ 25,000		
DNR Lease	0.3	acre	$ 20,000	$ 6,000		Offshore cap area off property
Subtotal				*$ 151,000*		
Tax	9.5%		$ 151,000	$ 14,345		Sales Tax
Contingency	25%		$ 165,345	$ 41,336		
Total 1st Year O&M Cost				$ 206,681		
Annual O&M						
Groundwater Monitoring	1	LS	$ 25,000	$ 25,000	Project experience	20 wells annually
Upland Cap inspection	6	hour	$ 80	$ 480	labor estimate	
DNR Lease	0.3	acre	$ 20,000	$ 6,000		Offshore cap area off property
Subtotal				*$ 31,480*		
Tax	9.5%		$ 31,480	$ 2,991		Sales Tax
Contingency	25%		$ 34,471	$ 8,618		
Total Annual O&M Cost				$ 43,088		
Professional Services (as percent of Annual O&M costs)						
Project management/Reporting	10%		$ 43,088	$ 4,309		
Total, Annual O&M:				**$ 47,397**		
Total Estimated O&M, 100 Years, No NPV Analysis:				**$ 4,900,000**		
Periodic Costs						
Sand Cap and ENR						
Sediment Sand Cap and ENR Sampling at 2 years				$ 25,000		
Sediment Sand Cap and ENR Sampling at 5 years				$ 25,000		
Sediment Sand Cap and ENR Sampling at 10 years				$ 25,000		
Sediment Cap Inspection at 2 years				$ 15,000		
Sediment Cap Inspection at 5 years				$ 15,000		
Sediment Cap Inspection at 10 years				$ 15,000		
Sand Cap Shoreline Maintenance at 30 years				$ 25,000		
Sand Cap Shoreline Maintenance at 60 years				$ 25,000		
Sand Cap Shoreline Maintenance at 90 years				$ 25,000		
Subtotal				*$ 195,000*		
TOTAL ESTIMATED COST, NO NPV ANALSYS				**$ 82,795,000**		
Net Present Value Analysis						
Annual O&M	100	year	$ 47,397	$ 2,356,613		
1st year O&M	1	LS	$ 206,681	$ 206,681		
Sediment Sand Cap and ENR Sampling at 2 years	1	LS	$ 25,000	$ 24,219		
Sediment Sand Cap and ENR Sampling at 5 years	1	LS	$ 25,000	$ 23,093		
Sediment Sand Cap and ENR Sampling at 10 years	1	LS	$ 25,000	$ 21,331		
Sediment Cap Inspection at 2 years	1	LS	$ 15,000	$ 14,531		
Sediment Cap Inspection at 5 years	1	LS	$ 15,000	$ 13,856		
Sediment Cap Inspection at 10 years	1	LS	$ 15,000	$ 12,798		
Sand Cap Shoreline Maintenance at 30 years	1	LS	$ 25,000	$ 15,528		
Sand Cap Shoreline Maintenance at 60 years	1	LS	$ 25,000	$ 9,645		
Sand Cap Shoreline Maintenance at 90 years	1	LS	$ 25,000	$ 5,991		
2013 discount rate for NPV	1.6%					
Total Estimated O&M and Periodic NPV				**$ 2,704,286**		
TOTAL ESTIMATED COST				**$ 80,404,286**		

Notes:
1. Mobilization/Demobilization costs are assumed to include equipment transport and setup, temporary erosion and sedimentation control (TESC) measures, bonds, and insurance.
2. Contingency costs include miscellaneous costs not currently itemized due to the current (preliminary) stage of design development, as well as costs to address unanticipated conditions encountered during construction.

Table D-8 - Alternative 8 Cost Estimate

Quendall Terminals
Renton, Washington

Site:	Quendall Terminals
Remedial Action Description:	Alternative 8 Containment with PTM Removal (Upland and Sediment)
Cost Estimate Accuracy:	FS Screening Level (+50/-30 percent)

Key Assumptions and Quantities:
(see Appendix E for calculations)

Capping of Upland Soil
- 21.6 acre — total area
- 940,896 SF — total area
- 133,521 SF — permeable area along shoreline
- 9,721 BCY — habitat excavation overlap
- 104,544 BCY — total volume based on 3' cap thickness

Enhanced Natural Recovery - Sand Material
- 14,300 BCY — total volume

Engineered Sand Cap
- 13,600 BCY — total sand volume
- 1,900 BCY — removal volume for offsetting sand cap
- 35,000 SF — area for offsetting sand cap
- 0.3 acre — DNR lease area

Soil/Sediment Density
- 1.6 tons/BCY — soil density
- 1.3 tons/BCY — sediment density
- 0.7 tons/CY — organoclay density

Removal of Upland Source Area Soil
- 210,100 BCY — total volume
- 9.7 acre — total area
- 30,474 BCY — volume classified as hazardous
- 179,626 BCY — volume classified as non-hazardous

Volume of sediment removal
- 56,400 BCY — sediment removal
- 58,300 BCY — total sediment removal volume (including for offsetting cap)
- 41,200 BCY — mechanical dredging
- 15,200 BCY — hydraulic dredging
- 930 BCY — residual cover - organoclay
- 4,300 BCY — residual cover - sand
- 51,200 BCY — backfill
- 63,000 SF — sheet pile area

Dewatering to maintain wet removal for upland soil
- 207 gpm — maximum upland dewatering rate
- 67 gpm — average upland dewatering rate
- 27 each — deep aquifer depressurization wells
- 2.02 year — upland soil removal time
- 19 feet — average excavation depth
- 30 feet — min.embed. depth
- 127,809 SF — shoring wall area

Item	Quantity	Unit	Unit Cost	Total Cost	Source	Notes
CAPITAL CONSTRUCTION COSTS						
Upland Soil Cap						
Mobilization/Demobilization	1	LS	$ 292,312	$ 292,312	percentage of construction costs	includes temporary facilities for duration of construction
Site Preparation	22	acre	$ 6,900	$ 149,040	Costworks	clearing, grubbing brush and stumps
Geotextile marker layer	104,544	SY	$ 2	$ 158,907	Costworks	non-woven, 120lb tensile strength
Import Fill - Permeable Cap	104,544	BCY	$ 30	$ 3,136,320	project experience	
Compaction	104,544	BCY	$ 5	$ 522,720	project experience	
Habitat Area - excavation	9,721	BCY	$ 6	$ 58,324		
Habitat Area - non-hazardous transport and disposal	15,553	ton	$ 50	$ 777,653		
Hydroseeding	14,836	SY	$ 1	$ 8,901	Costworks	includes seed and fertilizer for wetland area
Stormwater collection and detention system	1,500	LF	$ 40	$ 60,000	project experience	media filter drain
Subtotal				*$ 5,164,178*		
Tax	9.5%		$ 5,164,178	$ 490,597		Sales Tax
Contingency	25%		$ 5,654,774	$ 1,413,694		
Total Upland Soil Cap Cost				$ 7,068,468		
Enhanced Natural Recovery						
Mobilization/Demobilization	1	LS	$ 49,248	$ 49,248		
Sand Material	22,880	ton	$ 20	$ 457,600	vendor quote	
Sand Placement	22,880	ton	$ 15	$ 343,200	project experience	ENR placed as one lift
Confirmation of Placement	1	LS	$ 20,000	$ 20,000		
Subtotal				*$ 870,048*		
Tax	9.5%		$ 870,048	$ 82,655		Sales Tax
Contingency	25%		$ 952,703	$ 238,175.64		
Total Enhanced Natural Recovery Cost				$ 1,190,878		
Engineered Sand Cap						
Mobilization/Demobilization	1	LS	$ 54,474	$ 54,474		
Sand Material	21,760	ton	$ 20	$ 435,200	vendor quote	
Sand Placement	21,760	ton	$ 20	$ 435,200	project experience	Sand Cap placed in multiple lifts
Geotextile Separation Layer	35,000	SF	$ 1	$ 17,500	Vendor quote	Only in nearshore area
Confirmation of Placement	1	LS	$ 20,000	$ 20,000		
Subtotal				*$ 962,374*		
Tax	9.5%		$ 962,374	$ 91,426		Sales Tax
Contingency	25%		$ 1,053,800	$ 263,450		
Total Engineered Sand Cap Cost				$ 1,317,249		
Upland Soil Removal						
Mobilization/Demobilization	1	LS	$ 2,974,731	$ 2,974,731	percentage of construction costs	includes temporary facilities for duration of construction
Excavation	210,100	BCY	$ 6	$ 1,260,600	project experience	
Soil Handling and Stockpiling	210,100	BCY	$ 5	$ 1,050,500	project experience	segregation into hazardous/non-hazardous
Analytical Sampling	200	ea	$ 500	$ 100,000	project experience	VOCs and SVOCs
Compaction	210,100	BCY	$ 5	$ 1,050,500	project experience	
On-Site Treatment - Thermal Desorption	336,160	ton	$ 95	$ 31,935,200	vendor estimate	
Shoring	127,809	SF	$ 92	$ 11,758,426	project experience	sheet pile - stiffened to allow excavation in the wet (see Appendix F)
Dewatering - Deep Aquifer Depressurization Wells and Pumps	27	ea	$ 40,000	$ 1,080,000	project experience	
Dewatering - Equalization Tank	25	month	$ 980	$ 24,500	project experience	Rental - 20,000 gallon tank
Dewatering - Treatment system	25	month	$ 8,066	$ 201,650	Vendor quote	rental system: DNAPL separation, air stripping, filtration, GAC vessels
Dewatering - Arsenic Treatment and Media	1	LS	$ 23,071	$ 23,071	Vendor quote	based on usage rate of 4% by weight
Dewatering - Carbon Replacement	737	day	$ 40	$ 29,499	Vendor quote	based on usage rate of 65 lb/day @ 50gpm - $0.46/lb
Dewatering - Carbon Disposal	32	ton	$ 400	$ 12,826	Vendor quote	
Dewatering - Coagulant	593	lb	$ 2	$ 1,335	Vendor quote	$2.25 per lb, 1mg/L concentration, average flow rate
Dewatering - Miscellaneous Equipment	20%		$ 1,953,025	$ 390,605	percentage of dewatering capital co	
Dewatering - Equipment Operation and Maintenance	737	day	$ 700	$ 516,159	labor estimate	1 full-time operator, $70/hr, 10hr/day
Dewatering - Power	25	month	$ 2,540	$ 63,500	project experience	$0.0996/KWH estimated power rate
Dewatering - Outfall Piping	50	LF	$ 10	$ 486	Costworks	8" Concrete discharge pipe
Monitoring Well Installation	20	ea	$ 4,000	$ 80,000	project experience	confirmation monitoring program
Subtotal				*$ 52,553,588*		
Tax	9.5%		$ 52,553,588	$ 4,992,591		Sales Tax
Contingency	35%		$ 57,546,179	$ 20,141,163		
Total Upland Soil Removal Cost				$ 77,687,341		
Sediment Removal						
Mobilization/Demobilization	1	LS	$ 813,236	$ 813,236		
Mechanical Dredging	43,100	BCY	$ 35	$ 1,508,500		Mechanical dredging in nearshore and for offsetting nearshore cap
Hydraulic Dredging	15,200	BCY	$ 60	$ 912,000	Project experience	Assumes specialty hydraulic for T-Dock/Offshore
Debris Removal and Disposal	1	LS	$ 75,000	$ 75,000		Removal of piling
Transloading/Material Handling	58,300	BCY	$ 15	$ 874,500		
Dewatering	58,300	BCY	$ 10	$ 553,850	vendor quote	Assumes 5% amendment by weight
Water Treatment	1	LS	$ 500,000	$ 500,000	Project experience	
Residuals Cover Bulk Organoclay Material - (PM-199)	665	ton	$ 3,250	$ 2,162,599	Quote from Cetco	
Residuals Cover Sand Material	6,880	ton	$ 20	$ 137,600	vendor quote	
Residuals Cover Material Placement	7,545	ton	$ 15	$ 113,181	project experience	
Backfill Material	81,920	ton	$ 20	$ 1,638,400	vendor quote	
Backfill Material Placement	81,920	ton	$ 15	$ 1,228,800	project experience	Backfill placed in bulk
Transportation and Disposal - Non-Hazardous	75,790	ton	$ 50	$ 3,789,500		Subtitle D landfill disposal
Dredging Confirmation	1	LS	$ 60,000	$ 60,000		
Subtotal				*$ 14,367,166*		
Tax	9.5%		$ 14,367,166	$ 1,364,881		Sales Tax
Contingency	25%		$ 15,732,047	$ 3,933,012		
Total Sediment Removal Cost				$ 19,665,058		
Sheet Pile Enclosure						
Mobilization/Demobilization	1	LS	$ 340,200	$ 340,200	Project experience	
Steel Unit Cost	63,000	SF	$ 35	$ 2,205,000	Project experience	
Installation Unit Cost	63,000	SF	$ 45	$ 2,835,000	Project experience	
Removal Unit Cost	63,000	SF	$ 15	$ 945,000	Project experience	
Salvage Unit Value	3,150,000	lb	$ (0.1)	$ (315,000)	Project experience	50 pounds per sf
Subtotal				*$ 6,010,200*		
Tax	9.5%		$ 6,010,200	$ 570,969		Sales Tax
Contingency	25%		$ 6,581,169	$ 1,645,292		
Total Sheet Pile Enclosure Cost				$ 8,226,461		

Table D-8 - Alternative 8 Cost Estimate

Quendall Terminals
Renton, Washington

Sediment Environmental Controls and Monitoring							
Water Quality Monitoring	250	day	$ 2,500	$	625,000		
Water Quality Controls and BMPs (Absorbent Booms, Silt Curtains, Oil Bo	1	LS	$ 150,000	$	150,000		
Odor Control	150	day	$ 2,500	$	375,000		
Noise Monitoring	1	LS	$ 30,000	$	30,000		
Erosion Protection for Shoreline Area	1	LS	$ 250,000	$	250,000		
Subtotal				$	*1,430,000*		
Tax	9.5%		$ 1,430,000	$	135,850		Sales Tax
Contingency	25%		$ 1,565,850	$	391,463		
Total Sediment Environmental Controls and Monitoring Cost				$	1,957,313		
Subtotal Construction Costs				**$**	**117,112,769**		
Professional Services (as percent of construction and contingency costs)							
Project management	5%		$ 117,112,769	$	5,855,638		
Remedial design	6%		$ 117,112,769	$	7,026,766		Includes treatability studies for remedy components as necessary
Construction management	6%		$ 117,112,769	$	7,026,766		
Subtotal				$	*19,909,171*		
Total Estimated Capital Cost				**$**	**137,000,000**		
O&M COSTS							
1st Year O&M							
GW Monitoring	1	LS	$ 80,000	$	80,000	Project experience	
Sediment Sand Cap and ENR Sampling	1	LS	$ 25,000	$	25,000	Project experience	
Sediment Cap Inspection	1	LS	$ 15,000	$	15,000	Project experience	Visual and In-Water (Bathymetric/ Sediment Profile Image)
Backfilled Area Surface Sediment Monitoring	1	LS	$ 25,000	$	25,000		
DNR Lease	0.3	acre	$ 20,000	$	6,000		Offshore cap area off property
Subtotal				$	*151,000*		
Tax	9.5%		$ 151,000	$	14,345		Sales Tax
Contingency	25%		$ 165,345	$	41,336		
Total 1st Year O&M Cost				$	206,681		
Annual O&M							
Groundwater Monitoring	1	LS	$ 25,000	$	25,000	Project experience	20 wells annually
Upland Cap inspection	6	hour	$ 80	$	480	labor estimate	
DNR Lease	0	acre	$ 20,000	$	6,000		Offshore cap area off property
Subtotal				$	*31,480*		
Tax	9.5%		$ 31,480	$	2,991		Sales Tax
Contingency	25%		$ 34,471	$	8,618		
Total Annual O&M Cost				$	43,088		
Professional Services (as percent of Annual O&M costs)							
Project management/Reporting	10%		$ 43,088	$	4,309		
Total, Annual O&M:				**$**	**47,397**		
Total Estimated O&M, 100 Years, No NPV Analysis:				**$**	**4,900,000**		
Periodic Costs							
Sand Cap and ENR							
Sediment Sand Cap and ENR Sampling at 2 years				$	25,000		
Sediment Sand Cap and ENR Sampling at 5 years				$	25,000		
Sediment Sand Cap and ENR Sampling at 10 years				$	25,000		
Sediment Cap Inspection at 2 years				$	15,000		
Sediment Cap Inspection at 5 years				$	15,000		
Sediment Cap Inspection at 10 years				$	15,000		
Sand Cap Shoreline Maintenance at 30 years				$	25,000		
Sand Cap Shoreline Maintenance at 60 years				$	25,000		
Sand Cap Shoreline Maintenance at 90 years				$	25,000		
Subtotal				$	*195,000*		
TOTAL ESTIMATED COST, NO NPV ANALSYS				**$**	**142,095,000**		
Net Present Value Analysis							
Annual O&M	100	year	$ 47,397	$	2,356,613		
1st year O&M	1	LS	$ 206,681	$	206,681		
Sediment Sand Cap and ENR Sampling at 2 years	1	LS	$ 25,000	$	24,219		
Sediment Sand Cap and ENR Sampling at 5 years	1	LS	$ 25,000	$	23,093		
Sediment Sand Cap and ENR Sampling at 10 years	1	LS	$ 25,000	$	21,331		
Sediment Cap Inspection at 2 years	1	LS	$ 15,000	$	14,531		
Sediment Cap Inspection at 5 years	1	LS	$ 15,000	$	13,856		
Sediment Cap Inspection at 10 years	1	LS	$ 15,000	$	12,798		
Sand Cap Shoreline Maintenance at 30 years	1	LS	$ 25,000	$	15,528		
Sand Cap Shoreline Maintenance at 60 years	1	LS	$ 25,000	$	9,645		
Sand Cap Shoreline Maintenance at 90 years	1	LS	$ 25,000	$	5,991		
2013 discount rate for NPV	1.6%						
Total Estimated O&M and Periodic NPV				**$**	**2,704,286**		
TOTAL ESTIMATED COST				**$**	**139,704,286**		

Notes:
1. Mobilization/Demobilization costs are assumed to include equipment transport and setup, temporary erosion and sedimentation control (TESC) measures, bonds, and insurance.
2. Contingency costs include miscellaneous costs not currently itemized due to the current (preliminary) stage of design development, as well as costs to address unanticipated conditions encountered during construction.

Table D-9 - Alternative 9 Cost Estimate

Quendall Terminals
Renton, Washington

Site: Quendall Terminals
Remedial Action Description: Alternative 9 Containment with Solidfication and Removal of Contaminated Soil and Removal of Contaminated Sediment

Cost Estimate Accuracy: FS Screening Level (+50/-30 percent)

Key Assumptions and Quantities:
(see Appendix E for calculations)

Capping of Upland Soil
21.6 acre total area
940,896 SF total area
133,521 SF permeable area along shoreline
5,023 BCY habitat excavation overlap
104,544 BCY total volume based on 3' cap thickness
Enhanced Natural Recovery - Sand Material
14,300 BCY total volume
Engineered Sand Cap
9,700 BCY total sand volume
800 BCY removal volume for offsetting sand cap
15,000 SF area for offsetting sand cap
0.3 acre DNR lease area
Soil/Sediment Density
1.6 tons/BCY soil density
1.3 tons/BCY sediment density
0.7 tons/CY organoclay density
Solidification of Upland Source Area Soil
362,900 BCY volume of soil to be solidified
285,901 BCY volume of soil at shallow depths to be solidified
76,999 BCY volume of deeper soil to be solidified
Removal of Upland Source Area Soil
342,500 BCY total volume
14.1 acre total area
Volume of sediment removal
172,300 BCY sediment removal
173,100 BCY total sediment removal volume (including for offsetting cap)
148,600 BCY mechanical dredging
23,700 BCY hydraulic dredging
1,170 BCY residual cover - organoclay
5,400 BCY residual cover - sand
165,900 BCY backfill
91,860 SF sheet pile area
Dewatering to maintain wet removal for upland soil
289 gpm maximum upland dewatering rate
70 gpm average upland dewatering rate
60 each deep aquifer depressurization wells
3.29 year upland soil removal time
2.33 year upland soil solidification time
15 feet average excavation depth
35 feet min.embed. depth
101,385 SF shoring wall area

Item	Quantity	Unit	Unit Cost	Total Cost	Source	Notes
CAPITAL CONSTRUCTION COSTS						
Upland Soil Cap						
Mobilization/Demobilization	1	LS	$ 268,073	$ 268,073	percentage of construction costs	includes temporary facilities for duration of construction
Site Preparation	22	acre	$ 6,900	$ 149,040	Costworks	clearing, grubbing brush and stumps
Geotextile marker layer	104,544	SY	$ 2	$ 158,907	Costworks	non-woven, 120lb tensile strength
Import Fill - Permeable Cap	104,544	BCY	$ 30	$ 3,136,320	project experience	
Compaction	104,544	BCY	$ 5	$ 522,720	project experience	
Habitat Area - excavation	5,023	BCY	$ 6	$ 30,139		
Habitat Area - non-hazardous transport and disposal	8,037	ton	$ 50	$ 401,858		
Hydroseeding	14,836	SY	$ 1	$ 8,901	Costworks	includes seed and fertilizer for wetland area
Stormwater collection and detention system	1,500	LF	$ 40	$ 60,000	project experience	media filter drain
Subtotal				*$ 4,735,959*		
Tax	9.5%		$ 4,735,959	$ 449,916		Sales Tax
Contingency	25%		$ 5,185,875	$ 1,296,469		
Total Upland Soil Cap Cost				$ 6,482,343		
Enhanced Natural Recovery						
Mobilization/Demobilization	1	LS	$ 49,248	$ 49,248		
Sand Material	22,880	ton	$ 20	$ 457,600	vendor quote	
Sand Placement	22,880	ton	$ 15	$ 343,200	project experience	ENR placed as one lift
Confirmation of Placement	1	LS	$ 20,000	$ 20,000		
Subtotal				*$ 870,048*		
Tax	9.5%		$ 870,048	$ 82,655		Sales Tax
Contingency	25%		$ 952,703	$ 238,175.64		
Total Enhanced Natural Recovery Cost				$ 1,190,878		
Engineered Sand Cap						
Mobilization/Demobilization	1	LS	$ 38,898	$ 38,898		
Sand Material	15,520	ton	$ 20	$ 310,400	vendor quote	
Sand Placement	15,520	ton	$ 20	$ 310,400	project experience	Sand Cap placed in multiple lifts
Geotextile Separation Layer	15,000	SF	$ 1	$ 7,500	Vendor quote	Only in nearshore area
Confirmation of Placement	1	LS	$ 20,000	$ 20,000		
Subtotal				*$ 687,198*		
Tax	9.5%		$ 687,198	$ 65,284		Sales Tax
Contingency	25%		$ 752,482	$ 188,120		
Total Engineered Sand Cap Cost				$ 940,602		
Upland Soil Solidification						
Mobilization/Demobilization	1	LS	$ 1,616,579	$ 1,616,579	percentage of construction costs	includes temporary facilities for duration of construction
Solidification - 8-ft diameter auger	285,901	BCY	$ 70	$ 20,013,065	project experience	8-ft auger used to cost-effectively treat shallower soils
Solidification - 4-ft diameter auger	76,999	BCY	$ 90	$ 6,929,917	project experience	4-ft auger used to treat deeper soils, below 8-ft auger limit
Subtotal				*$ 28,559,560*		
Tax	9.5%		$ 28,559,560	$ 2,713,158		Sales Tax
Contingency	30%		$ 31,272,719	$ 9,381,816		
Total Upland Soil Solidification Cost				$ 40,654,534		
Upland Soil Removal						
Mobilization/Demobilization	1	LS	$ 4,108,079	$ 4,108,079	percentage of construction costs	includes temporary facilities for duration of construction
Excavation	342,500	BCY	$ 6	$ 2,055,000	project experience	
Soil Handling and Stockpiling	342,500	BCY	$ 5	$ 1,712,500	project experience	segregation into hazardous/non-hazardous
Analytical Sampling	200	ea	$ 500	$ 100,000	project experience	VOCs and SVOCs
Compaction	342,500	BCY	$ 5	$ 1,712,500	project experience	
On-Site Treatment - Thermal Desorption	548,000	ton	$ 95	$ 52,060,000	vendor estimate	
Shoring	101,385	SF	$ 61	$ 6,184,485	project experience	sheet pile (see Appendix F)
Dewatering - Deep Aquifer Depressurization Wells and Pumps	60	ea	$ 40,000	$ 2,400,000	project experience	
Dewatering - Equalization Tank	40	month	$ 980	$ 39,200	project experience	Rental - 20,000 gallon tank
Dewatering - Treatment system	40	month	$ 8,066	$ 322,640	Vendor quote	rental system: DNAPL separation, air stripping, filtration, GAC vessels
Dewatering - Arsenic Treatment and Media	1	LS	$ 23,071	$ 23,071	Vendor quote	based on usage rate of 4% by weight
Dewatering - Carbon Replacement	1,202	day	$ 42	$ 50,328	Vendor quote	based on usage rate of 65 lb/day @ 50gpm - $0.46/lb
Dewatering - Carbon Disposal	55	ton	$ 400	$ 21,882	Vendor quote	
Dewatering - Coagulant	1,012	lb	$ 2	$ 2,277	Vendor quote	$2.25 per lb, 1mg/L concentration, average flow rate
Dewatering - Miscellaneous Equipment	20%		$ 3,802,913	$ 760,583	percentage of dewatering capital co	
Dewatering - Equipment Operation and Maintenance	1,202	day	$ 700	$ 841,430	labor estimate	1 full-time operator, $70/hr, 10hr/day
Dewatering - Power	40	month	$ 2,540	$ 101,600	project experience	$0.0996/KWH estimated power rate
Dewatering - Outfall Piping	50	LF	$ 10	$ 486	Costworks	8" Concrete discharge pipe
Monitoring Well Installation	20	ea	$ 4,000	$ 80,000	project experience	confirmation monitoring program
Subtotal				*$ 72,576,060*		
Tax	9.5%		$ 72,576,060	$ 6,894,726		Sales Tax
Contingency	35%		$ 79,470,785	$ 27,814,775		
Total Upland Soil Removal Cost				$ 107,285,560		
Sediment Removal						
Mobilization/Demobilization	1	LS	$ 2,106,270	$ 2,106,270		
Mechanical Dredging	149,400	BCY	$ 35	$ 5,229,000		Mechanical dredging in nearshore and for offsetting nearshore cap
Hydraulic Dredging	23,700	BCY	$ 60	$ 1,422,000	Project experience	Assumes specialty hydraulic for T-Dock/Offshore
Debris Removal and Disposal	1	LS	$ 75,000	$ 75,000		Removal of piling
Transloading/Material Handling	173,100	BCY	$ 15	$ 2,596,500		
Dewatering	173,100	BCY	$ 10	$ 1,644,450	vendor quote	Assumes 5% amendment by weight
Water Treatment	1	LS	$ 500,000	$ 500,000	Project experience	
Residuals Cover Bulk Organoclay Material - (PM-199)	837	ton	$ 3,250	$ 2,720,689	Quote from Cetco	
Residuals Cover Sand Material	8,640	ton	$ 20	$ 172,800	vendor quote	
Residuals Cover Material Placement	9,477	ton	$ 15	$ 142,157	project experience	
Backfill Material	265,440	ton	$ 20	$ 5,308,800	vendor quote	
Backfill Material Placement	265,440	ton	$ 15	$ 3,981,600	project experience	Backfill placed in bulk
Transportation and Disposal - Non-Hazardous	225,030	ton	$ 50	$ 11,251,500		Subtitle D landfill disposal
Dredging Confirmation	1	LS	$ 60,000	$ 60,000		
Subtotal				*$ 37,210,766*		
Tax	9.5%		$ 37,210,766	$ 3,535,023		Sales Tax
Contingency	25%		$ 40,745,788	$ 10,186,447		
Total Sediment Removal Cost				$ 50,932,235		

Table D-9 - Alternative 9 Cost Estimate

Quendall Terminals
Renton, Washington

Sheet Pile Enclosure						
Mobilization/Demobilization	1	LS	$ 496,044	$ 496,044	Project experience	
Steel Unit Cost	91,860	SF	$ 35	$ 3,215,100	Project experience	
Installation Unit Cost	91,860	SF	$ 45	$ 4,133,700	Project experience	
Removal Unit Cost	91,860	SF	$ 15	$ 1,377,900	Project experience	
Salvage Unit Value	4,593,000	lb	$ (0.1)	$ (459,300)	Project experience	50 pounds per sf
Subtotal				*$ 8,763,444*		
Tax	9.5%		$ 8,763,444	$ 832,527		Sales Tax
Contingency	25%		$ 9,595,971	$ 2,398,993		
Total Sheet Pile Enclosure Cost				$ 11,994,964		
Sediment Environmental Controls and Monitoring						
Water Quality Monitoring	250	day	$ 2,500	$ 625,000		
Water Quality Controls and BMPs (Absorbent Booms, Silt Curtains, Oil Bo	1	LS	$ 200,000	$ 200,000		
Odor Control	220	day	$ 2,500	$ 550,000		
Noise Monitoring	1	LS	$ 30,000	$ 30,000		
Erosion Protection for Shoreline Area	1	LS	$ 250,000	$ 250,000		
Subtotal				*$ 1,655,000*		
Tax	9.5%		$ 1,655,000	$ 157,225		Sales Tax
Contingency	25%		$ 1,812,225	$ 453,056		
Total Sediment Environmental Controls and Monitoring Cost				$ 2,265,281		
Subtotal Construction Costs				**$ 221,746,399**		
Professional Services (as percent of construction and contingency costs)						
Project management	5%		$ 221,746,399	$ 11,087,320		
Remedial design	6%		$ 221,746,399	$ 13,304,784		Includes treatability studies for remedy components as necessary
Construction management	6%		$ 221,746,399	$ 13,304,784		
Subtotal				*$ 37,696,888*		
Total Estimated Capital Cost				**$ 259,400,000**		
O&M COSTS						
1st Year O&M						
GW Monitoring	1	LS	$ 80,000	$ 80,000	Project experience	
Sediment Sand Cap and ENR Sampling	1	LS	$ 25,000	$ 25,000	Project experience	
Sediment Cap Inspection	1	LS	$ 15,000	$ 15,000	Project experience	Visual and In-Water (Bathymetric/ Sediment Profile Image)
Backfilled Area Surface Sediment Monitoring	1	LS	$ 25,000	$ 25,000		
DNR Lease	0.3	acre	$ 20,000	$ 6,000		Offshore cap area off property
Subtotal				*$ 151,000*		
Tax	9.5%		$ 151,000	$ 14,345		Sales Tax
Contingency	25%		$ 165,345	$ 41,336		
Total 1st Year O&M Cost				$ 206,681		
Annual O&M						
Groundwater Monitoring	1	LS	$ 25,000	$ 25,000	Project experience	20 wells annually
Upland Cap inspection	6	hour	$ 80	$ 480	labor estimate	
DNR Lease	0.3	acre	$ 20,000	$ 6,000		Offshore cap area off property
Subtotal				*$ 31,480*		
Tax	9.5%		$ 31,480	$ 2,991		Sales Tax
Contingency	25%		$ 34,471	$ 8,618		
Total Annual O&M Cost				$ 43,088		
Professional Services (as percent of Annual O&M costs)						
Project management/Reporting	10%		$ 43,088	$ 4,309		
Total, Annual O&M:				**$ 47,397**		
Total Estimated O&M, 100 Years, No NPV Analysis:				**$ 4,900,000**		
Periodic Costs						
Sand Cap and ENR						
Sediment Sand Cap and ENR Sampling at 2 years				$ 25,000		
Sediment Sand Cap and ENR Sampling at 5 years				$ 25,000		
Sediment Sand Cap and ENR Sampling at 10 years				$ 25,000		
Sediment Cap Inspection at 2 years				$ 15,000		
Sediment Cap Inspection at 5 years				$ 15,000		
Sediment Cap Inspection at 10 years				$ 15,000		
Sand Cap Shoreline Maintenance at 30 years				$ 25,000		
Sand Cap Shoreline Maintenance at 60 years				$ 25,000		
Sand Cap Shoreline Maintenance at 90 years				$ 25,000		
Subtotal				*$ 195,000*		
TOTAL ESTIMATED COST, NO NPV ANALSYS				**$ 264,495,000**		
Net Present Value Analysis						
Annual O&M	100	year	$ 47,397	$ 2,356,613		
1st year O&M	1	LS	$ 206,681	$ 206,681		
Sediment Sand Cap and ENR Sampling at 2 years	1	LS	$ 25,000	$ 24,219		
Sediment Sand Cap and ENR Sampling at 5 years	1	LS	$ 25,000	$ 23,093		
Sediment Sand Cap and ENR Sampling at 10 years	1	LS	$ 25,000	$ 21,331		
Sediment Cap Inspection at 2 years	1	LS	$ 15,000	$ 14,531		
Sediment Cap Inspection at 5 years	1	LS	$ 15,000	$ 13,856		
Sediment Cap Inspection at 10 years	1	LS	$ 15,000	$ 12,798		
Sand Cap Shoreline Maintenance at 30 years	1	LS	$ 25,000	$ 15,528		
Sand Cap Shoreline Maintenance at 60 years	1	LS	$ 25,000	$ 9,645		
Sand Cap Shoreline Maintenance at 90 years	1	LS	$ 25,000	$ 5,991		
2013 discount rate for NPV	1.6%					
Total Estimated O&M and Periodic NPV				**$ 2,704,286**		
TOTAL ESTIMATED COST				**$ 262,104,286**		

Notes:
1. Mobilization/Demobilization costs are assumed to include equipment transport and setup, temporary erosion and sedimentation control (TESC) measures, bonds, and insurance.
2. Contingency costs include miscellaneous costs not currently itemized due to the current (preliminary) stage of design development, as well as costs to address unanticipated conditions encountered during construction.

Table D-10 - Alternative 10 Cost Estimate

DRAFT FINAL

Quendall Terminals
Renton, Washington

Site:	Quendall Terminals			
Remedial Action Description:	Alternative	10	Containment with Removal of Contaminated Soil and Removal of Contaminated Sediment	
Cost Estimate Accuracy:	FS Screening Level (+50/-30 percent)			
Key Assumptions and Quantities:	Capping of Upland Soil			
(see Appendix E for calculations)	21.6	acre	total area	
	940,896	SF	total area	
	133,521	SF	permeable area along shoreline	
	5,023	BCY	habitat excavation overlap	
	104,544	BCY	total volume	based on 3' cap thickness
	Enhanced Natural Recovery - Sand Material			
	14,300	BCY	total volume	
	Engineered Sand Cap			
	9,700	BCY	total sand volume	
	800	BCY	removal volume for offsetting sand cap	
	15,000	SF	area for offsetting sand cap	
	0.3	acre	DNR lease area	
	Soil/Sediment Density			
	1.6	tons/BCY	soil density	
	1.3	tons/BCY	sediment density	
	0.7	tons/CY	organoclay density	
	Removal of Upland Source Area Soil			
	705,400	BCY	total volume	
	14.1	acre	total area	
	Volume of sediment removal			
	172,300	BCY	sediment removal	
	173,100	BCY	total sediment removal volume (including for offsetting cap)	
	148,600	BCY	mechanical dredging	
	23,700	BCY	hydraulic dredging	
	1,170	BCY	residual cover - organoclay	
	5,400	BCY	residual cover - sand	
	165,900	BCY	backfill	
	91,860	SF	sheet pile area	
	Dewatering to maintain wet removal for upland soil			
	281	gpm	maximum upland dewatering rate	
	221	gpm	average upland dewatering rate	
	60	each	deep aquifer depressurization wells	
	6.78	year	upland soil removal time	
	31	feet	average excavation depth	
	65	feet	min.embed. depth	
	399,505	SF	shoring wall area	
	353,331	SF	extra embedment	
	Pump-and-Treat of remaining contaminated groundwater			
	8	wells		
	90	gpm	total	

Item	Quantity	Unit	Unit Cost	Total Cost	Source	Notes
CAPITAL CONSTRUCTION COSTS						
Upland Soil Cap						
Mobilization/Demobilization	1	LS	$ 268,073	$ 268,073	percentage of construction costs	includes temporary facilities for duration of construction
Site Preparation	22	acre	$ 6,900	$ 149,040	Costworks	clearing, grubbing brush and stumps
Geotextile marker layer	104,544	SY	$ 2	$ 158,907	Costworks	non-woven, 120lb tensile strength
Import Fill - Permeable Cap	104,544	BCY	$ 30	$ 3,136,320	project experience	
Compaction	104,544	BCY	$ 5	$ 522,720	project experience	
Habitat Area - excavation	5,023	BCY	$ 6	$ 30,139		
Habitat Area - non-hazardous transport and disposal	8,037	ton	$ 50	$ 401,858		
Hydroseeding	14,836	SY	$ 1	$ 8,901	Costworks	includes seed and fertilizer for wetland area
Stormwater collection and detention system	1,500	LF	$ 40	$ 60,000	project experience	media filter drain
Subtotal				*$ 4,735,959*		
Tax	9.5%		$ 4,735,959	$ 449,916		Sales Tax
Contingency	25%		$ 5,185,875	$ 1,296,469		
Total Upland Soil Cap Cost				$ 6,482,343		
Enhanced Natural Recovery						
Mobilization/Demobilization	1	LS	$ 49,248	$ 49,248		
Sand Material	22,880	ton	$ 20	$ 457,600	vendor quote	
Sand Placement	22,880	ton	$ 15	$ 343,200	project experience	ENR placed as one lift
Confirmation of Placement	1	LS	$ 20,000	$ 20,000		
Subtotal				*$ 870,048*		
Tax	9.5%		$ 870,048	$ 82,655		Sales Tax
Contingency	25%		$ 952,703	$ 238,175.64		
Total Enhanced Natural Recovery Cost				$ 1,190,878		
Engineered Sand Cap						
Mobilization/Demobilization	1	LS	$ 38,898	$ 38,898		
Sand Material	15,520	ton	$ 20	$ 310,400	vendor quote	
Sand Placement	15,520	ton	$ 20	$ 310,400	project experience	Sand Cap placed in multiple lifts
Geotextile Separation Layer	15,000	SF	$ 1	$ 7,500	Vendor quote	Only in nearshore area
Confirmation of Placement	1	LS	$ 20,000	$ 20,000		
Subtotal				*$ 687,198*		
Tax	9.5%		$ 687,198	$ 65,284		Sales Tax
Contingency	25%		$ 752,482	$ 188,120		
Total Engineered Sand Cap Cost				$ 940,602		
Upland Soil Removal						
Mobilization/Demobilization	1	LS	$ 9,567,627	$ 9,567,627	percentage of construction costs	includes temporary facilities for duration of construction
Excavation	705,400	BCY	$ 6	$ 4,232,400	project experience	
Soil Handling and Stockpiling	705,400	BCY	$ 5	$ 3,527,000	project experience	segregation into hazardous/non-hazardous
Analytical Sampling	200	ea	$ 500	$ 100,000	project experience	VOCs and SVOCs
Compaction	705,400	BCY	$ 5	$ 3,527,000	project experience	
On-Site Treatment - Thermal Desorption	1,128,640	ton	$ 95	$ 107,220,800	vendor estimate	
Shoring	399,505	SF	$ 72	$ 28,764,360	project experience	sheet pile (see Appendix F)
Extra Embedment	353,331	SF	$ 15	$ 5,299,966	project experience	
Dewatering - Deep Aquifer Depressurization Wells and Pumps	60	ea	$ 40,000	$ 2,400,000	project experience	
Dewatering - Equalization Tank	82	month	$ 980	$ 80,360	project experience	Rental - 20,000 gallon tank
Dewatering - Treatment system	82	month	$ 8,066	$ 661,412	Vendor quote	rental system: DNAPL separation, air stripping, filtration, GAC vessels
Dewatering - Arsenic Treatment and Media	1	LS	$ 23,071	$ 23,071	Vendor quote	based on usage rate of 4% by weight
Dewatering - Carbon Replacement	2,476	day	$ 132	$ 327,144	Vendor quote	based on usage rate of 65 lb/day @ 50gpm - $0.46/lb
Dewatering - Carbon Disposal	356	ton	$ 400	$ 142,236	Vendor quote	
Dewatering - Coagulant	6,578	lb	$ 2	$ 14,800	Vendor quote	$2.25 per lb, 1mg/L concentration, average flow rate
Dewatering - Miscellaneous Equipment	20%		$ 5,590,767	$ 1,118,153	percentage of dewatering capital cos	
Dewatering - Equipment Operation and Maintenance	2,476	day	$ 700	$ 1,732,978	labor estimate	1 full-time operator, $70/hr, 10hr/day
Dewatering - Power	82	month	$ 2,540	$ 208,280	project experience	$0.0996/KWH estimated power rate
Dewatering - Outfall Piping	50	LF	$ 10	$ 486	Costworks	8" Concrete discharge pipe
Monitoring Well Installation	20	ea	$ 4,000	$ 80,000	project experience	confirmation monitoring program
Subtotal				*$ 169,028,073*		
Tax	9.5%		$ 169,028,073	$ 16,057,667		Sales Tax
Contingency	35%		$ 185,085,739	$ 64,780,009		
Total Upland Soil Removal Cost				$ 249,865,748		
Sediment Removal						
Mobilization/Demobilization	1	LS	$ 2,106,270	$ 2,106,270		
Mechanical Dredging	149,400	BCY	$ 35	$ 5,229,000		Mechanical dredging in nearshore and for offsetting nearshore cap
Hydraulic Dredging	23,700	BCY	$ 60	$ 1,422,000	Project experience	Assumes specialty hydraulic for T-Dock/Offshore
Debris Removal and Disposal	1	LS	$ 75,000	$ 75,000		Removal of piling
Transloading/Material Handling	173,100	BCY	$ 15	$ 2,596,500		
Dewatering	173,100	BCY	$ 10	$ 1,644,450	vendor quote	Assumes 5% amendment by weight
Water Treatment	1	LS	$ 500,000	$ 500,000	Project experience	
Residuals Cover Bulk Organoclay Material - (PM-199)	837	ton	$ 3,250	$ 2,720,689	Quote from Cetco	
Residuals Cover Sand Material	8,640	ton	$ 20	$ 172,800	vendor quote	
Residuals Cover Material Placement	9,477	ton	$ 15	$ 142,157	project experience	
Backfill Material	265,440	ton	$ 20	$ 5,308,800	vendor quote	
Backfill Material Placement	265,440	ton	$ 15	$ 3,981,600	project experience	Backfill placed in bulk
Transportation and Disposal - Non-Hazardous	225,030	ton	$ 50	$ 11,251,500		Subtitle D landfill disposal
Dredging Confirmation	1	LS	$ 60,000	$ 60,000		
Subtotal				*$ 37,210,766*		
Tax	9.5%		$ 37,210,766	$ 3,535,023		Sales Tax
Contingency	25%		$ 40,745,788	$ 10,186,447		
Total Sediment Removal Cost				$ 50,932,235		
Sheet Pile Enclosure						
Mobilization/Demobilization	1	LS	$ 496,044	$ 496,044	Project experience	
Steel Unit Cost	91,860	SF	$ 35	$ 3,215,100	Project experience	
Installation Unit Cost	91,860	SF	$ 45	$ 4,133,700	Project experience	
Removal Unit Cost	91,860	SF	$ 15	$ 1,377,900	Project experience	
Salvage Unit Value	4,593,000	lb	$ (0.1)	$ (459,300)	Project experience	50 pounds per sf
Subtotal				*$ 8,763,444*		
Tax	9.5%		$ 8,763,444	$ 832,527		Sales Tax
Contingency	25%		$ 9,595,971	$ 2,398,993		
Total Sheet Pile Enclosure Cost				$ 11,994,964		
Sediment Environmental Controls and Monitoring						
Water Quality Monitoring	250	day	$ 2,500	$ 625,000		
Water Quality Controls and BMPs (Absorbent Booms, Silt Curtains, Oil Boon	1	LS	$ 200,000	$ 200,000		
Odor Control	220	day	$ 2,500	$ 550,000		
Noise Monitoring	1	LS	$ 30,000	$ 30,000		
Erosion Protection for Shoreline Area	1	LS	$ 250,000	$ 250,000		
Subtotal				*$ 1,655,000*		
Tax	9.5%		$ 1,655,000	$ 157,225		Sales Tax
Contingency	25%		$ 1,812,225	$ 453,056		
Total Sediment Environmental Controls and Monitoring Cost				$ 2,265,281		

Table D-10 - Alternative 10 Cost Estimate

DRAFT FINAL

Quendall Terminals
Renton, Washington

Pump and Treat Installation						
Treatment System	1 LS	$ 154,000	$ 154,000	Vendor quote		DNAPL separation, air stripping, filtration, GAC vessels
Arsenic Treatment and Media	1 LS	$ 23,071	$ 23,071	Vendor quote		Two - 3000lb vessels
Deep Aquifer Wells and Pumps	6 each	$ 40,000	$ 240,000			
Piping/Trenching	1,400 LF	$ 8	$ 11,760	Costworks		Includes electrical conduit and water transfer piping
Treatment Enclosure	500 SF	$ 189	$ 94,500	Costworks		1-Story w/office on metal studs
Power Installation	1 LS	$ 8,500	$ 8,500	Project experience		
Miscellaneous Items and Infrastructure	50%	$ 531,831	$ 265,916			percentage of pump and treat capital costs
Instrumentation and Automated Controls	10%	$ 531,831	$ 53,183			percentage of pump and treat capital costs
Subtotal			*$ 850,930*			
Tax	9.5%	$ 850,930	$ 80,838			Sales Tax
Contingency	25%	$ 931,768	$ 232,942			
Total Pump and Treat Installation Cost			$ 1,164,710			
Subtotal Construction Costs			**$ 324,836,762**			
Professional Services (as percent of construction and contingency costs)						
Project management	5%	$ 324,836,762	$ 16,241,838			
Remedial design	6%	$ 324,836,762	$ 19,490,206			Includes treatability studies for remedy components as necessary
Construction management	6%	$ 324,836,762	$ 19,490,206			
Subtotal			*$ 55,222,250*			
Total Estimated Capital Cost			**$ 380,100,000**			
O&M COSTS						
1st Year O&M						
GW Monitoring	1 LS	$ 80,000	$ 80,000	Project experience		
Sediment Sand Cap and ENR Sampling	1 LS	$ 25,000	$ 25,000	Project experience		
Sediment Cap Inspection	1 LS	$ 15,000	$ 15,000	Project experience		Visual and In-Water (Bathymetric/ Sediment Profile Image)
Backfilled Area Surface Sediment Monitoring	1 LS	$ 25,000	$ 25,000			
DNR Lease	0.3 acre	$ 20,000	$ 6,000			Offshore cap area off property
Subtotal			*$ 151,000*			
Tax	9.5%	$ 151,000	$ 14,345			Sales Tax
Contingency	25%	$ 165,345	$ 41,336			
Total 1st Year O&M Cost			$ 206,681			
Annual O&M						
Groundwater Monitoring	1 LS	$ 25,000	$ 25,000	Project experience		20 wells annually
Upland Cap inspection	6 hour	$ 80	$ 480	labor estimate		
DNR Lease	0.3 acre	$ 20,000	$ 6,000			Offshore cap area off property
Pump and Treat Maintenace	20% capital	$ 850,930	$ 170,186			20% of capital cost
Pump and Treat GAC Replacement/Displosal	1.2 ton	$ 1,320	$ 1,566			Based on 6.5lb/day usage rate
Pump and Treat Coagulant	395 lb	$ 2	$ 889	Vendor quote		$2.25 per lb, 1mg/L concentration
Pump and Treat Power Consumption	12 month	$ 1,140	$ 13,680	Project experience		
Pump and Treat Monitoring and Reporting	2,080 hour	$ 70	$ 145,600			40 hours per week
Subtotal			*$ 363,400*			
Tax	9.5%	$ 363,400	$ 34,523			Sales Tax
Contingency	25%	$ 397,924	$ 99,481			
Total Annual O&M Cost			$ 497,404			
Professional Services (as percent of Annual O&M costs)						
Project management/Reporting	10%	$ 497,404	$ 49,740			
Total, Annual O&M:			**$ 547,145**			
Total Estimated O&M, 100 Years, No NPV Analysis:			**$ 54,900,000**			
Periodic Costs						
Sand Cap and ENR						
Sediment Sand Cap and ENR Sampling at 2 years			$ 25,000			
Sediment Sand Cap and ENR Sampling at 5 years			$ 25,000			
Sediment Sand Cap and ENR Sampling at 10 years			$ 25,000			
Sediment Cap Inspection at 2 years			$ 15,000			
Sediment Cap Inspection at 5 years			$ 15,000			
Sediment Cap Inspection at 10 years			$ 15,000			
Sand Cap Shoreline Maintenance at 30 years			$ 25,000			
Sand Cap Shoreline Maintenance at 60 years			$ 25,000			
Sand Cap Shoreline Maintenance at 90 years			$ 25,000			
Pump and treat system						
Replace P&T System at 20 yrs			$ 850,930			
Replace P&T System at 40 yrs			$ 850,930			
Replace P&T System at 60 yrs			$ 850,930			
Replace P&T System at 80 yrs			$ 850,930			
Subtotal			*$ 3,598,718*			
TOTAL ESTIMATED COST, NO NPV ANALSYS			**$ 438,598,718**			
Net Present Value Analysis						
Annual O&M	100 year	$ 547,145	$ 27,204,391			
1st year O&M	1 LS	$ 206,681	$ 206,681			
Sediment Sand Cap and ENR Sampling at 2 years	1 LS	$ 25,000	$ 24,219			
Sediment Sand Cap and ENR Sampling at 5 years	1 LS	$ 25,000	$ 23,093			
Sediment Sand Cap and ENR Sampling at 10 years	1 LS	$ 25,000	$ 21,331			
Sediment Cap Inspection at 2 years	1 LS	$ 15,000	$ 14,531			
Sediment Cap Inspection at 5 years	1 LS	$ 15,000	$ 13,856			
Sediment Cap Inspection at 10 years	1 LS	$ 15,000	$ 12,798			
Sand Cap Shoreline Maintenance at 30 years	1 LS	$ 25,000	$ 15,528			
Sand Cap Shoreline Maintenance at 60 years	1 LS	$ 25,000	$ 9,645			
Sand Cap Shoreline Maintenance at 90 years	1 LS	$ 25,000	$ 5,991			
Replace P&T System at 20 yrs	1 LS	$ 850,930	$ 619,469			
Replace P&T System at 40 yrs	1 LS	$ 850,930	$ 450,968			
Replace P&T System at 60 yrs	1 LS	$ 850,930	$ 328,300			
Replace P&T System at 80 yrs	1 LS	$ 850,930	$ 239,000			
2013 discount rate for NPV	1.6%					
Total Estimated O&M and Periodic NPV			**$ 29,189,800**			
TOTAL ESTIMATED COST			**$ 409,289,800**			

Notes:
1. Mobilization/Demobilization costs are assumed to include equipment transport and setup, temporary erosion and sedimentation control (TESC) measures, bonds, and insurance.
2. Contingency costs include miscellaneous costs not currently itemized due to the current (preliminary) stage of design development, as well as costs to address unanticipated conditions encountered during construction.

APPENDIX E

Engineering Calculation Sheets

Table of Contents: Engineering Calculation Sheets

E-1 Habitat Excavation Volumes
E-2 PRB and DNAPL Collection Trench Excavation Volumes
E-3 Alternative 4 and 6 - Excavation Volumes
E-4 Alternative 8 - Excavation Volumes
E-5 Alternative 9 - Excavation and Solidification Volumes
E-6 Alternative 10 - Excavation Volumes
E-7 DNAPL Volume Calculations
E-8 DNAPL Volume Treated for Development of Alternative 3
E-9 Removal of DNAPL by Excavation for All Alternatives
E-10 Deep Solidification Volumes for Alternatives 3, 5 and 6
E-11 QP-U DNAPL Area Solidification – Alternative 5
E-12 Shallow Solidification Volumes for Alternatives 5 and 6
E-13 Solidification Volumes for Alternative 7
E-14 Increase in Volume of Soil from Solidification for All Alternatives
E-15 Estimated Recovery from DNAPL Collection Trench
E-16 Arsenic Treatment Breakthrough Time
E-17 Permeable Treatment Wall GAC Volume and Breakthrough Time
E-18 Average Excavation Depth for Alternatives 4 and 6
E-19 Average Excavation Depths for Each Cell in Alternative 8
E-20 Dewatering Rate Estimates for Alternative 8
E-21 Dewatering Rate Estimates for Alternative 9
E-22 Cost Benefit Analysis of Shoring Cutoff Wall for Alternative 10
E-23 Alternatives 2 Sediment Capping Volumes
E-24 Alternatives 3 Sediment Capping Volumes
E-25 Alternatives 4, 5, and 6 Sediment Capping Volumes
E-26 Alternatives 7 and 8 Sediment Capping Volumes
E-27 Alternatives 9 and 10 Sediment Capping Volumes
E-28 Alternatives 2 Dredging Volumes
E-29 Alternatives 3 Dredging Volumes

E-30 Alternatives 4, 5, and 6 Dredging Volumes
E-31 Alternatives 7 and 8 Dredging Volumes
E-32 Alternatives 9 and 10 Dredging Volumes – Part 1
E-33 Alternatives 9 and 10 Dredging Volumes – Part 2
E-34 Offshore Duration Estimates of Alternatives

Engineering Calculation Sheet E-1: Habitat Excavation Volumes

			Engineer	Date
Site:	Quendall Terminals			
Calculations:	Estimate overexcavation volume to place clean cap in habitat area	Calculations By:	ELG	8/7/2013
		Checked By:	JJP	8/14/2013

Assumptions:

Existing grade within future habitat area maintained
3-foot-depth 100 feet inland along shoreline
Exclude alternative-specific DNAPL excavation areas ("Overlap Area")

Equations:

Habitat Excavation Area = Total Area - Overlap Area
Excavation Volume = Depth x Excavation Area

Alternative	Total Habitat Area in Square Feet[1]	Area of Excavation Overlap in Square Feet[2]	Area of Habitat for Excavation in Square Feet	Depth of Excavation in Feet	Volume of Non-Hazardous Soil Excavation in BCY
2,3,5,7	133,521	--	133,521	3	14,836
4,6	133,521	21,556	111,965	3	12,441
8	133,521	46,035	87,486	3	9,721
9-10	133,521	88,312	45,209	3	5,023

Notes:

[1]Area based on AutoCad calculation for 'Permeable Cap/Habitat Area' on Figure 6-1.

[2]Areas based on AutoCad calculation of excavation areas on Figures 6-6, 6-11, 6-16, 6-18, and 6-21 within 100 feet of the shoreline

Conversion factors:

1 cy = 27 CF

Engineering Calculation Sheet E-2: PRB and DNAPL Collection Trench Excavation Volumes

			Engineer	Date
Site:	Quendall Terminals			
Calculations:	Estimate the volume of hazardous and non-hazardous soil to be removed for PRB (Alternatives 3 through 6) and DNAPL collection trenches (Alternatives 3 and 4)	Calculations By:	ELG	8/7/2013
		Checked By:	JJP	8/14/2013

Assumptions:

18% of soil removed contains DNAPL[(1)]

Soil containing DNAPL would be designated as hazardous waste

Equations:

Volume = Length x Width x Depth

Hazardous Soil Volume = 18% x Excavated Soil Volume

Non-Hazardous Soil Volume = Excavated Soil Volume - Hazardous Soil Volume

Trench	Depth in Feet	Width in Feet	Total Length in Feet	Excavated Soil Volume in BCY	Hazardous Soil Volume in BCY	Non-Hazardous Soil Volume in BCY
PRB	25	2	1,100	2,037	367	1,670
DNAPL Collection	25	2	500	926	167	759
Total:				**2,963**	**533**	**2,430**

Notes:

[(1)]Based on site-wide ratio of DNAPL-containing soil volume to DNAPL-containing soil and overburden soil volume (see Table G-6 of the RI Report).

Conversion factors:

1 cy = 27 CF

Engineering Calculation Sheet E-3: Alternatives 4 and 6 - Excavation Volumes

			Engineer	Date
Site:	Quendall Terminals			
Calculations:	Estimate the volume of upland soil to be removed under Alternatives 4 and 6	Calculations By:	ELG	8/7/2013
	Estimate area and perimeter of shoring walls under Alternatives 4 and 6	Checked By:	JJP	8/14/2013
	Estimate volume of hazardous and non-hazardous soil removed			

Assumptions:

18% of excavated soil contains DNAPL and would be designated as hazardous waste [(1)]

Equations:

Excavated Soil Volume = Area x Average DNAPL Depth

Exposed Shoring Wall Area = Perimeter x Average DNAPL Depth

Volume of Solidified DNAPL (gal) = soil volume (yd^3) x 1.6 tons/yd^3 × 909 kg/ton × 0.011 $kg_{BTEX+PAHs}/kg_{soil}$ × 3.05 $kg_{hydrocarbons}/kg_{BTEX+PAHs}$ × 264 gal/m^3 ÷ 1,040 $kg_{hydrocarbons}/m^3$

Excavation Area	Area in Square Feet	Area in Acres	Perimeter Length in Feet	Maximum DNAPL Depth in Feet	Average DNAPL Depth in Feet	Exposed Area of Shoring Wall in Square Feet	Volume of Soil to be Excavated in BCY	Hazardous Soil Volume in BCY	Estimated Volume of DNAPL Removed in Gallons	Non-Hazardous Soil Volume in BCY
QP-U DNAPL Area	21,556	0.5	636	19.0	15.9	10,109	12,700	2,286	28,315	10,414

Notes:

[(1)]Based on site-wide ratio of DNAPL-containing soil volume to DNAPL-containing soil and overburden soil volume (see Table G-6 of the RI Report).

Cell area and perimeter calculated by AutoCad based on excavation extent shown on Figure 6-6 and 6-11.

Average depth calculated using depth and area of thiessen polygons (See Appendix G of the RI Report) for borings within Excavation Area - see calculation sheet E-18.

Conversion factors:

1 acre = 43,560 SF

1 cy = 27 CF

Engineering Calculation Sheet E-4: Alternative 8 - Excavation Volumes

			Engineer	Date
Site:	Quendall Terminals			
Calculations:	Estimate the volume of upland soil to be removed under Alternative 8	Calculations By:	ELG	8/7/2013
	Estimate area and perimeter of shoring walls under Alternative 8	Checked By:	JJP	8/14/2013

Equations: Excavation Volume = Area x Average DNAPL Depth
Exposed Area = Perimeter x Average DNAPL Depth

Excavation Cell	Area in Square Feet[1]	Area in Acres	Perimeter Length in Feet	Maximum DNAPL Depth in Feet	Average DNAPL Depth in Feet	Exposed Area of Shoring Wall in Square Feet	Volume of Soil to be Excavated in BCY
1	15,672	0.4	502	33.7	25.5	12,804	14,800
2	10,105	0.2	447	22.0	20.6	9,210	7,700
3	164,325	3.8	1,626	13.8	9.1	14,782	55,300
4	86,433	2.0	1,752	17.8	14.2	24,913	45,500
5	12,616	0.3	471	24.0	24.0	11,304	11,200
6	5,773	0.1	321	26.5	26.5	8,507	5,700
7	74,327	1.7	1,319	22.0	14.1	18,603	38,800
8	14,529	0.3	488	19.0	16.6	8,122	9,000
9	24,276	0.6	778	15.0	11.7	9,113	10,500
10	12,809	0.3	426	31.5	24.5	10,451	11,600
TOTAL	**420,865**	**9.7**	**8,130**			**127,809**	**210,100**

Notes:
[1]Cell areas and perimeters calculated by AutoCad based on cells shown on Figure 6-16.
[2]Average depth calculated using depth and area of thiessen polygons (see Appendix G of the RI Report) for borings within each Excavation Cell - see calculation sheet E-19.

Conversion factors:
1 acre = 43,560 SF
1 cy = 27 CF

Engineering Calculation Sheet E-5: Alternative 9 - Excavation and Solidification Volumes

Site:	Quendall Terminals		Engineer	Date
Calculation:	Estimate the volume of upland soil to be removed and solidified under Alternative 9	Calculations By:	ELG	8/7/2013
	Estimate area and perimeter of shoring walls under Alternative 9	Checked By:	JJP	8/14/2013

Assumptions:

Area to be excavated includes:

Shallow Alluvium within benzo[a]pyrene and arsenic plume to a depth of 15 feet

Area to be solidified extends to same depth of excavation in Alternative 10

705,400 BCY total volume excavated for Alternative 10 - see calculation sheet E-6

Area of 4-foot-diameter auger solidification equal to area of Alternative 10 excavation cells penetrating the Deeper Alluvium

Procedure: Estimate the volume of each excavation cell and sum result

Subtract from total volume of upland soil to be treated to get volume solidified

Volume of Upland Soil Removed

Equations: Volume = Area x Depth

Exposed Area = Perimeter x Depth

Cell Number	Area in Square Feet	Perimeter in Feet	Depth in Feet	Volume in BCY	Exposed Sheet Pile Area in SF
1	177,498	1,901	15	98,600	28,515
2	137,990	1,662	15	76,700	24,930
3	140,036	1,574	15	77,800	23,610
4	160,980	1,622	15	89,400	24,330
Total	**616,504**	**6,759**		**342,500**	**101,385**

Volume of Upland Soil Solidified

Equations: Volume of Upland Soil Solidified = Volume of Upland Soil Removed for Alternative 10 - Volume of Upland Soil Removed for Alternative 9

362,900 BCY

Volume of Upland Soil Solidified with 4-foot-diameter auger = 25 feet x Area of Cells 2 and 12 from calculation sheet E-6

76,999 BCY

Notes:

Cell areas and perimeters calculated by AutoCad based on cells shown on Figure 6-18

Conversion factors:

1 acre = 43,560 SF

1 cy = 27 CF

Engineering Calculation SheetE-6: Alternative 10 - Excavation Volumes

			Engineer	Date
Site:	Quendall Terminals			
Calculations:	Estimate the volume of upland soil to be removed under Alternative 10	Calculations By:	ELG	8/7/2013
	Estimate area and perimeter of shoring walls under Alternative 10	Checked By:	JJP	8/14/2013

Assumptions:

Area includes:

Shallow Alluvium within benzo[a]pyrene and arsenic plume

Deeper Alluvium includes benzo[a]pyrene plume

Equations: Volume = Area x Depth

Exposed Area = Perimeter x Depth

Cell Number	Area in Square Feet[(1)]	Perimeter in Feet	Depth in Feet	Depth Basis	Volume in BCY	Exposed Shoring Wall Area in Square Feet
1	38,499	775	25	(2)	35,600	19,375
2	36,768	801	40	(4)	54,500	32,040
3	40,078	801	35	(3)	52,000	28,035
4	45,320	895	35	(3)	58,700	31,325
5	47,719	874	25	(2)	44,200	21,850
6	40,456	824	35	(3)	52,400	28,840
7	30,174	701	35	(3)	39,100	24,535
8	29,388	820	25	(2)	27,200	20,500
9	53,560	943	25	(2)	49,600	23,575
10	29,539	690	35	(3)	38,300	24,150
11	32,969	745	35	(3)	42,700	26,075
12	46,391	862	40	(4)	68,700	34,480
13	46,504	910	25	(2)	43,100	22,750
14	31,043	728	25	(2)	28,700	18,200
15	25,384	665	35	(3)	32,900	23,275
16	40,740	820	25	(2)	37,700	20,500
Total	**614,532**	**12,854**			**705,400**	**399,505**
Total Area	**14**	**Acres**				
Avg. Depth	**31**	**Feet**				

Notes:

[(1)] Cell areas and perimeters calculated by AutoCad based on cells shown on Figure 6-21

[(2)] 25-foot depth assumes average depth of B[a]P contamination in areas (other than deeper DNAPL at MC-1 and BH-30) without arsenic exceedences.

[(3)] 35-foot depth assumes average depth to Shallow Alluvium in areas of elevated arsenic concentrations in groundwater.
Applied to cells, except those covered by Note 4, where the shallow arsenic plume is estimated to cover more than 50% of cell area.

[(4)] 40-foot depth assumes B[a]P contamination in Deeper Alluvium extends on average 5 feet into Deeper Alluvium in cells with BH-30 (cell 2) and MC-1 (cell 12).

Conversion factors:
1 acre = 43,560 SF
1 cy = 27 CF

Engineering Calculation Sheet E-7: DNAPL Volume Calculations

Site: Quendall Terminals

Calculations: Estimate the volume of DNAPL using depth and area of theissen polygons

	Engineer	Date
Calculations By:	ELG	8/7/2013
Checked By:	JJP	8/14/2013

Equations: Volume of DNAPL Contaminated Soil = DNAPL Thickness x Area

Volume of Excavated DNAPL (gal) = soil volume (yd^3) x 1.6 tons/yd^3 × 909 kg/ton × 0.011 $kg_{BTEX+PAHs}/kg_{soil}$ × 3.05 $kg_{hydrocarbons}/kg_{BTEX+PAHs}$ × 264 gal/m^3 ÷ 1,040 $kg_{hydrocarbons}/m^3$

(see Appendix G of the RI Report)

Boring Containing DNAPL	Site DNAPL Area	Total DNAPL Thickness in Feet	DNAPL Thickness to 20' Below Ground Surface	DNAPL Thickness to 15' Below Ground Surface	Maximum Depth of DNAPL in Feet	Area in Square Feet	Volume of DNAPL-Contaminated Soil or Sediment in Cubic Feet	Volume of Soil or Sediment to Bottom of DNAPL in Cubic Feet	Volume of DNAPL-Contaminated Soil to 15' Below Ground Surface in Cubic Feet
BH-5	Quendall Pond/North Sump Area	2	2	1	19	5,879	11,758	111,701	218
BH-20C	Quendall Pond/North Sump Area	1	0	0	26.5	5,542	5,542	146,863	-
BH-23	Quendall Pond/North Sump Area	5.5	4.5	3	24	9,113	50,121	218,710	1,013
BH-5B	Quendall Pond/North Sump Area	2.5	2.5	0.5	16	3,076	7,690	49,215	57
HC-2	Quendall Pond/North Sump Area	3.9	3.9	3.8	15.1	14,230	55,498	214,875	2,003
QP-1[3]	Quendall Pond/North Sump Area	2	2	0	18.5	4,649	9,297	85,997	-
QP-5	Quendall Pond/North Sump Area	1	1	1	12	4,210	4,210	50,520	156
RB-9	Quendall Pond/North Sump Area	5.2	5	0	20.2	6,694	34,811	135,226	-
RB-11	Quendall Pond/North Sump Area	2	2	0	18	2,810	5,620	50,579	-
RB-12	Quendall Pond/North Sump Area	0.4	0.4	0	18	4,639	1,856	83,511	-
RB-14	Quendall Pond/North Sump Area	2	1	0	21	3,800	7,601	79,809	-
RB-19	Quendall Pond/North Sump Area	1.6	1.6	1.6	12.6	7,274	11,638	91,647	431
RB-23	Quendall Pond/North Sump Area	4	4	4	12	6,539	26,156	78,469	969
SP-2[3]	Quendall Pond/North Sump Area	0.2	0	0	22	2,583	517	56,826	-
SP-3[3]	Quendall Pond/North Sump Area	2	2	1	16	5,073	10,145	81,164	188
SP-4[3]	Quendall Pond/North Sump Area	1.9	1.9	1.9	12.5	3,412	6,483	42,648	240
SP-5	Quendall Pond/North Sump Area	6	6	5	16	7,037	42,221	112,590	1,303
SP-6	Quendall Pond/North Sump Area	3.5	3.5	3.5	13	9,418	32,961	122,428	1,221
SP-7	Quendall Pond/North Sump Area	3.2	3.2	3	17.8	9,810	31,393	174,621	1,090
SP-8[3]	Quendall Pond/North Sump Area	2.2	2.2	0.8	18	1,668	3,669	30,015	49
SWB-4	Quendall Pond/North Sump Area	1.5	1.5	1.5	14	1,619	2,429	22,667	90
SWB-4A	Quendall Pond/North Sump Area	1	1	1	11	6,404	6,404	70,440	237
					Total DNAPL-Containing Soil in Cubic Yards		13,630		
					Total Soil Volume to Bottom of DNAPL in Cubic Yards			78,167	
							Total Volume of DNAPL to 15' in Gallons		114,750
							Total Volume of DNAPL in Gallons		168,831
BH-21A	Former May Creek Channel Area	5.5	5.5	1.5	19	4,773	26,252	90,687	265
BH-30C	Former May Creek Channel Area	3.25	2.75	2.75	33.75	3,558	11,564	120,087	362
HC-7	Former May Creek Channel Area	6.5	6.5	6.5	15	5,455	35,458	81,827	1,313
MC-1	Former May Creek Channel Area	8.75	6.75	4.25	31.5	3,840	33,603	120,970	604
MC-2	Former May Creek Channel Area	1.4	1.4	1.4	14.5	3,755	5,257	54,451	195
MC-7	Former May Creek Channel Area	2	2	0	18	2,389	4,778	43,000	0
MC-8	Former May Creek Channel Area	3	3	3	14	1,546	4,639	21,647	172
MC-13	Former May Creek Channel Area	0.3	0.3	0	18.3	4,291	1,287	78,523	0
MC-16[3]	Former May Creek Channel Area	0.2	0.2	0.2	13	1,428	286	18,564	11
MC-18	Former May Creek Channel Area	0.8	0.8	0.8	13	12,477	9,982	162,202	370
MC-20	Former May Creek Channel Area	2.5	2.5	2.5	12.25	9,527	23,818	116,709	882
MC-23	Former May Creek Channel Area	2.5	2.5	2.5	13	6,507	16,266	84,586	602
Q2-D	Former May Creek Channel Area (portion) [2]	11	7	2.5	30	1,236	13,596	37,080	114
Q4	Former May Creek Channel Area (portion) [2]	2.5	2.5	1	16.5	870	2,175	14,355	32
SP-1	Former May Creek Channel Area	0.6	0.6	0.6	9.8	2,699	1,619	26,450	60
					Total DNAPL-Containing Soil/Sediment in Cubic Yards		7,059		
					Total Soil Volume to Bottom of DNAPL in Cubic Yards			39,672	
							Total Volume of DNAPL to 15' in Gallons		61,726
							Total Volume of DNAPL in Gallons		87,430
BH-8	Still House Area	4	4	4	12.5	18,456	73,825	230,704	2,734
BH-9	Still House Area	2	2	2	3.5	21,173	42,345	74,104	1,568
HC-4	Still House Area	1	1	1	10	20,752	20,752	207,520	769
HC-5	Still House Area	2.5	2.5	2.5	13	5,429	13,573	70,578	503
Q1-D	Still House Area (portion) [2]	6	4	2	22	4,139	24,834	91,058	307
Q7	Still House Area (portion) [2]	0.5	0.5	0	19	3,018	1,509	57,342	-
QP-6	Still House Area	1.25	1.25	1.25	12.25	9,872	12,340	120,933	457
QP-7	Still House Area	2.25	2.25	2.25	13.75	13,112	29,502	180,290	1,093
					Total DNAPL-Containing Soil in Cubic Yards		8,099		
					Total Soil Volume to Bottom of DNAPL in Cubic Yards			38,242	
							Total Volume of DNAPL to 15' in Gallons		92,034
							Total Volume of DNAPL in Gallons		100,321
Q1-D	Railroad Loading Area (portion) [2]	6	4	2	22	1,357	8,142	29,854	101
Q2-C	Railroad Loading Area	1	1	0	18	1,868	1,868	33,626	-
Q2-D	Railroad Loading Area (portion) [2]	11	7	2.5	30	598	6,578	17,940	55
Q4	Railroad Loading Area (portion) [2]	2.5	2.5	1	16.5	1,566	3,915	25,839	58
Q7	Railroad Loading Area (portion) [2]	0.5	0.5	0	19	1,758	879	33,402	-
Q9	Railroad Loading Area	8.5	6	1.5	25	2,839	24,132	70,975	158
					Total DNAPL-Containing Soil in Cubic Yards		1,686		
					Total Soil Volume to Bottom of DNAPL in Cubic Yards			7,838	
							Total Volume of DNAPL to 15' in Gallons		4,603
							Total Volume of DNAPL in Gallons		20,880
QPN-07 [1]	Nearshore Quendall Pond Area (DA-8)	0.2	--	--	8.7	3,971	794	34,548	--
VS2[1]	Nearshore Quendall Pond Area (DA-8)	0.3	--	--	16.3	17,057	5,117	278,029	--
QPN-02 [1]	Nearshore Quendall Pond Area (DA-6)	1.7	--	--	7.4	5,035	8,560	37,259	--
VS30[1]	Nearshore Quendall Pond Area (DA-6)	5	--	--	9	7,460	37,300	67,140	--
NS15-C1 [1]	Nearshore Quendall Pond Area (DA-8)	0.1	--	--	9.3	4,235	424	39,389	--
SP-2[3]	Nearshore Quendall Pond Area (DA-8)	0.2	--	--	22	10,332	2,066	227,304	--
SP-3[3]	Nearshore Quendall Pond Area (DA-6)	2	--	--	16	1,268	2,536	20,291	--
SP-4[3]	Nearshore Quendall Pond Area (DA-6)	1.9	--	--	12.5	2,275	4,322	28,432	--
SP-8[3]	Nearshore Quendall Pond Area (DA-6)	2.2	--	--	18	1,668	3,669	30,015	--
QP-1[3]	Nearshore Quendall Pond Area (DA-8)	2	--	--	18.5	1,550	3,099	28,666	--
					Total DNAPL-Containing Sediment in Cubic Yards		2,514		
					Total Sediment Volume to Bottom of DNAPL in Cubic Yards			29,299	
							Total Volume of DNAPL in Gallons		31,143
EPA-1	T-Dock Area (DA-2)	0.5	--	--	0.5	8,048	4,024	4,024	--
EPA-8	T-Dock Area (DA-5)	1	--	--	1	2,050	2,050	2,050	--
TD-01	T-Dock Area (DA-4)	0.1	--	--	0.8	16,096	1,610	12,877	--
TD-08	T-Dock Area (DA-2)	0.1	--	--	0.4	10,123	1,012	4,049	--
VS-27	T-Dock Area (DA-3)	0.2	--	--	2.7	10,592	2,118	28,598	--
VT-1	T-Dock Area (DA-1)	1	--	--	1	11,251	11,251	11,251	--
VT-4	T-Dock Area (DA-1)	3.8	--	--	3.8	15,057	57,217	57,217	--
					Total DNAPL-Containing Sediment in Cubic Yards		2,936		
					Total Sediment Volume to Bottom of DNAPL in Cubic Yards			4,447	
							Total Volume of DNAPL in Gallons		36,371
MC-16[3]	Former May Creek Channel Area (DA-7)	0.2	--	--	13	1,428	286	18,564	--
					Total DNAPL-Containing Sediment in Cubic Yards		11		
					Total Sediment Volume to Bottom of DNAPL in Cubic Yards			688	
							Total Volume of DNAPL in Gallons		131

SOIL TOTAL IN CUBIC YARDS	**30,474**	
SEDIMENT TOTAL IN CUBIC YARDS	**5,451**	
SOIL TOTAL IN CUBIC YARDS		**163,919**
SEDIMENT TOTAL IN CUBIC YARDS		**34,433**
SOIL DNAPL TOTAL IN GALLONS		**377,462**
SOIL DNAPL TOTAL TO 15' IN GALLONS		**273,113**
SEDIMENT DNAPL TOTAL IN GALLONS		**67,646**

Notes:

-- Not calculated

Calculation sheet adapted from Table G-5 of the RI Report

See Tables G-1 through G-4 of the RI Report for DNAPL depth intervals at each boring.

See Figure G-1 of the RI Report for Thiessen polygon locations associated with each boring.

[1] Sediment boring in the offshore portion of the Quendall Pond/North Sump Area. The volumes shown in columns 6 and 7 are of sediment rather than soil.

[2] Includes area in both the Former May Creek Channel Area or the Still House Area (on Quendall property) and the Railroad Loading Area (on Railroad property), as follows:

Boring	Area of Theissen Polygon in Sq. Feet: Quendall Property	Area of Theissen Polygon in Sq. Feet: Railroad Property	Total Area in Square Feet
BH-17B	10,565	5,096	15,661
HC-8	4,074	1,749	5,823
MC-24	7,477	839	8,316
Q13	1,696	1,426	3,122
Q14	14,141	9,752	23,893
Q17	1,141	9,019	10,160
Q1-D	4,139	1,357	5,496
Q2-D	1,236	598	1,834
Q4	870	1,566	2,436
Q5	5,023	2,232	7,255
Q6	4,694	1,983	6,677
Q7	3,018	1,758	4,776

[3] Includes area in both upland soil and nearshore sediment, as follows:

Boring	Theissen Polygons split along shoreline: Estimated Percent Upland	Total Area of Theissen Polygon in sq. Feet	Portion of Theissen Polygon in Sq. Feet: Upland Soil	Portion of Theissen Polygon in Sq. Feet: Nearshore Sediment
SP-2	20%	12,915	2,583	10,332
SP-3	80%	6,341	5,073	1,268
SP-4	60%	5,686	3,412	2,275
SP-8	50%	3,335	1,668	1,668
QP-1	75%	6,198	4,649	1,550
MC-16	50%	2,856	1,428	1,428

Engineering Calculation Sheet E-8: DNAPL Volume Treated for Development of Alternatve 3

Site: Quendall Terminals		Engineer	Date
Calculations:	Calculations By:	SDM	8/20/2013
	Checked By:	DAH	10/9/2013

Estimate the DNAPL Volume Treated Under Scenarios 1, 2, 3, and 4 to develop Alternative 3

Assumptions:

Equations:

Volume of DNAPL Contaminated Soil = DNAPL Thickness x Area

Volume of Treated DNAPL (gal) = soil volume (ft^3) ÷ 27 ft^3/yd^3 x 1.6 tons/yd^3 × 909 kg/ton × 0.011 $kg_{BTEX+PAHs}/kg_{soil}$ × 3.05 $kg_{hydrocarbons}/kg_{BTEX+PAHs}$ × 264 gal/m^3 ÷ 1,040 $kg_{hydrocarbons}/m^3$

Cell	Boring	Total DNAPL Thickness in Feet	Thissen Polygon Area in Square Feet	Total Volume of DNAPL Contaminated Soil Treated in Cu ft.
	Q9	8.5	2,839	
	Q2-C	1.0	1,868	
	Q4	2.5	2,436	
	Q2-D	11.0	1,834	
	BH-30C	3.3	3,558	
1	Total Soil Volume Treated in Cu ft.:			63,828
	HC-5	2.5	5,429	
	MC-20	2.5	9,527	
	MC-23	2.5	6,507	
2	Total Soil in Cu ft.:			53,657
	BH-9	2.0	21,173	
	HC-4	1.0	20,752	
	MC-18	0.8	12,477	
3	Total Soil in Cu ft.:			73,079
	MC-1	8.8	3,840	
4	Total Soil in Cu ft.:			33,603
	SP-7	3.2	9,810	
	BH-23	5.5	9,113	
	SP-6	3.5	9,418	
	SP-5	6.0	7,037	
	RB-19	1.6	7,274	
5	Total Soil in Cu ft.:			168,334
	BH-5B	2.5	3,076	
	BH-5	2.0	5,879	
	RB-12	0.4	4,639	
	SP-3	2.0	5,073	
	SP-4	1.9	3,412	
	QP-5	1.0	4,210	
	SP-8	2.2	1,668	
	BH-20C	1.0	5,542	
6	Total Soil in Cu ft.:			51,352

Scenario	Cell	Soil Volume in Cu. Ft.	DNAPL Volume Treated in Gallons
	1	63,828	
1	Total DNAPL Volume in Gallons:		29,281
	1	63,828	
	2	53,657	
2	Total DNAPL Volume in Gallons:		53,897
	1	63,828	
	2	53,657	
	3	73,079	
3	Total DNAPL Volume in Gallons:		87,422
	1	63,828	
	4	33,603	
	5	168,334	
	6	51,352	
4	Total DNAPL Volume in Gallons:		145,480

Notes:

Total DNAPL thickness and area of Thiessen polygons from Table G-5 of the RI Report

Engineering Calculation Sheet E-9: Removal of DNAPL by Excavation for All Alternatives

			Engineer	Date
Site:	Quendall Terminals			
Calculations:	Estimate the volume of DNAPL to be removed under all alternatives by excavation	Calculations By:	ELG	8/7/2013
		Checked By:	JJP	8/14/2013

Assumptions:

18% of soil removed for PRB, DNAPL Collection Trench, and QP-U DNAPL Upland excavations contain DNAPL

Equations: Volume of Excavated DNAPL (gal) = soil volume (yd^3) x 1.6 tons/yd^3 × 909 kg/ton × 0.011 $kg_{BTEX+PAHs}/kg_{soil}$ × 3.05 $kg_{hydrocarbons}/kg_{BTEX+PAHs}$ × 264 gal/m^3 ÷ 1,040 $kg_{hydrocarbons}/m^3$

(see Appendix G of the RI Report)

Volume of DNAPL-containing soil excavated from PRB - see calculation sheet E-2

367 BCY

Volume of DNAPL-containing soil excavated from DNAPL collection trenches - see calculation sheet E-2

167 BCY

Volume of DNAPL excavated in Alternatives 4 and 6 - see calculation sheet E-3

28,315 Gallons

Volume of all DNAPL in upland soil- see calculation sheet E-7

377,462 Gallons

Volume of DNAPL to 15-feet below ground surface in upland soil - see calculation sheet E-7

273,113 Gallons

Volume of DNAPL in T-dock and Nearshore Quendall Pond areas (DA-1, DA-2, and DA-6) - see calculation sheet E-7

60,560 Gallons

Volume of all DNAPL-containing Nearshore/Offshore sediment - see calculation sheet E-7

67,646 Gallons

Alternative	Volume of Excavated Upland DNAPL in Gallons	Volume of Excavated DNAPL from Trenchwork in Gallons	Volume of Excavated Sediment DNAPL in Gallons	Total DNAPL Removed in Gallons
3	--	6,606	--	6,606
4	28,315 (1)	6,606	60,560 (4)	95,481
5	--	4,542	60,560 (4)	65,102
6	28,315 (1)	4,542	60,560 (4)	93,417
7	--	--	67,646 (5)	67,646
8	377,462 (2)	--	67,646 (5)	445,107
9	273,113 (3)	--	67,646 (5)	340,759
10	377,462 (2)	--	67,646 (5)	445,107

Notes:

(1) QP-U DNAPL area only

(2) All upland DNAPL

(3) All upland DNAPL to 15-feet below ground surface

(4) Nearshore Quendall Pond area sediment and T-dock sediment DNAPL

(5) Includes all nearshore and offshore DNAPL

Conversion factors:

1 cy = 27 CF

Engineering Calculation Sheet E-10: Deep Solidification Volumes for Alternatives 3, 5, and 6

			Engineer	Date
Site:	Quendall Terminals			
Calculations:	Estimate the volume in areas of deep DNAPL solidification (RR DNAPL Area & MC-1) for Alternatives 3, 5, and 6	Calculations By:	ELG	8/7/2013
	Estimate the volume of soil to be solidified with 4-ft auger in areas of deep DNAPL solidification	Checked By:	JJP	8/14/2013
	Estimate the volume of soil to be solidified with 8-ft auger in areas of deep DNAPL solidification			

Assumptions:

Solidification of Deeper Alluvium DNAPL requires a 4-foot-diameter auger.
Area of solidification equivalent to area of Thiessen polygons around borings MC-1, BH-30C, Q2-D, Q2-C, Q4, and Q9 (see Table G-5 of the RI Report).

Equations: Volume = Area x Depth

Volume of Solidified DNAPL (gal) = soil volume (yd^3) x 1.6 tons/yd^3 × 909 kg/ton × 0.011 $kg_{BTEX+PAHs}/kg_{soil}$ × 3.05 $kg_{hydrocarbons}/kg_{BTEX+PAHs}$ × 264 gal/m^3 ÷ 1,040 $kg_{hydrocarbons}/m^3$
(see Calculation Sheet E-7)

4-ft Diameter Auger

Boring	Area in Square Feet	Maximum Depth in Feet[1]	Volume of Solidified Soil in BCY	Volume of DNAPL-Containing Soil in BCY[2]	Volume of DNAPL Solidified in Gallons
BH-30C	3,558	36	4,711	428	5,305
MC-1	3,840	34	4,765	1,245	15,416
Total:			**9,476**	**1,673**	**20,721**

8-ft Diameter Auger

Boring	Area in Square Feet	Maximum Depth in Feet[1]	Volume of Solidified Soil in BCY	Volume of DNAPL-Containing Soil in BCY[2]	Volume of DNAPL Solidified in Gallons
Q2-D	1,834	32	2,174	747	9,255
Q2-C	1,868	20	1,384	69	857
Q4	2,436	19	1,669	226	2,794
Q9	2,839	27	2,839	894	11,071
Total:			**8,066**	**1,936**	**23,976**

Notes:
8-ft-diameter auger used to solidify shallow soils
4-ft-diameter auger used to solidify deep soils
[1]Maximum depth is maximum depth of DNAPL (see Sheet E-7) in boring plus 2 feet
[2]Volume of DNAPL-containing soil from Sheet E-7

Conversion factors:
1 cy = 27 CF

Engineering Calculation Sheet E-11: QP-U DNAPL Area Solidification - Alternative 5

			Engineer	Date
Site:	Quendall Terminals			
Calculations:	Estimate the volume of solidification in the QP-U DNAPL area for Alternative 5	Calculations By:	ELG	8/7/2013
	Estimate the volume of soil to be solidified with 8-ft auger	Checked By:	JJP	8/14/2013
	Estimate the volume of DNAPL solidified			

Assumptions:

18% of solidified soil contains DNAPL[(1)]

Equations: Volume = Area x Depth

8-ft Diameter Auger

Area	Area in Square Feet	Average Solidification Depth in Feet[(2)]	Maximum Solidification Depth in Feet[(3)]	Volume of Solidified Soil in BCY	Volume of DNAPL-Containing Soil in BCY[(4)]	Volume of DNAPL Solidified in Gallons[(4)]
QP-U DNAPL Area	21,556	18	21	14,287	2,284	28,294

Notes:

8-ft-diameter auger used to solidify shallow soils

[(1)]Based on site-wide ratio of DNAPL-containing soil volume to DNAPL-containing soil and overburden soil volume (see Table G-6 of the RI Report).

[(2)]Average depth is average depth of DNAPL in borings (see Sheet E-3) plus 2 feet

[(3)]Maximum depth is maximum depth of DNAPL in borings (see Sheet E-3) plus 2 feet

[(4)]Based on hazardous soil volume - see Calculation Sheet E-3

Conversion factors:

1 cy = 27 CF

Engineering Calculation Sheet E-12: Shallow Solidification Volumes for Alternatives 5 and 6

			Engineer	Date
Site:	Quendall Terminals			
Calculations:	Estimate the volume of soil to be solidified in the shallow DNAPL solidification areas for Alternatives 5 and 6	Calculations By:	ELG	8/7/2013
	Estimate the volume of DNAPL in that soil	Checked By:	JJP	8/14/2013
Assumptions:	Area of solidification equivalent to area of Thiessen polygons around the borings listed below (see Table E-7).			
Equations:	Volume = Area x Depth			
	Volume of DNAPL Containing Soil = Area x DNAPL Thickness			
	Volume of Solidified DNAPL (gal) = soil volume (yd^3) x 1.6 tons/yd^3 × 909 kg/ton × 0.011 $kg_{BTEX+PAHs}/kg_{soil}$ × 3.05 $kg_{hydrocarbons}/kg_{BTEX+PAHs}$ × 264 gal/m^3 ÷ 1,040 $kg_{hydrocarbons}/m^3$			
	(see Sheet E-7)			

				Alternative 5 - Thickness > 4 Feet			Alternative 6 - Thickness > 2 Feet		
Boring	Area in Square Feet	Solidification Depth in Feet	DNAPL-Containing Soil Thickness in Feet[1]	Volume of Solidified Soil in BCY[2]	Volume of DNAPL-Containing Soil in BCY	Volume of DNAPL Solidified in Gallons	Volume of Solidified Soil in BCY	Volume of DNAPL-Containing Soil in BCY	Volume of DNAPL Solidified in Gallons
30% of BH-5	1764	20	2.0				1,306	131	1,618
90% of BH-5B	2768	20	2.5				2,051	256	3,175
BH-8	18,456	20	4.0	13,671	2,734	33,868	13,671	2,734	33,868
BH-9	21,173	20	2.0				15,683	1,568	19,426
BH-21A	4,773	20	5.5	3,536	972	12,043	3,536	972	12,043
BH-23	9,113	20	4.5	6,750	1,519	18,813	6,750	1,519	18,813
HC-2	14,230	20	3.9				10,541	2,055	25,460
HC-5	5,429	20	2.5				4,022	503	6,227
HC-7	5,455	20	6.5	4,041	1,313	16,267	4,041	1,313	16,267
MC-7	2,389	20	2.0				1,770	177	2,192
MC-8	1,546	20	3.0				1,145	172	2,128
MC-20	9,527	20	2.5				7,057	882	10,927
MC-23	6,507	20	2.5				4,820	602	7,462
Q1-D	5,496	20	4.0	4,071	814	10,085	4,071	814	10,085
75% of QP-1	4,649	20	2.0				3,443	344	4,265
QP-7	13,112	20	2.3				9,713	1,093	13,534
RB-9	6,694	20	5.0	4,959	1,240	15,355	4,959	1,240	15,355
RB-11	2,810	20	2.0				2,081	208	2,578
RB-23	6,539	20	4.0	4,844	969	11,999	4,844	969	11,999
SP-5	7,037	20	6.0	5,212	1,564	19,369	5,212	1,564	19,369
SP-6	9,418	20	3.5				6,976	1,221	15,121
SP-7	9,810	20	3.2				7,267	1,163	14,402
Total:				**47,084**	**11,125**	**137,800**	**124,959**	**21,501**	**266,315**

Notes:

[1]Thickness of DNAPL containing soil above 20 feet - see calculation sheet E-7

[2]Alternative 5 also includes solidification of QP-U DNAPL Area - see calculation sheet E-11.

Conversion factors:

1 cy = 27 CF

Engineering Calculation Sheet E-13: Solidification Volumes for Alternative 7

			Engineer	Date
Site:	Quendall Terminals			
Calculations:	Estimate the volume of upland soil to be solidified with 4-ft auger for Alternative 7	Calculations By:	ELG	8/7/2013
	Estimate the volume of upland soil to be solidified with 8-ft auger for Alternative 7	Checked By:	JJP	8/14/2013

Assumptions:

8-ft-diameter auger used to solidify areas where solidification is limited to the Shallow Alluvium.
4-ft-diameter auger used to solidify areas including Deeper Alluvium soils.
Deep DNAPL area includes only BH-30 and MC-1.
Total volume of solidified soil equal to volume of soil removed under Alternative 8 (see calculation sheet E-4) plus 2 feet below over area of solidification.
Volume of DNAPL solidified equal to that removed by Alternative 8.
4-ft-diameter auger area based on Thiessen polygon area around each boring.

Equations: Volume = Area x Depth

Volume of Soil Excavated under Alternative 8 - see calculation sheet E-4
210,100 BCY
Area of Solidification[(1)]
420,865 Square Feet
Thickness of solidification below maximum DNAPL extent
2 Feet
Extra Volume of solidified soil
31,175 BCY
Total volume of solidified soil
241,275 BCY

4-ft Diameter Auger

Boring	Area in Square Feet	Maximum Depth in Feet[(2)]	Volume of Solidified Soil in BCY
BH-30C	3,558	36	4,711
MC-1	3,840	34	4,765
Total:	**7,398**		**9,476**

Total volume to be solidified with 8-foot diameter auger
231,799 BCY

Notes:
Polygon areas for borings BH-30C and MC-1 from RI Table G-5
[(1)]Area of solidification calculated by AutoCad based on Figure 6-13.
[(2)]Solidification depth is maximum depth of DNAPL in boring plus 2 feet

Conversion factors:
1 acre = 43,560 SF
1 cy = 27 CF

Engineering Calculation Sheet E-14: Increase in Volume of Soil from Solidification for All Alternatives

			Engineer	Date
Site:	Quendall Terminals			
Calculation:	Estimate the volume increase of upland soil during solidification	Calculations By:	ELG	8/7/2013
		Checked By:	JJP	8/14/2013

Assumptions:

20% Increase in soil volume during solidification procedure

Equations: Increase in Volume = Bank Volume x Percentage Increase

Alternative	Volume of Soil to be Solidified in BCY[(1)]	Volume of Solidified Soil in BCY	Increase in Soil Volume in BCY
3	17,542	21,050	3,508
5	78,913	94,695	15,783
6	142,501	171,001	28,500
7	241,275	289,530	48,255
9	362,900	435,480	72,580

Notes:

[(1)]See calculation sheets E-5, E-10, E-11, E-12 and E-13

Engineering Calculation Sheet E-15: Estimated Recovery from DNAPL Collection Trench

			Engineer	Date
Site:	Quendall Terminals			
Calculations:	Estimate the volume of DNAPL collected in DNAPL collection trenches	Calculations By:	JJP	5/2/2012
		Checked By:	DAH	6/19/2012

Assumptions:

Initial recovery rate and long-term recovery rate based on pumping test pilot study utilizing 3 wells (see RI Report Figure 4.3-1)

Equations:

Yearly Reduction = (Year 1 Removal Rate - Year 2 Removal Rate) / Year 1 Removal Rate

DNAPL Removal Rate, Full Scale = DNAPL Removal Rate, Pilot Test x $\left(\frac{Full\ Scale\ Effective\ Length\ of\ Trench}{Pilot\ Test\ Effective\ Length\ of\ Influence}\right)$

Pilot Test Removal Rate - Year 1	76	gal/yr
Pilot Test Removal Rate - Year 2	53	gal/yr
Yearly Reduction in Removal Rate	30%	
Pilot Test - Assumed Radius of Influence	10	ft
Pilot Test - Effective LF of Influence	188	lf
Full Scale - Effective LF of Trench	1000	lf

Year	DNAPL Removal Rate in Gallons per Year	Total DNAPL Removed in Gallons
1	403	403
2	282	686
3	198	883
4	138	1022
5	97	1119
6	68	1186
7	47	1234
8	33	1267
9	23	1290
10	16	1307
11	11	1318
12	8	1326
13	6	1332
14	4	1336
15	3	1338
16	2	1340

Notes:
Effective LF of influence is the circumference of the well area of influence at 10-foot radius for 3 wells.
Effective LF of trench assumes both sides of 500-foot-long trench.
LF = liner feet

Engineering Calculation Sheet E-16: Arsenic Treatment Breakthrough Time

			Engineer	Date
Site:	Quendall Terminals			
Calculations:	Estimate capacity of arsenic treatment media	Calculations By:	ELG	8/7/2013
	Estimate breakthrough time and lifetime of treatment vessels	Checked By:	JJP	8/14/2013

Equations:

Time to breakthrough = Capacity / Concentration / Pumping Rate

Amount of Arsenic Removed = Dewatering Period x Pumping Rate x Arsenic Concentration

	Parameter	Value		Notes
Arsenic Media				
	Media type	Ferric Adsorptive Media		
	Number of vessels	2	ea	
	Size of vessels	3000	lb	
	Media capacity	4%	by weight	Provided by vendor
	Media capacity	240	lbs arsenic	
	Maximum dewatering period	1,752	days	Alternative 10 - See Section 6.3.10.1.4
	Average Groundwater pumping rate	210	gpm	Alternative 10
	Arsenic concentration	39	ug/L	Average Plume Concentration - See Table A-2
	Time to Breakthrough	2,439	days	
	Amount of arsenic removed	172	lbs	

Notes:

Conversion Factors:

1 Gallon = 3.785 Liters

1 lb = 453,592,000 ug

1 day = 1440 min

Engineering Calculation Sheet E-17: Permeable Treatment Wall GAC Volume and Breakthrough Time

			Engineer	Date
Site:	Quendall Terminals			
Calculations:	Estimate volume of granular activated carbon (GAC) for treatment wall	Calculations By:	ELG	8/7/2013
	Estimate breakthrough time and lifetime of treatment wall	Checked By:	JJP	8/14/2013

Assumptions:

- Treatment wall consists of two 100-foot gate sections
- Groundwater velocity based on model (see Appendix A)
- Carbon usage rate of 1.9 lb/1000gal based on vendor modeling
- GAC density is 37.5 lb/ft^3
- Effective lifetime is assumed to be approximately 50% of breakthrough time

Equations:

Carbon Usage Rate (ft^3_{GAC}/ft^3_{Water}) = Carbon Usage Rate (lb/1000gal) / GAC Density (lb/ft^3_{GAC}) x 7.48 (gal/ft^3_{Water})

Time to Breakthrough (years) = Carbon Usage Rate (ft^3/ft^3) / Site Groundwater Flowrate ($ft^3/ft^2/day$) / Volume per unit area (ft^3/ft^2) / 365 (days/year)

Volume = Depth x Width x Length

Mass = Density x Volume

Parameter	Value		Notes/Assumptions
Treatment Wall			
Minimum Width	2	ft	
Length	200	ft	
Average Treatment Media Height	22	ft	
Carbon Compositions Calculations			
Carbon Usage Rate	0.00038	ft3 GAC/ft3 water	based on maximum groundwater concentrations
Treatment Gate Average Groundwater Velocity	0.90	ft/day	See Appendix A
Porosity	0.30		
Treatment Gate Average Groundwater Flowrate	0.27	ft3/ft2/day	
Wall Width	2	ft	
GAC Composition	100	percent	
Volume of GAC in Wall	2.0	ft3/ft2	
Time to Breakthrough	53.5	years	
Target Lifetime	22	years	
Earthwork Calculations			
Average Width	2.0	ft	
Average Depth	25	ft	
Volume of Soil Excavated	370	cy	
Volume GAC	326	cy	
Volume Structural Fill	44	cy	
Mass of Soil Excavated	630	tons	Assumed density of 1.7 tons per cubic yard
Mass GAC	163	tons	Assumed density of 0.5 tons per cubic yard
Mass Structural Fill	71	tons	Assumed density of 1.6 tons per cubic yard

Conversions:

1 cubic foot = 7.48 gallons

1 year = 365 days

Engineering Calculation Sheet E-18: Average Excavation Depth for Alternatives 4 and 6

			Engineer	Date
Site:	Quendall Terminals			
Calculations:		Calculations By:	ELG	8/7/2013
	Estimate the average excavation depth for Alternatives 4 and 6	Checked By:	JJP	8/14/2013

Assumptions:

Equations:

Average = ∑ [(Polygon Area/Total Area) x Maximum DNAPL Depth]

Cell	Boring	Maximum DNAPL Depth in Feet[(1)]	Thiessen Polygon Area in Feet[(1)]	Average Depth in Feet
QP-U DNAPL Area	SP-3	16.0	6,341	
	SP-4	12.5	5,686	
	SP-8	18.0	3,335	
	QP-5	12.0	4,210	
	RB-12	18.0	4,639	
	BH-5	19.0	5,879	
		Total Area:	30,090	
			Average Depth in Feet:	15.9

Notes:

[(1)]Polygon areas and maximum DNAPL depth from RI Table G-5.

Engineering Calculation Sheet E-19: Average Excavation Depths for Each Cell in Alternative 8

			Engineer	Date
Site:	Quendall Terminals			
Calculations:		Calculations By:	ELG	8/7/2013
	Estimate the average depth of each excavation cell for Alternative 8	Checked By:	JJP	8/14/2013

Assumptions:

Equations:

Average Depth = ∑ [(Polygon Area/Total Area) x Maximum DNAPL Depth]

Cell	Boring	Maximum DNAPL Depth in Feet	Thissen Polygon Area in Square Feet	Average Excavation Depth in Feet
	BH-30C	33.7	3,558	
	Q2-D	30.0	1,835	
	Q4	16.5	2,437	
	Q2-C	18.0	1,868	
	Q9	25.0	2,839	
		Total Area:	12,537	
1		Average Depth in Feet:		25.5
	Q7	19.0	4,776	
	Q1-D	22.0	5,496	
		Total Area:	10,272	
2		Average Depth in Feet:		20.6
	BH-8	12.5	18,456	
	QP-7	13.8	13,112	
	QP-6	12.3	9,872	
	MC-18	13.0	12,477	
	HC-4	10.0	20,752	
	BH-9	3.5	21,173	
	HC-5	13.0	5,429	
	MC-20	12.3	9,527	
	MC-23	12.8	6,507	
	HC-8	0.0	5,823	
	Q5	0.0	7,255	
	Q6	0.0	6,677	
		Total Area:	137,060	
3		Average Depth in Feet:		9.1
	SP-6	13.0	9,418	
	SP-7	17.8	9,810	
	HC-2	15.0	14,230	
	RB-19	12.6	7,274	
	SP-5	16.0	7,037	
	RB-23	12.0	6,539	
	SWB-4A	11.0	6,404	
	SWB-4	14.0	1,619	
		Total Area:	62,331	
4		Average Depth in Feet:		14.2
	BH-23	24.0	9,113	
		Total Area:	9,113	
5		Average Depth in Feet:		24.0
	BH-20C	26.5	5,542	
		Total Area:	5,542	
6		Average Depth in Feet:		26.5
	SP-8	18.0	3,335	
	QP-5	12.0	4,210	
	BH-5	19.0	5,879	
	BH-5B	16.0	3,076	
	RB-9	20.2	6,694	
	SP-4	12.5	5,686	
	SP-3	16.0	6,341	
	RB-12	18.0	4,639	
	SP-2	22.0	12,915	
	QP-1	18.5	6,198	
	RB-11	18.0	2,810	
	RB-14	21.0	3,800	
	BH-19B	0.0	4,137	
	RB-10	0.0	7,141	
	RB-13	0.0	7,646	
		Total Area:	84,507	
7		Average Depth in Feet:		14.1
	MC-16	13.0	2,856	
	MC-8	14.0	1,546	
	MC-7	18.0	2,389	
	BH-21A	19.0	4,773	
		Total Area:	11,564	
8		Average Depth in Feet:		16.6
	HC-7	15.0	5,455	
	MC-14	0.0	1,983	
	SP-1	9.8	2,699	
	MC-2	14.5	3,755	
		Total Area:	13,892	
9		Average Depth in Feet:		11.7
	MC-1	31.5	3,840	
	MC-13	18.3	4,291	
		Total Area:	8,131	
10		Average Depth in Feet:		24.5

Notes:
Maximum depth and area of Thiessen polygons from Table G-5 of the RI Report

Engineering Calculation Sheet E-20: Dewatering Rate Estimates for Alternative 8

			Engineer	Date
Site:	Quendall Terminals			
Calculations:	Estimate dewatering rate and total amount dewatered for Alternative 8	Calculations By:	ELG	8/7/2013
	Estimate excavation duration	Checked By:	JJP	8/14/2013

Assumptions:

Estimated Deep Aquifer dewatering rates based on modeling for wet excavations - see Appendix A

Assumes dewatering volumes due to internal storage and precipitation are incidental.

Cell	Area in Square Feet	Area in Acres[1]	Maximum Excavation Depth in Feet[2]	Average Exposed Depth in Feet	Estimated Dewatering Rate in GPM	Excavation Duration in Days[3]	Total Groundwater Flow in MG
1	15,672	0.4	33.7	25.5	91	37	5
2	10,105	0.2	22.0	20.6	0	20	0
3	164,325	3.8	13.8	9.1	0	139	0
4	86,433	2.0	17.8	14.2	137	114	22
5	12,616	0.3	24.0	24.0	0	28	0
6	5,773	0.1	26.5	26.5	68	15	1
7	74,327	1.7	22.0	14.1	207	97	29
8	14,529	0.3	19.0	16.6	47	23	2
9	24,276	0.6	15.0	11.7	0	27	0
10	12,809	0.3	31.5	24.5	119	29	5
Totals	**420,865**	**9.7**				**529**	**64**

Notes:

[1]Maximum Excavation Depth based on maximum depth of DNAPL observed within cell area - see calculation sheet E-19

[2]Average Exposed Depth based on average excavation depth of each cell - see calculation sheet E-19

[3]Excavation duration based on 400 cy/day removal/fill rate

Conversion factors:

1 acre = 43,560 SF

Engineering Calculation Sheet E-21: Dewatering Rate Estimates for Alternative 9

Site:	Quendall Terminals			Engineer	Date
Calculation:	Estimate dewatering quantities for Alternative 9		Calculations By:	ELG	8/16/2013
			Checked By:	DAH	10/9/2013

Assumptions:

Dewatering of leakage into excavation cell only: no depressurization of Deep Aquifer

3	feet	yearly precipitation rate	
0.25	feet/day	maximum daily precipitation rate	
4.0	year	Duration of dewatering	Assumes 400 cy/day removal soil rate and 600 cy/day solidification rate
0.3		porosity	
5	feet	depth to water	
15	feet	average depth of excavation	see calculation sheet E-5
56	gpm	leakage rate into excavation cell	
14	acre	total area of excavation	see calculation sheet E-5

Dewatering Flow Rate due to Storage

Storage Volume = Volume of Saturated Soil Removed x Porosity

Volume of Saturated Soil Removed = (Average Depth of Excavation - Average Depth to Water) x Area of Excavation

13,834,350 gallons

Average Storage Flow Rate = Storage Volume x Duration

7 gpm

Dewatering Flow Rate due to Precipitation

Maximum Flow Rate = Maximum Precipitation Rate x Cell Area

Average Flow Rate = Annual Preciptation Rate x Cell Area

Storage Flow Rate = Storage Volume x Duration

	Flow Rate in gpm	
Cell Area in acres	Maximum	Average
4	226	7.4

Total Flow Rate = Storage Flowrate + Precipitation Flowrate + Leakage Flowrate

289	gpm	Maximum Flowrate
70	gpm	Average Flowrate

Conversion factors:

1 acre = 43,560 SF

1 CF = 7.48 gal

1 yr = 525,600 min

Engineering Calculation Sheet E-22: Cost Benefit Analysis of Shoring Cutoff Wall for Alternative 10

Site: Quendall Terminals — Engineer — Date

Calculation: Cost benefit analysis to estimate the optimum depth and area of shoring cutoff wall — Calculations By: ELG 8/16/2013 — Checked By: DAH 10/9/2013

NOTE: quantities in this cost-benefit calculation are approximate based on nominal cell areas and depths, and have not been adjusted for specific cells proposed in the alternative

Assumptions:

Shoring walls constructed of temporary sheetpiling with tiebacks

Dimensions:

31 feet	Average depth of excavation	see volume calculation sheet E-6
40 feet	Maximum depth of excavation	see volume calculation sheet E-6
65 feet	Minimum embedment depth	60% embedment - see preliminary shoring design criteria
14 acres	Total area of excavation	

Assume square layout

Unit Costs:

$70 sf	Cost per exposed face of shoring	See Appendix F
$15 sf	Cost for extra embedment	See Appendix F
$83 Mgal /yr	Capital cost of P&T system	systems >20M gal/yr (EPA 2001) - 75% percentile used because both VOCs and SVOCs will require treatment. Adjusted for 10 yrs of inflation at 3%
$9 M gal	O&M cost of P&T system	systems >20M gal/yr (EPA 2001) - 75% percentile used because both VOCs and SVOCs will require treatment. Adjusted for 10 yrs of inflation at 3%
M gal = 1,000 gallons		

Parameters affecting dewatering treatment rate:

3 feet	yearly precipitation rate	
0.25 feet/day	maximum daily precipitation rate	
4.8 year	Duration of dewatering	Assumes 400 cy/day removal soil rate
0.3	porosity	
5 feet	depth to water	

Estimated steady-state dewatering flowrates in gpm (see Appendix A):

	Maximum Flowrate (at shoreline)			Minimum Flowrate (at railroad)			Average Flowrate (Average of Max and Min)		
	Embedment Depth			Embedment Depth			Embedment Depth		
Cell area in acres	55 Feet	75 Feet	95 Feet	55 Feet	75 Feet	95 Feet	55	75	95
2	940	570	400	740	510	360	840	540	380
1	680	350	210	570	310	200	625	330	205
0.5	400	190	*150*	330	160	100	365	175	125
0.25	210	94	*74*	180	79	52	195	87	63

italics indicates value extrapolated from other runs

Procedure:

Estimate the shoring cost for different excavation cell areas and cutoff wall depths

Estimate the P&T cost for different excavation cell areas and cutoff wall depths

Determine dimensions that result in minimum total cost (shoring + P&T)

Shoring Cost

Equations: Cell Perimeter = 4 x Square Root (Area) Assumes square layout

Cell Shoring Area = Cell Perimeter x Average Depth

				65 foot embedment		75 foot embedment			95 foot embedment		
Cell area in acres	Cell side length in feet	Cell perimeter in feet	Number of cells	Exposed area of shoring wall in square feet	Shoring Cost	Extra embedment depth in feet	Extra embedded area in square feet	Extra shoring cost	Extra embedment depth in feet	Extra embedded area in square feet	Extra shoring cost
2	295	1,181	7	258,107	$ 18,067,511	10	83,281	$ 1,249,214	30	249,843	$ 3,747,642
1	209	835	14	365,019	$ 25,551,318	10	117,777	$ 1,766,655	30	353,331	$ 5,299,966
0.5	148	590	28	516,215	$ 36,135,021	10	166,562	$ 2,498,428	30	499,686	$ 7,495,284
0.25	104	417	56	730,038	$ 51,102,637	10	235,554	$ 3,533,311	30	706,662	$ 10,599,932

Total Shoring Cost

	Embedment Depth		
Cell area in acres	55 Feet	75 Feet	95 Feet
2	$ 18,067,511	$ 19,316,725	$ 21,815,152
1	$ 25,551,318	$ 27,317,974	$ 30,851,284
0.5	$ 36,135,021	$ 38,633,449	$ 43,630,305
0.25	$ 51,102,637	$ 54,635,948	$ 61,702,569

Dewatering Flow Rate due to Storage

Storage Volume = Volume of Saturated Soil Removed x Porosity

Volume of Saturated Soil Removed = (Average Depth of Excavation - Average Depth to Water) x Area of Excavation

35,843,726 gallons

Average Storage flow rate = Storage Volume x Duration

14 gpm

Dewatering Flow Rate due to Precipitation

Maximum Flow Rate = Maximum Precipitation Rate x Cell Area

Average Flow Rate = Annual Preciptation Rate x Cell Area

Storage Flow Rate = Storage Volume x Duration

	Flow Rate in gpm	
Cell area in acres	Maximum	Average
2	113	3.7
1	57	1.9
0.5	28	0.9
0.25	14	0.5

Capital Cost (based on maximum flowrate)

		55 Foot Embedment			75 Foot Embedment			95 Foot Embedment		
Cell area in acres	Maximum Dewatering Rate - Storage and Precipitation	Maximum Total Flowrate in gpm	Maximum Dewatering flowrate in 1000 gal/yr	Capital Cost	Maximum Total Flowrate in gpm	Maximum Dewatering flowrate in 1000 gal/yr	Capital Cost	Maximum Total Flowrate in gpm	Maximum Dewatering flowrate in 1000 gal/yr	Capital Cost
2	127	1067	560947	$46,739,642	697	433357	$36,108,526	527	344005	$28,663,466
1	71	751	431709	$35,971,230	421	258261	$21,519,054	281	184677	$15,387,828
0.5	42	442	254809	$21,231,434	232	144433	$12,034,595	192	123409	$10,282,816
0.25	28	238	140079	$11,671,813	122	79110	$6,591,654	102	68708	$5,724,984

O&M Cost (based on average flowrate)

		55 Foot Embedment			75 Foot Embedment			95 Foot Embedment		
Cell area in acres	Average Dewatering Rate (gpm)- Storage and Precipitation	Average Dewatering Flowrate	Total Dewatering flow (1000 gal)	Cost	Average Dewatering Flowrate	Total Dewatering flow (1000 gal)	Cost	Average Dewatering Flowrate	Total Dewatering flow (1000 gal)	Cost
2	18	858	2,223,708	$20,919,343	558	1,461,876	$13,752,474	398	1,055,566	$9,930,143
1	16	641	1,668,283	$15,694,229	346	919,148	$8,646,807	221	601,718	$5,660,612
0.5	15	380	1,003,306	$9,438,514	190	520,812	$4,899,496	140	393,840	$3,705,018
0.25	15	210	569,240	$5,355,073	101	293,710	$2,763,055	78	234,301	$2,204,165

Total Dewatering Cost

	Embedment Depth		
Cell area in acres	55 Feet	75 Feet	95 Feet
2	$ 67,658,985	$ 49,860,999	$ 38,593,609
1	$ 51,665,459	$ 30,165,862	$ 21,048,440
0.5	$ 30,669,948	$ 16,934,091	$ 13,987,834
0.25	$ 17,026,886	$ 9,354,709	$ 7,929,150

Total Shoring + Dewatering Cost

	Embedment Depth		
Cell area in acres	55 Feet	75 Feet	95 Feet
2	$ 85,726,496	$ 69,177,724	$ 60,408,761
1	$ 77,216,778	$ 57,483,836	$ 51,899,725
0.5	$ 66,804,969	$ 55,567,540	$ 57,618,139
0.25	$ 68,129,523	$ 63,990,657	$ 69,631,718

Conversion factors:

1 acre = 43,560 SF

1 CF = 7.48 gal

1 yr = 525,600 min

Engineering Calculation Sheet E-23: Alternative 2 Sediment Capping Volumes

Site:	Quendall Terminals	Date	Engineer	
Calculations:	Estimate of offshore capping volumes for Alternative 2	Calculations By:	A. Skwarski	9/10/2013
		Checked By:	G. Gummadi	9/10/2013

Assumptions:

Area includes: All offshore cap areas.
Excavation is required to maintain current Ordinary High Water Line.
Excavation assumes cap depth at the shoreline and meets existing grade to 75' offshore for length of affected shoreline
The Reactive Capping Material (RCM) is an area calculation.
The sand portion of the RCM is a volume calculation.
Amended sand cap would be installed on the existing grade; no offset dredging assumed

Equations: V=[A x D]+[p x (D x 2D/2)

Note: 2nd term accounts for 2H:1V slopes at edge of cap material after placement

V = volume
A = area
D = depth
p = perimeter

				Reactive Cap				Amended Sand Cap			Erosion Protection Area (ft^2)	
								Attenuation Layer		Rest of Cap		
Cell Number	Area (ft^2)	Perimeter (ft)	Offset Excavation (Y or N)	RCM (ft^2)	Sand (CY)	ENR (CY)	Engineered Sand Cap (CY)	Organoclay (CY) (10% by weight)	Sand (CY) (90% by weight)	Sand (CY)	5 ft below OLWM (90 ft from shoreline)	between 5 and 15 ft below OLWM (between 90 ft and 220 ft from shoreline)
DA-1	77,392	1,166	--	77,392	1,444	--	--	--	--	--	--	--
DA-2	40,622	814	--	40,622	760	--	--	--	--	--	--	--
DA-3	15,370	497	--	15,370	289	--	--	--	--	--	--	--
DA-4	8,699	373	--	8,699	165	--	--	--	--	--	--	--
DA-5	4,276	261	--	4,276	82	--	--	--	--	--	--	--
DA-6	32,165	1,060	--	--	--	--	--	429	1,954	3,773	24,276	10,067
DA-8, <75-ft of OHWM	26,882	--	Yes	26,882	498	--	--	--	--	--	31,997	21,342
DA-8, >75-ft of OHWM	38,001	1,023	No	38,001	713	--	--	--	--	--		
DA-7, <75-ft of OHWM	3,542	246	Yes	3,542	68	--	--	--	--	--	3,542	--
Sand Cap Area <75-ft of OHWM	38,694	--	Yes	--	--	--	2,150	--	--	--	46,752	98,583
Sand Cap Area >75-ft of OHWM	230,116	3,559	No	--	--	--	13,081	--	--	--		
ENR Area	767,136	4,303	No	--	--	14,246	--				--	--
Subtotals (rounded)				**214,800**	**4,100**	**14,300**	**15,300**			**6,156**	**107,000**	**130,000**

ENR (sand) Thickness	0.5 ft	Area (acres)	17.6
Sand Cap Thickness	1.5 ft	Area (acres)	6.2
RCM Reactive Cap Thick	0.5 ft	Area (acres)	4.9
Amended Sand Cap	4.5 ft	Area (acres)	0.7

Notes:
1: Areas and perimeters calculated by AutoCad - Cell locations are shown on Figure 6-1
2: Offshore sediment is not expected to characterize as hazardous

Conversion factors:
1 acre = 43,560 SF
1 CY = 27 CF

Engineering Calculation Sheet E-24: Alternative 3 Sediment Capping Volumes

			Engineer	Date
Site:	Quendall Terminals			
Calculations:	Estimate of offshore capping volumes for Alternative 3	Calculations By:	G. Gummadi	8/13/2013
		Checked By:	A. Skwarski	8/14/2013

Assumptions:

Area includes: All offshore cap areas.
Excavation is required to maintain current Ordinary High Water Line.
Excavation assumes cap depth at the shoreline and meets existing grade to 75' offshore for length of affected shoreline
The Reactive Capping Material (RCM) is an area calculation.
The sand portion of the RCM is a volume calculation.

Equations: V=[A x D]+[p x (D x 2D/2)

Note: 2nd term accounts for 2H:1V slopes at edge of cap material after placement

V = volume
A = area
D = depth
p = perimeter

Cell Number	Area (ft^2)	Perimeter (ft)	Offset Excavation (Y or N)	Reactive Cap RCM (ft^2)	Reactive Cap Sand (CY)	ENR (CY)	Engineered Sand Cap (CY)	Erosion Protection Area (ft^2): 5 ft below OLWM (90 ft from shoreline)	Erosion Protection Area (ft^2): between 5 and 15 ft below OLWM (between 90 ft and 220 ft from shoreline)
DA-1	77,392	1,166	--	77,392	1,444	--	--	--	--
DA-2	40,622	814	--	40,622	760	--	--	--	--
DA-3	15,370	497	--	15,370	289	--	--	--	--
DA-4	8,699	373	--	8,699	165	--	--	--	--
DA-5	4,276	261	--	4,276	82	--	--	--	--
DA-6/8, <75-ft of OHWM	47,236	--	Yes	47,236	875	--	--	56,609	40,076
DA-6/8, >75-ft of OHWM	49,813	1,613	No	49,813	937	--	--		
DA-7, <75-ft of OHWM	3,542	246	Yes	3,542	68	--	--	3,542	--
Sand Cap Area <75-ft of OHWM	38,694	--	Yes	--	--	--	2,150	46,752	98,583
Sand Cap Area >75-ft of OHWM	230,116	3,559	No	--	--	--	13,081		
ENR Area	767,136	4,303	No	--	--	14,246	--	--	--
Subtotals (rounded)				**247,000**	**4,700**	**14,300**	**15,300**	**107,000**	**138,700**

ENR (sand) Thickness	0.5 ft	Area (acres)	17.6
Sand Cap Thickness	1.5 ft	Area (acres)	6.2
Reactive Cap Thickness	0.5 ft	Area (acres)	5.7

Notes:
1: Areas and perimeters calculated by AutoCad - Cell locations are shown on Figure 6-4.
2: Offshore sediment is not expected to characterize as hazardous.

Conversion factors:
1 acre = 43,560 SF
1 CY = 27 CF

Engineering Calculation Sheet E-25: Alternative 4, 5 and 6 Sediment Capping Volumes

Site:	Quendall Terminals		Engineer	Date
Calculations:	Estimate of offshore capping volumes for Alternative 4, 5, and 6	Calculations By:	G. Gummadi	8/13/2013
		Checked By:	A. Skwarski	8/14/2013

Assumptions:

Area includes: All offshore cap areas.
Excavation is required to maintain current Ordinary High Water Line.
Excavation assumes cap depth at the shoreline and meets existing grade 75' offshore for length of affected shoreline
The Reactive Capping Material (RCM) is an area calculation.
The sand portion of the RCM is a volume calculation.

Equations: V=[A x D]+[p x (D x 2D/2)

Note: 2nd term accounts for 2H:1V slopes at edge of cap material after placement

V = volume
A = area
D = depth
p = perimeter

Cell Number	Area (ft^2)	Perimeter (ft)	Offset Excavation (Y or N)	Reactive Cap		ENR (CY)	Engineered Sand Cap (CY)	Erosion Protection Area (ft^2)	
				RCM (ft^2)	Sand (CY)			5 ft below OLWM (90 ft from shoreline)	between 5 and 15 ft below OLWM (between 90 ft and 220 ft from shoreline)
DA-1	77,392	1,166	--	--	--	--	--	--	--
DA-2	40,622	814	--	--	--	--	--	--	--
DA-3	15,370	497	No	15,370	289	--	--	--	--
DA-4	8,699	373	No	8,699	165	--	--	--	--
DA-5	4,276	261	No	4,276	82	--	--	--	--
DA-6	32,165	1,060	--	--	--	--	--	24,276	10,067
DA-7, <75-ft of OHWM	3,542	246	Yes	3,542	68	--	--	3,542	--
DA-8, <75-ft of OHWM	26,884	--	Yes	26,884	498	--	--	31,997	21,342
DA-8, >75-ft of OHWM	26,820	1,023	No	26,820	506	--	--		
Sand Cap Area <75-ft of OHWM	38,697	--	Yes	--	--	--	2,150	47,095	107,664
Sand Cap Area >75-ft of OHWM	239,204	3,567	No	--	--	--	13,586		
ENR Area	767,136	4,303	No	--	--	14,246	--	--	--
Subtotals (rounded)				**85,600**	**1,700**	**14,300**	**15,800**	**107,000**	**139,100**

ENR (sand) Thickness	0.5 ft	Area (acres)	17.6
Sand Cap Thickness	1.5 ft	Area (acres)	6.4
Reactive Cap Thickness	0.5 ft	Area (acres)	2.0

Notes:
1: Areas and perimeters calculated by AutoCad - Cell locations are shown on Figure 6-7.
2: Offshore sediment is not expected to characterize as hazardous.

Conversion factors:
1 acre = 43,560 SF
1 CY = 27 CF

Engineering Calculation Sheet E-26: Alternative 7 and 8 Sediment Capping Volumes

Site:	Quendall Terminals		Engineer	Date
Calculations:	Estimate of offshore capping volumes for Alternative 7 and 8	Calculations By:	G. Gummadi	8/13/2013
		Checked By:	A. Skwarski	8/14/2013

Assumptions:

Area includes: All offshore cap areas.
Excavation is required to maintain current Ordinary High Water Line.
Excavation assumes cap depth at the shoreline and meets existing grade 75' offshore for length of affected shoreline
In the nearshore, sediment will be offset/dredged at elevations above 11 ft
The Reactive Capping Material (RCM) is an area calculation.
The sand portion of the RCM is a volume calculation.

Equations: V=[A x D]+[p x (D x 2D/2)

Note: 2nd term accounts for 2H:1V slopes at edge of cap material after placement

V = volume
A = area
D = depth
p = perimeter

Cell Number	Area (ft^2)	Perimeter (Feet)	Offset Excavation (Y or N)	ENR (CY)	Engineered Sand Cap (CY)	Erosion Protection Area (ft^2)	
						5 ft below OLWM (90 ft from shoreline)	Between 5 and 15 ft below OLWM (between 90 ft and 220 ft from shoreline)
DA-1	77,392	1,166	--	--	--	--	--
DA-2	40,622	814	--	--	--	--	--
DA-3	15,370	497	--	--	--	--	--
DA-4	8,699	373	--	--	--	--	--
DA-5/6/8	131,005	1,794	--	--	--	62,117	67,298
DA-7	3,542	246	--	--	--	3,542	--
Sand Cap Area <75-ft of OHWM	34,115	--	Yes	--	1,895	41,197	75,296
Sand Cap Area >75-ft of OHWM	204,948	3,383	No	--	11,668		
ENR Area	767,136	4,303	No	14,246	--	--	--
Subtotals (rounded)				**14,300**	**13,600**	**106,900**	**142,600**

ENR (sand) Thickness	0.5 ft	Area (acres)	17.6
Sand Cap Thickness	1.5 ft	Area (acres)	5.5

Notes:
1: Areas and perimeters calculated by AutoCad - Cell locations are shown on Figure 6-13
2: Offshore sediment is not expected to characterize as hazardous.

Conversion factors:
1 acre = 43,560 SF
1 CY = 27 CF

Engineering Calculation Sheet E-27: Alternative 9 and 10 Sediment Capping Volumes

			Engineer	Date
Site:	Quendall Terminals			
Calculations:	Estimate of offshore capping volumes for Alternative 9 and 10	Calculations By:	G. Gummadi	8/13/2013
		Checked By:	A. Skwarski	8/14/2013

Assumptions:

Area includes: All offshore cap areas.
Excavation is required to maintain current Ordinary High Water Line.
Excavation assumes cap depth at the shoreline and meets existing grade 75' offshore for length of affected shoreline
In the nearshore, sediment will be offset/dredged at elevations above 11 ft.
The Reactive Capping Material (RCM) is an area calculation.
The sand portion of the RCM is a volume calculation.

Equations: V=[A x D]+[p x (D x 2D/2)

Note: 2nd term accounts for 2H:1V slopes at edge of cap material after placement

V = volume
A = area
D = depth
p = perimeter

Cell Number	Area (ft^2)	Perimeter (Feet)	Offset Excavation (Y or N)	ENR (CY)	Engineered Sand Cap (CY)	Erosion Protection Area (ft^2)	
						5 ft below OLWM (90 ft from shoreline)	between 5 and 15 ft below OLWM (between 90 ft and 220 ft from shoreline)
DA-1	77,392	1,166	--	--	--	--	--
DA-2	40,622	814	--	--	--	--	--
DA-3	15,370	497	--	--	--	--	--
DA-4	8,699	373	--	--	--	--	--
DA-7	3,542	246	--	--	--	3,542	--
NA-1, NA-2, NA-3, NA-4, NA-5	200,902	--	--	--	--	85,961	107,012
Sand Cap Area <75-ft of OHWM	14,137	--	Yes	--	785	17,194	38,322
Sand Cap Area >75-ft of OHWM	154,500	2,821	No	--	8,818		
ENR Area	767,136	4,303	No	14,246	--	--	--
Subtotals (rounded)				**14,300**	**9,700**	**106,700**	**145,400**

ENR (sand) Thickness	0.5 ft	Area (acres)	17.6
Sand Cap Thickness	1.5 ft	Area (acres)	3.9

Notes:
1: Areas and perimeters calculated by AutoCad - Cell locations are shown on Figure 6-19.
2: Offshore sediment is not expected to characterize as hazardous.

Conversion factors:
1 acre = 43,560 SF
1 CY = 27 CF

Engineering Calculation Sheet E-28: Alternative 2 Dredging Volumes

			Engineer	Date
Site:	Quendall Terminals			
Calculations:	Estimate the volume of sediment to be dredged or excavated for Alternatives 2.	Calculations By:	A. Skwarski	9/10/2013
		Checked By:	G. Gummadi	9/10/2013

Assumptions: Sediment in the nearshore capping areas would be removed to offset for cap and erosion protection. This would include all sediment area above 11 ft elevation.

Equations:
Sediment Removal Volume = A x D
Side-Slope Sediment Removal Volume = P x D x 2D / 2

A = area
D = total depth
P = perimeter

	Mechanical Dredge to Off-Set Capping							
Dredge Area	**Area (ft^2)**	**Perimeter (ft)**	**Target Depth (ft bss)**	**Total Depth (ft bss)**	**Sediment Removal Volume (CY)**	**Side-Slope Sediment Removal Volume (CY)**	**Total Sediment Volume (CY)**	**Target Depth based on**
DA-8, <75-ft of OHWM	26,882	1,613	0.5	0.5	498	14.9	513	Reactive Cap Thickness
DA-7, <75-ft of OHWM	3,542	245.57	0.5	0.5	66	2.3	68	Reactive Cap Thickness
Sand Cap Area < 75-ft of OHWM	38,694	--	1.5	1.5	2,150	--	2,150	Sand Cap Thickness
Subtotal (rounded)							**2,800**	

	Dredging Depth for Offsetting
Reactive Cap Areas	0.5 ft
Sand Cap Area	1.5 ft

Notes:
1. Dredge areas and perimeters calculated by AutoCad - Cell locations are shown on Figure 6-1.
2. Volume estimate is based on plume footprint and 2:1 sideslopes.

Conversion factors:
1 acre = 43,560 SF
1 cy = 27 CF

Engineering Calculation Sheet E-29: Alternative 3 Dredging Volumes

Site:	Quendall Terminals	**Engineer**	**Date**
Calculations:	Estimate the volume of sediment to be dredged or excavated for Alternatives 3.	Calculations By: G. Gummadi	8/13/2013
		Checked By: A. Skwarski	8/14/2013

Assumptions: Sediment in the nearshore capping areas would be removed to offset for cap and erosion protection. This would include all sediment area above 11 ft elevation.

Equations:
Sediment Removal Volume = A x D
Side-Slope Sediment Removal Volume = P x D x 2D / 2

A = area
D = total depth
P = perimeter

	Mechanical Dredge to Off-Set Capping							
Dredge Area	**Area (ft^2)**	**Perimeter (ft)**	**Target Depth (ft bss)**	**Total Depth (ft bss)**	**Sediment Removal Volume (CY)**	**Side-Slope Sediment Removal Volume (CY)**	**Total Sediment Volume (CY)**	**Target Depth based on**
DA-6/8, <75-ft of OHWM	47,236	1,613	0.5	0.5	875	14.9	890	Reactive Cap Thickness
DA-7, <75-ft of OHWM	3,542	245.57	0.5	0.5	66	2.3	68	Reactive Cap Thickness
Sand Cap Area < 75-ft of OHWM	38,694	--	1.5	1.5	2,150	--	2,150	Sand Cap Thickness
Subtotal (rounded)							**3,200**	

	Dredging Depth for Offsetting
Reactive Cap Areas	0.5 ft
Sand Cap Area	1.5 ft

Notes:
1. Dredge areas and perimeters calculated by AutoCad - Cell locations are shown on Figure 6-4.
2. Volume estimate is based on plume footprint and 2:1 sideslopes.

Conversion factors:
1 acre = 43,560 SF
1 cy = 27 CF

Engineering Calculation Sheet E-30: Alternative 4, 5 and 6 Dredging Volumes

Site: Quendall Terminals

Calculations: Estimate the volume of sediment to be dredged or excavated for Alternatives 4, 5, and 6.

	Engineer	Date
Calculations By:	G. Gummadi	8/13/2013
Checked By:	A. Skwarski	8/14/2013

Assumptions: Sediment in the nearshore capping areas would be removed to offset for cap and erosion protection. This would include all sediment area above 11 ft elevation.

Equations:
Sediment Removal Volume = A x D
Side-Slope Sediment Removal Volume = P x D x 2D / 2

A = area
D = total depth
P = perimeter

Dredge Area	Area (ft^2)	Perimeter (ft)	Target Depth (ft bss)	Total Depth (ft bss)	Sediment Removal Volume (CY)	Side-Slope Sediment Removal Volume (CY)	Total Sediment Volume (CY)	Reactive Residual Cover: Organoclay (CY) (10% by weight)	Reactive Residual Cover: Sand (CY) (90% by weight)	Backfill (CY)	Core that Target Depth Based on
Hydraulic Dredging (off-shore)											
DA-1	77,392	1,166	2.4	3.4	9,746	97	9,843	260	1,184	8,399	3.8 ft for DNAPL area (half of dredge area) based on VT-4; 1.0 ft of removal within rest of DA-1
DA-2	40,622	814	0.5	1.5	2,257	68	2,325	137	623	1,565	TD-08
DA-3	--	--	--	--	--	--	--	--	--		VS27
DA-4	--	--	--	--	--	--	--	--	--		TD-01
DA-5	--	--	--	--	--	--	--	--	--		EPA-8
Subtotal (Rounded)	**118,100**	**2.7**	**acres**				**12,200**	**400**	**1,900**	**10,000**	
Mechanical Dredging (within sheetpile)											
DA-6	32,165	--	8.2	9.2	10,960	--	10,960	107	488	10,364	Average of VS-30 and QPN-02
Subtotal (Rounded)	**32,200**	**0.7**	**acres**				**11,000**	**110**	**490**	**10,370**	
Mechanical Dredging for Cap Off-Set											
DA-7	3,542	246	0.5	0.5	66	--	66	--	--		Reactive Cap Thickness
DA-8 <75-ft of OHWM	26,884	1,023	0.5	0.5	498	--	498	--	--		Reactive Cap Thickness
Sand Cap Area < 75-ft of OHWM	38,697	--	1.5	1.5	2,150	--	2,150	--	--		Sand Cap Thickness
Subtotal (Rounded)	**69,200**	**1.6**	**acres**				**2,720**				
Total (Rounded)							**25,900**	**510**	**2,300**	**20,400**	

	Dredging Depth for Offsetting
Reactive Cap Areas	0.5 ft
Sand Cap Area	1.5 ft

Notes:
1. Dredge areas and perimeters calculated by AutoCad - Cell locations are shown on Figure 6-7.
2. Total depth assumes nearest observation of NAPL in a boring, and includes 1-foot of overdredge.
3. Offshore sediment is not expected to characterize as hazardous.
4. Volume estimate is based on plume footprint and 2:1 sideslopes.
5. Assumed bulk densities for OC to be 53 lb/ft^3 and sand to be 105 lb/ft^3. This translates to 18% OC and 82% Sand by volume.

Conversion factors:
1 acre = 43,560 SF
1 cy = 27 CF

Engineering Calculation Sheet E-31: Alternative 7 and 8 Dredging Volumes

Site:	Quendall Terminals	**Engineer**	**Date**
Calculations:	Estimate the volume of sediment to be dredged or excavated for Alternatives 7 and 8.	Calculations By: G. Gummadi	8/13/2013
		Checked By: A. Skwarski	8/14/2013

Assumptions: Sediment in the nearshore capping areas would be removed to offset for cap and erosion protection. This would include all sediment area above 11 ft elevation.

Equations:
Sediment Removal Volume = A x D
Side-Slope Sediment Removal Volume = P x D x 2D / 2

A = area
D = total depth
P = perimeter

Dredge Area	Area (ft^2)	Perimeter (ft)	Target Depth (ft bss)	Total Depth (ft bss)	Sediment Removal Volume (CY)	Side-Slope Sediment Removal Volume (CY)	Total Sediment Volume (CY)	Reactive Residual Cover		Backfill (CY)	Core that Target Depth Based on
								Organoclay (CY) (10% by weight)	Sand (CY) (90% by weight)		
Hydraulic Dredging (off-shore)											
DA-1	77,392	1,166	2.4	3.4	9,746	97	9,843	260	1,184	8,399	3.8 ft for DNAPL area (half of dredge area) based on VT-4; 1.0 ft of removal within rest of DA-1
DA-2	40,622	814	0.5	1.5	2,257	68	2,325	137	623	1,565	TD-08
DA-3	15,370	497	2.7	3.7	2,106	252	2,358	52	237	2,069	VS27
DA-4	8,699	373	0.8	1.8	580	45	625	30	135	460	TD-01
Subtotal (Rounded)	**142,100**		**3.3 acres**				**15,200**	**480**	**2,200**	**12,500**	
Mechanical Dredging (within sheetpile)											
DA-5	4,276	--	3.0	4.0	634	--	634	14	65	554	EPA-8
DA-6	32,165	--	8.2	9.2	10,960	--	10,960	107	488	10,364	Average of VS-30 and QPN-02
DA-8	53,704	--	11.4	12.4	24,664	--	24,664	179	816	23,669	Average of VS-2, QPN-07 and NS15-C1
Additional Area within sheetpile/slopes	40,860	--	--	2.0	3,027	--	3,027	136	620	2,270	NA
DA-7	3,542	246	13.0	14.0	1,837	--	1,837	12	54	1,771	MC-16
Subtotal (Rounded)	**134,600**		**3.1 acres**				**41,200**	**450**	**2,100**	**38,600**	
Mechanical Dredging for Cap Off-Set											
Sand Cap Area < 75-ft of OHWM	34,115	--	1.5	1.5	1,895	--	1,895	--	--		Sand Cap Thickness
Subtotal (Rounded)	**34,200**		**0.8 acres**				**1,900**				
Total (Rounded)							**58,300**	**930**	**4,300**	**51,200**	

	Dredging Depth for Offsetting
Sand Cap Area	1.5 ft

Notes:
1. Dredge areas and perimeters calculated by AutoCad - Cell locations are shown on Figure 6-13.
2. Total depth assumes nearest observation of NAPL in a boring, and includes 1-foot of overdredge.
3. Offshore sediment is not expected to characterize as hazardous.
4. Volume estimate is based on plume footprint and 2:1 sideslopes.
5. Assumed bulk densities for OC to be 53 lb/ft^3 and sand to be 105 lb/ft^3. This translates to 18% OC and 82% Sand by volume.

Conversion factors:
1 acre = 43,560 SF
1 cy = 27 CF

Engineering Calculation Sheet E-32: Alternative 9 and 10 Dredging Volumes - Part 1

			Engineer	Date
Site:	Quendall Terminals			
Calculations:	Estimate the volume of sediment outside temporary sheetpile wall enclosure to be dredged or excavated for Alternatives 9 and 10.	Calculations By:	G. Gummadi	8/13/2013
		Checked By:	A. Skwarski	8/14/2013

Assumptions: Sediment in the nearshore capping areas would be removed to offset for cap and erosion protection. This would include all sediment area above 11 ft elevation.

Equations:
Sediment Removal Volume = A x D
Side-Slope Sediment Removal Volume = P x D x 2D / 2

A = area
D = total depth
P = perimeter

Dredge Area	Area (ft^2)	Perimeter (ft)	Target Depth (ft bss)	Total Depth (ft bss)	Sediment Removal Volume (CY)	Side-Slope Sediment Removal Volume (CY)	Total Sediment Volume (CY)	Reactive Residual Cover		Backfill (CY)	Core that Target Depth Based on
								Organoclay (CY) (10% by weight)	Sand (CY) (90% by weight)		
Hydraulic Dredging (off-shore)											
DA-1	77,392	1,166	3.4	4.4	12,612	97	12,709	260	1,184	11,265	NAPL Depth plus 2' 5.8 ft for DNAPL area (half of dredge area) based on VT-4; 1.0 ft of removal within rest of DA-1
DA-2	40,622	814	2.5	3.5	5,266	369	5,635	137	623	4,875	NAPL depth plus 2'
DA-3	15,370	497	4.7	5.7	3,245	598	3,843	52	237	3,553	NAPL depth plus 2'
DA-4	8,699	373	2.8	3.8	1,224	200	1,424	30	135	1,259	NAPL depth plus 2'
Subtotal (Rounded)	**142,100**	**3.3**	**acres**				**23,700**	**480**	**2,200**	**21,000**	
Mechanical Dredging for Cap Off-Set											
Sand Cap Area < 75-ft of OHWM	14,137	--	1.5	1.5	785	--	785	--	--	--	Sand Cap Thickness
Subtotal (Rounded)	**14,200**	**0.3**	**acres**				**800**	--	--	--	

	Dredging Depth for Offsetting
Sand Cap Area	1.5 ft

Notes:
1. Dredge areas and perimeters calculated by AutoCad - Cell locations are shown on Figure 6-19.
2. Total depth assumes nearest observation of NAPL in a boring, and includes 1-foot of overdredge.
3. Offshore sediment is not expected to characterize as hazardous.
4. Volume estimate is based on plume footprint and 2:1 sideslopes. This translates to 18% OC and 82% Sand by volume.

Conversion factors:
1 acre = 43,560 SF
1 cy = 27 CF

Engineering Calculation Sheet E-33: Alternative 9 and 10 Dredging Volumes - Part 2

Site: Quendall Terminals

Calculations: Estimate the volume of nearshore sediment to be excavated for Alternatives 9 and 10

	Engineer	Date
Calculations By:	G. Gummadi	8/13/2013
Checked By:	A. Skwarski	8/14/2013

Assumptions:

Area includes: Shallow Alluvium within benzo[a]pyrene and arsenic plumes and includes Nearshore NAPL deposits

Equations:

Sediment Removal Volume = A x D

Side-Slope Sediment Removal Volume = P x D x 2D / 2

A = area
D = total depth
P = perimeter

Cell Number	Total Cell Area (ft^2)	Length of Transect with adjacent dredge cell (ft)	Extent of B[a]P Plume (ft^2)	Target Depth (ft bss)	Total Depth (ft bss)	Perimeter (ft)	Sediment Removal Volume (CY)	Sideslope Sediment Removal Volume (CY)	Total Sediment Volume in CY	Reactive Residual Cover		Backfill (CY)
										Organoclay (CY) (10% by weight)	Sand (CY) (90% by weight)	
Mechanical Dredging (within sheetpile)												
NA-1	65,305	--	3,490	15	15	1,003	36,280	--	36,280	218	992	35,071
NA-2	25,649	192	4,766	27	27	684	25,649	1,025	26,674	85	389	26,199
NA-3	47,961	200	8,482	19	19	872	33,750	473	34,224	160	728	33,336
NA-4	16,680	242	15,015	20	20	619	12,355	8.9	12,364	56	253	12,055
NA-5	45,307	240	12,422	22	22	891	36,917	35	36,952	151	688	36,113
DA-7	3,542	--	2,949	15	16	246	2,099	--	2,099	12	54	2,033
Subtotal (Rounded)	**204,500**	**4.7**	**acres**						**148,600**	**690**	**3,200**	**144,900**

Notes:
1. Dredge areas and perimeters calculated by AutoCad - Cell locations are shown on Figure 6-21.
2. Total depth assumes average depth of B[a]P and arsenic contamination from Section E-E'.
3. Volume estimate is based on plume footprint and 2:1 sideslopes.
4. Approximate dredge elevations in each dredge unit are: NA-1 = -3.5 ft, NA-2 = -12 ft, NA-1 = -6.5 ft, NA-2 = -8 ft, and NA-1 = -11 ft.
5. Assumed bulk densities for OC to be 53 lb/ft^3 and sand to be 105 lb/ft^3. This translates to 18% OC and 82% Sand by volume.

Conversion factors:
1 acre = 43,560 SF
1 cy = 27 CF

Engineering Calculation Sheet E-34: Offshore Duration Estimates of Alternatives

Site: Quendall Terminals

Calculations: Estimate the sediment remedy implementation durations of alternatives

	Engineer	Date
Calculations By:	A. Skwarski	9/10/2013
Checked By:	G. Gummadi	9/10/2013

Assumptions: Rate of implementation of various technologies is based on previous project experience.

		Alternative 2	Alternative 3	Alternatives 4, 5, & 6	Alternatives 7 & 8	Alternatives 9 & 10
Enhanced Natural Recovery	Volume of material (CY)	14,300	14,300	14,300	14,300	14,300
	Rate of material placement (CY/day)	500	500	500	500	500
	Numer of days for implementation (days)	29	29	29	29	29
	Number of weeks for implementation	5	5	5	5	5
Engineered Sand Cap	Volume of material (CY)	15,300	15,300	15,800	13,600	9,700
	Rate of material placement (CY/day)	500	500	500	500	500
	Numer of days for implementation (days)	31	31	32	28	20
	Number of weeks for implementation	5	5	6	5	4
Amended Sand Cap	Volume of material (CY)	6,156	--	--	--	--
	Rate of material placement (CY/day)	500	--	--	--	--
	Numer of days for implementation (days)	13	--	--	--	--
	Number of weeks for implementation	3	--	--	--	--
Reactive Cap	Area to be capped (ft^2)	214,800	247,000	85,600	--	--
	Rate of material placement (ft^2/day)	10,000	10,000	10,000	--	--
	Numer of days for implementation (days)	22	25	9	--	--
	Number of weeks for implementation	4	5	2	--	--
Dredging for Remedy Offsetting	Volume of material (CY)	2,800	3,200	2,720	1,900	800
	Rate of dredging (CY/day)	400	400	400	400	400
	Numer of days for implementation (days)	7	8	7	5	2
	Number of weeks for implementation	2	2	2	1	1
Offshore Hydraulic Dredging	Volume of material (CY)	--	--	12,200	15,200	23,700
	Rate of dredging (CY/day)	--	--	400	400	400
	Numer of days for implementation (days)	--	--	31	38	60
	Number of weeks for implementation	--	--	6	7	10
Sheet Pile Containment - Installation	Total length (linear ft)	--	--	700	1,260	1,531
	Rate of installation (linear ft/day)	--	--	20	20	20
	Number of days for installation (days)	--	--	36	64	77
	Number of weeks for implementation	--	--	6	11	13
Nearshore Mechanical Dredging	Volume of material (CY)	--	--	11,000	41,200	148,600
	Rate of dredging (CY/day)	--	--	400	400	400
	Numer of days for implementation (days)	--	--	28	103	372
	Number of weeks for implementation	--	--	5	18	62
Sheet Pile Containment - Removal	Total length (linear ft)	--	--	700	1,260	1,531
	Rate of removal (linear ft/day)	--	--	30	30	30
	Number of days for removal (days)	--	--	24	43	52
	Number of weeks for implementation	--	--	4	8	9
Residual Reactive Cover	Volume of material (CY)	--	--	2,810	5,230	6,570
	Rate of material placement (CY/day)	--	--	500	500	500
	Numer of days for implementation (days)	--	--	6	11	14
	Number of weeks for implementation	--	--	1	2	3
Backfilling	Volume of material (CY)	--	--	20,400	51,200	165,900
	Rate of material placement (CY/day)	--	--	500	500	500
	Numer of days for implementation (days)	--	--	41	103	332
	Number of weeks for implementation	--	--	7	18	56
Total Duration (weeks)		**16**	**17**	**44**	**75**	**163**

Notes:
1. Volumes of materials is estimated from dredge areas and perimeters estimated in AutoCad.
2. One week assumes 6 work days per week. All weeks have been rounded up to the nearest whole week.

APPENDIX F

Construction Shoring Design Considerations

Project No.: 020027-010

June 14, 2012

To: Jeremy Porter
Aspect Consulting LLC

From: **Andrew J. Holmson, EIT**
Project Geotechnical Engineer

John L. Peterson, PE
Senior Associate Geotechnical Engineer

Re: **Excavation and Shoring Considerations – Quendall Terminals**

This memorandum summarizes the preliminary excavation and shoring considerations of Aspect Consulting, LLC (Aspect) for the proposed excavation alternatives being considered for incorporation into the environmental remediation project at the Quendall Terminals property located in Renton, Washington (Site).

Current environmental remediation plans include alternatives for excavation and removal of contaminated soil within the property. Multiple excavation scenarios are being considered. In general the two types of scenarios consist of:

1. Fully dewatered (dry) excavation scenarios that would include excavation and removal of contaminated soils to depths ranging from 20 to 40 feet below the existing Site grades over areas ranging from 1 to 2 acres.

2. Partially dewatered (wet) excavation scenarios that would include excavation and removal of contaminated soils to depths ranging from 10 to 34 feet below the existing Site grades.

Variations of the two scenario types described above are also being considered including breaking the proposed larger excavations areas into smaller, segmented cell excavations. Shallow groundwater conditions across the Site will require dewatering and/or impermeable shoring as part of the excavation and removal processes.

Site Geology

Generally, the Site geology within the depth range of the proposed excavation alternatives can be broken into three separate units for geotechnical engineering purposes.

Our characterization of subsurface conditions suggests the Site is underlain by a surface layer of Fill that is variable in composition and density, and is generally on the order of 8 to 10 feet thick. The Fill mantles a sequence of very soft Shallow Alluvium ranging in thickness from about 20 to 35 feet and consisting primarily of fine-grained organic-rich and peaty soils with scattered loose sand layers. The Deeper Alluvium consists of generally more competent sands and gravels to a

depth of 130 feet or more. Very soft, fine-grained Lacustrine deposits were encountered beneath the alluvium. Competent, glacially consolidated soil and/or bedrock were encountered beneath the alluvium on the adjacent shoreline properties (Football Northwest to the north), but were not encountered in explorations on the Site.

Groundwater

Over twenty groundwater monitoring wells are located on the project Site. Groundwater is typically encountered between approximately 2 and 10 feet below the existing Site grades, with groundwater flow generally east to west/northwest direction toward the lake. Vertical groundwater flow gradients in the Shallow and Deeper Alluvium units at the Site exhibit downward gradients along the eastern portion of the Site becoming upward near the lake shoreline.

The shallow groundwater across the Site would present construction challenges for trenching and excavating below the water table. Construction dewatering should be anticipated for these deep excavations. If deep excavations occur after parts of the Site are developed, construction dewatering plans will have to consider the potential of dewatering-induced settlement caused by drawdown of the water table. Any dewatering activities will need to consider health, safety, and water treatment issues associated with potential exposure to and extraction of dissolved phase chemical constituents in groundwater.

Excavation and Shoring Considerations

Shoring Alternatives

Taking into consideration the Site geology, groundwater conditions, and proposed excavation and removal alternatives, steel sheet piles are likely the most practical and cost-effective method for support of the large excavations being considered.

Steel sheet piling can be installed and configured to achieve an impermeable shoring system to help reduce the amount of dewatering required for the proposed excavations. Sheet piling can also be salvaged and possibly re-used in a scenario involving a segmented approach of multiple, smaller excavation cells. Sheet piles can be installed as a cantilever system to support an excavation height of approximately 16 feet and would require tieback soil anchors or internal bracing for extra support of excavation heights greater than 16 feet.

Steel sheet piles could feasibly be installed to depths of 80 feet or greater at the Site provided the installation contractor was prepared to use a vibratory hammer and/or high pressure jetting at the toe of the piles to loosen the denser deep alluvium soils. Typically ‘Z-section’ steel sheet piles are used for deep excavations because of their high rigidity to weight ratio. Heavy duty sheet pile sections, such as an AZ50 section, may be required for the partial dewatering scenarios that intend on minimizing groundwater drawdown by maximizing the support elevations and load carrying capabilities of the sheet pile section.

Other alternatives for an impermeable shoring system include the use of a continuous or secant pile wall or a structural slurry wall system for support of the proposed excavations; however, these systems would require multiple installation components, would not be fully salvageable or re-usable, and appear to be less cost-effective for this application.

Tieback Anchors/Internal Bracing

Impermeable shoring systems for this application will be subject to both lateral earth pressures and unbalanced hydrostatic pressures and could require additional restraint through tieback anchors or internal braces to help support the excavations.

While a cantilever system may be adequate for the shallow excavation scenario, it may be more cost-effective to include at least one row of anchors or bracing. For the dry excavation scenarios extending to depths of 40 feet, at least three rows of tiebacks or internal bracing would be needed for additional support. Wet excavation scenarios extending to depths of 34 feet may only require two rows of tieback anchor supports depending on the amount of partial dewatering and location of the supports.

Tieback anchors are typically installed on 6- to 8-foot center-to-center spacing, cannot be re-used, but maintain an open excavation for easier access. For these preliminary studies, we recommend assuming the uppermost tieback anchor will be located at a minimum of 5 feet below the ground surface. Internal braces or struts can be installed on greater spacing (10- to 20-foot center-to-center), require a reaction source, can be re-used, but will span the interior of the excavation creating access issues. The reaction source for an internal brace system can be an adjacent shoring wall or deadmen at the base of the excavation.

Tieback anchors would be preferred if a single mass excavation is planned with shoring required around the perimeter only. Internal braces or struts would be more efficient for smaller, segmented excavations. An internal brace system can span an excavation width of up to 100 feet, but a raker system with struts directed to reaction deadmen anchors in the base of the excavation would be needed to span larger widths. A raker system could only be used in a “dry” excavation and given the construction interference it would cause, tiebacks again appear as the preferred alternative for preliminary analysis.

Shoring Analyses

Preliminary shoring analyses were completed with the aid of Shoring Suite v8.10g, a shoring analysis software program developed by CivilTech Software. Shoring Suite software can determine shoring size and embedment criteria as well as estimated moment, shear, and deflection of shoring systems. The Shoring Suite is based on methods and design data as presented by the U.S. Navy Design Manual DM-7, Steel Sheet Piling Design Manual (USS), and Federal Highway Design and Construction Summary (FHWA-RD-75). For the purposes of our analyses, the Shoring Suite software was used to develop preliminary and generalized shoring embedment and support criteria for the various scenarios.

Our analyses typically used a conservative representation of the Site subsurface conditions. As the remediation plan develops and specific areas are identified for excavation, we recommend more detailed and refined excavation and shoring analyses be completed for the individual areas.

Note, the basal stability of the proposed excavations will require a more thorough hydrogeologic analysis. Our preliminary study did not include detailed basal stability analyses and the embedment and support criteria provided below should be taken as minimums with the understanding that a detailed hydrogeologic analysis may result in deeper embedment criteria and groundwater cutoff requirements to prevent blowout at the base of the excavations.

Dry Excavation Scenarios

Two dry excavation scenarios, where dewatering below the base of the excavation for a dry work environment is assumed, were considered. In general deeper embedment of the shoring wall and/or more supports are required for the dry excavation scenarios to account for the unbalanced hydrostatic pressures created by the full dewatering of the excavation.

- **Shallow Excavation Scenario (20 Feet)**. An anchored sheet pile wall can be used with a minimum required embedment depth of 15 feet for a minimum total pile length of 35 feet and one row of tieback/strut support.
- **Deep Excavation Scenario (40 Feet).** An anchored sheet pile wall can be used with a minimum required embedment depth of 27 feet for a minimum total pile length of 67 feet with three rows of tiebacks/strut supports.

Wet Excavation Scenarios

Three wet excavation scenarios were considered. The goal of the wet excavation scenarios is to minimize the amount of dewatering associated with the shoring wall installation. The controlling feature to minimize dewatering is the location of the tieback anchor supports on the wall. Dewatering is assumed to be required to a minimum level of 3 feet below the lowest tieback anchor location to allow for a dry work environment during the installation of the anchors. Iterative analyses were performed to determine the required tieback anchor locations and associated amount of dewatering. The preliminary criteria for the three scenarios listed below include the assumption that a stiff sheet pile section, AZ50 or equivalent, will be used for the shoring wall. It is possible to locate the anchor supports higher on the shoring wall if a stiffer sheet pile section is used thereby reducing the required amount of dewatering.

- **Shallow Excavation Scenario (up to 16 Feet)**. A cantilever sheet pile wall can be used with a minimum embedment depth of approximately 35 feet for a minimum total pile length of 50 feet.
- **Moderately Deep Excavation Scenario (between 16 and 22 Feet).** An anchored sheet pile wall can be used with one row of tieback/strut supports and a minimum embedment depth ranging from 12 to 20 feet. The resulting total pile length will range from 27 to 42 feet, respectively.
- **Deep Excavation Scenario (between 22 and 34 Feet).** An anchored sheet pile wall can be used with two rows of tieback/strut supports and a minimum embedment depth ranging from 17 to 26 feet. The resulting total pile length will range from 39 to 60 feet, respectively.

Cost Estimate Considerations

The following cost information was derived from discussions with select local contractors and suppliers as well as the RSMeans Costworks database. These costs should be considered preliminary and we recommend adding a 25 to 30 percent contingency to these costs for estimating or budgeting purposes.

- **Shallow, Dry Excavation Scenario (20 Feet).** $61 per square foot of exposed wall at the end of excavation. Assumes an embedment depth of 15 feet for a total pile length of 35 feet and one row of tieback/strut support.

- **Deep, Dry Excavation Scenario (40 Feet).** $72 per square foot of exposed wall at the end of excavation. Assumes an embedment depth of 27 feet for total pile length of 67 feet with three rows of tiebacks/strut supports.
- **Wet Excavation Scenarios (10 to 34 Feet).** $92 per square foot of exposed wall at the end of excavation. Assumes embedment depths ranging from 12 to 35 feet for total pile lengths ranging from 27 to 60 feet with a maximum of two rows of tieback anchor supports. Assumes a stiff sheet pile section, AZ50 or equivalent, will be used.

The cost estimates above include the material costs, driving and removing/salvaging sheet piles, associated labor, and tieback/internal brace installation. Additional embedment of the sheet pile walls for purposes of cutting off groundwater or extending the excavation depths for the above scenarios would result in increased unit costs.

Limitations

Work for this project was performed and this memorandum 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. It is intended for the exclusive use of Aspect Consulting, LLC for specific application to the referenced project. This memorandum does not represent a legal opinion. No other warranty, expressed or implied, is made.

This memorandum is issued with the understanding that the information and considerations contained herein will be used as a basis for engineering design of the planned improvements.

V:\020027 Quendall Terminals\FS Report\Appendices\Appendix G\Appendix G Excavation and Shoring Considerations 7 3 12.doc