FEASIBILITY STUDY
Quendall Terminals Site

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

Project No. 020027 • December 2016

On behalf of

Altino Properties, Inc. and

J.H. Baxter & Co.

Prepared by

Aspect Consulting, LLC and

Arcadis U.S., Inc.

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FEASIBILITY STUDY EXECUTIVE SUMMARY

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EXECUTIVE SUMMARY

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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 Substances 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 water levels in Lake Washington were 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. Six 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.
- Quendall Pond, located near the shoreline, was constructed in an area where tank bottoms from nearby storage tanks were placed. This area also received wastes from North Sump overflows. Waste from Quendall Pond has migrated into adjacent Lake Washington.

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 the water level 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 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 can stop, slow, or alter migration 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.

There is no continuous aquitard layer separating the Shallow and Deep Aquifers; however, the Deep Aquifer is considered to be a semi-confined aquifer, as the vertical hydraulic interaction between the Shallow and Deep Aquifers is limited by the horizontal stratification and low permeability layers within the Shallow Alluvium, and varies depending on the 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. 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.

One of the expectations for remedial alternatives to be generally considered by EPA is the ability of remedial alternatives to address principal threat wastes (PTWs) to the extent practicable. PTWs 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. For the purposes of this FS, DNAPL, DNAPL-impacted soil, and DNAPL-impacted sediment (i.e., either oil-wetted or oil-coated materials; also referred to as residual DNAPL or ‘DNAPL-impacted’ soil or sediment in this FS) are considered to be PTWs.

The RAOs for the Site are defined by EPA and listed below. The alternatives assembled in this FS use a wide range of removal, treatment, and containment strategies to address Site contaminants, including PTWs.

The RAOs for the Site as defined by EPA are:

Source Control RAOs:

- **SC1: PTW.** 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: PTW.** Contain DNAPL in subsurface soils and groundwater where treatment or removal is not practicable.
- **SC3: Soil.** Reduce migration of COCs to groundwater from soils that exceed remediation goals for the protection of groundwater.
- **SC4: 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) and 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 containing DNAPL and areas with contaminant concentrations above PRGs, are shown on Figure ES-3.

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

- **RR DNAPL Area**: DNAPL-impacted soil in the former Railroad Tank Car Loading Area (deep occurrence, maximum thickness, and potentially mobile);
- **MC DNAPL Area**: DNAPL-impacted soil in the former May Creek Channel (deepest occurrence, moderate thickness, and potentially mobile);
- **QP-U DNAPL Area:** DNAPL-impacted soil around Quendall Pond (deep occurrence, moderate thickness, and potentially mobile);
- **QP-S DNAPL Area:** DNAPL-impacted sediments offshore of Quendall Pond (moderate depth and thickness, and potentially mobile); and
- **TD DNAPL Area**: DNAPL-impacted sediments along the former T-Dock (shallow sediment depth and moderate thickness).

DNAPL areas outside the five designated areas were grouped together as Other Upland and Other Aquatic DNAPL Areas. Many of these areas contain DNAPL with significant cumulative thickness, but they are more challenging to delineate individually. Other Upland DNAPL Areas generally exhibit DNAPL at shallow to moderate depth with fewer occurrences of oil-wetted DNAPL. They include DNAPL-impacted soil in other former process areas, specifically the Still House, the Boiler House, and the North and South Sumps. Other Aquatic DNAPL Areas include areas between the TD and QP-S DNAPL Areas.

Key factors influencing the remediation of DNAPL at the Site are as follows:

- EPA has determined that DNAPL at the Quendall Site, whether in soils or sediments, is to be considered PTW because of the high level of toxicity inherent in the creosote/coal tar DNAPL. Creosote/coal tar contaminants present in DNAPL (benzene and naphthalene) are leachable and mobile via groundwater, and DNAPL classified as oil-wetted may be also be mobile.
- EPA believes that DNAPL at the Site cannot be addressed through containment alone, because any vertical barrier/treatment wall that would be installed at the Site could only be a “hanging” wall. There is no continuous single-layer aquitard in which to anchor a barrier/treatment wall.
- DNAPL is accessible. The majority of DNAPL in the uplands is found within the top 20 feet of the Shallow Aquifer with two exceptions (RR Area and Former May Creek Channel).

Figure ES-4 provides a cross section, oriented as shown on Figure ES-3, with delineated DNAPL areas highlighted. Particular areas of DNAPL were identified for the purposes of developing a range of remedial alternatives, including areas that represent a relatively higher risk due to their promixity to Lake Washington and/or mobilization potential (QP-U, QP-S, and TD DNAPL Areas), and deep areas that represent a more significant source to groundwater contamination (RR DNAPL Area and the eastern portion of the MC DNAPL Area). Site areas were also differentiated with respect to DNAPL cumulative thickness.

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.

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. 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. The following technologies and process options were used to assemble remedial alternatives:

- Upland excavation to remove source material with either off-site disposal or on-site *ex situ* thermal treatment;
- DNAPL collection trenches to remove mobile DNAPL from the subsurface and further reduce the potential migration of DNAPL from the uplands to the lake sediments;
- A funnel and gate system using a passive reactive barrier (PRB) to reduce migration of contamination in groundwater from the uplands and aid in the recovery of lake sediments and porewater;
- Upland cap to protect human health from direct contact with contaminated surface soils;
- Upland *in situ* solidification to immobilize DNAPL and contaminants in soil.

- Dredging of sediment PTW with either off-site disposal or on-site *ex situ* thermal treatment; placement of reactive residuals covers over dredged areas to manage residuals if necessary;
- Reactive core mat (RCM) and amended sand reactive caps over aquatic PTW areas to sorb DNAPL and control DNAPL migration;
- Enhanced natural recovery (ENR) to remediate areas of lower concentrations of cPAHs in sediment;
- Engineered sand cap to remediate sediment areas with higher concentrations of cPAHs and/or areas impacted by upwelling contaminated groundwater;
- Institutional controls to help ensure the effectiveness of engineering controls; and
- Monitoring to verify that the remedy is performing as intended.

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**
- **Alternative 2 – Containment:** permeable soil, engineered sand, and RCM sediment capping
- **Alternative 3 – Targeted PTW0F1 Solidification (RR and MC-1 DNAPL Areas):** targeted treatment of two areas of deep upland PTWs via *in situ* solidification, passive groundwater treatment, and soil and sediment capping
- **Alternative 4 – Targeted PTW Removal (TD, QP-S, and QP-U DNAPL Areas):** targeted treatment of three areas of PTWs via removal/off-site disposal, passive groundwater treatment, and soil and sediment capping
- **Alternative 4a – Targeted PTW Solidification (QP-U, RR and MC-1 DNAPL Areas) and Removal (TD DNAPL Area):** targeted treatment of two areas of deep upland PTWs and one nearshore upland PTW area via *in situ* solidification, targeted treatment of one area of sediment PTWs via removal/off-site disposal, passive groundwater treatment, and soil and sediment capping

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

- **Alternative 5 – Targeted PTW Solidification (RR, MC, and QP-U DNAPL Areas and ≥ 4-Foot-Thickness) and Removal (TD and QP-S DNAPL Areas):** targeted treatment of multiple upland areas of PTWs via *in situ* solidification and targeted removal/off-site disposal of sediment PTWs, passive groundwater treatment, and soil and sediment capping
- **Alternative 6 – Targeted PTW Solidification (RR and MC DNAPL Areas and ≥ 2-Foot-Thickness) and Removal (TD, QP-S, and QP-U DNAPL Areas):** targeted treatment of multiple upland areas of PTWs via *in situ* solidification and targeted removal/off-site disposal of upland and sediment PTWs, passive groundwater treatment, and soil and sediment capping
- **Alternative 7 – PTW Solidification (Upland) and Removal (Sediment):** treatment of all upland PTWs via *in situ* solidification, treatment of all sediment PTWs via removal/off-site disposal, and soil and sediment capping. The purpose of treating or removing all PTW is to eliminate sources of groundwater contamination to a greater extent than other previous alternatives
- **Alternative 8 – PTW Removal (Upland and Sediment):** treatment of all upland and sediment PTWs via removal/on-site *ex situ* thermal treatment, and soil and sediment capping
- **Alternative 9 – Solidification and Removal of Upland PTW and Contaminated Soil, and Removal of Sediment PTW and Contaminated Sediment:** treatment of all upland PTWs and contaminated soil via *in situ* solidification or removal/on-site *ex situ* thermal treatment, treatment of all sediment PTWs and contaminated sediment via removal/on-site *ex situ* thermal treatment, and soil and sediment capping
- **Alternative 10 – Removal of Upland PTW, Sediment PTW, Contaminated Soil, and Contaminated Sediment:** treatment of all PTWs and contaminated soil and sediment via removal/on-site *ex situ* thermal treatment, 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. Also, for the purposes of the FS, it was assumed that the habitat area would consist of a 100-foot-wide corridor along the shoreline. There would be limitations on allowable work within the area and remedial components requiring future access for monitoring or maintenance, such as PRBs or groundwater extraction wells, would be placed outside and east of the habitat area.

The components of Alternatives 2 through 10 are depicted on Figures ES-5 through ES-14, respectively.

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 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 and tribal acceptance; and
9. Community acceptance.

Consistent with 40 CFR 300.430, each alternative is first evaluated using the threshold criteria of Overall Protectiveness of Human Health and the Environment and Compliance with ARARs. For threshold criteria, each alternative is identified as meeting or not meeting the criteria. If it is not technically practicable to comply with an ARAR, EPA may grant a technical impracticability (TI) waiver under certain circumstances, as listed in 40 CFR 300.430(f)(1)(ii)(C).

The alternatives that meet the threshold criteria are evaluated further with respect to the balancing criteria. For all of the balancing criteria except cost, each alternative is evaluated using a qualitative scale to rate the relative degree (i.e., low, moderate, high) to which the alternative meets the requirements of that criterion. For cost, the evaluation is based on estimated capital and long-term operation, maintenance, and monitoring (OM&M) costs[2]. The two modifying criteria are evaluated by EPA at a later stage in the CERCLA process.

A summary of the comparative rating of alternatives is provided in Table ES-2. Results of the comparative analysis are discussed below.

[2] 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.

Threshold Criteria Comparison

This section presents a comparative analysis of the two threshold criteria: Overall Protection of Human Health and the Environment, and Compliance with ARARs.

Overall Protection of Human Health and the Environment

This threshold 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 comply with ARARs. This threshold criterion also evaluates whether the alternative achieves the RAOs for protection of human health and the environment.

The adequacy of how the risks associated with the exposure pathways delineated in the RAOs for protection of human health and the environment are eliminated, reduced, or controlled through treatment, engineering, or institutional controls for each alternative describes its **protectiveness**. However, the **Overall Protectiveness** threshold criterion draws on the assessments conducted under other evaluation criteria, especially long-term effectiveness and permanence, and short-term effectiveness. The Overall Protectiveness of Human Health and the Environment criterion was rated as “No,” or “Yes,” based on consideration of whether: 1) all exposure pathways are mitigated (i.e., the alternative is protective); 2) the alternative provides long-term effectiveness and permanence; and 3) the alternative does not pose a high short-term risk.

RAOs for Protection of Human Health

Alternative 1 does not achieve any of the RAOs for protection of human health. Alternatives 2 through 6 will achieve the RAOs for human health that focus on protection of beach users, subsistence fishers, upland residents, commercial workers, and construction workers. However, Alternatives 2 through 6 will not achieve the RAO to restore groundwater to its highest beneficial use (drinking water) by meeting MCLs because PTWs that cause the groundwater contamination remain in place to varying degrees. Alternatives 7 through 10, which treat or remove all known PTWs that are sources to groundwater contamination[3], have a greater effect on plume reduction than other alternatives (see Figure ES-16); however, groundwater modeling predicts that the RAO to restore groundwater to its highest beneficial use (drinking water) by meeting all MCLs would not be achieved for all COCs by Alternatives 7 through 10. Groundwater modeling predicts that groundwater concentrations will meet MCLs for benzene within 100 years under Alternatives 8 and 10 and will meet MCLs for benzo[a]pyrene under Alternative 10. For all alternatives, institutional controls that specifically address use of drinking water may be required in perpetuity.

There would be a heavier reliance on institutional controls to restrict activities that may compromise the integrity of the soil cap for Alternatives 2 through 6; whereas a thinner soil cap may be acceptable for Alternatives 7 through 10, in which all PTWs are removed

[3] All “known PTWs” refers to PTWs identified during site investigations supporting the FS. It is anticipated that the lateral and vertical extent of PTWs in both the upland and aquatic areas of the Site will be based on a field performance standard that would be developed during remedial design. It is also anticipated that small volumes and masses of DNAPL residuals could be inadvertently missed during remedial implementation.

or treated[4]. Alternatives 2 through 10 would all initially rely on institutional controls to control exposure to contaminated sediment and surface water by restricting activities that could cause damage to sediment caps designed to mitigate the release of contamination into surface water. However, Alternatives 7 through 10 would rely less on caps, which may not be required in perpetuity because all PTWs are removed from the aquatic environment.

RAOs for Protection of the Environment

Alternative 1 does not achieve any of the RAOs for protection of the environment. Alternatives 2 through 10 will achieve the RAOs for the environment that focus on protection of upland wildlife and plants, as well as aquatic benthos, fish, plants, and aquatic-dependent wildlife. There would be a heavier reliance on institutional controls to restrict activities that may compromise the integrity of the soil cap for Alternatives 2 through 6; whereas a thinner soil cap may be acceptable for Alternatives 7 through 10, in which all known PTWs are removed or treated. Alternatives 2 through 10 would all rely on institutional controls to control exposure to contaminated sediment and surface water by restricting activities that could cause damage to sediments caps designed to mitigate the release of contamination into surface water. However, there would be a lesser reliance on caps in perpetuity for Alternatives 7 through 10 because all known PTWs are removed from the aquatic environment.

Overall Protection of Human Health and the Environment Summary

Alternative 1 would not meet this threshold criterion. Alternatives 2 through 10 would meet this threshold criterion. Alternatives 2 through 6 leave varying amounts of known PTWs in place and rely on engineering and institutional controls to be protective. Alternatives 7 through 10 would also require engineering and institutional controls to be protective, but they may be more limited than those associated with Alternatives 2 through 6.

Compliance with ARARs

This threshold 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 Safe Drinking Water Act (SDWA), which requires achievement of groundwater MCLs throughout the Site. The degree to which MCLs would be achieved for each alternative varies based on the amount, nature, and location of PTWs addressed.

As described in Section 7.1.1.2, the Compliance with ARARs criterion was rated as “No” or “Yes with TI Waiver.”

Compliance with the MCL ARAR

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,

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[4] A full upland soil cap may not be necessary in other alternatives where portions of the upland soils have been excavated or treated, and therefore, do not pose a dermal or inhalation exposure risk.

and arsenic 100 years following implementation of each alternative. Results are provided on Figure ES-16 and are summarized below:

- Benzene was predicted to exceed its MCL after 100 years for Alternatives 1 through 7 and 9. It was predicted to achieve its MCL after 28 years for Alternative 8, and after 14 years for Alternative 10.
- Benzo(a)pyrene was predicted to exceed its MCL in groundwater after 100 years for all alternatives except for Alternative 10. For Alternative 10, the groundwater model predicted that the benzo(a)pyrene MCL would be achieved when construction is complete.
- Arsenic was predicted to exceed its MCL in groundwater 100 years following implementation of all alternatives.

Alternative 2 slightly reduced the estimated volume of groundwater exceeding MCLs after 100 years (by 13 percent for the aggregate plume). 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 (ranging from 33 to 50 percent aggregate reduction) and significantly reduced by implementing Alternatives 7 through 10 (ranging from 79 to 93 percent aggregate reduction).

Compliance with ARARs Summary

Alternative 1 does not satisfy the threshold criteria for compliance with ARARs. Alternatives 2 through 10 would satisfy the threshold criterion for compliance with ARARs, with the exception of meeting MCLs everywhere in groundwater. If meeting MCLs in groundwater is deemed technically impracticable, EPA may consider granting a TI waiver.

Threshold Criteria Summary

Overall protection of human health and the environment and compliance with ARARs serve as threshold determinations in that they must be met by any alternative in order for it to be eligible for selection.

As described above, Alternative 1 does not meet either threshold criterion and, therefore, is not carried forward in the Balancing Criteria comparison. Alternatives 2 through 10 would satisfy the threshold criterion for compliance, with the exception of meeting MCLs everywhere in groundwater. If meeting MCLs in groundwater is deemed technically impracticable, EPA may consider granting a TI waiver. Therefore, Alternatives 2 through 10 are carried forward in the Balancing Criteria comparison. Section 7 includes the detailed analysis used to evaluate these threshold criteria that drew on evaluation of the balancing criteria and interpretation of groundwater modeling results.

Balancing Criteria Comparison

Long-Term Effectiveness and Permanence

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

- Alternatives 2 and 3 would not substantially reduce the volume of contaminated materials. In particular, these alternatives would rely on passive controls with a risk of failure to address higher-risk PTWs. Therefore, these alternatives are rated low for this criterion.
- Alternatives 4, 4a, 5, and 6 would achieve a significantly larger reduction in the volume of contamination compared to Alternatives 2 and 3, and would also improve effectiveness by treating or removing deep DNAPL and all or most of the DNAPL areas targeted due to their proximity to Lake Washington and/or mobilization potential. However, a significant volume of PTWs and contaminated groundwater would remain on site. Therefore, these alternatives are rated moderate for this criterion.
- Alternatives 7 through 10 would remove or treat all known PTWs. Alternatives 9 and 10 remove or treat additional contaminated soil and sediment, but the vast majority of the contaminant mass is present in the PTWs. With the exception of a smaller residual arsenic plume for Alternative 10, all of these alternatives provide for similar and substantial reductions in the volume of contaminated groundwater. These alternatives are all rated high for this criterion.

Reduction of Toxicity, Mobility, or Volume through Treatment

This balancing criterion evaluates the degree to which each remedial alternative reduces toxicity, mobility, or volume through treatment. The alternatives employ two primary treatment methods for PTW:

- *In situ* solidification of upland PTWs (Alternatives 3, 4a, 5, 6, 7, and 9); and
- On-site thermal treatment of PTWs (Alternatives 8, 9, and 10).

For the purposes of this FS, treatment by thermal destruction technologies (incineration/thermal treatment) 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 bind COCs.

Groundwater treatment would be achieved through treatment of PTWs 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).

Alternatives 2 through 10 were rated with respect to this criterion as follows:

- RCM and amended sand caps in Alternative 2 would provide negligible treatment of PTWs or groundwater. This alternative is rated low.
- Alternatives 3 and 4a would treat 10 and 6 percent of PTWs, respectively, via *in situ* solidification. By targeting deep PTWs for treatment and by using a PRB to treat groundwater near the shoreline, these alternatives would achieve modest reductions in groundwater volume and mass flux. However, these alternatives are rated low because only a small portion of PTWs would be addressed by treatment.
- Alternative 4 includes negligible treatment of PTWs, and would achieve only modest reductions in groundwater volume and mass flux by removing PTWs in the QP-U DNAPL Area and installing a PRB. This alternative is rated low.
- Alternatives 5 and 6 would treat approximately 47 and 70 percent of PTWs, respectively. These alternatives would also achieve more substantial reductions in groundwater volume and flux compared to the earlier alternatives. These alternatives are rated moderate.
- Alternative 7 would treat approximately 85 percent of PTWs through *in situ* solidification, while Alternative 8 would treat all PTWs through on-site thermal treatment. In addition, both alternatives would greatly reduce the volume and mass flux of contaminated groundwater. Both alternatives are rated high for this criterion. Alternative 8 satisfies this criterion to a higher degree than Alternative 7 due to more complete treatment of PTWs and the more permanent nature of treatment and reduction in contaminant volume.
- Alternatives 9 and 10 would treat all PTWs 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 thermal treatment, while Alternative 10 would use on-site thermal treatment. Alternative 10 also would achieve the greatest reduction in groundwater plume volume. These alternatives are rated high for this criterion.

Short-Term Effectiveness

This balancing criterion is used to evaluate the effects and potential risks associated with remedial alternative implementation, considering the protection of the community, the protection of workers, 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 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 BMPs, but the potential for increased exposures, or releases to the neighboring community, on-site workers, and the environment could occur due to failure of construction equipment and/or protective controls when remediating greater volumes of contaminated materials. In addition, several impacts would be challenging to control, including the following:

- Vapor and dust 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.
- Vapor and dust emissions from handing, stockpiling, and transporting contaminated materials off-site (Alternatives 2 through 7).
- Alternatives involving on-site thermal treatment of contaminated materials (Alternatives 8, 9, and 10) also would have the potential for air emissions from on-site handling and treatment; however, these emissions would be more easily controlled by available process technologies employed in the treatment train.
- Water quality impacts from capping and dredging. Impacts from dredging 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.
- "Quality of life" impacts to the community from construction noise, traffic, and aesthetics could result. However, these are not related to risks caused from potential exposure to contaminated media.

The short-term effectiveness of Alternatives 2 through 10 is compared in Table ES-2 and summarized as follows:

- Alternative 2 has a construction duration of less than 1 year5. This alternative would have the greatest short-term effectiveness and is rated high for this criterion. Alternative 2 would disturb a minimum of contaminated material, and would present the lowest risk to workers, the community, and the environment.
- Alternative 3 has a construction duration of approximately 1.5 years. This alternative 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 PTWs, and the construction of a PRB and DNAPL collection trenches. These activities all create the potential for exposure to dust and vapors for both the community and Site workers; however, no unacceptable risk is expected to the community or workers because of the use of protective equipment and practices. In addition, the total volume of soil disturbed in this alternative would be relatively modest. This alternative is also rated high for short-term effectiveness.
- Alternative 4, which has a construction duration of approximately 2.5 years, would have increased short-term impacts from dredging of PTWs in sediment. The greatest impacts would be expected in the aquatic environment; however, BMPs would be used to minimize water quality impacts and habitat recovery would be expected to occur relatively quickly following placement of the residuals cover over dredged areas. Alternative 4 also would involve excavation

[5] The construction durations noted in this section do not include time required for remedial design.

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 4a, which also has a construction duration of approximately 2.5 years, would present a lower short-term risk than Alternative 4 because the QP-U DNAPL area is solidified rather than excavated, which is expected to cause fewer air emissions. In addition, a significantly smaller volume of contaminated sediments is dredged than in Alternative 4. This alternative is rated high for short-term effectiveness.

- Alternative 5, which has a construction duration of 2.5 years, has a similar 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 rather than excavation, resulting in fewer short-term impacts. This alternative is rated moderate for short-term effectiveness.

- Alternative 6 would have a slightly longer construction duration (3 years) than Alternatives 4, 4a, and 5. This alternative would have a similar potential as Alternatives 4 and 5 for water quality impacts through dredging, but slightly greater short-term impacts due to more extensive upland construction (primarily *in situ* solidification). This alternative is rated moderate for short-term effectiveness.

- Alternative 7 involves *in situ* stabilization of known upland PTWs and dredging of known aquatic PTWs, and would have a construction duration of approximately 4.5 years. Dredged materials would be trucked offsite for disposal. Similar to Alternatives 3 through 6, these activities all create the potential for exposure to dust and vapors for both the community and Site workers; however, no unacceptable risk is expected to the community or workers because of the use of protective equipment and practices. The greatest impacts would be expected in the aquatic environment; however, BMPs would be used to minimize water quality impacts, and habitat recovery is expected to occur relatively quickly following placement of the residuals cover over dredged areas. Although Alternative 7 would have greater short-term impacts than Alternatives 5 and 6 because of the substantially larger volume of dredging, this alternative is rated moderate for short-term effectiveness (the same as Alternatives 5 and 6) to differentiate it from Alternatives 8 through 10, which have even greater short-term impacts.

- Alternative 8 involves excavation of upland PTWs, the same dredging of PTW sediments as Alternative 7, and on-site thermal treatment of all removed PTW materials. Alternative 8 would have a longer construction period (approximately 5.5 years). It would include additional materials handling and stockpiling of PTW materials, as well as air emissions from on-site treatment; therefore, it would likely have higher short-term impacts than Alternative 7. Alternative 8 is rated low for short-term effectiveness.

- Alternatives 9 and 10 would have the greatest potential short-term impacts to workers, the community, and the environment, and would have very long construction durations (10 and 12 years, respectively). Therefore, they 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.

Implementability

This balancing criterion is used to evaluate the relative implementability of Alternatives 2 through 10, 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 RCM and amended sand 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 there is increasing field experience with the installation of RCM and amended sand caps, there is no field information/experience regarding the maintenance/repair of such caps.

Differences in complexity include the following:

- Alternatives that involve RCM or amended sand caps (Alternatives 2 through 6) would require ongoing maintenance and monitoring in perpetuity.
- Alternatives that involve PRBs (Alternatives 3 through 6) would require bench and/or pilot testing of potential treatment media, though this is not considered to be an implementability concern. PRBs will also require ongoing maintenance and monitoring in perpetuity.
- Alternatives involving *in situ* solidification (Alternatives 3, 4a, 5, 6, 7, and 9) would require bench and/or pilot testing of potential amendment mixtures to determine proper mixes to optimize effectiveness, though this is not considered to be an implementability concern.
- Alternatives that involve more construction elements are generally more complex to implement.
- Alternatives that include mechanical dredging of DNAPL-containing sediments in the QP-S DNAPL area have increased complexity due to installation and removal of sheetpile shoring systems and removal of relatively deep sediments.
- 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. On-site thermal treatment would also require air emission controls and extensive monitoring.

All alternatives would require coordination with numerous federal and state regulatory agencies, during remedial design, to ensure that all ARARs (including ESA consultation and substantive compliance with Section 401 and 404 of the CWA), policies, and regulations are met. Coordination with these agencies, by EPA, has become routine in the Puget Sound area of Washington. Little coordination is expected during remedial action because reasons for coordination would be addressed during remedial design. Maintenance of caps would require coordination with the Department of Natural Resources (DNR) and the Muckleshoot Tribe regarding future aquatic land use and Tribal treaty rights. Alternatives with longer construction durations and/or more construction elements 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 ES-2 and summarized as follows:

- Alternative 2 would be the easiest alternative to construct. This alternative has fewer construction elements (3) than the subsequent alternatives, would present no unusual construction challenges, and necessary engineering and construction services are available. However, there are concerns about the successful use of RCM caps, and the sediment capping technologies will require maintenance and monitoring. This alternative is rated moderate for implementability.

- Alternative 3 would involve slightly more technical complexity compared to Alternative 2 due to additional treatment and containment measures, including PRBs that will require maintenance and monitoring in perpetuity. This alternative is also rated moderate for implementability.

- Alternative 4 would have greater technical complexity compared to Alternative 3, with two additional construction elements including dredging of DNAPL-containing sediments. However, Alternative 4 reduces the acreage of sediment covered by RCM caps, which reduces long-term monitoring and maintenance obligations. This alternative is rated moderate for implementability.

- Alternative 4a reduces the acreage of sediment covered by RCM caps compared to Alternatives 2 and 3, which reduces long-term monitoring maintenance obligations. In addition, unlike Alternative 4, this alternative does not implement mechanical dredging of DNAPL-containing sediments in the nearshore area. This alternative is rated high for implementability

- Alternatives 5 and 6 are similar to Alternative 4 but would have more complicated upland remedial components due to more extensive solidification. These alternatives are rated moderate for implementability.

- Alternative 7 involves more extensive solidification and dredging than Alternative 6, but has significantly fewer construction elements and long-term maintenance and monitoring obligations. This alternative is rated moderate for implementability.

- 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 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.

Cost

The estimated present worth cost for each alternative, in 2015 dollars and using a discount factor of 1.4 percent, is listed in Table ES-2. Capital and OM&M costs are also provided in Table ES-2. Alternative costs ranged as follows:

- Alternative 2 would have the lowest capital ($20 million [M]) and total ($28M) costs of the alternatives. Capital costs are fairly evenly split between upland capping and sediment capping/ENR components. Estimated OM&M costs ($8.2M) are largely for the assumed periodic repair of the RCM and amended sand caps.

- Alternative 3 would have somewhat higher capital ($25M) and OM&M ($10M) costs than Alternative 2 due to the *in situ* solidification of deep PTWs and installation of the DNAPL collection trenches and a PRB. These measures result in a somewhat higher total cost ($35M).

- Alternative 4 would have much higher capital ($41M) and total ($46M) costs than Alternative 3, primarily due to dredging instead of capping of several DNAPL-impacted areas and removal of the QP-U DNAPL Area. The OM&M costs of this alternative ($5.2M) are lower than Alternative 3 because OM&M costs for dredging residual covers are less than for RCM or amended sand caps.

- Alternative 4a would have a lower capital cost ($33M) than Alternative 4 because the QP-S Area would be capped instead of dredged, and *in situ* solidification of the QP-U DNAPL Area would be cheaper than removal/off-site disposal. The OM&M costs ($5.6M) would be slightly higher than Alternative 4, primarily due to OM&M of the QP-S DNAPL Area cap. The total cost of this alternative ($39M) is more than Alternative 3 but less than Alternative 4.

- Alternative 5 would have a higher capital cost ($43M) than Alternative 4a due the expanded treatment (via *in situ* solidification) of upland PTWs and removal of the QP-S DNAPL Area. The OM&M cost of this alternative ($4.5M) is less than Alternatives 4a because no DNAPL collection trenches are needed, due to the increased volume of PTW being treated. The total cost of this alternative ($48M) is slightly higher than Alternative 4.

- Alternative 6 would have a much higher capital cost ($58M) because it would remove the QP-U DNAPL Area and expand solidification treatment of upland PTWs and it would have the same OM&M cost ($4.5M) as Alternative 5. The total cost of this alternative is $62M.

- Alternative 7 would have a much higher capital cost ($79M) than Alternative 6, primarily due to treatment of all upland PTWs via *in situ* solidification. The OM&M cost of $2.9M, based on groundwater monitoring and inspection/maintenance of the upland cap, engineered sand cap, and ENR, would be lower than in Alternative 6. The total cost of this alternative is $82M.

- Alternative 8 would have much higher capital ($143M) and total ($146M) costs than Alternative 7 because all PTWs would be removed and thermally treated on-site, which has a much higher unit cost than *in situ* solidification of upland PTWs and removal/off-site disposal of PTWs in sediment. The OM&M cost ($2.9M) is the same as Alternative 7.

- Alternative 9 would have much higher capital ($277M) and total ($280M) costs compared to Alternatives 7 and 8 because of the much larger volume of soil and sediments addressed. The OM&M cost ($2.9M) is the same as Alternatives 7 and 8.

- Alternative 10 would have the highest capital ($397M) and total ($425M) costs of the alternatives. These costs are much higher than Alternative 9 because all contaminated soils would be removed and thermally treated onsite, which has a greater unit cost than *in situ* solidification. The OM&M cost ($28M) is also much higher because of long-term operation of a groundwater pump-and-treat system.

Comparative Analysis Summary

In this FS, 11 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.

Alternative 1 does not meet the threshold requirements for overall protectiveness and ARAR compliance and thus was not carried forward in the balancing criteria evaluation. Alternatives 2 through 10 satisfy the Overall Protection of Human Health and the Environment criterion, and would meet all ARARs if a TI waiver is granted for achieving MCLs in groundwater. Alternatives 2 through 10 were carried through to the comparative evaluation against the balancing criteria, as presented in Table ES-2 and summarized as follows:

- **Long-Term Effectiveness and Permanence.** Alternatives 2 and 3 are rated low, Alternatives 4 through 6 are rated moderate, and Alternatives 7 through 10 are rated high for this criterion.

- **Reduction of Toxicity, Mobility, or Volume through Treatment.** Alternatives 2 through 4a are rated low, Alternatives 5 and 6 are rated moderate, and Alternatives 7 through 10 are rated high for this criterion.

- **Short-Term Effectiveness.** Alternatives 2, 3, and 4a are rated high, Alternatives 4, 5, 6, and 7 are rated moderate, and Alternatives 8 through 10 are rated low for this criterion.

- **Implementability**. Alternative 4a is rated high, Alternatives 2, 3, 4, 5, 6, and 7 are rated moderate, and Alternatives 8 through 10 are rated low for this criterion.

- **Cost**. The estimated present worth costs of the alternatives cover a wide range, from $28M for Alternative 2 to $425M for Alternative 10. Capital costs range from $20 M (Alternative 2) to $397M (Alternative 10). OM&M costs range from $2.9M (Alternatives 7 through 9) to $28M (Alternative 10).

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 remedy may be one of the alternatives described in the FS or a combination of elements from different alternatives, as appropriate. State, tribal, and community acceptance of the preferred remedy will be evaluated in the ROD once comments on the FS and proposed plan are received.

EXECUTIVE SUMMARY TABLES

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

Quendall Terminals
Renton, Washington

	Technology General Response Actions	Remedial Technologies/ Process Options	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 4a	Alternative 5	Alternative 6	Alternative 7	Alternative 8	Alternative 9	Alternative 10
			No Action	**Containment**	**Targeted PTW Solidification (RR and MC DNAPL Areas)**	**Targeted PTW Removal (TD, QP-S, and QP-U DNAPL Areas)**	**Targeted PTW Solidification (QP-U DNAPL Area) and Removal (TD DNAPL Area)**	**Targeted PTW Solidification (RR, MC, and QP-U DNAPL Areas and ≥ 4-Foot-Thickness) and Removal (TD and QP-S DNAPL Areas)**	**Targeted PTW Solidification (RR and MC DNAPL Areas and ≥ 2-Foot-Thickness) and Removal (TD, QP-S, and QP-U DNAPL Areas)**	**PTW Solidification (Upland) and Removal (Sediment)**	**PTW Removal (Upland and Sediment)**	**Solidification and Removal of Contaminated Soil and Removal of Contaminated Sediment**	**Removal of Contaminated Soil and Sediment**
Upland DNAPL/Soil	Institutional Controls	Deed and Access Restrictions	--	X	X	X	X	X	X	X	X	X	X
	In Situ Containment	Cover or Cap	--	X	X	X	X	X	X	X	X	X	X
	In Situ Treatment	Solidification	--	--	Deep PTWs2	--	QP-U DNAPL Area and deep PTWs[2]	QP-U DNAPL Area plus shallow PTWs >4-foot cumulative thickness1 and deep PTWs2	ShallowPTWs >2-foot cumulative thickness1 and deep PTWs2	All PTWs	--	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	At former May Creek and Quendall Pond shoreline	--	--	--	--	--	--
		Excavation	--	--	--	QP-U DNAPL Area	--	--	QP-U DNAPL Area	--	All PTWs	All shallow contaminated soil (above approx. 15 feet bgs)	All contaminated soil
	Ex Situ Treatment	On-site Thermal Treatment	--	--	--	--	--	--	--	--			
	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	X
	Monitoring	Biological/Physical Recovery	--	X	X	X	X	X	X	X	X	X	X
	Enhanced Natural Recovery (ENR)	Thin-layer Placement	--	Offshore sediments outside PTW areas exceeding BTV	Offshore sediments outside PTW areas exceeding BTV	Offshore sediments outside PTW areas exceeding BTV	Offshore sediments outside PTW areas exceeding BTV	Offshore sediments outside PTW areas exceeding BTV	Offshore sediments outside PTW areas exceeding BTV	Offshore sediments outside PTW areas exceeding BTV	Offshore sediments outside PTW areas exceeding BTV	Offshore sediments outside PTW areas exceeding BTV	Offshore sediments outside PTW areas exceeding BTV
	In Situ Containment	Engineered Sand Cap	--	Nearshore sediments outside PTW areas	Nearshore sediments outside PTW areas	Nearshore sediments outside PTW areas	Nearshore sediments outside PTW areas	Nearshore sediments outside PTW areas	Nearshore sediments outside PTW areas	Nearshore sediments outside PTW areas	Nearshore sediments outside PTW areas	Nearshore sediments outside areas of PTWs or MCL exceedances	Nearshore sediments outside areas of PTWs or MCL exceedances
	In Situ Treatment	Amended Sand Cap	--	Aquatic DNAPL area DA-6	Aquatic DNAPL area DA-6	--	Aquatic DNAPL area DA-6	--	--	--	--	--	--
		RCM Cap	--	All aquatic DNAPL areas except DA-6	All aquatic DNAPL areas except DA-6	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	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 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 PTWs or MCL exceedances	Nearshore sediments in areas of PTWs 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)	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 Treatment	--	--	--	--	--	--	--	--	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	All removed sediment	--	--	--
Groundwater	Institutional Controls	Deed Restrictions	--	X	X	X	X	X	X	X	X	X	X
	Monitoring	Groundwater Monitoring	--	X	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	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 PTWs 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.

BTV = background threshold value
DNAPL = dense non-aqueous phase liquid
PTW = principal threat waste
QP-U= Quendall Pond-Upland
RCM = Reactive core mat
RR = Railroad

Table ES-2 - Summary of 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 (Note 2)	No	--	--	--	--	Capital	OM&M	Total
2	Containment	Yes	Yes with TI Waiver (Note 3)	○	○	●	◑	20	8.2	$28
3	Targeted PTW Solidification (RR and MC DNAPL Areas)	Yes	Yes with TI Waiver (Note 3)	○	○	●	◑	25	10	$35
4	Targeted PTW Removal (TD, QP-S, and QP-U DNAPL Areas)	Yes	Yes with TI Waiver (Note 3)	◑	○	◑	◑	41	5.2	$46
4a	Targeted PTW Solidification (QP-U DNAPL Area) and Removal (TD DNAPL Area)	Yes	Yes with TI Waiver (Note 3)	◑	○	●	●	33	5.6	$39
5	Targeted PTW Solidification (RR, MC, and QP-U DNAPL Areas and ≥ 4-Foot-Thickness) and Removal (TD and QP-S DNAPL Areas)	Yes	Yes with TI Waiver (Note 3)	◑	◑	◑	◑	43	4.5	$48
6	Targeted PTW Solidification (RR and MC DNAPL Areas and ≥ 2-Foot-Thickness) and Removal (TD, QP-S, and QP-U DNAPL Areas)	Yes	Yes with TI Waiver (Note 3)	◑	◑	◑	◑	58	4.5	$62
7	PTW Solidification (Upland) and Removal (Sediment)	Yes	Yes with TI Waiver (Note 3)	●	●	◑	◑	79	2.9	$82
8	PTW Removal (Upland and Sediment)	Yes	Yes with TI Waiver (Note 3)	●	●	○	○	143	2.9	$146
9	Solidification and Removal of Contaminated Soil and Removal of Contaminated Sediment	Yes	Yes with TI Waiver (Note 3)	●	●	○	○	277	2.9	$280
10	Removal of Contaminated Soil and Sediment	Yes	Yes with TI Waiver (Note 3)	●	●	○	○	397	28	$425

Notes:

[1] Estimated mid-range present worth costs are in 2015 dollars, and were calculated using a discount factor of 1.4 percent. The itemized estimates are provided in Appendix D.

[2] Because this alternative does not satisfy the Threshold Criteria, it is not carried forward in the Balancing Criteria comparison.

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

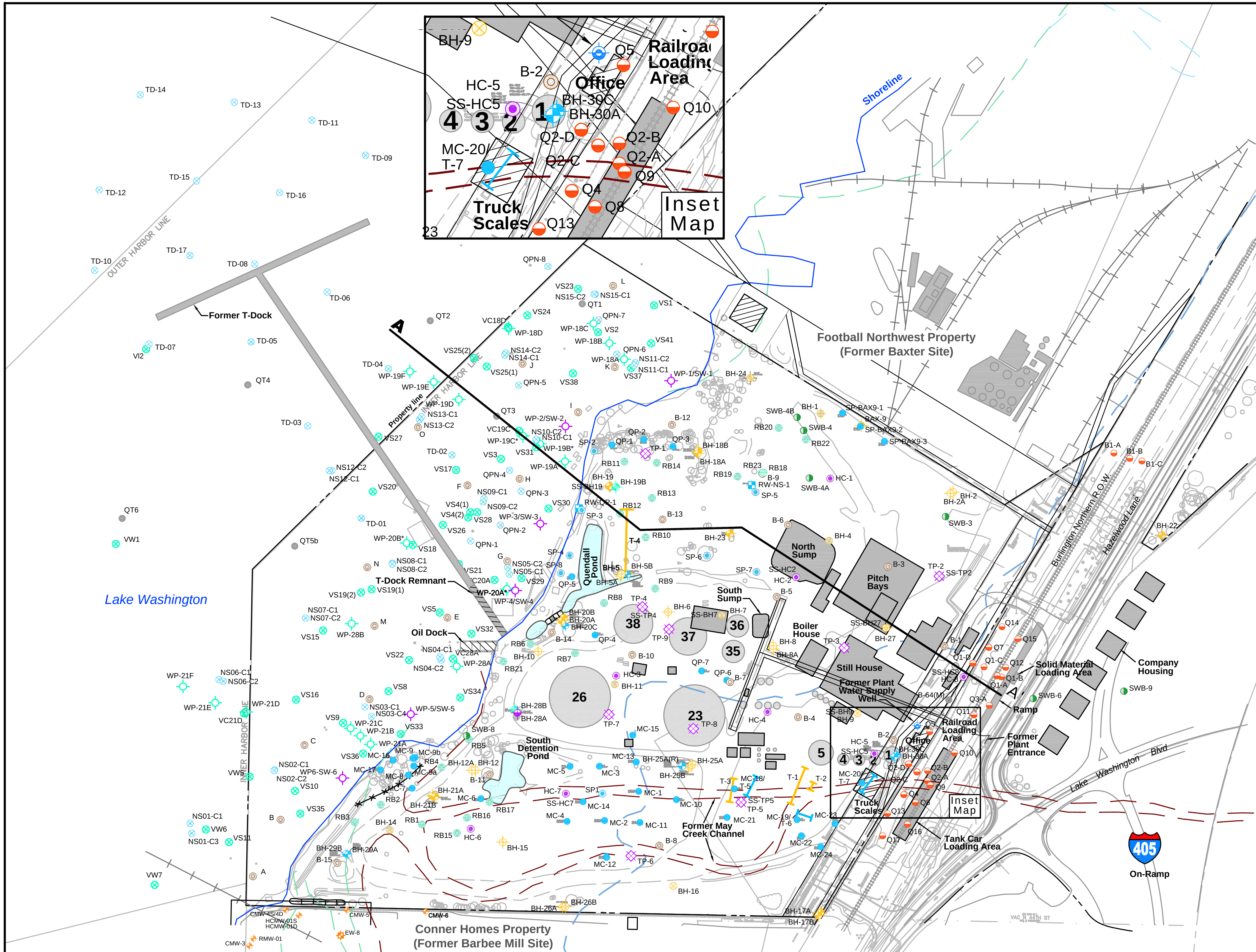
Legend:

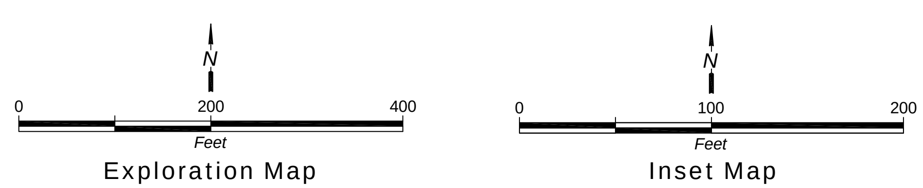
○	The alternative rates low for the criterion.
◑	The alternative rates moderate for the criterion.
●	The alternative rates high for the criterion.

Abbreviations:

DNAPL = dense non-aqueous phase liquid
MC = May Creek
PTW = principal threat wastes
QP-S = Quendall Pond-Sediment
QP-U = Quendall Pond-Upland
RR = Railroad
TD = T-Dock

EXECUTIVE SUMMARY FIGURES





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

Site Plan Showing Historical Features

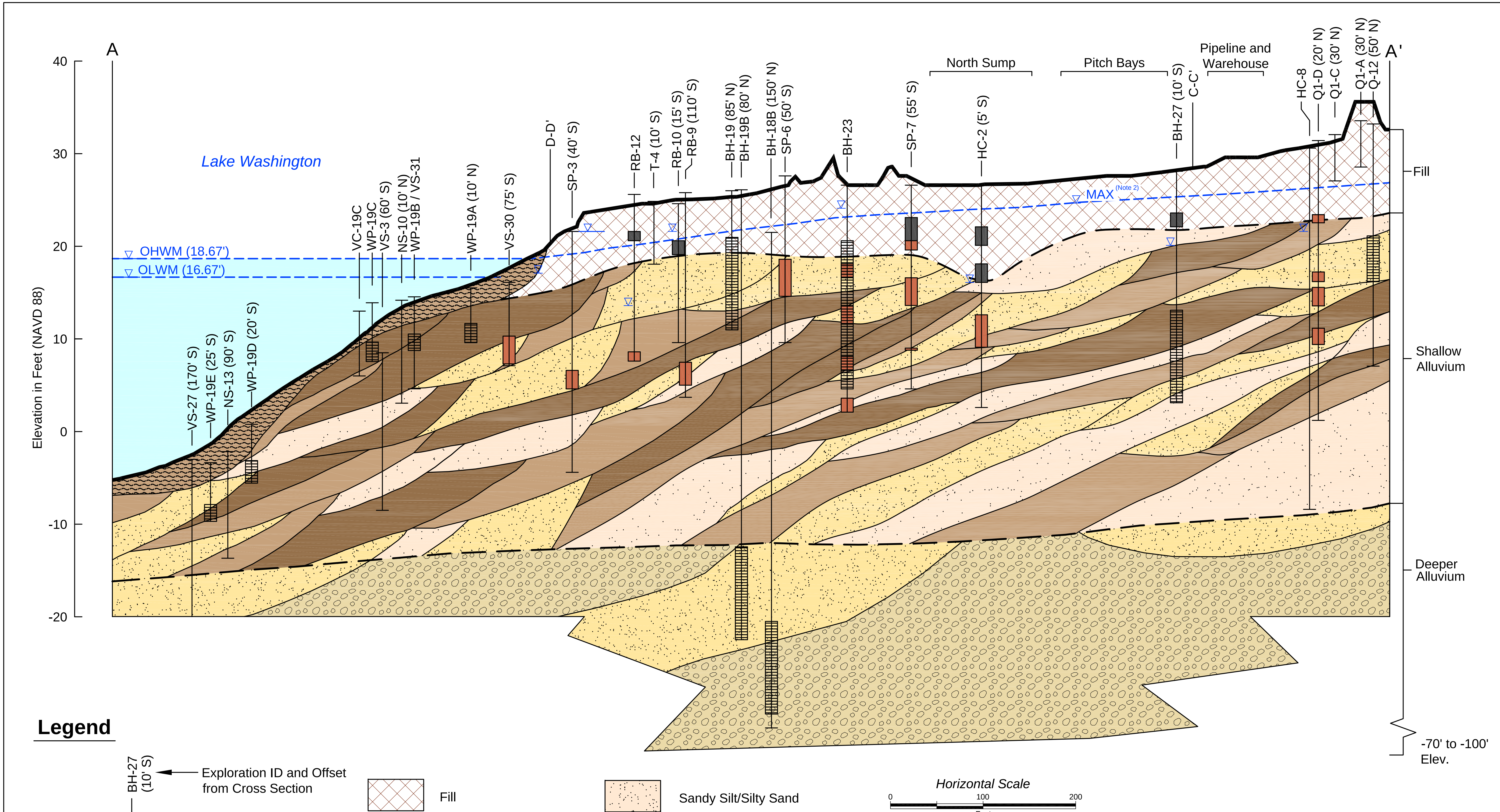
Quendall Terminals Feasibility Study Report
Renton, Washington

Aspect CONSULTING   ARCADIS

FIRM: ASPECT
DRAWN BY: JJP/DAH/SCC

FIGURE NO. ES-1

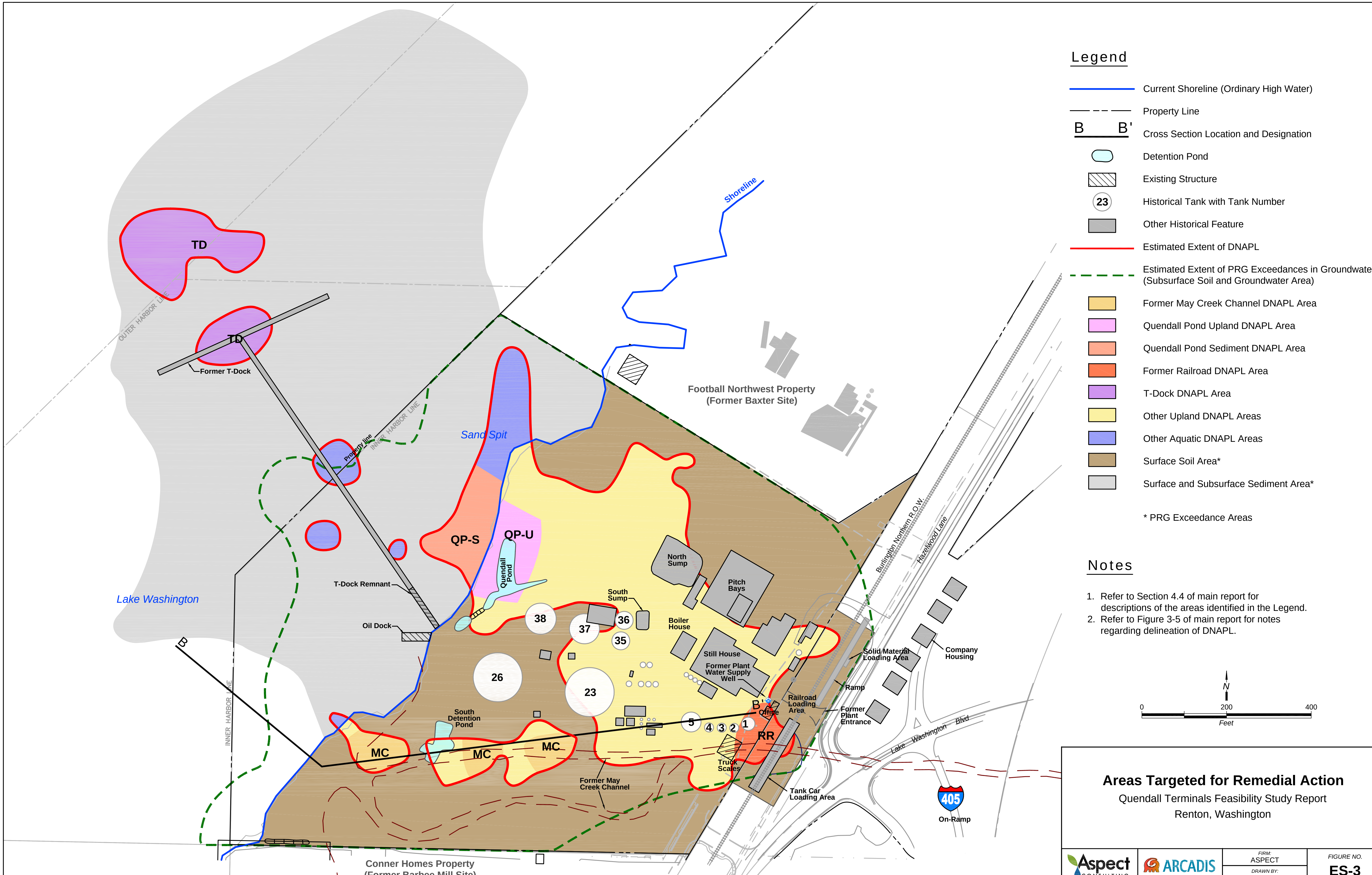
CAD Path: Q:\Quendall\020027 Quendall Terminals\2015-09 Interim Delivery\Executive Summary\020027-3-1.dwg Figure 3-1 (11 x 17) || Coordinate System: NAD 1983 State Plane Washington North FIPS 4601 Feet || Date Saved: Oct 12, 2015 2:42pm || User: scudd



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

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



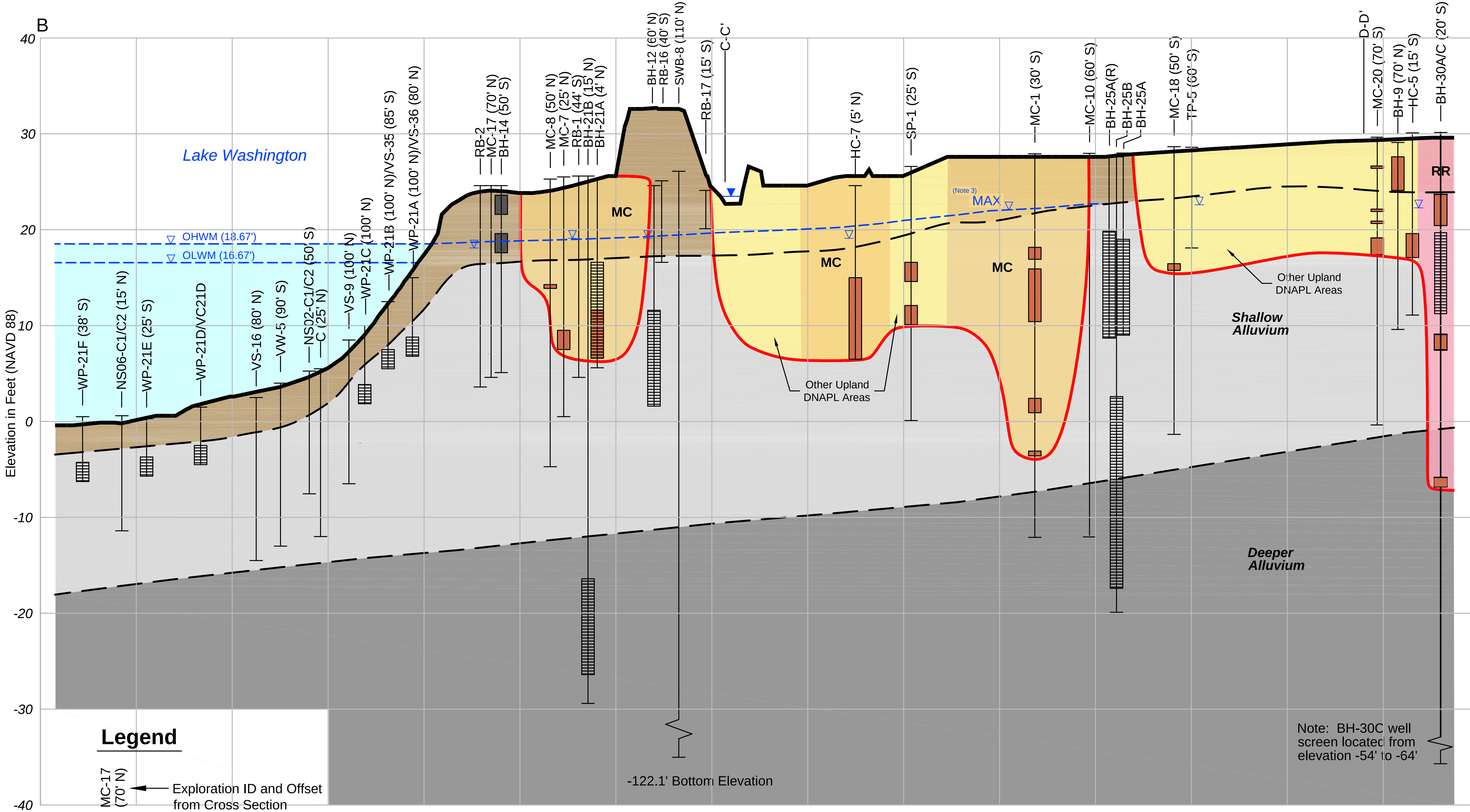
Areas Targeted for Remedial Action

Quendall Terminals Feasibility Study Report

Renton, Washington

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

CAD Path: Q:\Quendall\020027 Quendall Terminals\2015-09 Interim Delivery\Executive Summary\020027-41.dwg Figure 4-1 (11 x 17) || Date Saved: Oct 12, 2015 3:21pm || User: scudd



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

Estimated Extent of DNAPL along Cross Section B-B'

Quendall Terminals Feasibility Study Report

Renton, Washington

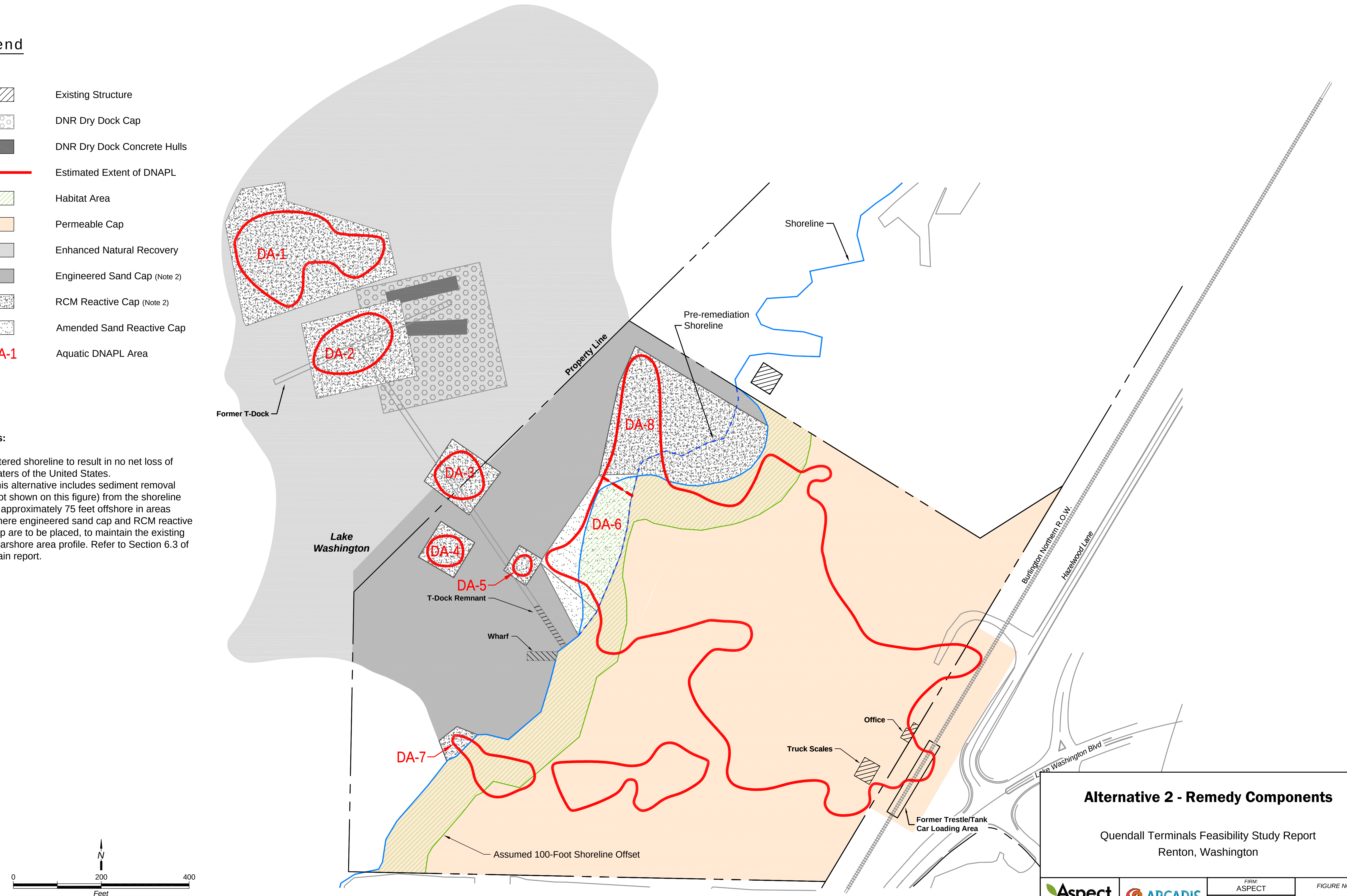
Aspect CONSULTING | ARCADIS | FIRM: ASPECT | DRAWN BY: JJP/DAH/SCC | FIGURE NO. ES-4

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:

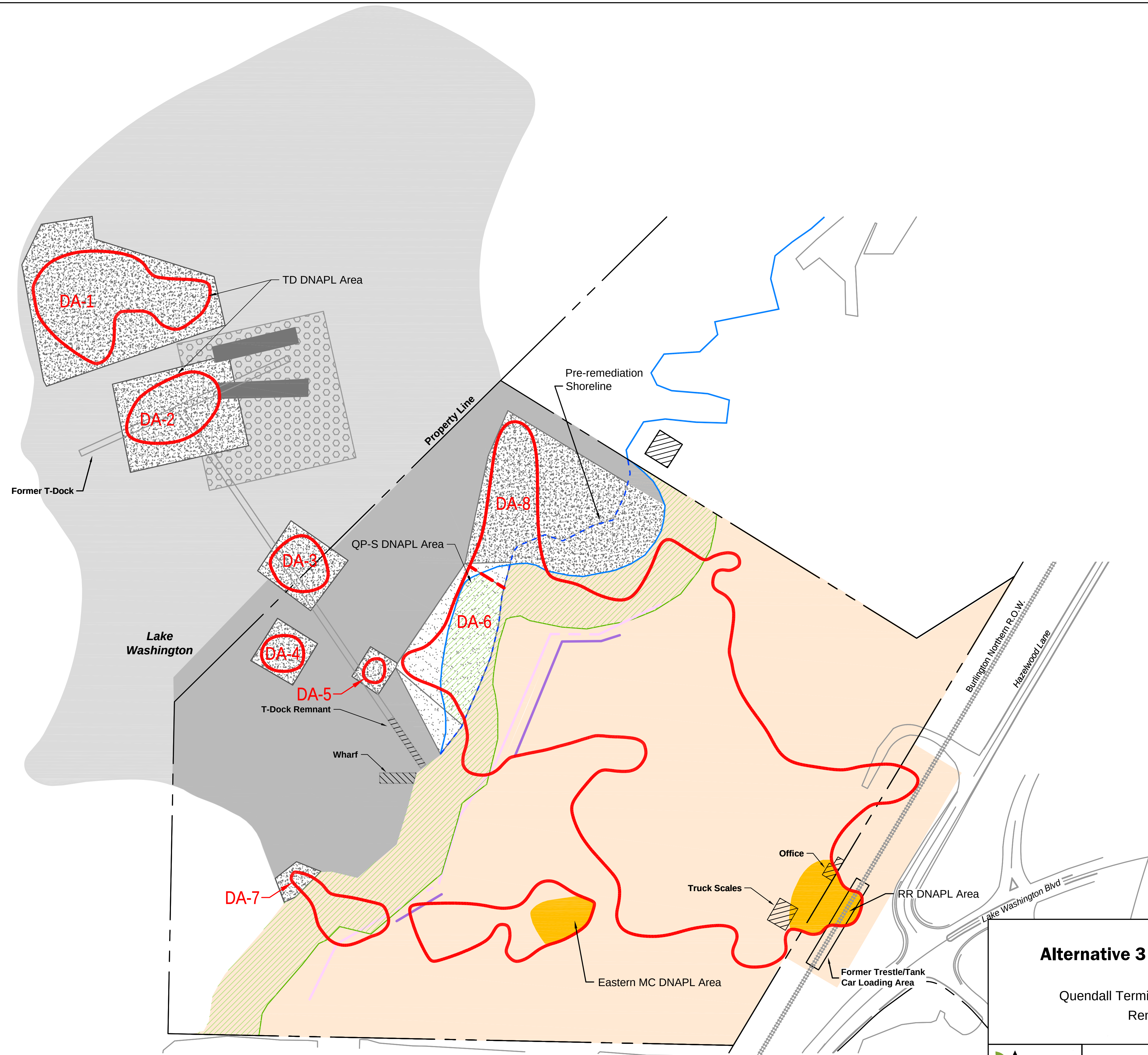
1. Altered shoreline to result in no net loss of waters of the United States.
2. This alternative includes sediment removal (not shown on this figure) from the shoreline to approximately 75 feet offshore in areas where engineered sand cap and RCM reactive cap are to be placed, to maintain the existing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



Alternative 2 - Remedy Components

Quendall Terminals Feasibility Study Report
Renton, Washington

Aspect CONSULTING | ARCADIS | FIRM: ASPECT | DRAWN BY: JJP/PMB/ELG/SCC | FIGURE NO. ES-5



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)
- 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.

Alternative 3 - Remedy Components

Quendall Terminals Feasibility Study Report
Renton, Washington

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

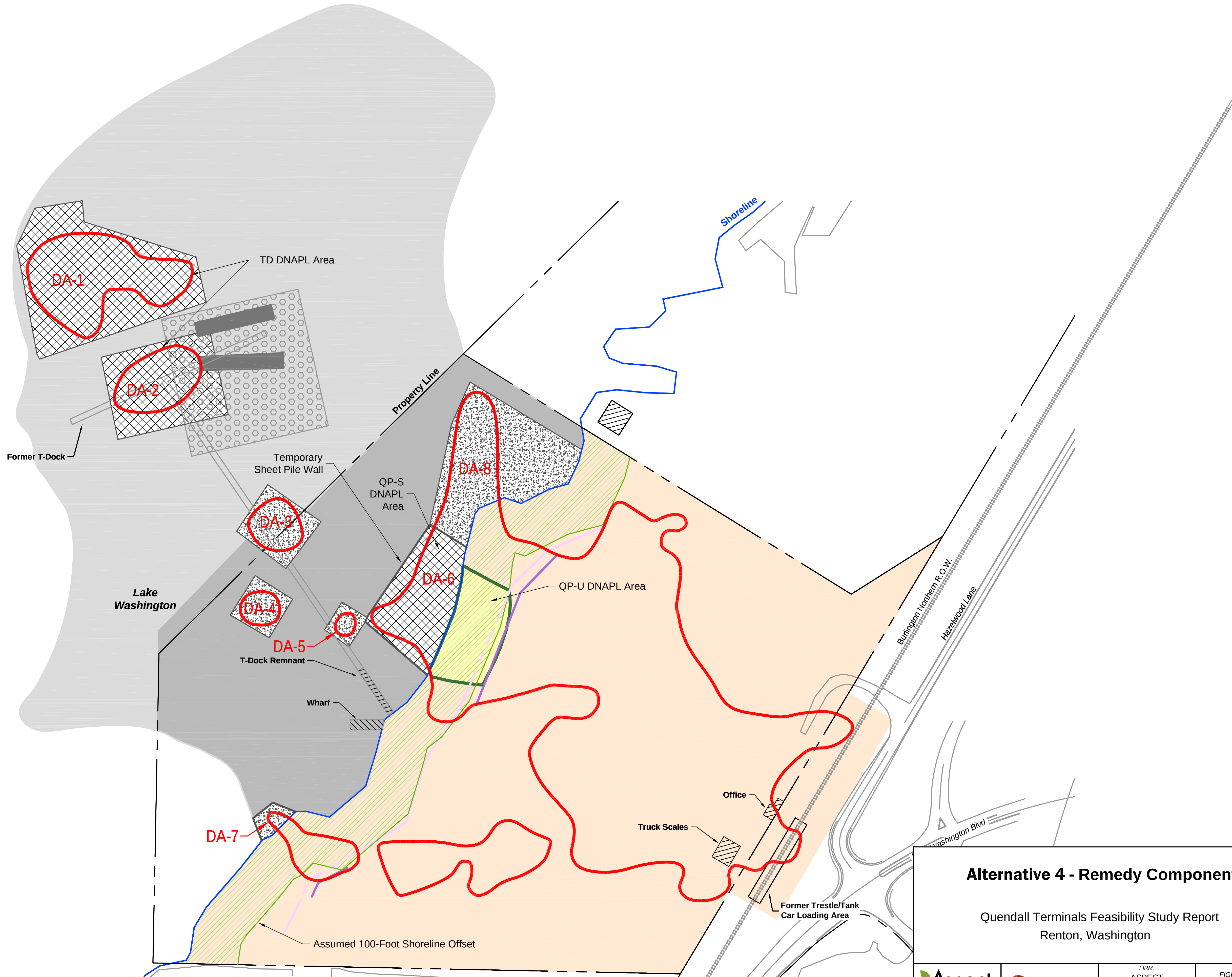
CAD Path: Q:\Quendall\020027 Quendall Terminals\2015-09 Interim Delivery\Executive Summary\020027_Plan-Alternatives 3 and 4a (Shoreline Change).dwg ALT 3 || Date Saved: Oct 12, 2015 3:44pm || User: scudd

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
- 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 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

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

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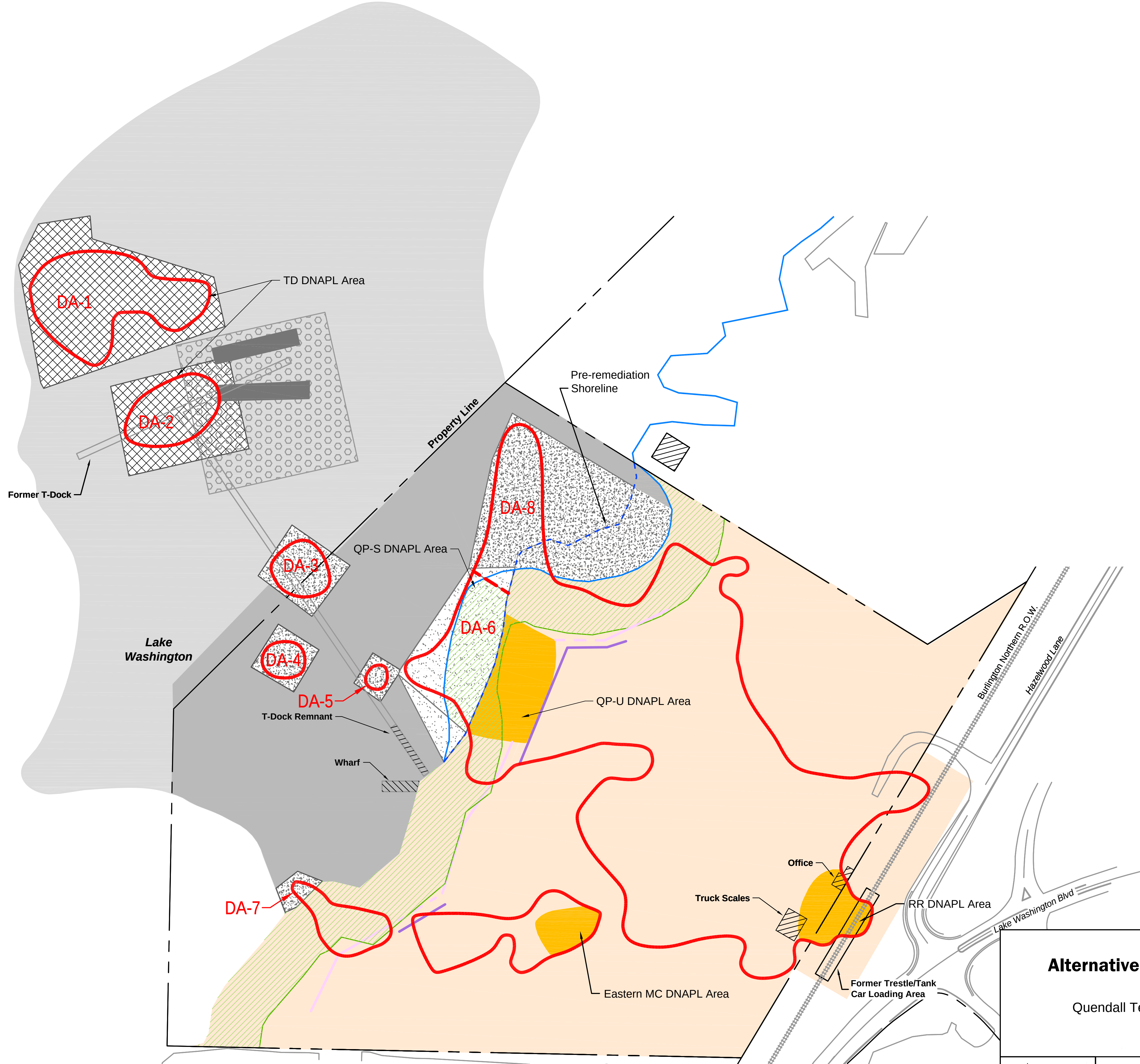

Legend

- 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)
- Dredge Area
- RCM Reactive Cap (Note 1)
- 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 4a - Remedy Components

Quendall Terminals Feasibility Study Report
Renton, Washington

Aspect CONSULTING | ARCADIS

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

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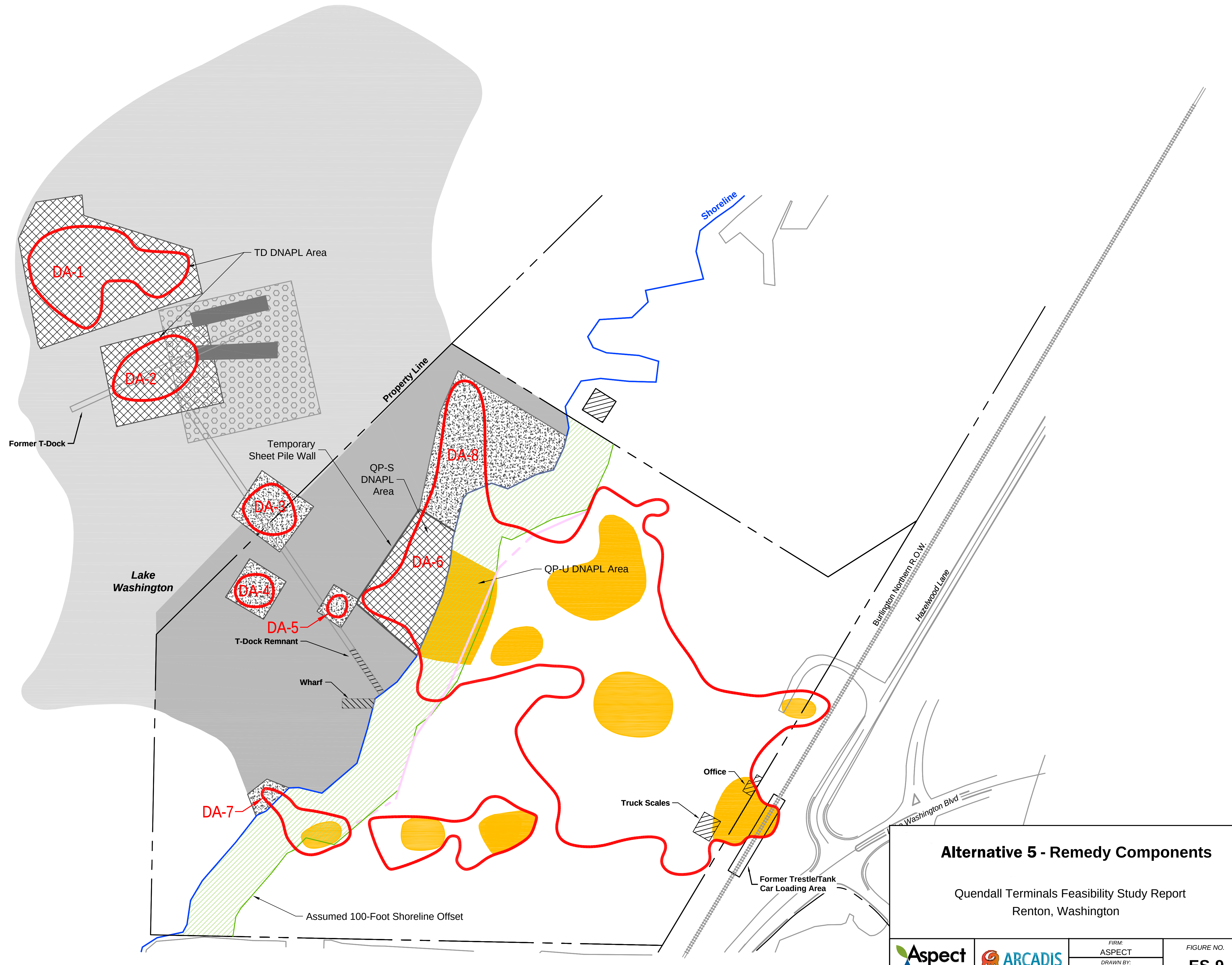
Legend

- 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 4. Refer to Figure 6-6 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 5 - Remedy Components

Quendall Terminals Feasibility Study Report
Renton, Washington

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

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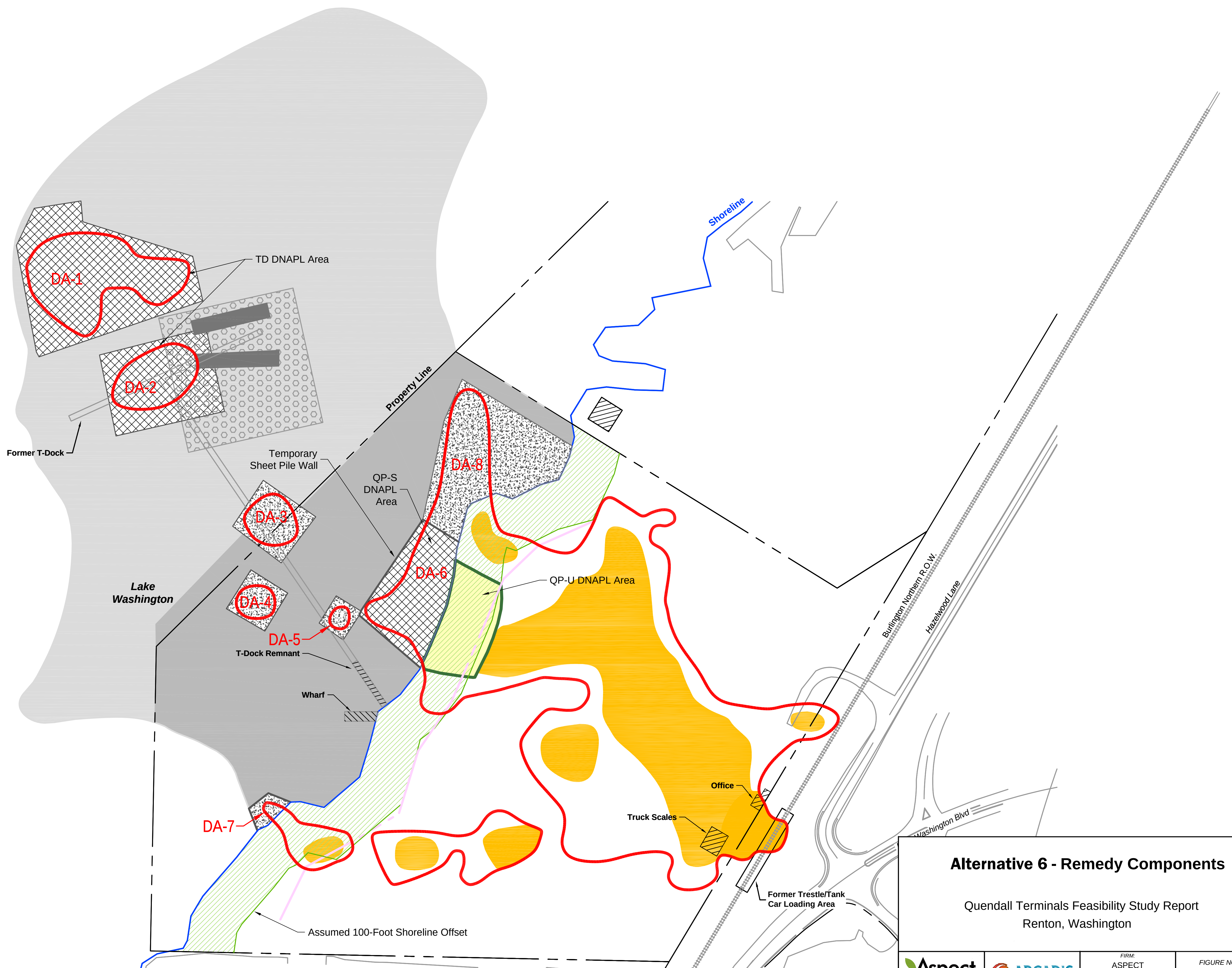
Legend

- 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 4. Refer to Figure 6-6 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 6 - Remedy Components

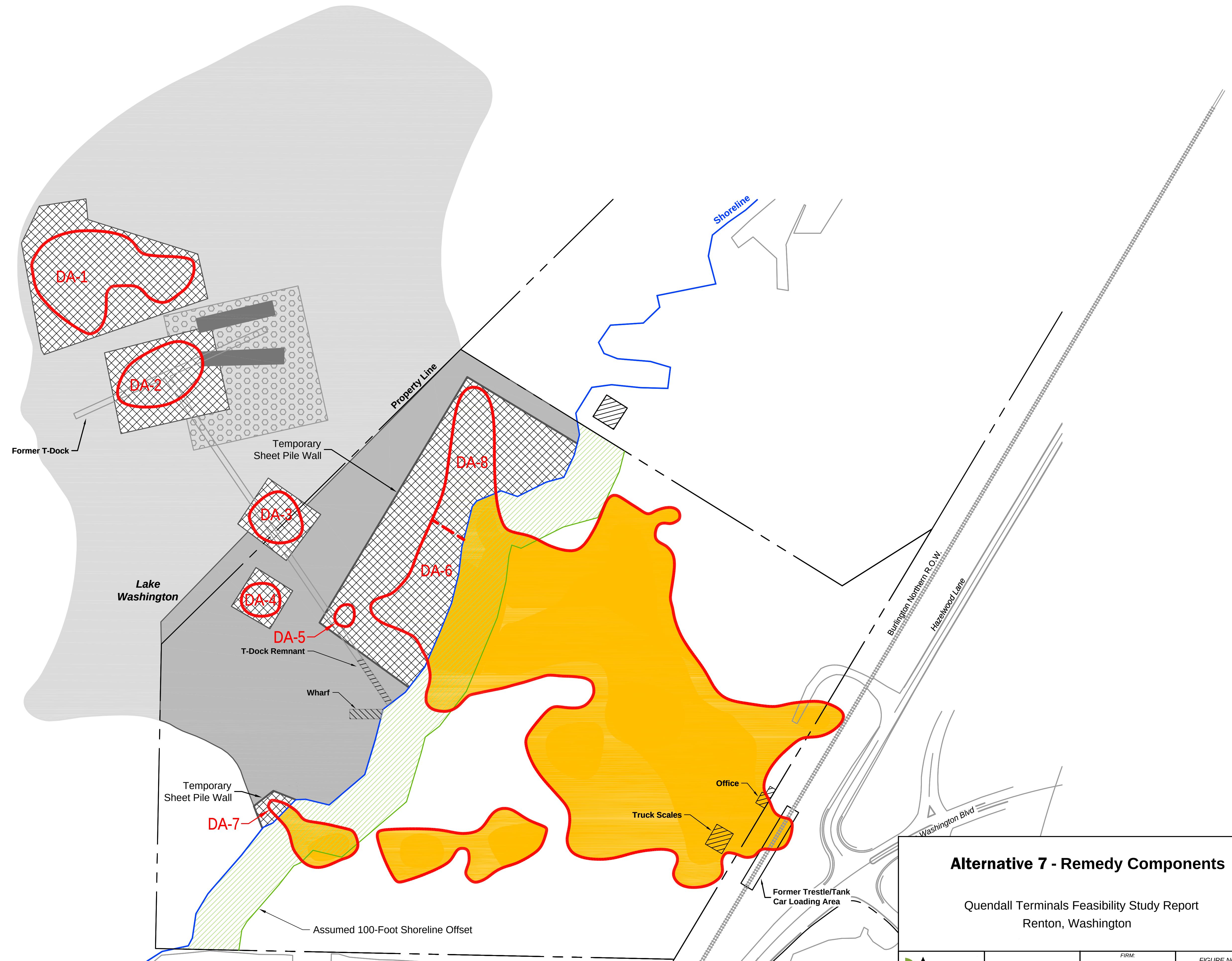
Quendall Terminals Feasibility Study Report
Renton, Washington

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

CAD Path: Q:\Quendall\020027 Quendall Terminals\2015-09 Interim Delivery\Executive Summary\020027_Plan-Alternatives 2-8.dwg ALT 6 NEW || Date Saved: Oct 12, 2015 4:15pm || 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 4. Refer to Figure 6-6 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.

Alternative 7 - Remedy Components

Quendall Terminals Feasibility Study Report
Renton, Washington

Aspect CONSULTING	ARCADIS	FIRM: ASPECT DRAWN BY: JJP/ELG/PMB/SCC	FIGURE NO. ES-11

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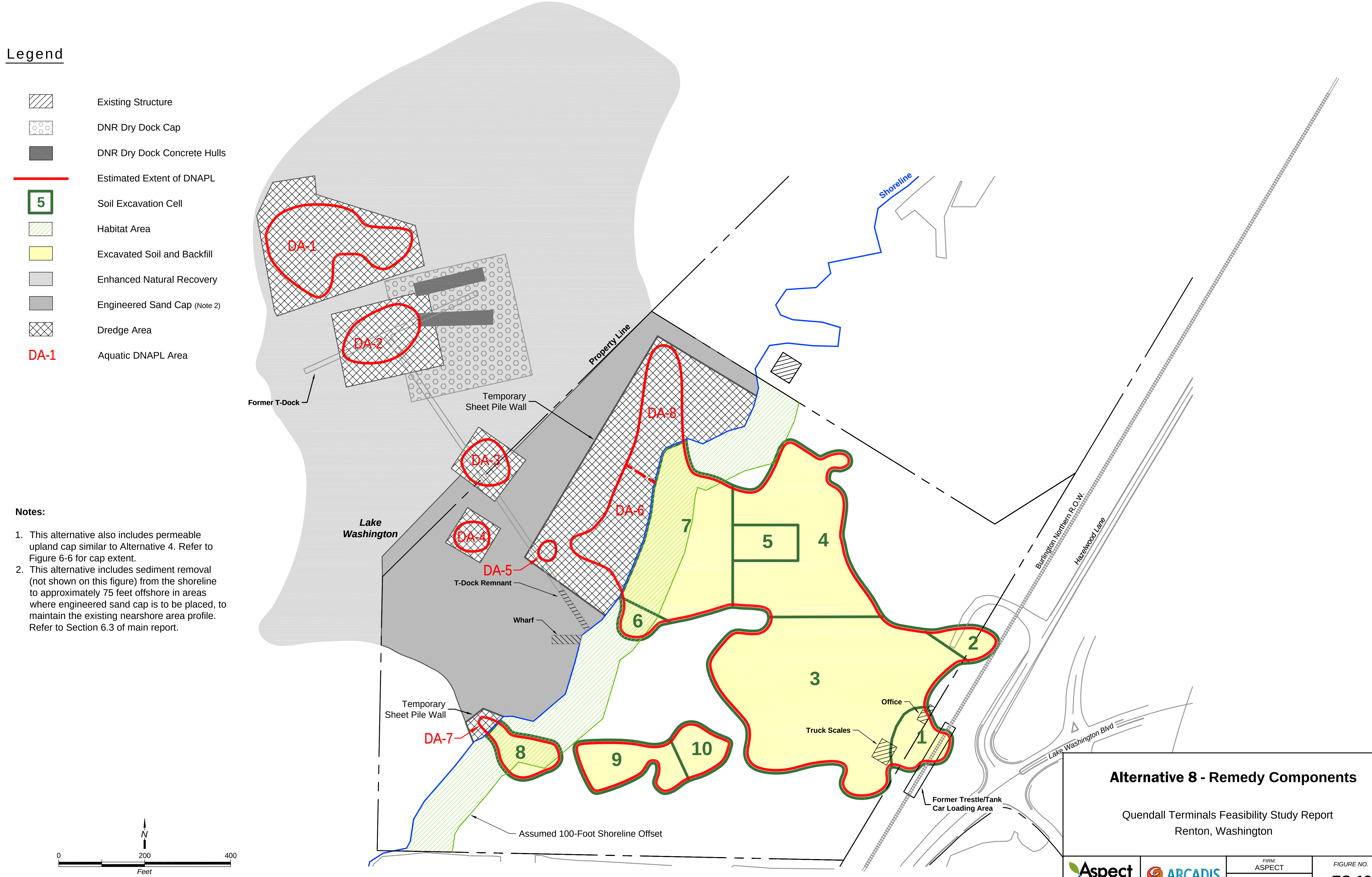


Notes:

1. This alternative also includes permeable upland cap similar to Alternative 4. Refer to Figure 6-6 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.

Alternative 8 - Remedy Components

Quendall Terminals Feasibility Study Report
Renton, Washington

Aspect CONSULTING | ARCADIS | FIRM: ASPECT | DRAWN BY: JJP/ELG/PMB/SCC | FIGURE NO. ES-12

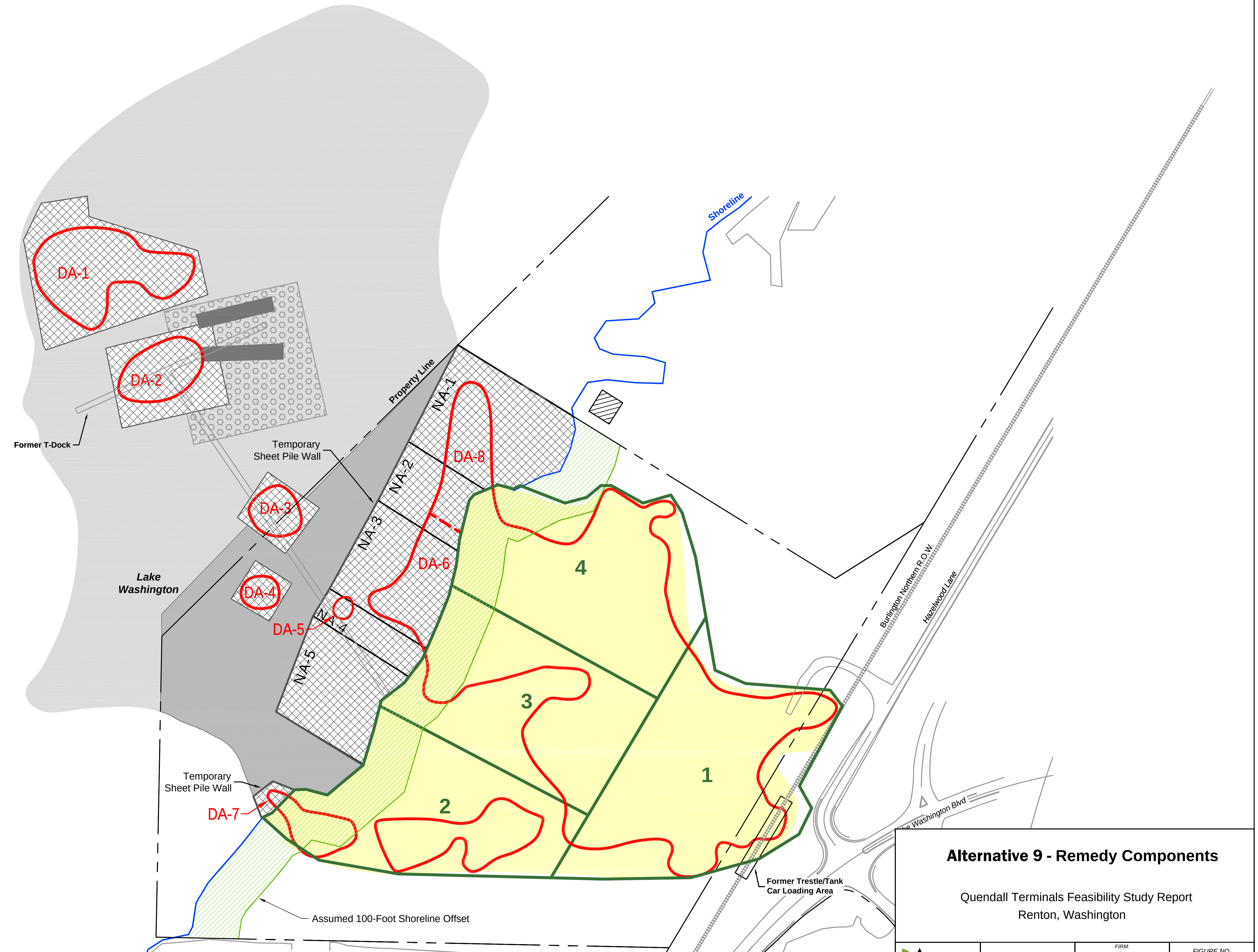
CAD Path: Q:\Quendall\020027 Quendall Terminals\2015-09 Interim Delivery\Executive Summary\020027_Plan-Alternatives 2-8.dwg ALT 8 NEW || Date Saved: Oct 12, 2015 4:20pm || User: scudd

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 4. Refer to Figure 6-6 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 9 - Remedy Components

Quendall Terminals Feasibility Study Report
Renton, Washington

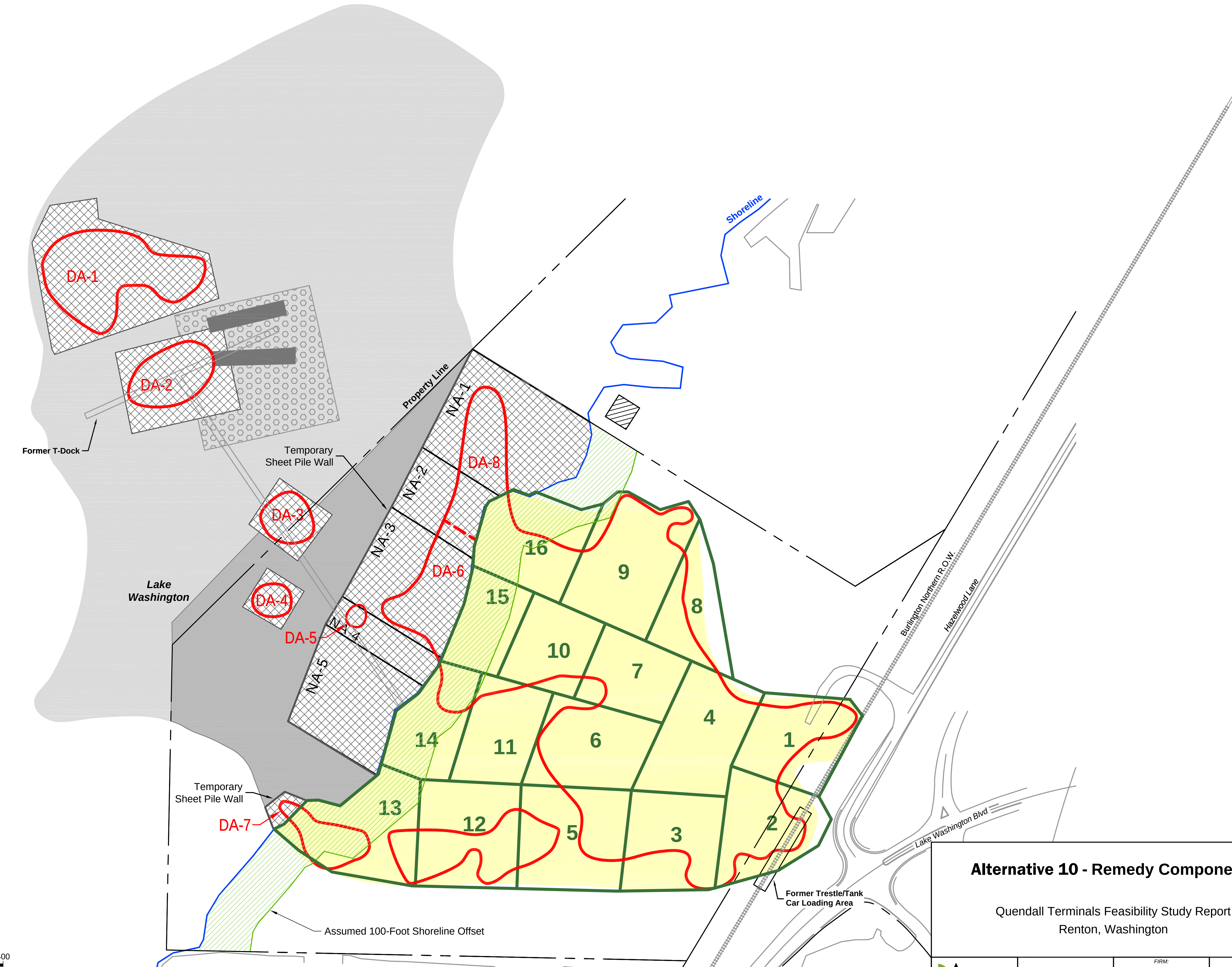
Aspect CONSULTING | ARCADIS | FIRM: ASPECT | DRAWN BY: JJP/PMB/SCC | FIGURE NO. ES-13

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:

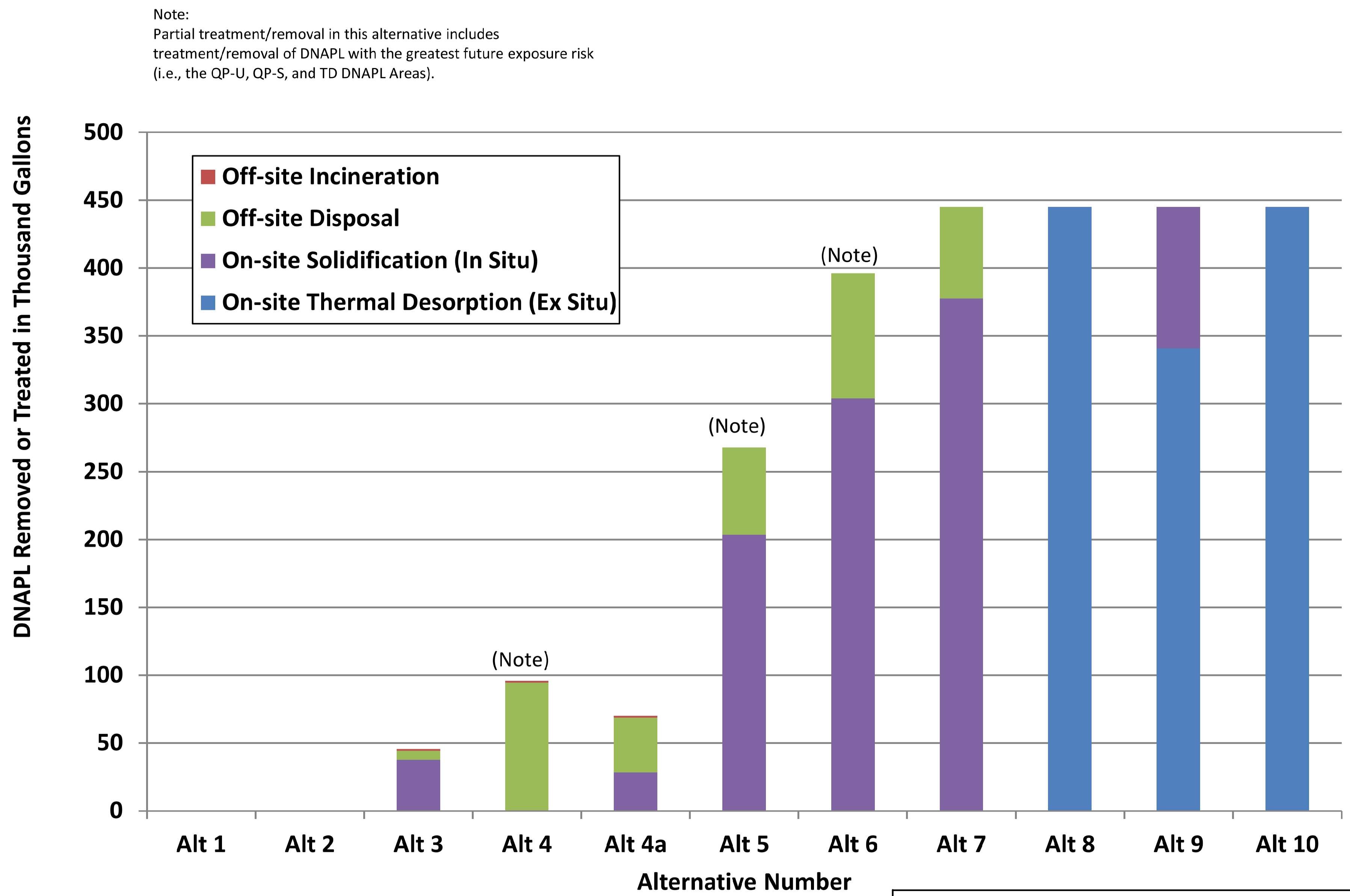
1. Soil removal and sediment dredging areas based on maximum extent of DNAPL and of cPAHs and arsenic exceeding PRGs in groundwater and porewater.
2. This alternative also includes permeable upland cap similar to Alternative 4. Refer to Figure 6-6 for cap extent.
3. This alternative includes sediment 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

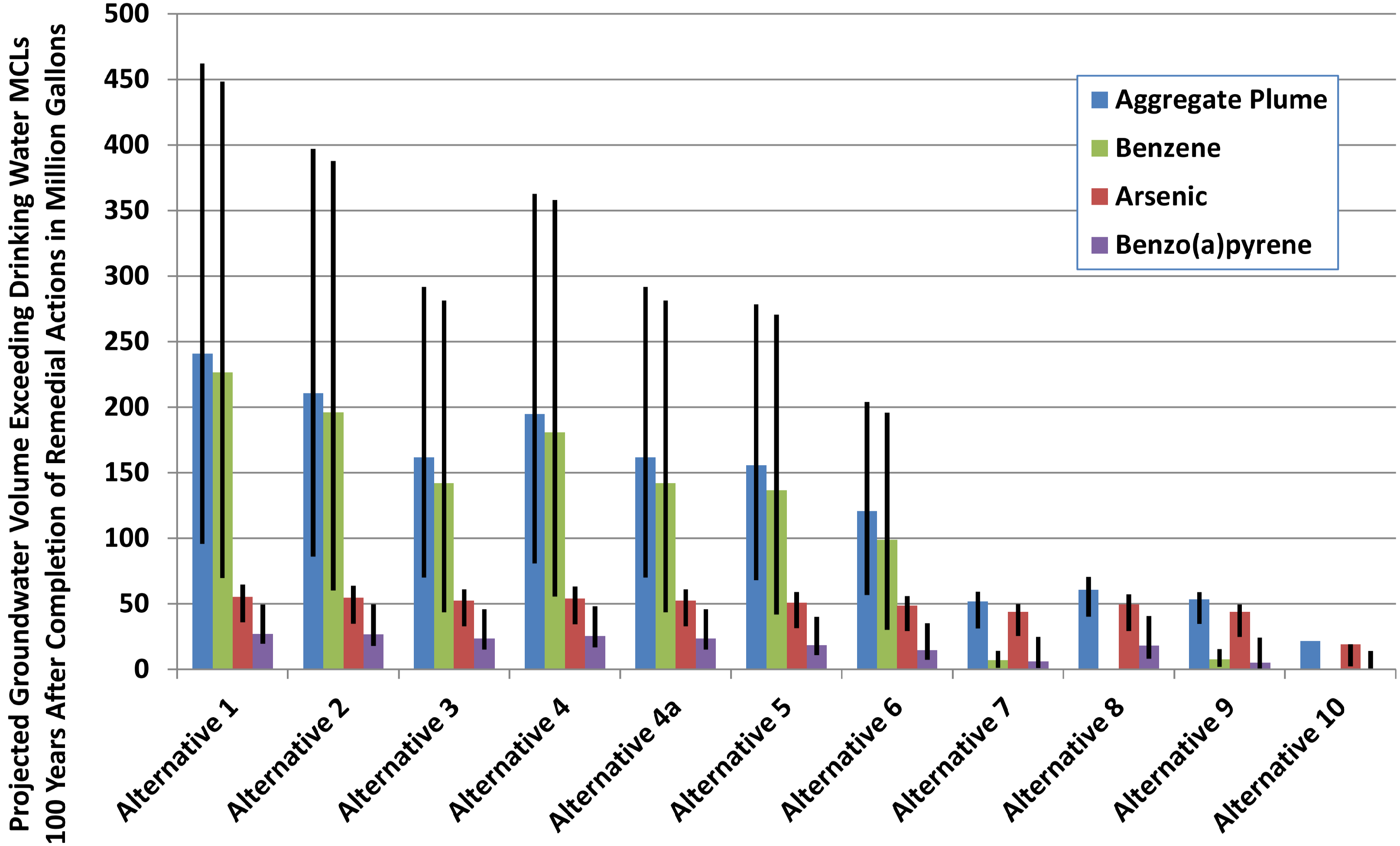
Aspect CONSULTING | ARCADIS | FIRM: ASPECT | DRAWN BY: JJP/PMB/SCC | FIGURE NO. ES-14



Estimated DNAPL Volumes Removed or Treated Under Alternative Remedial Actions

Quendall Terminals Feasibility Study Report
Renton, Washington

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



Notes:

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

Restoration of groundwater for Alternative 4a is assumed to be similar to FS Alternative 3.

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: SCC | FIGURE NO. ES-16

FEASIBILITY STUDY MAIN TEXT

Quendall Terminals Site

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

Project No. 020027 • December 2016

On behalf of

Altino Properties, Inc. and
J.H. Baxter & Co.

Prepared by

Aspect Consulting, LLC and
Arcadis U.S., Inc.

Contents

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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
RNA	Regulated Navigation Area
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 average 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 and Tribal 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 Barbee Mill 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 Barbee Mill 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 also occurs offshore from the Quendall Terminals Property.

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

[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.

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 six 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. 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.

- Quendall Pond, located near the shoreline, was constructed in an area where tank bottoms from nearby storage tanks were placed. This area also received wastes from North Sump overflows. Waste from Quendall Pond has migrated into adjacent Lake Washington.

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 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 such as pump and treat and *in situ* thermal and chemical treatment.

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.

There is no continuous aquitard layer separating the Shallow and Deep Aquifers; however, the Deep Aquifer is considered to be a semi-confined aquifer, as the vertical hydraulic interaction between the Shallow and Deep Aquifers is limited by the horizontal stratification and low permeability layers within the Shallow Alluvium, and varies depending on the 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;

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

- 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 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 Barbee Mill 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 Barbee Mill properties, and may be caused by localized reducing conditions associated with peat deposits in the vicinity of both wells.

[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.

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 PRG of 1.7 micrograms per liter (µg/L; refer to Section 4.3.2 and Table 4-5) in well BH-20C (screened from 113 to 120 feet bgs). However, elevated naphthalene concentrations do not extend into the underlying low-permeability lacustrine silt/clay unit at this location.

The vertical extent of cPAH concentrations (TEQ basis)[8] 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[9]. 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. There are a few instances of very low detections of benzo(a)pyrene above the MCL in areas outside of the DNAPL "footprint", but they are either bordering on the footprint (2 µg/L in BH-12 and 2.3 µg/L at BH-18A) or are at concentrations very close to the MCL (0.24 µg/L at BH-29A and 0.23 µg/L at WP-4).

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 (see Table 4-6) in surface and subsurface

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[8] 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.

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

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 cPAH background threshold value (BTV) of 17.5 milligrams per kilogram normalized to organic carbon (mg/kg-OC).[10]. The derivation of the BTV is described in Appendix B (B-1). It was used in this FS to approximate the extent of sediments that may require remediation. As depicted on Figure 3-11, approximately 29 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

[10]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[11]. Migration rates of these indicator chemicals in groundwater[12] were estimated in the RI Report (Anchor QEA and Aspect 2012) as follows[13]:

- 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

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

[12] 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.

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

presented in the RI Report estimate naphthalene would move across the Site in approximately 40 years.

- 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 groundwater and surface sediments/porewater. 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). The model was used to simulate downward flux of sulfate from overlying lake water, and the results are consistent with the reduction in BTEX and LPAH concentrations over the last several feet of transition zone between Site groundwater and the surface water of Lake Washington. Sulfate reduction processes may be occurring at the Site (even though there are no data to confirm sulfate reduction).

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[14,15]. The baseline human health risk assessment (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

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[14] 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.
[15] See *Section 7.2 – Baseline Ecological Risk Assessment* of the RI Report for a list of EPA Guidance Documents for ERA.

bioaccumulate in fish/shellfish tissue and incidental ingestion of and dermal contact with sediment during angling activities.

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)[16]. 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

[16] 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.

evaluated to determine whether and to what degree they may be at risk from contaminated media at the Site.

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 x 10^{-4} was exceeded for a given medium, the individual chemicals that pose an ELCR of 1 x 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 advective east-to-west groundwater flow and contaminant-specific mobility. Benzene and naphthalene are relatively mobile and, based on both empirical data and groundwater modeling, have likely migrated deeper primarily due to dispersion (to 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 identifies and discusses the Quendall ARARs that are most likely to have a significant influence on the identification and assembly of remedial alternatives to be evaluated in this FS. However, any alternative selected for the remediation of the Quendall site will have to comply with all ARARs unless an ARAR is waived by EPA. A preliminary list of ARARs for Quendall is presented in Tables 4-1 through 4-3[17]. 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

[17] "To be considereds" (TBCs) that ensure protectiveness of the remedial action, such as risk-based concentrations for COCs without an ARAR, may also play a significant role in remedy selection. These are also identified in Tables 4-1 through 4-3.

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, and state 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)[18]; 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

[18] Many Federal and State environmental and public health agencies develop criteria, advisories, guidance, and proposed standards that are not legally enforceable but contain information that would be helpful in carrying out, or in determining the level of protectiveness of, selected remedies. In other words, "to be considered" materials (TBCs) are meant to complement the use of ARARs, not to compete with or replace them. Because TBCs are not ARARs, their identification and use are not mandatory.

certain portions of the Site. Some location-specific ARARs overlap with action-specific ARARs. Location-specific ARARs are listed in Table 4-3.

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 that 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.[19]

One of the expectations to be generally considered by EPA is the ability of remedial alternatives to address principal threat wastes (PTWs) to the extent practicable (see Section 1.1). PTWs 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, EPA has determined that DNAPL, DNAPL-impacted soil, and DNAPL-impacted sediment (i.e., either oil-wetted or oil-coated materials[20]; also referred to as residual DNAPL or 'DNAPL-impacted' soil or sediment in this FS) are to be considered PTWs. The RAOs and remedial alternatives assembled in this FS use a wide range of removal, treatment, and containment strategies to address Site media, including PTWs. The NCP evaluation of individual alternatives and a comparative evaluation of alternatives are presented in Sections 7 and 8, respectively, in this FS Report.

4.2.1 *RAOs for Principal Threat Waste*

The RAOs for PTWs at the Site are:

- **SC1:** 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:** 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).

4.2.2 *RAOs for Soil*

The RAOs for soil address source control, human health protection, and environmental protection:

- **HH6:** Reduce to acceptable levels the human health risk from direct contact or incidental ingestion of COCs in surface and subsurface soil exceeding soil remediation goals.
- **SC3:** Reduce migration of COCs to groundwater from soils that exceed remediation goals for the protection of surface water.
- **EP2:** 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.

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[19] The RAOs are grouped by media in this section of the FS. Codes refer to original groups: SC – source control; HH – human health; and EP – environmental protection.

[20] 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.

4.2.3 RAO for Groundwater

The RAO for groundwater addresses human health protection:

- **HH1:** 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.

4.2.4 RAOs for Sediment

The RAOs for sediment address source control, human health protection, and environmental protection:

- **HH2:** Reduce to acceptable levels the risk to adults and children who ingest resident fish and shellfish taken from the Site for subsistence.
- **HH3:** 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.
- **SC4:** Reduce migration of COCs to surface water from sediments that exceed remediation goals for the protection of surface water.
- **EP3:** Reduce to acceptable levels the risk to aquatic-dependent wildlife (sediment probing birds and piscivorous mammals) and benthos where surface sediments containing COCs exceed remediation goals.[21]

4.2.5 RAOs for Surface Water

The RAOs for surface water address human health and environmental protection:

- **HH4:** 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).
- **EP1:** 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).

4.2.6 RAO for Vapor

The RAO for vapor addresses human health protection:

- **HH5:** 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.

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

[21] This RAO is modified to include risks to benthos, which was originally a separate RAO (EP4).

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/porewater 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).** RBCs were calculated using 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^{-6} or HQ of 1 was selected as the PRG. The exception is naphthalene in groundwater. The RBC at 1×10^{-5} was used to define the extent of the naphthalene plume.[22]

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

[22] The RBC for naphthalene is for the purposes of the FS only. Cleanup levels will be determined in the ROD. Table 4-5 shows the PRG for naphthalene based on risk of 10^{-6} is 0.17 µg/L. Of 154 detected naphthalene results for groundwater (representing multiple samples at the same location for some wells), only 2 results were detected at lower concentrations than 0.17 µg/L. Of the 33 non-detected naphthalene results, only 7 were lower. Therefore, a PRG of 0.17 µg/L is below most of the detection limits that were achievable during the RI. Naphthalene concentrations in the groundwater beneath the lake drop off fairly dramatically in the vicinity of the inner harbor line (based on well point comparisons – e.g., from 6,400 µg/L in WP-19B to 6.1 µg/L in WP-19C, and then 0.042 µg/L in WP-19D). The inner harbor line is also the furthest extent of upwelling groundwater from the site that is predicted by modeling. Therefore, a PRG of 1.7 µg/L best serves to estimate the naphthalene plume resulting from contamination at Quendall (as opposed to other potential sources).

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 (based on porewater concentrations), 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) has been identified in this FS as the PRG for sediment porewater.

If the PRG was less than background, the PRG was adjusted to the background concentration[23]. PRGs for two soil COCs (arsenic and lead) were adjusted based on natural background concentrations for Puget Sound (Ecology 1994).

As discussed in Section 3.5, the approximate extent of surface sediment contamination requiring remediation is defined by a BTV of 17.5 mg/kg-OC. The BTV was developed based on an evaluation of cPAH sediment samples collected in the vicinity of the site that have concentrations of cPAH resulting from human activities that are unrelated to releases from the Site.[24] Offsite sediment samples to characterize local non-site-related cPAH concentrations were collected during the 2009 RI (Anchor QEA and Aspect 2012). These samples were collected because preliminary risk calculations for human consumption of fish from Lake Washington, based on available Lake Washington sediment data for cPAH (King County 2000) and conservative biota-sediment accumulation factors and EPA default shellfish ingestion rates, indicated an excess cancer risk in the range of 10^{-4} to 10^{-5}.

Because a risk-based PRG would be lower than these levels (especially if tribal fish consumption rates were used), an additional data collection effort was included in the Quendall RI (described as a "background study"). The revised State of Washington Sediment Standards (SMS) include definitions for, and the applicability of, both natural and regional background sediment concentrations for use in site characterization and cleanup efforts. At this time, there are no published natural or regional background values for Lake Washington. The purpose of the "background study" for Quendall was not intended to be used to define either natural or regional background as defined in the SMS.

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.

[23] 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.

[24] Per WAC 173-340-200 (Definitions): "Area background" means the concentrations of hazardous substances that are consistently present in the environment in the vicinity of a site which are the result of human activities unrelated to releases from that site.

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 based on natural background for Puget Sound (Ecology 1994).

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.

RBCs 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, phenanthrene, 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, fluoranthene, and indeno(1,2,3-cd)pyrene.

For ecological receptors, the risk driver COCs include:

- **PAHs.** Benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene, dibenz(a,h)anthracene, fluoranthene, 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 site-specific RBCs for cPAHs in surface sediment (Table 4-7) are based on fish consumption modeled using conservative biota-sediment accumulation factors and 99th percentile U.S. population fish/shellfish ingestion rates.[25] The RBC at 10^{-6} of 0.19 mg/kg-OC is approximately an order of magnitude lower than the lowest detected OC-normalized cPAH concentration in Lake Washington or Lake Sammamish (based on the most recent publicly-available data [King County, 1999 and 2000]). As noted, the PRG is based on a conservative fish consumption rate estimate for the general U.S. population (an annualized rate of 143.4 grams per day, [EPA, 2002]); however, tribal consumption rates may be higher. Therefore it is assumed that the 10^{-6} RBC for cPAHs in sediment is below natural and/or regional background for Lakes Washington and Sammamish. As noted above, neither natural nor regional background concentrations have been established for Lake Washington or Lake Sammamish. Therefore, a sediment cPAH BTV was used for the purpose of delineating the approximate extent of sediments that may require remediation based on a background-based criterion. The derivation of the BTV is described in Appendix B (B-1).

4.4 Site Areas and Media Targeted for Remedial Action

To identify Site areas to be remediated, areas containing PTW are first distinguished, followed by the areas of the Site with media that exceed PRGs. Site areas with DNAPL or with contaminant concentrations above PRGs in each Site media were identified based on the data presented in the RI Report (Anchor QEA and Aspect 2012). These Site areas are not meant to represent any particular priority for remediation but instead present a way to organize the Site for purposes of the FS.

Site Areas containing PTWs were differentiated by considering the following:

- **Effect on Shallow and Deep Aquifers.** 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. They are the RR DNAPL Area and the easternmost MC DNAPL Area (near MC-1).

- **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) or shallow DNAPL-impacted sediments (e.g., in the top 5 feet) are easier to implement than remedial alternatives involving excavation of deep DNAPL-impacted soil (down to 34 feet bgs) or sediment (down to 16 feet bgs). Therefore, distinct Site areas containing DNAPL at significantly deeper depths were

[25] Using the same calculations and assumptions as the Baseline Human Health Risk Assessment in the Quendall RI Report (Anchor QEA and Aspect, 2012).

identified. They are the RR DNAPL Area, the easternmost MC DNAPL Area (MC-1), and the QP-S DNAPL Area.

- **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., oil-coated DNAPL) and is not expected to be mobile. DNAPL that is above residual saturation (i.e., oil-wetted DNAPL) is considered to be mobile even through low-permeability soil layers may stop, slow down, or alter the movement of DNAPL. It is possible that DNAPL that is currently impeded by low-permeability layers 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). Areas containing a high percentage of oil-wetted DNAPL include the QP-U DNAPL Area and certain areas in the MC and QP-S DNAPL Areas.

- **DNAPL Cumulative Thickness**. Greater cumulative thicknesses of DNAPL (either oil-coated or oil-wetted) may contribute more significantly to groundwater contamination. Each of the upland sources have at least one occurrence of where DNAPL has been observed at a cumulative thickness of 4 feet or more. A single contiguous DNAPL occurrence likely impacts groundwater differently than multiple layers of equivalent cumulative thickness. Cohen and Mercer (1993) note that DNAPL fingers and ganglia may produce higher chemical concentrations in groundwater, while depleting the DNAPL source more quickly than a DNAPL pool of equivalent mass. Conversely, DNAPL pools (greater thicknesses of oil-wetted materials) may provide a source of groundwater contamination long after DNAPL fingers and ganglia have been depleted.

Section 4.4.1 below discusses how the four considerations above were used to delineate specific DNAPL areas.

Areas outside the DNAPL footprint with media that exceed PRGs are described in Section 4.4.2 and are designated as follows:

- The Surface Soil Area;
- The Subsurface Soil and Groundwater Area; and
- The Surface and Subsurface Sediment Area.[26]

4.4.1 *DNAPL Areas*

This section describes how specific areas of DNAPL were delineated and differentiated based on their effect on groundwater quality, depth, mobility, and cumulative thickness. Specific DNAPL areas are generally defined based on occurrences that have a particular impact on groundwater quality (such as on the Deep Aquifer), have significant amounts of DNAPL above residual saturation (considered potentially mobile), are located at depths that are particularly shallow (in sediments) or deep (in the uplands), and/or have significant thicknesses of DNAPL-impacted soil. Table 4-9 provides a summary of the

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[26] The surface sediment area includes characterization based on sediment porewater sampling and analysis.

DNAPL depth, thickness, estimated volumes, and percent logged as oil-wetted by source area.

Specific DNAPL areas that are notable with respect to the above criteria include:

- **RR DNAPL Area:** DNAPL-impacted soil in the former Railroad Tank Car Loading Area (deep occurrence, maximum thickness, and potentially mobile);
- **MC DNAPL Area:** DNAPL-impacted soil in the former May Creek Channel (deepest occurrence, moderate thickness, and potentially mobile);
- **QP-U DNAPL Area:** DNAPL-impacted soil around Quendall Pond (deep occurrence, moderate thickness, and potentially mobile);
- **QP-S DNAPL Area:** DNAPL-impacted sediments offshore of Quendall Pond (moderate depth and thickness, and potentially mobile); and
- **TD DNAPL Area:** DNAPL-impacted sediments along the former T-Dock (shallow sediment depth and moderate thickness).

Areas with DNAPL at shallow to moderate depth in the uplands with fewer occurrences of oil-wetted DNAPL were grouped separately and are described as Other Upland or Aquatic DNAPL Areas, as they are more challenging to delineate individually and they share similar characteristics. These areas include DNAPL-impacted soil in other former process areas, specifically the Still House, the Boiler House, and the North and South Sumps). Many of the Other Upland DNAPL Areas contain DNAPL with significant cumulative thickness, one of the distinguishing criteria mentioned above.

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.

4.4.1.1 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[27]), 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[28]. DNAPL occurrences west of the RR DNAPL Area are included in the "Other Upland DNAPL Areas" described in Section 4.4.2.4 below.

4.4.1.2 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 (though the nearest sediment boring, VS-9, is located approximately 100 feet from MC-16). It is uncertain whether DNAPL has migrated offshore in this area; therefore the extent of DNAPL in this area is

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

[28] 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.

conservatively depicted as extending offshore approximately half the distance between these two sampling locations (Figure 3-5).

In the easternmost MC DNAPL Area (Figure 3-5), 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 because of the slightly downward vertical gradient in this area. This contributes to the groundwater plume extending into the Deep Aquifer (see Section 6.4.2 of the RI Report [Anchor QEA and Aspect 2012]). In the western part of 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. 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 4.4.1.4).

4.4.1.3 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 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 shallow groundwater quality and its mobility (it contains the highest percentage of upland DNAPL logged as oil-wetted, Table 4-9).

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.

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 in the Shallow Aquifer, 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 [oil-coated] was observed from 25.5 to 26.5 feet bgs) is within the Shallow Alluvium, and groundwater flow is upward at this location; therefore it is not likely impacting the Deep Aquifer; however, based on contaminant transport via diffusion and dispersion and from contributions from DNAPL sources east of this area (RR Area and the easternmost MC DNAPL Area [MC-1], 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 Deep Aquifer.

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, but were included in Other DNAPL Areas (below), 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.
- **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.
- **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).
- **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.

4.4.1.4 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., oil-coated DNAPL), but may be present at significant cumulative thickness. While DNAPL in these areas likely do not significantly impact groundwater quality in the Deep Aquifer, some of these areas comprise an ongoing significant source of contamination to the Shallow Aquifer.

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.[29]

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 in a silty sand layer 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 from 13 to 23 feet bgs (the top of the screen beginning in a 2-foot silty clay layer beneath the silty sand), and no product was recorded in this well. DNAPL in BH-8A was characterized as abundant brown fluid, but interpreted as oil-coated due to lack of product in the well (though this characterization is uncertain).

- **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), with the largest accumulation observed at 6 feet (SP-5), characterized as dark brown free product. Most other DNAPL in this area has been identified as oil-coated, except for HC-2 (characterized as “saturated with yellowish viscous product” from 11.2 to 15.1 feet bgs), SWB-4 (characterized as “yellow-brown foamy sheen observed on auger” from 12.5 to

[29] 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.

14 feet bgs), and SWB-4a (characterized as oil-wetted from 10 to 11 feet bgs). Product has not accumulated in two wells installed in this area (BH-23 [screened from 6 to 21.5 feet bgs] and RW-NS-1 [installed adjacent to SP-5 and screened from 6.5 to 16.5 feet bgs]), 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.

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.[30] The maximum cumulative DNAPL thickness within the Other Upland DNAPL Areas is 6 feet at Q1-D and SP-5.

4.4.1.5 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 offshore into subsurface sediments through permeable soil layers. DNAPL in this offshore area is of particular concern due to its effect on groundwater quality beneath the lake, thickness, and potential mobility ((it contains the highest percentage of DNAPL logged as oil-wetted, Table 4-9).

This area includes two sediment boring locations where DNAPL-impacted sediment has been observed: at VS-30 (5 feet thick [oil-wetted], to a depth of 9 feet below mudline) and QPN-02 (cumulative thickness of 1.7 feet [mostly oil-wetted], 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 (WP-3 is in the vicinity of VS-30).

A thin layer of oil-coated 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 (oil-coated) and are located where surface sediments and groundwater porewater are below PRGs, this area is discussed under Other Aquatic DNAPL Areas described in Section 4.4.1.7.

4.4.1.6 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

[30] 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.

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 [characterized as black oil, product sludge] and 3.8 feet thick at VT-4 [characterized as visible drops of product]) 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.

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.

4.4.1.7 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), that are generally below residual saturation (one extremely thin [0.1 foot] oil-wetted layer in TD-01). They are located north of the QP-S DNAPL Area and west (offshore) of the MC DNAPL Area.

4.4.1.8 Key Factors Influencing DNAPL Remediation

Key factors influencing the remediation of DNAPL at the Site are as follows:

- EPA has determined that DNAPL at the Quendall Site, whether in soils or sediments, is to be considered PTW because of the high level of toxicity inherent in the creosote/coal tar DNAPL. Creosote/coal tar contaminants present in DNAPL (benzene and naphthalene) are leachable and mobile via groundwater, and DNAPL classified as oil-wetted may be also be mobile.

- EPA believes that DNAPL at the Site cannot be addressed through containment alone, because any vertical barrier/treatment wall that would be installed at the Site could only be a “hanging” wall. There is no continuous single-layer aquitard in which to anchor a barrier/treatment wall. The stratigraphy/geology of the shallow alluvium, in aggregate, limits downward and lateral migration of mobile DNAPL. However, leached constituents such as benzene and naphthalene from the DNAPL source have been observed at great depths in the coarse alluvium. Therefore, the lack of a substantial, continuous, horizontal aquitard separating the shallow alluvium from the coarse alluvium renders a downgradient hanging barrier/treatment wall less effective.

- DNAPL is accessible. The majority of DNAPL in the uplands is found within the top 20 feet of the Shallow Aquifer with two exceptions (RR Area and Former May Creek Channel).

For the purposes of developing a range of remedial alternatives, particular areas of DNAPL are targeted in various alternatives based on location, mobility potential, and depth. These are described below.

Targeted DNAPL Areas

While all DNAPL at the Site is considered to be PTW, specific DNAPL areas have been targeted based on location (e.g., proximity to Lake Washington) and mobility potential. Also, as with any DNAPL site, there are inherent uncertainties in the distribution and characteristics of DNAPL which contribute to risk. Although the Site has been extensively investigated and characterized, uncertainty still exists, particularly considering the highly heterogeneous nature of the Shallow Alluvium soils. Uncertainties in DNAPL distribution are of highest concern in areas closest to the lake, particularly in shallow sediments. In the upland, the primary uncertainty is the extent of thin layers, or "stringers", of DNAPL that are discontinuously distributed within the Shallow Alluvium. These stringers may not contain sufficient DNAPL volume to present a significant migration threat even in the event of an extreme (e.g., seismic) event.

For the purposes of this FS, the following DNAPL areas are targeted primarily due to their close proximity to Lake Washington and/or the potential for DNAPL to be mobilized:

- **TD DNAPL Area,** near the former T-Dock, where DNAPL released from surface spills at the dock is located in shallow sediments (less than 3 feet deep);
- **QP-S DNAPL Area,** offshore of Quendall Pond, where DNAPL is present in deeper sediments through subsurface migration from the uplands; and
- **QP-U DNAPL Area,** around Quendall Pond, where potentially mobile DNAPL is present in upland soils near the shoreline.

DNAPL Areas Affecting the Deep Aquifer

DNAPL areas also vary in their relative contribution to groundwater contamination. Areas of deep DNAPL are targeted because groundwater movement in the Deeper Aquifer may disperse contaminants to greater depths Groundwater modeling predicts that the greatest groundwater plume extent exceeding MCLs is caused by deep DNAPL in the following areas:

- **RR DNAPL Area**, where the deepest DNAPL (33.7 feet bgs) was observed; and
- **Eastern Portion of the MC DNAPL Area**, in the vicinity of a former sewer outfall, where the greatest DNAPL depth was observed outside of the RR DNAPL Area.

4.4.2 *PRG Exceedance Areas*

This section describes the Site surface soil, subsurface soil and groundwater, and surface and subsurface sediment areas where PRGs are exceeded. These areas define the extent of the "Site".

4.4.2.1 Surface Soil Area

The Surface Soil Area 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 naphthalene, cPAHs, and arsenic (see Section 5.3 of the RI Report [Anchor QEA and Aspect 2012]).

An extensive data collection effort for surface soil was not conducted for the RI/FS because:

- The Site is fenced, has been re-seeded, and access is prohibited.
- Future Quendall Terminals Property redevelopment, expected to follow completion of site remediation, 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. As a result, it is not certain whether there are still areas exceeding PRGs. Redevelopment plans will likely require that this material be removed or graded prior to paved-road construction, to minimize the potential for future settlement.
- Once the preferred remedy is identified, additional focused surface soil sampling and analysis can be completed if necessary to complete the remedial design.

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 two loading areas, but at concentrations and with a PAH fingerprint that is more consistent with contamination detected elsewhere along the Railroad Property (Pinnacle Geosciences 2009).

4.4.2.2 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. The reason these are considered together is that the plume also contaminates the soil and vice versa since the water table is high. 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, located east of Hazelwood Lane. 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 (Barbee Mill 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.

4.4.2.3 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 BTV exceedances (defining the sediment remediation footprint for the FS) 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.

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. Remedial technologies/process options are defined in the Record of Decision; however, during remedial design minor changes in a particular process option, such as exchanging the type of reactive material to be used in a RCM, may be considered if its implementation results in comparable or improved long-term effectiveness and reliability, lower cost, or a comparable or improved rating of any of the other CERCLA evaluation criteria. However, replacing one technology, such as an engineered sand cap for another technology, such as an RCM, could be viewed as a significant change and warrant an additional detailed technical evaluation and potential Explanation of Significant Differences.

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 controls or control of exposure to hazardous substances by use of institutional controls, or some combination of the above. GRAs for the Site media are as follows:

- **Institutional Controls.** Institutional controls are non-engineered measures that may be selected as remedial or response actions typically in combination with engineered remedies For example, institutional controls may include administrative and legal controls that minimize the potential for human exposure to contamination by limiting land or resource use (EPA 2000a). The NCP sets forth environmentally beneficial preferences for permanent solutions, such as complete elimination of risk or treatment of principal threat waste rather than control of risks using containment for example. Where permanent and/or complete elimination are not practicable, the NCP creates the expectation that

EPA will use institutional controls to supplement engineering controls as appropriate for short- and long-term management to prevent or limit exposure to hazardous substances, pollutants, or contaminants. It states that institutional controls may not be used as a sole remedy unless active measures are determined not to be practicable, based on balancing trade-offs among alternatives (40 CFR 300.430 [a][1][iii]).

- **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.
- ***Ex Situ* Treatment.** *Ex situ* treatment technologies destroy or immobilize contaminants that have been removed from the media surface or subsurface.
- **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.
- **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 carcinogenic PAHs (cPAHs) 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, heterogeneous subsurface 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 options 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 when combined with active remediation such as capping sediments, are 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 for treating creosote or coal tar

DNAPL 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 largely 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 when coupled with active remediation 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 representat*ive 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 and targeted long-term monitoring. 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 applicable and effective for immobilizing Site COCs in soil as it is a remedial technology commonly used at creosote/coal tar Superfund Sites. 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 based on multiple lines of evidence (EPA 2004b), including: 1) a stable or shrinking groundwater plume; 2) geochemical indicators of hydrocarbon biodegradation in contaminated areas; and 3) fate-and-transport modeling of contaminants in groundwater and porewater as described in the RI Report (Anchor and Aspect 2012). 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 certain SVOCs, achieving 90 to 99.7 percent reductions 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. However, for the purpose of this FS, it will be referred to as “thermal treatment,” as the specifications for the treated material and emission standards will be determined during remedial design.

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 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 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.

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.

Bioremediation 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. 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). 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 nearshore excavation include:

- **Upland-Based Excavation.** Use of long-reaching excavators positioned from upland staging areas to remove contaminated sediment combined with the use of sheet pile containment; 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 vary in size and can be retrofitted to address different degrees of sediment hardness. For example, at the Todd Shipyard Sediment Operable Unit at Harbor Island (Todd), large steel plates were soldered to the sides of an environmental bucket to provide more weight for penetrating sediments. Appropriately large environmental buckets can be used to handle debris. For example, at Todd large and cumbersome shipyard debris was successfully removed (see Figure 5-1). 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). However, many of these effects may be reduced due to recent innovations, increased operator expertise, 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 contaminated 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 some 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. For the purpose of the FS, the term “thermal treatment” will be used, as the specifications for the treated material and emission standards will be determined during remedial design.

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 11 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:** permeable soil, engineered sand, amended sand and RCM sediment capping
- **Alternative 3 – Targeted PTW[31] Solidification (RR and MC-1 DNAPL Areas):** targeted treatment of two areas of deep upland PTWs via *in situ* solidification, passive groundwater treatment, and soil and sediment capping
- **Alternative 4 – Targeted PTW Removal (TD, QP-S, and QP-U DNAPL Areas):** targeted treatment of three areas of PTWs via removal/off-site disposal, passive groundwater treatment, and soil and sediment capping
- **Alternative 4a – Targeted PTW Solidification (QP-U, RR and MC-1 DNAPL Areas) and Removal (TD DNAPL Area):** targeted treatment of two areas of deep upland PTWs and one nearshore upland PTW area via *in situ* solidification, targeted treatment of one area of sediment PTWs via removal/off-site disposal, passive groundwater treatment, and soil and sediment capping
- **Alternative 5 – Targeted PTW Solidification (RR, MC, and QP-U DNAPL Areas and ≥ 4-Foot-Thickness) and Removal (TD and QP-S DNAPL Areas):** targeted treatment of multiple upland areas of PTWs via *in situ* solidification and targeted removal/off-site disposal of sediment PTWs, passive groundwater treatment, and soil and sediment capping

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

- **Alternative 6 – Targeted PTW Solidification (RR and MC DNAPL Areas and ≥ 2-Foot-Thickness) and Removal (TD, QP-S, and QP-U DNAPL Areas):** targeted treatment of multiple upland areas of PTWs via *in situ* solidification and targeted removal/off-site disposal of upland and sediment PTWs, passive groundwater treatment, and soil and sediment capping
- **Alternative 7 – PTW Solidification (Upland) and Removal (Sediment):** treatment of all upland PTWs via *in situ* solidification, treatment of all sediment PTWs via removal/off-site disposal, and soil and sediment capping
- **Alternative 8 – PTW Removal (Upland and Sediment):** treatment of all upland and sediment PTWs via removal/on-site *ex situ* thermal treatment[32], and soil and sediment capping
- **Alternative 9 – Solidification and Removal of Upland PTW and Contaminated Soil, and Removal of Sediment PTW and Contaminated Sediment:** treatment of all upland PTWs and contaminated soil via *in situ* solidification or removal/on-site *ex situ* thermal treatment[2], treatment of all sediment PTWs and contaminated sediment via removal/on-site *ex situ* thermal treatment[2], and soil and sediment capping
- **Alternative 10 – Removal of Upland PTW, Sediment PTW, Contaminated Soil, and Contaminated Sediment:** treatment of all PTWs and contaminated soil and sediment via removal/on-site *ex situ* thermal treatment[2], 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 technologies and process options that make up each alternative (i.e., the remedy components) are summarized in Table 6-1. Estimated construction quantities are summarized in Table 6-2.

Not all remedial technologies or 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, such as the type of reactive media used in reactive containment and treatment technologies, would occur during remedy design.

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[32] As discussed in Sections 5.3.2.5 and 5.3.4.6, thermal desorption is the process option evaluated in this FS for *ex situ* thermal treatment of removed soil and sediment. The term "thermal treatment" is used since specifications for the treated material and emission standards will be determined during remedial design.

6.2 Common Elements

This section describes considerations that are common to the all 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), a summary description of predictive numerical and analytical modeling tools used to support development and evaluation of alternatives (Section 6.2.4) and certain remedial elements common to all alternatives, specifically institutional controls (Section 6.2.5) and monitoring (Section 6.2.6).

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 or prevent access to left in place contamination or remedial components. If additional remedial measures are needed in the future, the presence of these structures may also prevent additional remedial activities to be put in place or limit the scope or type of remedial measures that can be implemented.

Post-remediation Site development is assumed to include impermeable[33] 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), most DNAPL in the subsurface does not appear to be actively migrating. Future site development construction activities and the existence of a permanent development infrastructure have the potential to modify conditions that affect DNAPL mobility as follows:

- Reductions in stormwater infiltration from placement of impermeable surfaces related to future development would reduce hydraulic head and leaching, and may 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

[33] However, future "green" development regulations may require that some surfaces such roads and sidewalks be constructed of permeable or semi-permeable materials.

soils at the Site (e.g., peat) are low-permeability soils that limit DNAPL migration but do not contain significant quantities of DNAPL themselves.

- 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.

6.2.2 *Habitat Considerations*

It is anticipated that it would be necessary to fill on-site wetlands to complete the Site cleanup and as a result, mitigation would be required pursuant to Clean Water Act (CWA) Section 404(b)(1). EPA has determined that filling the wetlands cannot be avoided or minimized, and as a result mitigation is required. It is also anticipated that it would be necessary to disturb substantial existing shoreline habitats within and waterward of the 100-foot shoreline area to complete the Site cleanup and as a result, mitigation could also be required to offset these impacts. For purposes of evaluating FS alternatives, it is assumed that the entire shoreline and the area landward 100 feet (the habitat area, see Figure 6-1) would be used for habitat following cleanup and would remain undeveloped. This FS contains, in Appendix G (*Baseline Habitat Technical Memorandum*; Grette, 2016)], the site information required pursuant to the CWA to establish habitat and wetland baseline conditions. Also, Appendix G contains information according to CWA 404(b)(1) and its regulations that define the jurisdiction, delineation, and ranking of each on-site wetland. Habitat mitigations plans will be developed in the remedial design phase of the cleanup process. All of the alternatives in this FS, except Alternative 1, take into account the CWA 404(b)(1) statute and its requirements and all such alternatives included provisions for future habitat along the Quendall shoreline.

Remedial components planned and/or selected for the habitat area would need to consider potential access and use limitations. Accordingly, some potential remedial components of the FS alternatives may not be compatible with future habitat areas. For example, repair and replacement of sediment caps along the shoreline may require periodic use of heavy equipment that could cause degradation of the habitat area. EPA, the Muckleshoot Tribe, and Trustees would need to agree that such access for purposes of installation, operation, and maintenance were acceptable. This is considered in the evaluation of alternatives. Depending on the location of future habitat areas along the shoreline, the potential for contaminated groundwater to discharge into habitat areas and impact biota would need to be evaluated.

The habitat needs of juvenile Chinook salmon would be an important focus when evaluating alternatives and developing the mitigation plan during remedy design. The mitigation plan will be developed and approved in concert with EPA, the Trustees, and the Muckleshoot Tribe.

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

- The habitat area would consist of a 100-foot-wide corridor along the shoreline. Remedial components requiring future access for monitoring or maintenance, such as permeable reactive barriers (PRBs) or groundwater extraction wells, would be placed outside and east of the habitat area.

- Caps in the habitat area could require clean material to a minimum depth of 3 feet below current grade.
- 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 or soil would be excavated elsewhere along the Site shoreline to create new aquatic habitat to offset habitat lost from capping.

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.
- PTW 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 PTW 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 PTW soil) or decrease (based on the dilution of PTW 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 PTW 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. 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[34] 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
- 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 MCL of 5 µg/L. 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.[35] 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[36] detected in these areas (39 µg/L).

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[34] 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.

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

[36] 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).

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 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 UT Model 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). Initial modeling predicting the steady-state concentration of the COCs was performed using existing Site conditions to calibrate parameters that describe the various physical processes occurring at the Site (based on observed porewater cation concentration profiles) and the parameters that describe the various chemical and biological processes occurring at the Site (based on observed porewater COC concentration profiles).

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.

6.2.5 *Institutional Controls*

The institutional controls will be an important part of the overall cleanup at the Site, especially since contamination that exceeds cleanup levels will remain onsite for all alternatives to varying degrees. Institutional controls may be applied during remedy implementation to minimize the potential for human exposure (as temporary land use or exposure limitations). These controls may also extend beyond the end of construction (or be created at that time) or even after cleanup objectives are achieved to ensure the long-term protectiveness of remedial actions that leave contaminants on-site above cleanup levels (as long-term or permanent limitations, e.g., protecting sediment caps from being accidentally breached). EPA recommends that where it may provide greater protection, multiple institutional controls should be used in combination, referred to as "layering" by EPA.

The following is a summary of the array of institutional controls that could be used at Quendall, depending on the type of exposures that could result from contamination left in place or to protect engineering controls, such as sediment caps, that are meant to prevent exposures from the contamination left in place. More details about the need, use, and implementation of institutional controls will be delineated through the ROD and possibly supplemented with more specifics in remedial design and remedial action.

6.2.5.1 Government Controls

Government controls use the regulatory authority of governmental entities to impose restrictions on citizens or property under its jurisdiction. Governmental controls such as zoning and the permitting of discharges to Lake Washington or filling of wetlands are not described further in this section because these types of controls cannot be incorporated into the remedial alternatives (i.e., zoning and permitting requirements exist and cannot be changed regardless of the remedy selected for the Site). Government controls that could potentially be part of the Quendall remedial alternatives could include:

- **Fishing and swimming bans.** Restrictions that ban fishing and swimming are established by state departments of health or other governmental entities through coordination with EPA.
- **Notification of Waterway Use.** Notifications may need to be used to provide notice to vessel operators to prevent damage to caps, *in situ* treatment, ENR, or other remedy components. Notification to waterway users could further be provided through enhanced signage and other forms of public notice, education, and outreach (i.e., information devices). These would include:
    - 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.

6.2.5.2 Proprietary Controls

Proprietary controls are recorded rights or restrictions placed in deeds or other documents transferring property interests that restrict or affect the use of property. They include covenants (grants or transfers of contractual rights) and easements (grants of property rights by an owner.) Covenants and easements are essentially legally binding arrangements that allow or restrict usage of property for one or more specific objectives (e.g., habitat protection, protection of human health, etc.). They commonly survive the transfer of properties through real estate transactions and are binding on successors in interest who have not participated in their negotiation. They can be implemented without the intervention of any federal, state, or local regulatory authority. At cleanup sites, environmental covenants and easements commonly control or prevent current and future owners from conducting or allowing activity that could result in the release or exposure of buried contamination as long as necessary.

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, including:
  - Upland construction activities such as excavation; and
  - In-water vessel activities (e.g., anchoring, spudding, or vessel maneuvering) and construction activities (e.g., dredging, or pile driving/pulling);
- Evaluation of vapor intrusion potential and/or construction of vapor controls for 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 or dissolved-phase contaminants 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 or other domestic purposes and on construction of wells (other than for remediation or monitoring purposes).

Easements may also be needed to ensure access to remedy components such as PRBs or monitoring wells.

Traditionally, covenants or easements were only enforceable by whomever they were granted to, and their successors, depending on how they were crafted. In Washington State, MTCA gave Ecology the right to enforce covenants created under MTCA. More recently, Washington passed its Uniform Environmental Covenants Act (UECA), which allows EPA, as well as the state (in addition to the parties to an UECA covenant), to enforce environmental covenants. For this reason, UECA covenants are anticipated to be the primary proprietary control used for the Quendall Site.

6.2.5.3 Enforcement and Permit Tools

Enforcement tools include legal administrative orders, permits, and consent decrees that limit certain Site activities or require the performance of specific activities (e.g., to monitor and report on an institutional controls' effectiveness). These tools are not discussed at any depth in this FS because they do not inform the choices among alternative remedies.

6.2.5.4 Informational Devices

Information devices are tools that would rely on property record systems to provide the public with information about risks from remaining contamination at the Site. They may discourage inappropriate land use, but are not legally enforceable. For Quendall, they may include:

- **Deed Notices.** These are notices that provide information in public land records to alert persons regarding property conditions, including the type of contamination present and associated risks and activities that could result in exposure to contaminants left on the Site.

- **Advisories, Public Outreach, and Education.** The Washington State Department of Health (WDOH) publishes seafood consumption advisories in Washington. The WDOH currently recommends limits on Northern Pikeminnow, Carp, Cutthroat Trout, and Yellow Perch in Lake Washington. There is also advice on consumption of Sockeye Salmon, Rainbow Trout, and Pumpkin Seed as well.

- **The Washington State Department of Fish and Wildlife (WDFW).** WDFW develops and enforces seasonal restrictions on recreational fishing and seasonal and daily catch limits per individual for various seafood species. WDFW licensing and enforcement activities presumably limit resident Lake Washington seafood consumption to some unknown degree. While WDFW regulations summarize the WDOH seafood consumption advisories, which may enhance their reach and effectiveness, they do not prohibit fishing or shellfishing within Lake Washington. It is lawful to seasonally collect and consume certain fish and shellfish from Lake Washington.

- **Environmental Covenants Registry.** Placement and maintenance of Quendall areas, such as those with containment remedies (upland or sediment caps) or where contamination remains above cleanup objectives, on Ecology's Environmental Covenants Registry (in its Integrated Site Information System) would provide information regarding applicable restrictions (regulated navigation areas (RNAs)and proprietary controls) to anyone who uses or consults the state registry.

6.2.5.5 Institutional Controls Summary

There are many types of institutional controls that may be applied at the Site to control exposure pathways to humans and aquatic and terrestrial organisms. At Quendall, the larger the volume of contamination left in place, the more media that remain impacted and the more remedial technologies implemented to protect a variety of exposure pathways for humans and terrestrial and aquatic wildlife, the more extensive the type and use of institutional controls will be. Institutional controls placed in upland areas are generally expected to be more reliable and effective than those placed offshore.

6.2.6 *Monitoring*

Long-term monitoring would be conducted to confirm that the remedy is functioning as intended and according to the performance criteria established in the ROD and the Operation, Maintenance and Monitoring Plan (OMMP). 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 Alternatives 2 through 6, most monitoring is expected to be required in perpetuity because hazardous substances will be left in place. For Alternatives 7 through 10, where it is expected extensive treatment or removal of hazardous substances will take place, long-term monitoring is expected to be more limited. After remedial action is completed, a monitoring plan will be prepared that will reflect the extent to which hazardous substances have been left on-site.

Each alternative relies on an array of technologies when combined constitute an alternative. For the Quendall FS, the array of alternatives begins with remedies that rely primarily on capping, and as each additional remedy becomes more aggressive in removing or treating PTWs or other contaminated media, the necessity for monitoring is expected to decrease.

The extent of contamination left in place after remediation will be the major determinant regarding the extent of monitoring necessary to ensure that the remedy is functioning as intended and remains protective.

At the Quendall site, monitoring will require at a minimum the following:

- Inspection of upland cap integrity and sampling to determine whether uncapped areas remain below cleanup levels.

- Bathymetric surveys to assess the integrity of sediment caps and covers and sampling to determine whether the sediment remedy continues to function as designed and meets performance criteria.

- Groundwater monitoring for site COCs to determine whether the PRB and/ or DNAPL trench collection systems are functioning as intended and to assess the interim performance of the Quendall remedy.

The frequency and extent of monitoring will be determined and documented in an OMMP developed near the completion of remedial design. Monitoring requirements will reflect the extent to which contamination is left on-site, the reliability of engineering controls, repair/replacement frequency, etc. Because all alternatives include engineered sand capping, long term monitoring is expected to be required. The frequency and degree of monitoring will vary by alternative and in part depend on the magnitude of contamination left in place and the types of remedial technologies implemented. For the FS, the frequency of sampling under all alternatives is assumed to be at least annually due to the risks associated with remedy failure. All of the monitoring activities described above would also be conducted after significant natural events, such as earthquakes. Five-year reviews will be required in perpetuity and will require a more robust monitoring regime.

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. As with long-term monitoring specific requirements will be determined near the completion of remedial design.

6.3 Detailed Description of Alternatives

This section describes each of the 11 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 estimate remedial costs and to develop and compare remedial alternatives. Remedial area and material volume estimates are summarized in Table 6-2. 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, reactive materials in RCM and amended sand sediment caps and the 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, institutional controls or 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 all media to confirm that exposure pathways are controlled. Specific remedial components include the following:

- ENR to remediate areas of low concentrations of cPAHs in sediment;
- Engineered sand cap to remediate areas impacted by upwelling contaminated groundwater;
- RCM or amended sand cap in PTW areas to sorb DNAPL and control DNAPL migration;
- Upland cap to protect human health from direct contact with contaminated surface soils;
- Institutional controls to help ensure the effectiveness of engineering controls; and
- Monitoring to verify that the remedy is performing as intended.

A description of the remedial action components comprising this alternative is provided below and summarized in Table 6-1. 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. ENR would be applied in areas of sediment beyond the nearshore zone of upwelling groundwater, where the BTV value is exceeded in surface sediments by a factor of up to eight[37] (Appendix B1). 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.

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

[37] Eight times the BTV is assumed for the purposes of this FS (refer to Appendix B1b); the actual criterion will be developed during remedy design.

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[38].

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 where groundwater is upwelling and exceeds the groundwater PRGs. 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 PTW sediment areas. The sand cap extent would encompass the area where porewater data exceeds PRGs (outside of the PTW areas) and where, for the purposes of this FS, existing surface sediment concentrations are greater than 8 times the BTV.

Whether any of the capped shoreline areas would require erosion protection would be determined in remedial design. However, for the purposes of the FS and cost estimation, erosion protection is assumed conservatively. The assumption is that a shoreline cap in less than 15 feet of water depth would require erosion protection from wave energy and vessel-generated current. A preliminary evaluation regarding cap stability indicates that 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 (B-3) provides additional details regarding FS-level cap stability design calculations and conceptual material specifications for various cap layers. Further assessment regarding the need for armoring will be conducted in remedial design. If additional extensive analysis reveals that armoring that is not suitable for habitat is needed to prevent erosion, then capping may not be an acceptable remedial approach for alternatives that include shoreline capping. As an alternative to rip-rap, biotechnical stabilization (erosion protection which enhances

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[38] The estimated time to implement each remedy component described in this section is based on expected construction time only. Additional time will be required for remedy design. The total estimated duration to implement each alternative, including design and construction of all components, is provided in Section 7.

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 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 Core Mat Cap

As shown on Figure 6-1, seven aquatic DNAPL areas (DA-1 through DA-5, DA-7, and DA-8) would be capped with a 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, is expected to be relatively immobile due to weathering (e.g., in the T-Dock area) or where the shoreline bathymetry needs to be maintained to avoid mitigation for loss of aquatic habitat.

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, additional analysis will be required during remedial design to determine whether erosion protection is needed and, if so, the necessary specifications of erosion protection material needed to maintain stability. However, for the purposes of the FS and cost estimation, the need for erosion protection is assumed. In addition, the RCM layer would be permanently secured on the banks using an anchoring system.

For the FS, based on the assumed 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.

6.3.2.4 Alternative 2 Amended Sand Cap

The amended sand cap would be installed in the QP-S DNAPL Area (DA-6). The objective of the amended sand cap in this area is to sorb any disturbed DNAPL using a thicker reactive cap where DNAPL is present in greater volume and potentially more mobile, 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 offset the 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 in a manner that offsets loss of habitat. For the purposes of this FS, it is assumed that this offset would be accomplished by removing upland soil along the existing shoreline north of the amended cap, as shown on Figure 6-1.

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.

6.3.2.5 Alternative 2 Upland Cap

Areas where COCs exceed PRGs in surface soil would be covered with a permeable cap to prevent direct contact with affected soil. However, soil caps require ongoing monitoring and maintenance to ensure cap effectiveness. Institutional controls to prevent intentional disturbance of soil caps covering contaminated soils would be required and would include reference to the site OMMP.

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 where soil PRGs are exceeded, excluding the habitat area, as shown on Figure 6-1. Whether a cap would be necessary for the habitat area would be determined as part of remedial design and in conjunction with the design for habitat and wetland mitigation.

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

6.3.2.6 Alternative 2 Institutional Controls

Alternative 2 utilizes an upland soil cap, RCM cap, an engineered sand cap, and ENR. This remedy leaves all PTW, and contaminated soil and sediment in place. As a result, for Alternative 2 to remain protective, the use of institutional controls (and monitoring) are essential to ensure that remedial technologies remain intact, are functioning as intended, and are protective, in perpetuity. Institutional controls are needed to prevent: 1) exposure to media of concern or 2) remedy failure due to "controllable" events. If a remedial technology could fail due to events that are "uncontrollable" such as earthquakes, the remedy must be engineered properly to prevent remedy failure.

Remedies that leave most, if not all, contamination in place, are best protected by the use of layers of institutional controls, i.e., more than one type of institutional control for each type of remedial technology used, for exposure pathways and/or media of concern. For Alternative 2, the following types of institutional controls would be anticipated:

- Surface and subsurface soil – prohibitions regarding disturbance of caps and subsurface soils, and access to uplands.
- Groundwater – prohibition on well installation for any use and on all uses for existing wells.
- Sediment – prohibition on any activities that can damage or erode caps or ENR cover, such as boat anchoring, boat speed, no wake restrictions, no in-water work (such as pier construction), no swimming, and no wading.
- Surface water – no fishing, no swimming, and no wading.

As noted in the Section 6.2.5, certain institutional controls are more reliably enforced than others. It is generally more difficult to monitor and enforce institutional controls that focus on activities that may disturb sediment or sediment caps/covers or activities that can result in exposure to sediment and/or surface water than institutional controls that restrict disturbance of soil or use of groundwater.

6.3.3 *Alternative 3 –Targeted PTW Solidification (RR and MC-1 DNAPL Areas)*

Alternative 3 includes the same use of upland and sediment capping, monitoring, and institutional controls as Alternative 2, but also involves treatment of targeted areas of upland PTWs and additional treatment measures to further address contaminant migration near the shoreline. Alternative 3 includes the following components:

- *In situ* solidification of deep PTWs in the RR DNAPL Area and MC DNAPL Area to remove source material contributing to contamination of the Deep Aquifer;
- DNAPL collection trenches east of the habitat area, to remove mobile DNAPL from the subsurface and further reduce the potential migration of DNAPL from the uplands to the lake sediments;
- A PRB east of the habitat area (downgradient of the DNAPL collection trenches) to reduce migration of contamination in groundwater from the uplands and aid in the recovery of lake sediments and porewater;
- ENR to remediate areas of low concentration of cPAHs in sediment;
- Engineered sand cap to remediate sediment areas impacted by upwelling contaminated groundwater;
- RCM or amended sand caps in sediment PTW areas to sorb DNAPL and control DNAPL migration;
- Upland cap to protect human health from direct contact with contaminated surface soils;
- Institutional controls to help ensure the effectiveness of engineering controls; and
- Monitoring to verify that the remedy is performing as intended.

A description of the remedial actions that would be taken in this alternative is provided below and summarized in Table 6-1. 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 Figure 6-5. Remedial area and material volume estimates are summarized in Table 6-2.

6.3.3.1 Alternative 3 Solidification of Deep Upland PTWs

To reduce the volume of the Deep Aquifer contaminant plume, this alternative targets treatment of PTWs with the greatest potential effect on the Deep Aquifer: 1) PTWs located close to or in the Deep Aquifer; and 2) PTWs 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, PTWs may be present in the transition zone between the Shallow Aquifer and the Deep Aquifer in the RR DNAPL Area. DNAPL in the eastern portion of the MC DNAPL Area (near MC-1) is within approximately 2 feet of the Deep Aquifer. 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 PTW 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:

- Solidification of the RR DNAPL Area (Area 1 on Figure A-2), which includes the easternmost[39] and deepest (34 feet, at the top of the Deep Aquifer, at boring BH-30C) DNAPL occurrences;
- Solidification of the RR DNAPL Area and PTWs 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, PTWs directly west of the RR DNAPL Area, and additional PTWs located around borings BH-9, MC-18, and HC-4 (Areas 1, 2, and 3 on Figure A-2);

Additional scenarios involving PTW 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 PTWs further west results in additional reduction in groundwater contaminant plume volume, but the reduction is not proportional to the amount of soil

[39] 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.

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.

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 PTWs in this area would be difficult and expensive because of the presence of PTWs 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.

Area and Volume of Solidified Soils

In this alternative, PTWs 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 PTWs 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 PTWs. 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.

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[40], 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.

6.3.3.2 Alternative 3 DNAPL Collection Trenches

Collection trenches would be installed 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 would provide a means of 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:

[40] 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.

- 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. One trench would be constructed near the mouth of the former May Creek Channel, and four trenches would be constructed east of the habitat area, adjacent to the Quendall Pond Uplands area. Multiple trenches are assumed for this area to target different depths along the edge of the habitat area 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.
- Trenches would be excavated using an excavator and temporary sheet piling for shoring. Trenches would be keyed into the low-permeability soil layers beneath the deepest DNAPL occurrence along each alignment, to the extent that low permeability layers are present and properly aligned to successfully key in trenches that prevent contamination from migrating under a wall or trench. 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, PTW 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 PTW 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.

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 in the Shallow Alluvium to intercept contaminated groundwater and reduce the flux of contamination toward Lake Washington.

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[41] 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. Because groundwater velocities would be highest directly downgradient of the gates, gates would not be placed in areas upgradient of PTWs 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.

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[41] 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.

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 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 PTW areas) and where existing surface sediment concentrations are 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 Core Mat Cap

RCM sediment caps would be placed over sediments containing near-surface PTWs (seven of the eight aquatic DNAPL areas). The RCM sediment caps would cover the same footprint as described for Alternative 2 and would be constructed using the same methodologies described in Section 6.3.2.3.

6.3.3.7 Alternative 3 Amended Sand Cap

An amended sand cap would be placed over the QP-S DNAPL Area (DA-6). The amended sand cap would cover the same footprint as described for Alternative 2 and would be constructed using the same methodologies described in Section 6.3.2.4.

6.3.3.8 Alternative 3 Upland Cap

Areas where COCs exceed PRGs in surface soil would be covered with a permeable engineered cap to prevent direct contact with affected soil. The cap would be constructed as described in Alternative 2 (see Section 6.3.2.5 above). Areas solidified would not require a cap.

6.3.3.9 Alternative 3 Institutional Controls

Alternative 3 utilizes an upland soil cap, RCM cap, an engineered sand cap, and ENR as in Alternative 2. However, in addition to the Alternative 2 remedial elements, Alternative 3 includes *in situ* solidification, PRBs, and DNAPL collection trenches. Like Alternative 2, this remedy leaves most of the PTW, and contaminated soil and sediment in place. As a result, for Alternative 3 to remain protective, the following types of institutional controls would be anticipated:

- Surface and subsurface soil – prohibitions against disturbing the area where PRBs and collection trenches have been installed in addition to those regarding disturbance of caps and subsurface soils, and access to uplands. The areas where contaminated soils have been solidified are not expected to require a soil cap but would require prohibitions against any action that may compromise the integrity of the solidified soil.

- Groundwater – prohibition on well installation for any use and on all uses for existing wells.

- Sediment – prohibition on any activities that can damage or erode caps or ENR cover, such as boat anchoring, boat speed, no wake restrictions, no in-water work (such as pier construction), no swimming, and no wading.

- Surface water – no fishing, no swimming, and no wading.

As with Alternative 2, most institutional controls that focus on activities that may disturb sediment or sediment caps/covers or activities that can result in exposure to contaminated sediment and/or surface water are more difficult to enforce than controls that focus on disturbance of upland soil or use of groundwater. In addition, Alternative 3 includes more remedial elements than Alternative 2. Even though less contaminated material is left in place, there will be a need for more institutional controls than in Alternative 2 because there are more remedial tools than comprise Alternative 2. However, the additional institutional controls for protecting PRBs, collection trenches, and solidified soil are expected to be similar to prohibitions for disturbing subsurface soil and would not significantly affect the reliability or complexity of the controls.

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

Alternative 4 includes the same remedial technologies as Alternative 3, but instead of treating deep upland PTWs in the RR and MC-1 DNAPL Areas to reduce the groundwater contaminant plume volume in the Deep Aquifer, Alternative 4 includes targeted removal of PTWs in the Quendall Pond (QP) and selected T-Dock (TD) DNAPL Areas. The reason for targeting the TD DNAPL Area sediments is to remove PTW present as DNAPL in shallow sediments. The QP DNAPL Area includes oil-wetted, mobile DNAPL close to the Lake Washington shoreline (QP-U DNAPL Area) and in sediments located immediately off-shore (QP-S DNAPL Area), at approximately 10 feet below the mudline. The purpose of targeting these areas is to remove the greatest mass of potentially mobile PTW in the shoreline area of the Site. In the event of a seismic event, PTW in the QP-U DNAPL Area could migrate into Lake Washington and expand the area of PTW contamination in the nearshore area. Similarly, DNAPL in the QP-S DNAPL Area could also migrate further within the lake. Alternative 4 includes the following components:

- Excavation of PTWs in the QP-U DNAPL Area to remove source material adjacent to the lake;
- DNAPL collection trenches east of the habitat area, to remove mobile DNAPL from the subsurface and further reduce the potential migration of DNAPL from the uplands to the lake sediments;
- A PRB east of the habitat area (downgradient of the DNAPL trenches) to reduce migration of contamination in groundwater from the uplands and aid in the recovery of lake sediments and porewater;
- ENR to remediate areas of low concentration of cPAHs in sediment;
- Engineered sand cap to remediate sediment areas impacted by upwelling contaminated groundwater; removal of sediment PTW in the QP-S and TD (DA-1, DA-2 and DA-6) DNAPL Areas to eliminate most PTW in lake sediments; placement of reactive residuals covers over dredged areas to manage residuals if necessary;
- RCM caps in other aquatic PTW areas to sorb DNAPL and control DNAPL migration; upland cap to protect human health from direct contact with contaminated surface soils;
- Institutional controls to help ensure the effectiveness of engineering controls; and
- Monitoring to verify that the remedy is performing as intended.

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 6-4] but not on the plan views of subsequent alternatives) are shown on Figure 6-6. Representative cross sections illustrating this alternative's subsurface components are provided on Figures 6-7 and 6-8. Each component is discussed below.

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

In this alternative, PTWs 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. Additionally, 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.

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 PTWs is described in Section 6.3.4.6.

Figure 6-6 depicts the area of soil to be removed, and Figure 6-7 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.

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 longer timeframes for groundwater restoration compared to dredging in the "dry". 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. Only for the purposes of estimating construction costs for the FS, the areas excavated in the wet would be backfilled with a material such as 1-inch rock that can be adequately compacted under saturated conditions. Backfill material will be determined during remedial design in consultation with regulatory agencies with oversight for the remedial action, ESA, Magnuson-Stevens Act, etc. 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[42] 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.

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 6-6, and the estimated embedment depth is shown on Figure 6-7.

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 PTWs 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 area addressed by this alternative, wet excavation can be accomplished with a

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[42] 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.

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; 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.

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, PTW 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 outside the eastern boundary of the habitat area to intercept potentially mobile DNAPL. DNAPL collection trenches would provide a means of both monitoring and removing DNAPL that has the potential to migrate from the uplands toward the Habitat Area and 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 outside the eastern boundary of the habitat area in the Shallow Alluvium to intercept contaminated groundwater and reduce the flux of contamination toward the Habitat Area and Lake Washington. The treatment wall would assist natural attenuation to protect potential Habitat Area, sediment and surface water receptors and enhance recovery of the contaminated groundwater, 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 PTWs 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 PTW areas) and where existing surface sediment concentrations are 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 Core Mat Sediment Cap

The RCM sediment 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 RCM sediment caps over aquatic DNAPL areas DA-3, DA-4, DA-5, DA-7, and DA-8. 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 TD areas contain near-surface DNAPL deposits that may be potentially disturbed by boating activities such as anchoring, erosional forces from natural events such as wind or following a large seismic event. As described in Section 4.4.1.6, the TD DNAPL Area is of particular concern due to the presence of DNAPL shallow sediments. The purpose of targeting the QP-S DNAPL area is to remove DNAPL that is of particular concern due to its effect on groundwater quality beneath the lake, thickness, and potentially mobility.

The effectiveness of dredging these areas may be limited by short-term impacts during dredging (i.e., resuspension of sediments; release of particles contaminated with COCs, 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 experienced operators, 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.

Areas and Volumes of Sediment to be Removed

Figure 6-6 depicts the area of sediment to be removed, and Figure 6-8 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.

Sediment Removal Methods

Hydraulic Dredging. Offshore PTWs 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 6-6). 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 PTWs. 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 PTWs 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 and dredging practices and BMPs as required by EPA 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.

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. 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 based on post-dredge sediment sampling. 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).

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 6-6. 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 a permeable engineered cap to prevent direct contact with affected soil. Excavated areas would not require a cap.

6.3.4.9 Alternative 4 Institutional Controls

Alternative 4 utilizes an upland soil cap, RCM cap, an engineered sand cap, and ENR as in Alternative 2. However, in addition to the Alternative 2 remedial elements, Alternative 4 includes upland excavation, dredging, PRBs, and DNAPL collection trenches. This remedy leaves most of the PTW, and contaminated soil and sediment in place. As a result, for Alternative 4 to remain protective, the following types of institutional controls would be anticipated:

- Surface and subsurface soil – prohibitions against disturbing the area where PRBs and collection trenches have been installed in addition to those regarding disturbance of caps and subsurface soils, and access to uplands. The areas where contaminated soils have been excavated are not expected to require a soil cap.
- Groundwater – prohibition on well installation for any use and on all uses for existing wells.
- Sediment – prohibition on any activities that can damage or erode caps or ENR cover, such as boat anchoring, boat speed, no wake restrictions, no in-water work (such as pier construction), no swimming, and no wading. Sediments that have been dredged may require a thin cover over dredged residuals that would require prohibitions against any activities that could adversely impact the cover. The area of sediments subject to restrictions are expected to be the same as Alternative 2 but could be less depending on the results from sampling sediment areas around the dredged areas.
- Surface water – no fishing, no swimming, and no wading.

As with Alternative 2, most institutional controls that focus on activities that may disturb sediment or sediment caps/covers or activities that can result in exposure to contaminated sediment and/or surface water are more difficult to enforce than controls that focus on disturbance of upland soil or use of groundwater. In addition, Alternative 4 includes more remedial elements than Alternative 2. Even though less contaminated material is left in place, there will be a need for more institutional controls than in Alternative 2 because there are more remedial tools than comprise Alternative 2. However, the additional institutional controls for protecting PRBs and collection trenches are expected to be similar to prohibitions for disturbing subsurface soil and would not significantly affect the reliability or complexity of the controls.

6.3.5 *Alternative 4a –Targeted PTW Solidification (RR, MC-1, and QP-U DNAPL Areas) and Removal (TD DNAPL Area)*

Alternative 4a incorporates the same upland remedial technologies as Alternative 3 to solidify deep DNAPL in the RR and MC-1 DNAPL Areas to treat groundwater and restore a portion of the Deep Aquifer. Alternative 4a adds solidification of the QP-U DNAPL Area, to target potentially mobile DNAPL located adjacent to Lake Washington. In the event of a seismic event PTW in the QP-U Area could migrate into Lake Washington and expand the area of PTW contamination.

Alternative 4a includes the same offshore remedies as Alternative 4, except that instead of dredging shallow sediments in the QP-S DNAPL area, those sediments would be addressed with an amended sand cap, identical to Alternative 2.

Alternative 4a includes the following components:

- *In situ* solidification of deep PTWs in the RR DNAPL Area and MC DNAPL Area to remove source material contributing to contamination of the Deep Aquifer, and of PTWs in the QP-U DNAPL Area to remove source material adjacent to the lake;
- DNAPL collection trenches east of the habitat area, to remove mobile DNAPL from the subsurface and further reduce the potential migration of DNAPL from the uplands to the lake sediments;
- A PRB east of the habitat area (downgradient of the DNAPL collection trenches) to reduce migration of contamination in groundwater from the uplands and aid in the recovery of lake sediments and porewater;
- ENR to remediate areas of low concentration of cPAHs in sediment;
- Engineered sand cap to remediate sediment areas impacted by upwelling contaminated groundwater;
- Removal of sediment PTW in the TD (DA-1 and DA-2) DNAPL Area to eliminate shallow PTW in lake sediments, with placement of reactive residuals covers over dredged areas to manage residuals if necessary;
- Amended sand cap in the QP-S (DA-6) DNAPL area;
- RCM caps in other sediment PTW areas to sorb DNAPL and control DNAPL migration;

- Upland cap to protect human health from direct contact with contaminated surface soils;
- Institutional controls to help ensure the effectiveness of engineering controls; and
- Monitoring to verify that the remedy is performing as intended.

The areas addressed by different components of Alternative 4a are shown on Figure 6-9. Subsurface components of this alternative are illustrated along representative cross sections on Figures 6-5 and 6-10. Each remedy component is discussed below.

6.3.5.1 Alternative 4a Targeted Solidification of Upland PTWs

In this alternative, deep PTWs would be solidified as described under Alternative 3 (see Section 6.3.3.1). In addition, PTWs in the QP-U DNAPL Area would also be solidified.

Figure 6-9 depicts the soil area 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 is approximately 0.9 acres for a total volume of approximately 38,000 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 3 months. Additional time would be required for mobilization, Site setup, and demobilization. It is estimated that construction of this remedy component would take 6 months.

6.3.5.2 Alternative 4a DNAPL Collection Trenches

Collection trenches would be installed outside the eastern boundary of the habitat area to intercept potentially mobile DNAPL. DNAPL collection trenches would provide a means of both monitoring and removing DNAPL that has the potential to migrate from the uplands toward the Habitat Area and lake sediments. This alternative assumes DNAPL collection trenches would be constructed as described in Alternative 3 (see Section 6.3.3.2 above).

6.3.5.3 Alternative 4a Permeable Reactive Barrier

A PRB would be installed in the Shallow Alluvium to intercept contaminated groundwater and reduce the flux of groundwater contamination toward Lake Washington. This alternative assumes the PRB would be constructed as described in Alternative 3 (see Section 6.3.3.3).

6.3.5.4 Alternative 4a ENR

ENR would be implemented in areas containing surface sediments exceeding the BTV but not dredged or covered with sand or RCM 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.

6.3.5.5 Alternative 4a Engineered Sand Cap

An engineered sand cap would be placed over sediments where porewater data exceeds PRGs (outside of PTW areas) and where existing surface sediment concentrations are 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.

6.3.5.6 Alternative 4a Reactive Core Mat Cap

RCM caps would be placed over sediments containing near-surface PTWs outside of dredged areas. The RCM caps would cover the same footprint as described for Alternative 4 (see Section 6.3.4.6), and they would be constructed using the same methodologies.

6.3.5.7 Alternative 4a Amended Sand Cap

An amended sand cap would be placed over the QP-S DNAPL Area (DA-6). The amended sand cap would cover the same footprint as described for Alternative 2 and 3 and would be constructed using the same methodologies described in Section 6.3.2.4.

6.3.5.8 Alternative 4a Sediment Removal

The extent and methods of sediment removal for Alternative 4a is the same as for Alternative 4 (see Section 6.3.4.7), and includes targeted PTWs in the offshore TD DNAPL Area (DA-1 and DA-2). As in Alternative 4, offshore areas would be dredged using hydraulic dredging methods. 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.

6.3.5.9 Alternative 4a 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). Areas solidified would not require a cap.

6.3.5.10 Alternative 4a Institutional Controls

Alternative 4a utilizes an upland soil cap, RCM cap, an engineered sand cap, and ENR as in Alternative 2. However, in addition to the Alternative 2 remedial elements, Alternative 4a includes *in situ* solidification, dredging, PRBs, and DNAPL collection trenches. Like Alternative 2, this remedy leaves most of the PTW, and contaminated soil and sediment in place. As a result, for Alternative 4a to remain protective, the following types of institutional controls would be anticipated:

- Surface and subsurface soil – prohibitions against disturbing the area where PRBs and collection trenches have been installed in addition to those regarding disturbance of caps and subsurface soils, and access to uplands. The areas where contaminated soils have been solidified are not expected to require a soil cap but would require prohibitions against any action that may compromise the integrity of the solidified soil.

- Groundwater – prohibition on well installation for any use and on all uses for existing wells.

- Sediment – prohibition on any activities that can damage or erode caps or ENR cover, such as boat anchoring, boat speed, no wake restrictions, no in-water work (such as pier construction), no swimming, and no wading. Sediments that have been dredged may require a thin cover over dredged residuals that would require prohibitions against any activities that could adversely impact the cover. The area of sediments subject to restrictions are expected to be the same as Alternative 2 but could be less depending on the results from sampling sediment areas around the dredged areas.

- Surface water – no fishing, no swimming, and no wading.

As with Alternative 2, most institutional controls that focus on activities that may disturb sediment or sediment caps/covers or activities that can result in exposure to contaminated sediment and/or surface water are more difficult to enforce than controls that focus on disturbance of upland soil or use of groundwater. In addition, Alternative 4a includes more remedial elements than Alternative 2. Even though less contaminated material is left in place, there will be a need for more institutional controls than in Alternative 2 because there are more remedial tools than comprise Alternative 2. However, the additional institutional controls for protecting PRBs, collection trenches, and solidified soil are expected to be similar to prohibitions for disturbing subsurface soil and would not significantly affect the reliability or complexity of the controls.

6.3.6 *Alternative 5 –Targeted PTW 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 4a to solidify deep PTWs in the RR and MC-1 DNAPL Areas to treat groundwater and restore a portion of the Deep Aquifer, and to solidify PTWs in the QP-U DNAPL Area, to target potentially mobile DNAPL located adjacent to Lake Washington. To provide additional treatment of PTWs, it also includes solidification of other areas of the uplands where greater than 4 cumulative feet of PTW soils are in the top 20 feet of soil column.

The greatest cumulative thicknesses of PTW soil (greater than 4 cumulative feet) [43] 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. Alternative 5 includes the same offshore remedies as Alternative 4.

Alternative 5 includes the following components:

- *In situ* solidification of upland PTWs, including the QP-U DNAPL Area, deep PTWs in the RR and MC DNAPL Areas, and areas with PTW soil greater than 4-feet cumulative thickness in the top 20 feet of soil column to treat PTWs;

- A PRB east of the habitat area to reduce migration of contamination in groundwater from the uplands and aid in the recovery of lake sediments and porewater;

[43] 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).

- ENR to remediate areas of low concentration of cPAHs in sediment;
- Engineered sand cap to remediate sediment areas impacted by upwelling contaminated groundwater;
- RCM caps in other sediment PTW areas to sorb DNAPL and control DNAPL migration;
- Removal of sediment PTW in the QP-S and TD (DA-1, DA-2 and DA-6) DNAPL Areas to eliminate most PTWs in lake sediments; placement of reactive residuals covers over dredged areas to manage residuals if necessary;
- Upland cap to protect human health from direct contact with contaminated surface soils;
- Institutional controls to help ensure the effectiveness of engineering controls; and
- Monitoring to verify that the remedy is performing as intended.

The areas addressed by different components of Alternative 5 are shown on Figure 6-11, and a representative cross section for upland components is provided on Figure 6-12. Sediment components are the same as for Alternative 4; therefore, refer to Figure 6-8 for illustration of components along a sediment cross section. Each component remedy is discussed below.

6.3.6.1 Alternative 5 Targeted Solidification of Upland PTWs

In this alternative, deep PTWs would be solidified as described under Alternative 3 (see Section 6.3.3.1). In addition, PTWs in the QP-U DNAPL Area and upland areas containing 4 feet or more (cumulative thickness) of PTW soil in the upper 20 feet would also be solidified.

For the purposes of this FS, it is assumed that solidification outside of deep PTW areas would include soil up to a depth of 20 feet. Additional vertical delineation of shallow PTW in these areas would be performed as part of the design to determine the required solidification depth for PTWs above 20 feet.

Figure 6-11 depicts the soil area to be solidified, and Figure 6-12 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.

6.3.6.2 Alternative 5 Permeable Reactive Barrier

A PRB would be installed in the Shallow Alluvium to intercept contaminated groundwater and reduce the flux of groundwater contamination toward the Habitat Area and 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).

6.3.6.3 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.

6.3.6.4 Alternative 5 Engineered Sand Cap

An engineered sand cap would be placed over sediments where porewater data exceeds PRGs (outside of PTW areas) and where existing surface sediment concentrations are 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 5 Reactive Core Mat Cap

Reactive sediment caps would be placed over sediments containing near-surface PTWs 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 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 PTWs 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 5 Upland Cap

Areas where COCs exceed PRGs in surface soil would be covered with a permeable 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). Areas solidified would not require a cap.

6.3.6.8 Alternative 5 Institutional Controls

Alternative 5 utilizes an upland soil cap, RCM cap, an engineered sand cap, and ENR as in Alternative 2. However, in addition to the Alternative 2 remedial elements, Alternative 5 includes dredging, *in situ* solidification, PRBs, and DNAPL collection trenches. This remedy leaves much of the PTW, and contaminated soil and sediment in place. As a result, for Alternative 5 to remain protective, the following types of institutional controls would be anticipated:

- Surface and subsurface soil – prohibitions against disturbing the area where PRBs and collection trenches have been installed in addition to those regarding disturbance of caps and subsurface soils, and access to uplands. The areas where contaminated soils have been solidified are not expected to require a soil cap but would require prohibitions against any action that may compromise the integrity of the solidified soil.
- Groundwater – prohibition on well installation for any use and on all uses for existing wells.
- Sediment – prohibition on any activities that can damage or erode caps or ENR cover, such as boat anchoring, boat speed, no wake restrictions, no in-water work (such as pier construction), no swimming, and no wading. Sediments that have been dredged may require a thin cover over dredged residuals that would require prohibitions against any activities that could adversely impact the cover. The area of sediments subject to restrictions are expected to be the same as Alternative 2 but could be less depending on the results from sampling sediment areas around the dredged areas.
- Surface water – no fishing, no swimming, and no wading.

As with Alternative 2, most institutional controls that focus on activities that may disturb sediment or sediment caps/covers or activities that can result in exposure to contaminated sediment and/or surface water are more difficult to enforce than controls that focus on disturbance of upland soil or use of groundwater. In addition, Alternative 5 includes more remedial elements than Alternative 2. Even though less contaminated material is left in place, there will be a need for more institutional controls than in Alternative 2 because there are more remedial tools than comprise Alternative 2. However, the additional institutional controls for protecting PRBs, collection trenches, and solidified soil are expected to be similar to prohibitions for disturbing subsurface soil and would not significantly affect the reliability or complexity of the controls.

6.3.7 *Alternative 6 –Targeted PTW 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[44]. Alternative 6 also includes targeted solidification of deep PTWs (as in Alternatives 3 and 5) to reduce groundwater plume volume and solidification of shallow PTW soil exceeding 2 feet of cumulative thickness in the top 20 feet of soil column to provide additional treatment of PTWs.

Alternative 6 includes the following components:

- *In situ* solidification of upland PTWs, including the QP-U DNAPL Area, deep PTWs in the RR and MC DNAPL Areas, and areas with PTW soil greater than 2-

[44] Areas identified for DNAPL collection trenches in Alternative 4 are targeted for solidification in Alternative 6.

feet cumulative thickness in the top 20 feet of soil column to treat PTWs, which are source materials contributing to groundwater contamination;

- Excavation of upland PTWs in the QU-U DNAPL Area to eliminate PTWs adjacent to the lake;
- A PRB east of the habitat area to reduce migration of contamination in groundwater from the uplands and aid in the recovery of lake sediments and porewater;
- ENR to remediate areas of low concentration of cPAHs in sediment;
- Engineered sand cap to remediate sediment areas impacted by upwelling contaminated groundwater;
- RCM caps in other sediment PTW areas to sorb DNAPL and control DNAPL migration;
- Removal of sediment PTW in the QP-S and TD (DA-1, DA-2 and DA-6) DNAPL Areas to eliminate most PTWs in lake sediments; placement of reactive residuals covers over dredged areas to manage residuals if necessary;
- Upland cap to protect human health from direct contact with contaminated surface soils;
- Institutional controls to help ensure the effectiveness of engineering controls; and
- Monitoring to verify that the remedy is performing as intended.

The areas addressed by different components of Alternative 6 are shown on Figure 6-13, and upland components along a representative cross section are shown on Figure 6-14. Sediment components are the same as for Alternative 4; therefore, refer to Figure 6-8 for illustration of components along a sediment cross section. Each component remedy is discussed below.

6.3.7.1 Alternative 6 Targeted Solidification of Upland PTWs

The purpose of Alternative 6 is to reduce the mass of PTW and to reduce the plume volume to a greater extent than Alternative 5. Alternative 6 treats PTW in soil in the upper 20 feet containing 2 feet or more cumulative thickness of DNAPL using *in situ* solidification.

For the purposes of this FS, it is assumed that solidification outside of deep PTW areas would include soil up to a depth of 20 feet. Additional vertical delineation of shallow PTWs in these areas would be performed as part of the design to determine the required solidification depth for PTWs above 20 feet.

Figure 6-13 depicts the soil area to be solidified, and Figure 6-14 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.

6.3.7.2 Alternative 6 Removal of Upland PTWs (QP-U DNAPL Area)

In this alternative, PTWs in the QP-U DNAPL Area would be excavated, disposed of off site, and replaced with clean imported fill. The excavated area covers the same footprint as described for Alternative 4 and would be constructed using the same methodologies described in Section 6.3.4.1.

6.3.7.3 Alternative 6 Permeable Reactive Barrier

A PRB would be installed in the Shallow Alluvium to intercept contaminated groundwater and reduce the flux of contamination toward Lake Washington. 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.

6.3.7.4 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.

6.3.7.5 Alternative 6 Engineered Sand Cap

An engineered sand cap would be placed over sediments where porewater data exceeds PRGs (outside of PTW areas) and where existing surface sediment concentrations are 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.

6.3.7.6 Alternative 6 RCM Cap

Reactive sediment caps would be placed over sediments containing near-surface PTWs 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.

6.3.7.7 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 PTW areas in the offshore TD DNAPL Area (DA-1 and DA-2) and the nearshore QP-S DNAPL Area (DA-6).

6.3.7.8 Alternative 6 Upland Cap

Areas where COCs exceed PRGs in surface soil would be covered with a permeable 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). Areas solidified would not require a cap.

6.3.7.9 Alternative 6 Institutional Controls

Alternative 6 utilizes an upland soil cap, RCM cap, an engineered sand cap, and ENR as in Alternative 2. However, in addition to the Alternative 2 remedial elements, Alternative 4 includes dredging, *in situ* solidification, PRBs, and DNAPL collection trenches. This remedy leaves much of the PTW, and contaminated soil and sediment in place. As a result, for Alternative 5 to remain protective, the following types of institutional controls would be anticipated:

- Surface and subsurface soil – prohibitions against disturbing the area where PRBs have been installed in addition to those regarding disturbance of caps and subsurface soils, and access to uplands. The areas where contaminated soils have been solidified are not expected to require a soil cap but would require prohibitions against any action that may compromise the integrity of the solidified soil. The areas where contaminated soils have been excavated are also not expected to require a soil cap.
- Groundwater – prohibition on well installation for any use and on all uses for existing wells.
- Sediment – prohibition on any activities that can damage or erode caps or ENR cover, such as boat anchoring, boat speed, no wake restrictions, no in-water work (such as pier construction), no swimming, and no wading. Sediments that have been dredged may require a thin cover over dredged residuals that would require prohibitions against any activities that could adversely impact the cover. The area of sediments subject to restrictions are expected to be the same as Alternative 2 but could be less depending on the results from sampling sediment areas around the dredged areas.
- Surface water – no fishing, no swimming, and no wading.

As with Alternative 2, most institutional controls that focus on activities that may disturb sediment or sediment caps/covers or activities that can result in exposure to contaminated sediment and/or surface water are more difficult to enforce than controls that focus on disturbance of upland soil or use of groundwater. In addition, Alternative 6 includes more remedial elements than Alternative 2. Even though less contaminated material is left in place, there will be a need for more institutional controls than in Alternative 2 because there are more remedial tools than comprise Alternative 2. However, the additional institutional controls for protecting PRBs and solidified soil are expected to be similar to prohibitions for disturbing subsurface soil and would not significantly affect the reliability or complexity of the controls.

6.3.8 *Alternative 7 –PTW Solidification (Upland) and Removal (Sediment)*

Alternative 7 involves solidification of upland PTWs that are a source of groundwater contamination above MCLs, and removal and off-site disposal of sediment PTWs. The primary objective of this alternative is to treat the PTW on the Site that is a source of groundwater contamination above MCLs, in accordance with RAO SC1 (see Section 4.2.1). For the purposes of the FS, all upland and sediment PTWs are assumed to be treated or removed under this alternative. Containment measures described in Alternative 2 are also included in this alternative to maintain protectiveness.

Alternative 7 includes the following components:

- *In situ* solidification of all upland PTWs;
- ENR to remediate areas of low concentration of cPAHs in sediment;
- Engineered sand cap to remediate sediment areas impacted by upwelling contaminated groundwater;
- Removal of all sediment PTWs and placement of reactive residuals covers over dredged areas to manage residuals if necessary;
- Upland cap to protect human health from direct contact with contaminated surface soils;
- Institutional controls to help ensure the effectiveness of engineering controls; and
- Monitoring to verify that the remedy is performing as intended.

The areas addressed by different components of Alternative 7 are shown on Figure 6-15, and representative cross sections are provided on Figures 6-16 and 6-17. Each remedy component is discussed below.

6.3.8.1 Alternative 7 Solidification of Upland PTWs

In this alternative, PTWs 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.

Treatment Areas and Volumes

The lateral and vertical extent of PTWs 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 PTW in each area to provide a buffer between solidified PTWs and the surrounding aquifer.

Figure 6-15 depicts the area of solidification, and Figure 6-16 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.

Solidification Methods

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.

6.3.8.2 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.

6.3.8.3 Alternative 7 Engineered Sand Cap

An engineered sand cap would be placed over sediments where porewater data exceeds PRGs (outside of PTW areas) and where existing surface sediment concentrations are 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

6.3.8.4 Alternative 7 Removal of Sediment PTWs

The sediment removal approach for Alternative 7 is the same as described in Section 6.3.4.7.2 for Alternative 5, 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 PTW 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 PTWs. 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 6-17.

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 6-15. 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.

6.3.8.5 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. The cap would be constructed as described in Alternative 2 (see Section 6.3.2.4). Areas solidified would not require a cap.

6.3.8.6 Alternative 7 Institutional Controls

Alternative 7 utilizes *in situ* solidification of upland PTW and dredging of sediment PTW, an engineered sand cap, and ENR. An upland soil cap may or may not be necessary pending the results of post-remedy soil sampling. Alternative 7 involves fewer remedial elements compared to the previously described alternatives, Alternatives 2 through 6. Unlike other alternatives, the purpose of Alternative 7 is to remove all known PTW; however, contaminated soil and sediment remain in place. As a result, for Alternative 7 to remain protective, the following types of institutional controls would be anticipated:

- Surface and subsurface soil – the areas where contaminated soils have been solidified are not expected to require a soil cap but would require prohibitions against any action that may compromise the integrity of the solidified soil.
- Groundwater – prohibition on well installation for any use and on all uses for existing wells.
- Sediment – prohibition on any activities that can damage or erode engineered sand caps or an ENR cover, such as boat anchoring, boat speed, no wake restrictions, no in-water work (such as pier construction), no swimming, and no wading. Sediments that have been dredged may require a thin cover over dredged residuals that would require prohibitions against any activities that could adversely impact the cover. Restrictions would be required in the engineered sediment cap, dredge residuals cover, and ENR areas if post-remediation sampling indicates exceedance of PRGs. However, institutional controls for engineered sand caps, dredge residuals covers, and ENR are not expected to remain necessary in perpetuity as are institutional controls for Alternatives 2 through 6, since all PTWs are treated or removed. PRGs are expected to be obtained for engineered sand caps, dredge residuals covers, and ENR, thus eliminating the need for extensive institutional controls.
- Surface water – no fishing, no swimming, and no wading until PRGs are obtained for engineered sand caps, dredge residuals covers, and ENR areas.

As with Alternative 2, most institutional controls that focus on activities that may disturb sediment or sediment caps/covers or activities that can result in exposure to contaminated sediment and/or surface water are more difficult to enforce than controls that focus on disturbance of upland soil or use of groundwater. However, most institutional controls in Alternative 7 may not be required in perpetuity, because sources have been removed or treated and remaining contaminated sediments may remediate in time.

6.3.9 *Alternative 8 – PTW Removal (Upland and Sediment)*

Alternative 8 involves removal and on-site treatment of all upland and sediment PTWs. The primary objective of this alternative is to treat all PTWs on the Site. Containment measures described in Alternative 2, except reactive sediment capping[45], are also included in this alternative to maintain protectiveness.

Alternative 8 includes the following components:

- Removal of all upland PTWs and on-site *ex situ* thermal treatment;

[45] Reactive sediment capping is not included in Alternative 8 because sediment PTWs are removed.

- ENR to remediate areas of low concentration of cPAHs in sediment;
- Engineered sand cap to remediate sediment areas impacted by upwelling contaminated groundwater;
- Removal of all sediment PTWs and on-site *ex situ* thermal treatment; placement of reactive residuals covers over dredged areas to manage residuals if necessary;
- Upland cap to protect human health from direct contact with contaminated surface soils;
- Institutional controls to help ensure the effectiveness of engineering controls; and
- Monitoring to verify that the remedy is performing as intended.

The areas addressed by different components of Alternative 8 are shown on Figure 6-18, and a representative cross section of upland components is provided on Figure 6-19. Sediment components are the same as for Alternative 7; therefore, refer to Figure 6-17 for illustration of components along a sediment cross section. Each component remedy is discussed below.

6.3.9.1 Removal of Upland PTWs

In this alternative, PTWs 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 PTW 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 PTWs, 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.

Areas and Volumes of Soil Removal

The lateral and vertical extent of PTWs is described in Section 3.5.

Figure 6-18 depicts the area of soil to be removed, and Figure 6-19 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.

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 PTWs, the removal area would be divided into several discrete cells so that localized deeper PTWs 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 6-19.

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.

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 6-18, and the estimated embedment depths are shown on Figure 6-19.

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.

Management of Removed Soil

Excavated soil would be treated on site using *ex situ* thermal treatment. 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 treatment at achieving soil PRGs. For the purposes of this FS, it is assumed that thermal treatment would remove DNAPL but that the treated soil could still exceed PRGs and require containment (such as capping).

Thermal treatment 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.

6.3.9.2 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.

6.3.9.3 Alternative 8 Engineered Sand Cap

An engineered sand cap would be placed over sediments where porewater data exceeds PRGs (outside of PTW areas) and where existing surface sediment concentrations are 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.

6.3.9.4 Alternative 8 Removal of Sediment PTWs

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 PTW 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.

6.3.9.5 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. The cap would be constructed as described in Alternative 2 (see Section 6.3.2.4). Areas excavated may require a cap because, as discussed in Section 6.3.9.1.5, the treated soil to be used as backfill could still exceed PRGs.

6.3.9.6 Alternative 8 Institutional Controls

Alternative 8 utilizes excavation of upland PTW and dredging of sediment PTW, an engineered sand cap, and ENR. An upland soil cap may or may not be necessary pending the results of post-remedy soil sampling. Alternative 8 involves fewer remedial elements compared to the previously described alternatives, Alternatives 2 through 6; however, it includes *ex situ* thermal treatment. The purpose of Alternative 8 is to remove all known PTW; however, contaminated soil and sediment remain in place. As a result, for Alternative 8 to remain protective, the following types of institutional controls would be anticipated:

- Surface and subsurface soil – the areas where contaminated soils have been excavated are not expected to require a soil cap unless sampling of post-treatment backfill indicates exceedances of PRGs.
- Groundwater – prohibition on well installation for any use and on all uses for existing wells.
- Sediment – prohibition on any activities that can damage or erode engineered sand caps or an ENR cover, such as boat anchoring, boat speed, no wake restrictions, no in-water work (such as pier construction), no swimming, and no wading. Sediments that have been dredged may require a thin cover over dredged residuals that would require prohibitions against any activities that could adversely impact the cover. Restrictions would be required in the engineered sediment cap, dredge residuals cover, and ENR areas if post-remediation sampling indicates exceedance of PRGs. However, institutional controls for engineered sand caps, dredge residuals covers, and ENR are not expected to remain necessary in perpetuity as are institutional controls for Alternatives 2 through 6, since all PTWs are treated or removed. PRGs are expected to be obtained for engineered sand caps, dredge residuals covers, and ENR, thus eliminating the need for extensive institutional controls.
- Surface water – no fishing, no swimming, and no wading until PRGs are obtained for engineered sand caps, dredge residuals covers, and ENR areas.

As with Alternative 2, most institutional controls that focus on activities that may disturb sediment or sediment caps/covers or activities that can result in exposure to contaminated sediment and/or surface water more difficult to enforce than controls that focus on disturbance of upland soil or use of groundwater. However, most institutional controls in

Alternative 8 may not be required in perpetuity, because sources have been removed or treated and remaining contaminated sediments may remediate in time.

6.3.10 *Alternative 9 – Solidification and Removal of Upland PTW and Contaminated Soil, and Removal of Sediment PTW and 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 PTWs 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[46], excluding benzene[47]. 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[48]. 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 PTWs and to restore groundwater to the maximum extent possible. *In situ* solidification of deep soils was selected rather than excavation to reduce cost and improve implementability. Active polishing treatment (such as pump-and-treat) was considered to address this, but was not included in this alternative. (Polishing treatment is included in Alternative 10.)

Alternative 9 includes the following components:

- Removal of shallow upland PTWs and contaminated soil; on-site *ex situ* thermal treatment;
- *In situ* solidification of deep upland PTWs and contaminated soil;
- ENR to remediate areas of low concentration of cPAHs in sediment;
- Engineered sand cap to remediate sediment areas impacted by upwelling contaminated groundwater;

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[46] 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.

[47] 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.

[48] 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).

- Removal of all sediment PTWs and on-site *ex situ* thermal treatment; placement of reactive residuals covers over dredged areas to manage residuals if necessary; removal/on-site *ex situ* thermal treatment of contaminated sediment;
- Upland cap to protect human health from direct contact with contaminated surface soils;
- Institutional controls to help ensure the effectiveness of engineering controls; and
- Monitoring to verify that the remedy is performing as intended.

The areas addressed by different components of Alternative 9 are shown on Figure 6-20 and representative cross sections are provided on Figures 6-21 and 6-22. Each component of the remedy is discussed below.

6.3.10.1 Areas and Volumes of Contaminated Soil

The area of soil to be removed or treated is shown on Figure 6-20. 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 PTWs in the Shallow Alluvium would be addressed;
- The area of PTWs 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 to be removed or treated is shown on Figure 6-21. 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 PTW, 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.

6.3.10.2 Alternative 9 Removal of Shallow Contaminated Soil

Alternative 9 assumes that upland Source Area soils are excavated to a depth of 15 feet.[49] 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 PTWs and associated contaminant mass. By removing most of the upland PTWs rather than solidifying them, there is a greater likelihood that groundwater RAOs would be achieved.

[49] This is the estimated depth to which excavation is possible without dewatering to depressurize the Deeper Alluvium.

- 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 6-21 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 6-20 shows the upland areas in which excavation cells are assumed to be constructed in Alternative 9, along with a conceptual layout of individual cells.

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.

6.3.10.3 Alternative 9 Solidification of Deep Contaminated Soil

Upland Source Area soils below 15-foot depth would be solidified *in situ* in Alternative 9. Figure 6-21 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.

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.

6.3.10.4 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.

6.3.10.5 Alternative 9 Engineered Sand Cap

An engineered sand cap would be placed over sediments where surface sediment concentrations are 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.

6.3.10.6 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 6-20. 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 PTWs. In the offshore aquatic DNAPL areas (DA-1 through DA-4), the target dredge depth is 2 feet below the observed PTW 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 PTWs 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 6-20. 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.

6.3.10.7 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). Areas excavated may require a cap because, as discussed in Section 6.3.9.1.5, the treated soil to be used as backfill could still exceed PRGs.

6.3.10.8 Alternative 9 Institutional Controls

Alternative 9 utilizes excavation and *in situ* stabilization of upland PTW and contaminated soil, and dredging of sediment PTW and contaminated sediment, an engineered sand cap, and ENR. An upland soil cap may or may not be necessary pending the results of post-remedy soil sampling. Alternative 9 involves fewer remedial elements compared to the previously described alternatives, Alternatives 2 through 6; however it includes *ex situ* thermal treatment. The following types of institutional controls would be anticipated:

- Surface and subsurface soil – the areas where contaminated soils have been excavated are not expected to require a soil cap unless sampling of post-treatment backfill indicates exceedances of PRGs.
- Groundwater – prohibition on well installation for any use and on all uses for existing wells.
- Sediment – prohibition on any activities that can damage or erode engineered sand caps or an ENR cover, such as boat anchoring, boat speed, no wake restrictions, no in-water work (such as pier construction), no swimming, and no wading. Sediments that have been dredged may require a thin cover over dredged residuals that would require prohibitions against any activities that could adversely impact the cover. Restrictions would be required in the engineered sediment cap, dredge residuals cover, and ENR areas if post-remediation sampling indicates exceedance of PRGs. However, institutional controls for engineered sand caps, dredge residuals covers, and ENR are not expected to remain necessary in perpetuity as are institutional controls for Alternatives 2 through 6, since all PTWs are treated or removed. PRGs are expected to be obtained for engineered sand caps, dredge residuals covers, and ENR, thus eliminating the need for extensive institutional controls.
- Surface water – no fishing, no swimming, and no wading until PRGs are obtained for engineered sand caps, dredge residuals covers, and ENR areas.

As with Alternative 2, most institutional controls that focus on activities that may disturb sediment or sediment caps/covers or activities that can result in exposure to contaminated sediment and/or surface water are more difficult to enforce than controls that focus on disturbance of upland soil or use of groundwater. However, most institutional controls in Alternative 9 may not be required in perpetuity, because sources have been removed or treated and remaining contaminated sediments may remediate in time.

6.3.11 *Alternative 10 –Removal of Upland PTW, Sediment PTW, Contaminated Soil, and Contaminated Sediment*

The purpose of Alternative 10, similar to Alternative 9, is to treat PTWs 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 PTWs 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:

- Removal of all upland PTWs and contaminated soil; on-site *ex situ* thermal treatment;
- Groundwater treatment to address contamination remaining at depth below excavated areas;
- ENR to remediate areas of low concentration of cPAHs in sediment;
- Engineered sand cap to remediate sediment areas impacted by upwelling contaminated groundwater;
- Removal of all sediment PTWs and on-site *ex situ* thermal treatment; placement of reactive residuals covers over dredged areas to manage residuals if necessary; removal of contaminated sediment and on-site *ex situ* thermal treatment;
- Upland cap to protect human health from direct contact with contaminated surface soils;
- Institutional controls to help ensure the effectiveness of engineering controls; and
- Monitoring to verify that the remedy is performing as intended.

The areas addressed by different components of Alternative 10 are shown on Figure 6-23, and a representative cross section of upland components is provided on Figure 6-24. Sediment components are the same as for Alternative 9; therefore, refer to Figure 6-22 for illustration of components along a sediment cross section. Each component of the remedy is discussed below.

6.3.11.1 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.

Areas and Volumes of Contaminated Soil

The area of soil to be removed is shown on Figure 6-23. 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 PTWs in the Shallow Alluvium would be addressed;
- The area of PTWs 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 6-24. 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 PTWs, 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.

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.

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[50] and a minimum embedment depth of approximately 65 feet bgs. Preliminary shoring design considerations are described in Appendix F.

[50] 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.

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.

Figure 6-23 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 6-24. 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.

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.

Management of Removed Soil

Excavated soil would be treated on-site using thermal treatment as described in Section 6.3.9.1.5 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 treatment at achieving PRGs in soil and groundwater. For the purposes of this FS, it is assumed that thermal treatment 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 treatment would be performed on-site using propane-fired equipment. Contaminants in the offgas would be incinerated.

6.3.11.2 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.

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.

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.

6.3.11.3 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.

6.3.11.4 Alternative 10 Engineered Sand Cap

An engineered sand cap would be placed over sediments where surface sediment concentrations are 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.

6.3.11.5 Alternative 10 Removal of Contaminated Sediment

Sediments containing PTWs 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.

6.3.11.6 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). Areas excavated may require a cap because, as discussed in Section 6.3.11.1.5, the treated soil to be used as backfill could still exceed PRGs.

6.3.11.7 Alternative 10 Institutional Controls

Alternative 10 utilizes excavation of upland PTW and contaminated soil, and dredging of sediment PTW and contaminated sediment, an engineered sand cap, and ENR. An upland soil cap may or may not be necessary pending the results of post-remedy soil sampling. Alternative 10 involves fewer remedial elements compared to the previously described alternatives, Alternatives 2 through 6; however it includes *ex situ* thermal treatment. The following types of institutional controls would be anticipated:

- Surface and subsurface soil – the areas where contaminated soils have been excavated are not expected to require a soil cap unless sampling of post-treatment backfill indicates exceedances of PRGs.

- Groundwater – prohibition on well installation for any use and on all uses for existing wells.

- Sediment – prohibition on any activities that can damage or erode engineered sand caps or an ENR cover, such as boat anchoring, boat speed, no wake restrictions, no in-water work (such as pier construction), no swimming, and no wading. Sediments that have been dredged may require a thin cover over dredged residuals that would require prohibitions against any activities that could adversely impact the cover. Restrictions would be required in the engineered sediment cap, dredge residuals cover, and ENR areas if post-remediation sampling indicates exceedance of PRGs. However, institutional controls for engineered sand caps, dredge residuals covers, and ENR are not expected to remain necessary in perpetuity as are institutional controls for Alternatives 2 through 6, since all PTWs are treated or removed. PRGs are expected to be obtained for engineered sand caps, dredge residuals covers, and ENR, thus eliminating the need for extensive institutional controls.

- Surface water – no fishing, no swimming, and no wading until PRGs are obtained for engineered sand caps, dredge residuals covers, and ENR areas.

As with Alternative 2, most institutional controls that focus on activities that may disturb sediment or sediment caps/covers or activities that can result in exposure to contaminated sediment and/or surface water are more difficult to enforce than controls that focus on disturbance of upland soil or use of groundwater. However, most institutional controls in Alternative 10 may not be required in perpetuity, because sources have been removed or treated and remaining contaminated sediments may remediate in time.

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 CERCLA and NCP evaluation criteria and the general methodology used to perform the evaluations are summarized in Section 7.1. Sections 7.2 through 7.12 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 CERCLA and NCP Evaluation Criteria

CERCLA has statutory requirements that a remedial action must achieve and must be addressed in the ROD and supported by the FS. They are:

1. Be protective of human health and the environment;
2. Attain ARARs (or provide grounds for invoking a waiver);
3. Be cost-effective;
4. Utilize permanent solutions and alternative treatment technologies or resource recovery technologies, to the maximum extent practicable; and
5. Satisfy the preference for treatment that reduces toxicity, mobility, or volume as a principal element or provide an explanation in the ROD as to why it does not.

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.

The NCP requires that each remedial alternative be evaluated against nine criteria listed in 40 CFR 300.430(e)(9). The nine evaluation criteria have been developed to address the CERCLA requirements and considerations, and to address the additional technical and policy considerations that have proven to be important for selecting among remedial alternatives. 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 statutory threshold criteria: 1) overall protection of human health and the environment and 2) compliance 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[51] exposures to levels established during development of remediation goals consistent with 40 CFR 300.430(e)(2)(i)."* The protectiveness 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 protectiveness 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.

In the detailed evaluation of each alternative, the Compliance with ARARs criterion will be rated as "No," or "Yes," with justification as appropriate.

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" (TBC) criteria, advisories, and guidance identified in Section 4 (see Tables 4-1 through 4-3). CERCLA requires that remedial actions comply with the substantive provisions of ARARs. If it is not technically practicable to comply with an ARAR, EPA may grant a technical impracticability (TI) waiver under certain circumstances, as listed in 40 CFR 300.430(f)(1)(ii)(C).

Modeling was used to evaluate whether the ARAR to meet MCLs in groundwater (under the Safe Drinking Water Act [SDWA]) could be met by the implementation of any of the alternatives. Refer to Section 6.2.4.1 and Appendix A for discussion of the groundwater modeling performed to predict progress toward achieving MCLs under each remedial alternative. The groundwater flow and contaminant fate and transport model was used to calculate the approximate aquifer volume that may contain groundwater with COC concentrations exceeding MCLs 100 years after completion of remedial construction. The groundwater model was used as a relative tool to compare alternatives with respect to progress toward achieving MCLs. Due to the high degree of uncertainty, model predictions should only be interpreted in a relative sense for comparative analysis of alternatives.

EPA views the groundwater model results as conservative for the following reasons:

- The baseline condition plumes that the model generates for all primary COCs in DNAPL (benzene, naphthalene, and benzo[a]pyrene) significantly exceed the plume boundaries based on empirical data. This is due, in part, to:
    - DNAPL source strength set as a constant over the 100-year plume propagation period;

[51] "eliminating, reducing or controlling exposures…". Eliminating means contaminates are removed or treated; reducing means exposures to contaminates are based on containment; and controlling refers to the use of institutional controls. The distinction in the manner in which protectiveness is conferred by an alternative is important to ranking various alternatives to specific evaluation criteria.

- Use of potentially conservative half-lives; and
- Use of arithmetic averages of measured COC concentrations (as opposed to log-normal averages, which would result in lower initial concentrations).

- Given that coal tar/creosote production stopped in 1969 (46 years ago), it is reasonable to assume that the groundwater plumes are in steady state or reducing (i.e., they would not grow to the sizes predicted by the groundwater model). This is supported by groundwater data showing either steady or decreasing concentrations in shoreline monitoring wells (Figure 5.2-7 in the RI Report [Anchor QEA and Aspect, 2012]).

Modeling simplifications and assumptions may also result in underprediction of the extent and longevity of groundwater impacts following completion of remedial actions. For example, the model does not account for the impact of residuals.[52] These may include:

- **Residuals from dredging**. EPA expects that dredging would be conducted in such a way as to minimize the generation of residuals. If generated, they would be diluted from their *in situ* pre-remedy concentrations because they would be more evenly mixed and spread out over the area being remediated. All alternatives that include dredging also include placement of reactive covers over dredged areas.
- **Residuals from *in situ* solidification**. It is expected that there will be a “halo” around the solidified area(s). The mobile benzene and naphthalene that leaches from the block(s) will undergo degradation and will be dispersed and diluted in the groundwater. Because benzo(a)pyrene is essentially immobile, it will not likely leach from the block(s) or leach only a small amount.
- **Residuals from potentially not addressing every occurrence of DNAPL.** Although the lateral and vertical extent of PTW remediation in both the upland and aquatic areas of the Site will be based on a field performance standard (to be determined during remedial design), DNAPL residuals could be inadvertently missed during remedy implementation. DNAPL residuals would most likely be in thin laterally discontinuous sand stringers within the Shallow Aquifer bounded by relatively impermeable silts/clay, making them relatively low-strength groundwater contamination sources.

It is expected that issues related to residuals will be managed during remedial design, treatability testing, and remedial construction, in order to adequately characterize the nature and extent of DNAPL and maximize the effectiveness of removal and/or treatment technologies. All alternatives are expected to leave at least some quantity of DNAPL in

[52] EPA directed the Respondents to not consider residuals in the model because there are no data to reliably model the impact of residuals from dredging, excavation, *in situ* solidification, or contamination inadvertently left behind following the remedy.

place, even those that target all DNAPL. Residuals that remain after remedial construction will be addressed through compliance monitoring and institutional controls.

In summary, although there are significant modeling uncertainties, it is still considered to be a very useful tool for evaluating and comparing the relative effectiveness of the alternatives, particularly with regard to achieving MCLs. For "Compliance with ARARs", the percent reduction of the plume volume for each COC with an MCL is used as a relative metric. Uncertainties with regard to the model results are further discussed for each alternative as appropriate. Figure 7-1 shows projected groundwater volumes exceeding MCLs for the individual COCs benzene, benzo(a)pyrene, and arsenic, as well as for the aggregate plume (considering all three COCs simultaneously), 100 years after completion of remedial actions.

In the detailed evaluation of each alternative, the Compliance with ARARs criterion will be rated as "No" or "Yes with TI Waiver". A brief justification for each rating will be provided.

7.1.2 *Balancing Criteria*

Alternatives that satisfy both of the threshold criteria are then evaluated using the five 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

Long-term effectiveness and permanence are evaluated with respect to the magnitude of residual risk associated with waste left in place and the adequacy and reliability of controls used to manage remaining waste (untreated waste and treatment residuals) over the long-term. Alternatives that afford the highest degrees of long-term effectiveness and permanence are those that leave little or no waste remaining at the site such that long-term maintenance and monitoring and reliance on institutional controls are minimized. The components of this criterion include the following:

a. Magnitude of residual risk— risk remaining from untreated waste or treatment residuals left on-site after remedial action is completed.

   - The potential for this risk may be measured by numerical standards such as cancer risk levels or the volume or concentration of contaminants in waste, media, or treatment residuals remaining on the site. The characteristics of the residuals should be considered to the degree that they remain hazardous, taking into account their volume, toxicity, mobility, and propensity to bioaccumulate (EPA 1988a).

   - 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 PTW 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 PTW 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.

b. Adequacy and reliability of controls— used to manage treatment residuals or untreated wastes that remain at the site in the long-term and to determine if they are sufficient to ensure that any exposure to human and environmental receptors is within protective levels. Adequacy and reliability of controls can be assessed by examining the complexity and efficacy of requirements of long-term operation, maintenance, and monitoring of the alternative.

   - It also includes the assessment of the potential need to replace technical components of the alternative, such as reactive materials within an amended cap or RCM, or a PRB treatment system; and the potential exposure pathway and the risks posed should the remedial technology require replacement.

   - The adequacy and reliability of institutional controls can be evaluated based on how they are implemented and maintained and on how the institutional controls would be enforced by the relevant agency or government entity.

7.1.2.2 Reduction of Toxicity, Mobility, or Volume through Treatment

This evaluation criterion addresses the statutory preference for selecting remedial actions that employ treatment technologies that permanently and significantly reduce toxicity, mobility, or volume of the hazardous substances as their principal **element**, including the treatment of principal threats posed by the site. Analysis factors considered under this criterion include the following:

- Treatment processes used and materials treated;
- Amount of hazardous materials destroyed or treated (the vast majority of the contaminant mass at the Site is present as DNAPL or DNAPL-impacted soil or sediment [i.e., PTW]; therefore, this sub criterion is primarily evaluated based on the amount of PTW [as volume of DNAPL] that is treated);
- Degree of expected reductions in toxicity, mobility, and volume measured as a percentage of reduction (or order of magnitude);
- Degree to which treatment is irreversible;
- Type and quantity of residuals remaining after treatment; and
- Whether the alternative would satisfy the statutory preference for treatment as a principal element.

Four types of PTW treatment are employed to various degrees in the range of alternatives: 1) off-site incineration of mobile DNAPL accumulating in collection trenches, 2) *in situ* solidification of upland PTW, 3) on-site thermal treatment of PTW, and 4) absorption of DNAPL by organoclay sediment caps. Treatment of dissolved-phase groundwater contamination that is a direct result of groundwater in contact with PTW, via PRBs, organoclay sediment caps, engineered sand caps, and/or pump and treat systems are also employed in many of the alternatives. 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 the contaminant plume and mass flux to sediments would be reduced, relative to Alternative 1, No Action, 100 years after completion of remedial construction (refer to Figures 7-1 and 7-3). Only mass contributed from upland contamination was considered. The alternatives that employ one or more of these treatment technologies will be evaluated using the factors listed above.

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—addresses any risk that results from implementation of the proposed remedial action, such as dust from excavation, transportation of hazardous materials, or air-quality impacts from a thermal treatment operation that may affect human health;
- Protection of workers during remedial actions—assesses threats that may be posed to workers and the effectiveness and reliability of protective measures that would be taken;
- Environmental impacts—addresses the potential adverse environmental impacts that may result from the construction and implementation of an alternative and evaluates the reliability of the available mitigation measures in preventing or reducing the potential impacts; and
- Time until RAOs are achieved.

All alternatives will require establishment and adherence to proper health and safety and construction planning documents and protocols.

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.

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. Three costs were calculated for each alternative: one using a Net Present Value (NPV) analysis[53] assuming a discount rate of 7 percent[54], one using a NPV analysis assuming a discount rate of 1.4 percent[55], 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, 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) and Tribal 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 provides a baseline for comparing other alternatives. The No Action alternative does not include any remedial actions, monitoring, or institutional controls, and all contamination is left in place.

7.2.1 *Overall Protection of Human Health and the Environment*

The No Action alternative provides no control of exposure to contaminated media on site and contaminated groundwater continues to migrate into the lake. The No Action alternative is not protective of human health and the environment. The baseline risk

[53] NPV analysis is referred to as present worth analysis in the RI/FS guidance (EPA 1988a).

[54] The discount rate of 7 percent is based on the NCP and OSWER Directive 9355.3-20, as recommended in EPA's FS cost estimating guidance (EPA 2000b).

[55] The discount rate of 1.4 percent is based on the 2015 OMB Circular real interest rate.

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 satisfy the threshold criterion of Overall Protection of Human Health and the Environment.

7.2.2 *Compliance with ARARs*

Because no action is being taken, ARARs such as the MCL for benzene, benzo(a)pyrene and arsenic will not be met and ambient water quality standards will not be met for all relevant COCs. Therefore, the No Action alternative does not satisfy the threshold criterion of Compliance with ARARs.

7.2.3 *Long-term Effectiveness and Permanence*

Alternative 1, No Action, does not include controls for limiting exposure and has no long-term management measures. The baseline risk assessments (see Section 3.7) identified unacceptable risks to both human and ecological receptors associated with Site contamination. These risks are not reduced by Alternative 1, No Action.

7.2.4 *Reduction of Toxicity, Mobility, or Volume through Treatment*

Alternative 1 does not include treatment as a remedial action. There is no reduction in toxicity, mobility, or volume of contaminated soils, groundwater, sediment or surface water.

7.2.5 *Short-term Effectiveness*

There are no additional risks to the community, workers or the environment because Alternative 1 does not include any remedial activities.

7.2.6 *Implementability*

There are no implementability concerns because no remedial action is being implemented under Alternative 1.

7.2.7 *Cost*

There is no cost associated with Alternative 1 because no remedial action is being taken.

7.3 Detailed Evaluation of Alternative 2

Alternative 2 focuses on containment through the use of an upland soil cap, RCM and amended sand sediment caps over DNAPL-containing sediment, engineered sand cap over sediments affected by upwelling contaminated groundwater, and ENR over sediments exceeding the BTV for cPAHs. Alternative 2 includes reliance on institutional controls to prevent exposure to contaminated media. This alternative includes maintenance and monitoring of engineering controls to ensure that exposure pathways are controlled and cleanup numbers are achieved in perpetuity. 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 (Section 7.3.1.1) and the environment (Section 7.3.1.2) as follows:

7.3.1.1 RAOs for Protection of Human Health

- **HH1: Restore Groundwater to its Highest Beneficial Use by Meeting MCLs and RBC for Drinking Water.** None of the PTW, the predominant source of groundwater contamination, is removed or treated in this alternative. As depicted on Figure 7-1, the groundwater model predicts that the aggregate plume volume would be reduced by 11 percent (after 100 years) as compared to Alternative 1 (No Action). Note that the volumes shown on the figure 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).

  Human health risks would be addressed through a combination of institutional controls and monitoring. Institutional controls would prohibit use of groundwater for drinking water purposes and construction of wells for any purpose, including domestic uses (e.g., inhalation while showering). This institutional control would remain in effect in perpetuity.

  Future sources of drinking water and other domestic uses will be addressed by use of the in-place public water system operated by the City of Renton.

- **HH2: Reduce Risks to Recreational and Subsistence Consumers of Fish and Shellfish to Acceptable Levels.** Human health risk from recreational and subsistence ingestion of resident fish and shellfish taken from the Site would be reduced and controlled by the use of engineered sand, amended sand, and RCM caps, ENR, and institutional controls. Alternative 2 would initially reduce COC concentrations in surface sediments which, in turn, would reduce the levels of COCs in resident fish and shellfish to acceptable levels. Human health risks would be addressed by institutional controls to aid in preventing exposures and monitoring and maintenance would provide information that the controls are functioning as required. Monitoring and maintenance of all caps and ENR (inspection/repair program) would remain in place in perpetuity to ensure integrity of the caps and ENR.s

- **HH3: Reduce Risks to Recreational Beach Users From Exposure to Surface Sediment to Acceptable Levels.** Human health risk from playing, wading, or swimming resulting in incidental ingestion and/or dermal exposure to contaminated sediments would be reduced and controlled by the use of engineered sand, amended sand, and RCM caps, and institutional controls. Alternative 2 would reduce COC concentrations in surface sediments to acceptable levels. Sediment caps would reduce adult and child exposure to contaminated surface sediments. Institutional controls would control exposure to contaminated sediment by restricting activities that could cause damage to the caps and result in the release of contamination. Monitoring and maintenance of caps would remain in place in perpetuity to ensure the integrity of the caps.

- **HH4: Reduce Risks to Recreational Beach Users From Exposure to Surface Water to Acceptable Levels.** Human health risk from direct contact or incidental ingestion of surface water while playing, wading or swimming in contaminated surface water would be reduced and controlled through a combination of engineered sand, amended sand, and RCM caps, and institutional controls. Sediment caps would reduce upwelling contaminated groundwater through sediments to acceptable levels. Institutional controls would control exposure to contaminated surface water by restricting activities that could cause damage to sediments caps that mitigate the release of contamination into surface water. Monitoring and maintenance of caps would remain in place in perpetuity to ensure the integrity of the caps.

- **HH5: Reduce Risk to Future Residents from Exposure to Indoor Vapors to Acceptable Levels.** Human health risk from inhalation of vapors, in enclosed spaces, from groundwater and/or soils contaminated with COCs would be reduced and controlled to acceptable levels by a soil cap and institutional controls. A soil cap could reduce possible future indoor exposures to vapors. Institutional controls, however, would require that any future use that results in human occupation in enclosed spaces will require an assessment for potential vapor intrusion risks and, if necessary, require engineering controls to eliminate exposure to vapors. If engineering controls are implemented, indoor air monitoring and maintenance of vapor control devices may be required in perpetuity.

- **HH6: Reduce Risk to Future Residents, Commercial Workers, and Excavation/Construction Workers from Soil to Acceptable Levels.** Human health risk from direct contact or incidental ingestion of COCs in soil would be reduced and controlled to acceptable levels through a combination of a soil cap and institutional controls. The magnitude of contamination in surface soils would be reduced by the application of “clean” soil over contaminated surface soil. Institutional controls would control the disturbance of the soil cap from potential invasive activities (e.g., utility installation, gardening activities) by providing instructions and coordination of activities with EPA. Periodic inspection/repair of the soil cap would ensure the long-term cap integrity of the cap. The institutional controls and cap inspection/repair program would remain in place until soil exposure no longer poses an unacceptable risk (e.g., future development permanently and effectively prevents exposure to soil).

7.3.1.2 RAOs for Protection of the Environment

- **EP1: Reduce Risk to Aquatic Plants and Fish from Surface Water to Acceptable Levels**. Risk to aquatic-dependent organisms when direct contact with surface water or incidental ingestion of COCs in surface water would be reduced or controlled to acceptable levels (water quality standards). 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 engineered sand, amended sand, and RCM caps, and ENR. Additionally, RCM, amended sand, and engineered sand caps would reduce upwelling contaminated groundwater migrating through sediments to acceptable levels in porewater and surface water. Institutional controls would control exposure to contaminated surface water by restricting activities that could cause damage to sediments caps that mitigate the release of contamination into surface water. Monitoring and maintenance of caps would remain in place in perpetuity to ensure the integrity of the caps.

- **EP2: Reduce Risk to Terrestrial Plants, Birds, and Mammals from Contact with Soil to Acceptable Levels**. Risk to terrestrial wildlife from direct contact or incidental ingestion of COCs in soil or consumption of soil invertebrates containing COCs would be reduced and controlled to acceptable levels through a combination of a soil cap and institutional controls. The magnitude of contamination in surface soils would be reduced by the application of "clean" soil over contaminated surface soil. In the case of Alternative 2, the entire upland surface would require capping or soil data could be gathered to determine the extent of capping. Institutional controls would control the disturbance of the soil cap from activities that may compromise the integrity of the soil cap. Periodic inspection/repair to the soil cap would ensure the long-term cap integrity. The institutional controls and cap inspection/repair program would remain in place until soil exposure no longer poses an unacceptable risk (e.g., future development permanently and effectively prevents exposure to soil).
- **EP3: Reduce Risk to Aquatic-dependent Birds, Mammals, and Benthic Community from Sediment to Acceptable Levels.** Risk to aquatic-dependent wildlife (sediment probing birds and piscivorous mammals) and benthos resulting in incidental ingestion and/or direct contact to contaminated sediments or other aquatic organisms would be reduced and controlled by the use of engineered sand, amended sand, and RCM caps, ENR, and institutional controls. Alternative 2 would reduce COC concentrations in surface sediments to acceptable levels. Sediment caps would reduce exposure to contaminated surface sediments by providing a "clean" surface. ENR would reduce benthic exposure to contaminant levels in surface sediments. Institutional controls would control exposure to contaminated sediment by restricting activities that could cause damage to the caps or ENR coverage and result in the release of contamination. Monitoring and maintenance of caps would remain in place in perpetuity to ensure the integrity of the caps.

7.3.1.3 Alternative 2 Rating with Respect to this Criterion

Alternative 2 satisfies the threshold criterion for Overall Protection of Human Health and the Environment. The alternative is rated "high" for Short-Term Effectiveness (Section 7.3.5); however, the alternative is rated "low" for Long-Term Effectiveness and Permanence (Section 7.3.3). The RAO to restore groundwater to its highest beneficial use by meeting MCL ARARs and RBCs for drinking water would not be met within 100 years of completion of remedial construction; however, protectiveness would be addressed via institutional controls and monitoring (Section 7.3.1.1).

7.3.2 *Compliance with ARARs*

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. None of the PTW that causes the groundwater contamination is removed or treated in this alternative. The extent to which MCLs would be achieved in this alternative is discussed below.

7.3.2.1 Compliance with the MCL ARAR

For Alternative 2, the groundwater volume exceeding MCLs is predicted to decrease by 14 percent for benzene, 1 percent for benzo(a)pyrene and 1 percent for arsenic (assuming an impermeable upland soil cap[56]) relative to the No Action alternative 100 years after remedial construction completion (see Figure 7-1).

Refer to Section 7.1.1.2 and Appendix A for discussion of the groundwater modeling performed to predict progress toward achieving MCLs under each remedial alternative. 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.

7.3.2.2 Alternative 2 Rating with Respect to this Criterion

Alternative 2 would satisfy the threshold criterion for compliance with ARARs, with the exception of meeting MCLs everywhere in groundwater. If meeting MCLs in groundwater is deemed technically impracticable, EPA may consider granting a TI waiver. Groundwater modeling predicts that the MCLs for benzene, benzo(a)pyrene, and arsenic will not be met throughout the plume 100 years after remedial construction completion.

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, the magnitude of residual risks associated with untreated waste/ treatment residuals left on-site after remediation is presented in terms of the degree to which sources are remediated and the percent the plume is reduced.

All PTW is left in place as untreated waste; therefore, DNAPL-impacted soils and sediment remain in place and untreated at 30,500 and 58,300 cy, respectively. The dissolved-phase plumes exceeding the MCL ARARs and drinking water RBC are reduced (benzene at 14 percent, naphthalene at 10 percent, benzo(a)pyrene at 1 percent,

[56] The alternatives were evaluated for compliance with MCLs assuming an upland impermeable cap, which would be consistent with future development plans. Modeling results indicate that plume reduction is small regardless of whether an impermeable or permeable soil cap is used. For the purposes of the FS, all alternatives incorporate a permeable soil cap even though modeling assumed an impermeable soil cap because future development is likely and would include impermeable surfaces.

and arsenic at 1 percent) from the Alternative 1 (No Action) baseline volumes. Unacceptable risks remain in place should exposure occur.

7.3.3.2 Adequacy and Reliability of Controls

Controls in Alternative 2 include an upland soil cap, sediment caps (engineered sand, amended sand, and RCM caps), ENR, institutional controls, and monitoring. The adequacy and reliability of each of these controls are discussed below. Adequacy and reliability of controls can be assessed by examining the complexity and efficacy of requirements for long-term operation, maintenance and monitoring of the alternative.

Upland Soil Cap: An upland soil cap would be effective and reliable for preventing dermal contact and incidental ingestion of COCs in soil by residents, commercial workers and excavation/construction workers. Soil caps have been used routinely at Superfund sites to prevent exposure. The upland soil cap will remain effective if maintained properly (e.g., easy to repair/replace, monitor for remedial specifications, etc.). Institutional controls are needed to prevent intentional disturbance of soil caps covering contaminated soils.

Engineered Sand Caps. Engineered sand caps would be effective and reliable for protecting the benthic community and preventing dermal contact or incidental ingestion by swimmers or waders to surface water/porewater contaminated with COCs. The engineered sand cap would attenuate contaminated upwelling groundwater to safe levels. Engineered caps have a long history of use for successfully controlling contamination in sediment porewater. The caps will remain effective in perpetuity if maintained properly. Institutional controls will be required to restrict/prohibit activities that may compromise the integrity of the caps, such as prop wash. Long-term monitoring will be required to assess the concentrations of COCs in sediment porewater in the area covered by the engineered sand cap in perpetuity.

RCM Caps. Like engineered sand caps, RCM caps would be effective in protecting the benthic community. In addition, RCM caps are also effective in reducing potential migration of DNAPL or sheen. However, the adequacy and reliability of RCM caps is difficult to predict because although reactive caps, have been installed as the final remedy at many contaminated sediment sites across the United States, as described in Appendix C, there is little field information on long-term effectiveness and reliability of RCM caps. There is no field information about how RCM replacement/repair (if needed) may affect the long-term viability of the RCM caps. The limited long-term field experience is a significant concern about the reliability of a technology that will be required in perpetuity. There is considerable debris on and in the surface sediments at Quendall that will need to be sufficiently cleared to allow placement of the RCM cap and ensure effectiveness. The shoreline bathymetry needs to be maintained, which may limit RCM repair and replacement options. RCM caps may lose their effectiveness when the reactive material becomes saturated or damaged. Long-term monitoring and maintenance of RCM caps and maintenance and enforcement of institutional controls would be necessary, in perpetuity, to ensure effectiveness.

Amended Sand Cap. Amended sand caps would be effective for protecting the benthic community and reducing potential migration of DNAPL or sheen. However, like RCM caps, the long-term reliability of amended sand caps is uncertain due to relatively limited field information on long-term effectiveness of amended sand caps. Because the amended sand cap has significantly greater mass of reactive material than the RCM cap, it will have greater adequacy and reliability. There is considerable debris on and in the surface sediments at Quendall that will need to be sufficiently cleared to allow placement of the amended sand cap and ensure effectiveness. The shoreline bathymetry would need to be maintained, which may limit amended sand cap repair and replacement options. Amended sand caps may lose their effectiveness when the reactive material becomes saturated or damaged. Long-term monitoring and maintenance of amended sand caps and maintenance and enforcement of institutional controls would be necessary, in perpetuity, to ensure effectiveness.

ENR. The purpose of ENR is to provide a clean sediment surface in locations where contaminant concentrations are low. ENR has been used previously at other Superfund sites and has been shown to be adequate and reliable in facilitating the re-establishment of benthic organisms, by the placement of a thin layer of clean sand 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 cPAH BTV[57], evaluation of cPAH concentrations over time would be required in perpetuity.

Institutional Controls. Because all PTWs are left in place and restoration of groundwater to meet MCLs and RBCs would not be achieved, institutional controls would be required and relied upon in perpetuity. Proprietary controls (e.g., covenants to protect remedy components and limit future land use) would be more reliably enforceable in the uplands as compared with the aquatic environment. Fishing/swimming/wading bans would rely on the willingness and capability of local authorities to monitor for compliance and take enforcement actions. Permits and consent decree requirements (such as engineering controls) are more reliable as they are enforceable by EPA under CERCLA.

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 all PTW remains on-site and it relies wholly on capping and institutional controls to provide long-term protection.

7.3.4 *Reduction of Toxicity, Mobility, or Volume through Treatment*

7.3.4.1 Treatment Processes Used and Materials Treated

Alternative 2 includes the use of RCM and amended sand caps to sorb DNAPL in the event that DNAPL is disturbed and migrates upward to the cap.

[57] The protective cleanup level for sediment is below the surrounding anthropogenic background required.

7.3.4.2 Amount of Hazardous Materials Destroyed or Treated

Under Alternative 2, no DNAPL is treated. The amount of DNAPL that may be sorbed onto the RCM and amended sand caps is unknown.

7.3.4.3 Degree of Expected Reductions in Toxicity, Mobility, and Volume

Alternative 2 does not include any upland technologies that would reduce toxicity, mobility, or volume through treatment.

The aquatic RCM and amended sand caps are expected to be effective at preventing DNAPL migration from underlying sediments into the surface waters of Lake Washington; however, under ordinary circumstances, only a negligible amount of DNAPL is expected to be controlled or immobilized by the RCM caps.

Based on modeling, the mass reduction of benzene, naphthalene, benzo(a)pyrene, and arsenic plumes would be reduced by 10, 8, 1, and less than 1 percent, respectively. Mass flux for benzene, naphthalene, benzo(a)pyrene, and arsenic would be reduced by 27, 31, 27, and 5 percent, respectively (see Figure 7-3).

7.3.4.4 Degree to which Treatment is Irreversible

Treatment of DNAPL using RCM and amended sand caps containing organoclay would be irreversible by sorbing organic matter to the organoclay (Bullock 2009).

7.3.4.5 Type and Quantity of Residuals Remaining after Treatment

The remedial approach described in this Alternative results in very little treatment of contaminated media from the Quendall Site. If RCM and amended sand caps containing organoclay become saturated with DNAPL, the material would be removed and replaced. DNAPL-saturated organoclay would likely be treated by incineration. Therefore, no residuals absorbed by the RCM and amended sand caps would remain on-site once the “spent” organoclay is removed; however, an unknown quantity of organoclay with sorbed contaminants could be present on-site in perpetuity.

7.3.4.6 Whether the Alternative Would Satisfy the Statutory Preference for Treatment as a Principal Element

Alternative 2 does not satisfy the statutory preference for treatment as a primary element of the alternative because the majority of the alternative is based on containment and little PTW is treated.

7.3.4.7 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 surface sediments. However, only a negligible amount of the Site contamination would be treated.

7.3.5 *Short-Term Effectiveness*

Alternative 2 consists of capping upland surface soils and surface sediments. Also, dredging of some potentially contaminated sediments are included to accommodate capping in order to maintain the current sediment bathymetry.

7.3.5.1 Protection of Community during Remedial Actions

For Alternative 2, potential exposure to hazardous substances to the neighboring community may result from:

1) Inhalation exposure to vapors from during dredging of 2,800 cy of potentially contaminated sediment;

2) Inhalation exposure to dust or air emissions from handling and stockpiles for transport off-site, by truck, of 2,800 cy of potentially contaminated sediment.

3) Inhalation exposure of dust generated from the import and handling of clean material to cap up to 22 acres of soil, although a smaller area may be capped, which would be determined during remedial design; and

4) Inhalation exposure from the import and handling of clean or reactive material to cap/cover 29.4 acres of sediment.

No unacceptable health risks to the community are expected. This determination is based on the availability and use of BMPs and the amount of hazardous material handled on-site. Use of BMPs can mitigate inhalation exposure by active management of potential emissions by covering stockpiles and truck loads and/or keeping areas prone to generating emissions wet.

The community may be more concerned about activities that may negatively impact the local "quality of life"[58]. For example, construction activities including truck traffic may result in excessive noise, and traffic congestion. Remedial construction activities could cause negative visual impacts. The same BMPs and good housekeeping that are used to manage cleanup activities that may pose a risk to public health can also address many of the "quality of life" issues that may concern the neighboring community. Additionally, EPA will work with the community to discuss ways that "quality of life" disturbances can be mitigated. For example, remedial construction would be limited to routine Monday through Friday work hours.

7.3.5.2 Protection of Workers during Remedial Actions

For Alternative 2, potential risks to site workers include the same exposure pathways as those associated with the neighboring community. However, additional exposures to workers can result from their close proximity to sources of exposure. These additional exposure pathways not only include inhalation but also dermal exposure pathways. On-site workers may be exposed to greater COC concentrations or frequency of dermal exposure which may not be applicable to the nearby community, e.g., dermal contact with dredged contaminated sediment. Potential exposure to hazardous substances to on-site workers may result from:

1) Inhalation and dermal exposure to dust potentially containing hazardous substances from upland site clearing and grading activities;

[58] Quality of life impacts generally refer to the potential for an alternative to impact aesthetics, odor and dust, traffic, and noise; activities that do not cause a risk but are an ignorance.

2) Inhalation and dermal exposure to potential contaminants in surface sediments during construction of sediment caps;
3) Inhalation and dermal exposure during dredging, handling and off-site transport by truck of 2,800 cy of potentially contaminated sediments; and
4) Inhalation of dust generated from the import and handling of clean or reactive material to cap/cover 29.4 acres of sediment.

No health risks to on-site workers is expected because of the very small amount of hazardous substances expected to be in the dredged sediments and on-site use of BMPs, protective gear and clothing. BMPs include management of potential emissions by covering stockpiles and truck loads and/or keeping areas prone to generating emissions wet. Soil cap construction will not involve hazardous substances. Exposure of workers to dust and air emissions is not expected to be a concern because sources of exposure do not contain hazardous substances. Concerns about inhalation of dust can be controlled by the use of dust masks.

7.3.5.3 Environmental Impacts

Alternative 2 would involve relatively little construction and a correspondingly low overall potential for environmental impacts. Impacts to the environment could be caused by site grading, clearing, and capping of soil and sediments as well as some dredging activities. Dredging consists of removing 2,800 cy of potentially contaminated sediments to then be handled on-site and transported off-site for disposal. Small amounts of “clean” material will be used to cover approximately 30 acres of sediment for ENR and capping.

In the terrestrial environment, impacts to wildlife, typically present on-site, are expected to result in wildlife relocating to another area in the vicinity of Quendall during construction activities.

The limited shoreline dredging to offset cap construction could result in extremely localized, short-term acute water quality criteria exceedances. Monitoring would be performed to document turbidity and contaminant levels and BMPs may be modified if exceedances of specified criteria are recorded or anticipated. Short-term impacts associated with dredging clean sediments and cap placement would include possible minor effects on water quality. These impacts primarily consist of turbidity due to suspended clean dredged sediments and capping materials.

Capping and ENR will cause short-term impacts to the water column due to the material being placed and causing increased turbidity problems. Additionally, capping material can sink somewhat into the contaminated sediments being capped, especially if the sediments being capped are “soft,” and cause resuspension of contaminated sediments into the water column. Caps can fail or become damaged and require repair or replacement, causing additional short-term impacts. In areas where capping or ENR occurs, the benthic community would be significantly altered and/or eliminated in the short term. Assuming concentrations are acceptable, recolonization would be expected within several months (McCabe et al. 1998).

Construction practices to prevent uplands activities from impacting the aquatic environment will be monitored and enforced by on-site EPA personnel.

7.3.5.4 Time until Remedial Action Objectives are Achieved

Remedial construction and establishment of institutional controls would be expected to be completed within 1 year from initiation of remedial construction (Figure 7-5)[59]; however, not all RAOs (refer to Section 7.3.1) would be achieved at the end of the construction period. The RAO for restoring groundwater to its highest beneficial use is not expected to be achieved within 100 years. The RAOs to reduce risks to humans and aquatic wildlife from exposure to fish/shellfish are not expected to be met immediately, although caps and ENR will provide for a "clean" sediment surface and will reduce aquatic biota concentrations. However, seafood and aquatic wildlife that have already accumulated cPAHs will not be safe to consume. All other RAOs involving reduction of risk via direct contact with contaminated media would be met at the end of the construction period.

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). No unacceptable human health risks are expected to the community or site workers. Negative short-term environmental impacts are expected to the benthic community but recovery is expected.

7.3.6 *Implementability*

7.3.6.1 Technical Feasibility

Alternative 2 includes: 1) construction of an upland cap; 2) installation and maintenance/repair of engineered sand, amended sand, and RCM caps; 3) ENR covers; and 4) off-site disposal of potentially contaminated sediment. These remedial technologies are well understood technologies, have been widely used over a number of years, and are considered to be technically feasible for the Quendall site, with the possible exception of maintenance/repair of RCM and amended sand caps. RCM and amended sand caps are relatively new technologies and will be required to be in place in perpetuity. While there is increasing field experience with the installation of RCM and amended sand caps, there is no field information/experience regarding the maintenance/repair of such caps. As stated in Section 7.3.3.2, there is little information on long-term effectiveness and reliability of RCM and amended sand caps and no information about how RCM and amended sand replacement/repair (if needed) may affect the long-term viability of such caps. However, because the amended sand cap has significantly greater mass of reactive material than the RCM cap, it will have greater adequacy and reliability, and less need for replacement. Unusual technical challenges may be expected when RCM caps are repaired or replaced in the aquatic environment because they have only been in use for a short period of time. RCM and amended sand caps will only require replacement if their sorption capacity is exceeded and there is an ongoing source. The various DNAPL sediment deposits present a range of DNAPL volumes and potential mobility concerns. RCM caps will have greater implementability in those areas with low DNAPL volume and potential mobility such as DA-5 since

[59] Additional time will be required prior to construction to complete remedial design. Implementation timeframes shown on Figure 7-5 include the estimated duration of remedial design for each alternative.

replacement in these areas may not be needed. Amended sand caps are much more easily maintained and repaired and will be less problematic than RCM caps.

7.3.6.2 Administrative Feasibility

Alternative 2 is administratively feasible. Permits are not required for on-site remedial work. However, EPA oversight ensures that all substantive requirements are met. Coordination with numerous federal and state regulatory agencies, during remedial design, would be required to ensure that all ARARs (including ESA consultation and substantive compliance with Section 401 and 404 of the CWA), policies, and regulations are met. Coordination with these agencies, by EPA, has become routine in the Puget Sound area of Washington. Little coordination is expected during remedial action because reasons for coordination would be addressed during remedial design. Implementation of Alternative 2 is expected to be administratively feasible.

Various institutional controls would need to be put in place with the appropriate authorities to ensure that sediment caps and the ENR areas are protected from activities or events that could compromise these remedial technologies. In general, institutional controls are more reliably enforceable in the uplands compared to institutional controls intended to protect aquatic remedial technologies (see Section 7.3.3.2 on Adequacy and Reliability of Controls).

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, with the possible exception of services for RCM caps. 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 involves no dredging and minimum upland work, presenting no unusual construction challenges. Necessary engineering and construction services are readily available. Sediment caps will require maintenance and monitoring in perpetuity.

7.3.7 *Cost*

The estimated present worth cost of Alternative 2 is $28 million, including a projected $20 million for capital construction and $8.2 million (present worth) for OM&M.

7.4 Detailed Evaluation of Alternative 3

Alternative 3 is different from Alternative 2 (which relies solely on capping) in that, in addition to capping, it includes (1) *in situ* solidification of PTWs in the RR and MC-1 DNAPL Areas to address the deepest occurrences of DNAPL, which are a major source of contamination to the Deep Aquifer, (2) a DNAPL collection trench system to remove mobile PTWs from the shallow subsurface to further reduce the potential migration of DNAPL from the uplands to the lake sediments, and (3) a PRB to treat contaminated groundwater in the upland Shallow Aquifer as it migrates west toward the shoreline. 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 (Section 7.4.1.1) and the environment (Section 7.4.1.2) as follows:

7.4.1.1 RAOs for Protection of Human Health

- **HH1: Restore Groundwater to its Highest Beneficial Use by Meeting MCLs and RBC for Drinking Water.** Approximately 14 percent of the upland PTW (including deep PTW, a major contributor to groundwater contamination) is addressed in this alternative. In addition, treatment of shallow groundwater leaving the uplands and entering the lake using a PRB would restore an unknown amount of groundwater. Overall, the groundwater model predicts that the aggregate plume volume would be reduced by 28 percent (after 100 years) as compared to Alternative 1 (No Action). Human health risks would be addressed via institutional controls and monitoring in the same manner as Alternative 2.

- **HH2:** Reduce Recreational and Subsistence Ingestion of Seafood to Acceptable Levels. Same as Alternative 2.

- **HH3:** Reduce Recreational Beach Users Risk to Surface Sediment to Acceptable Levels. Same as Alternative 2.

- **HH4:** Reduce Recreational Beach Users Risk to Surface Water to Acceptable Levels. Same as Alternative 2.

- **HH5: Reduce Risk to Indoor Vapors to Acceptable Levels.** Same as Alternative 2, except vapor intrusion would be reduced by a nominal amount due to *in situ* solidification of the PTWs in the MC-1 DNAPL Area. Human health risk from inhalation of vapors, in enclosed spaces, from groundwater and/or soils contaminated with COCs throughout the Site would also be reduced and controlled to acceptable levels by soil caps and institutional controls. Treatment of the MC-1 DNAPL Area, which underlies the potential future location of mixed use buildings, would not reduce exposure to vapors sufficiently to reduce or change institutional controls, engineering controls or capping requirements for vapor intrusion as identified in Alternative 2.

- **HH6: Reduce Risk to Future Residents, Commercial Workers, and Excavation/Construction Workers from Soil to Acceptable Levels.** Same as Alternative 2, except very small areas of the uplands will be treated or excavated. These areas may not require a cap. Human health risk from direct contact or incidental ingestion of COCs in soil would be reduced and controlled to acceptable levels through a combination of a soil cap and institutional controls. A total of approximately 17,500 cy of soil would be treated with *in situ* solidification and approximately 2,900 cy of soil would be excavated during construction of the DNAPL collection trenches and the funnel and gate systems. It is assume that excavated PTWs and associated contaminated soil will be disposed at a RCRA Subtitle C Landfill.

7.4.1.2 RAOs for Protection of the Environment

- **EP1**: Reduce Risk to Aquatic Plants and Fish from Surface Water to Acceptable Levels. Same as Alternative 2.
- **EP2:** Reduce Risk to Terrestrial Plants, Birds, and Mammals from Contact with Soil to Acceptable Levels. Same as Alternative 2.
- **EP3:** Reduce Risk to Aquatic-dependent Birds, Mammals, and Benthic Community from Sediment to Acceptable Levels. Same as Alternative 2.

7.4.1.3 Alternative 3 Rating with Respect to this Criterion

Alternative 3 satisfies the threshold criterion for Overall Protection of Human Health and the Environment. The alternative is rated "high" for Short-Term Effectiveness (Section 7.4.5); however, the alternative is rated "low" for Long-Term Effectiveness and Permanence (Section 7.4.3). The RAO to restore groundwater to its highest beneficial use by meeting MCL ARARs and RBCs for drinking water would not be met within 100 years of completion of remedial construction; however, protectiveness would be addressed via institutional controls and monitoring (Section 7.4.1.1).

7.4.2 *Compliance with ARARs*

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. Approximately 12 percent of the PTW that causes the groundwater contamination is removed or treated in this alternative. The extent to which MCLs would be achieved in this alternative is discussed below.

7.4.2.1 Compliance with the MCL ARAR

For Alternative 3, groundwater volume exceeding MCLs is predicted to decrease by 37 percent for benzene, 13 percent for benzo(a)pyrene and 5 percent for arsenic, relative to the No Action alternative, 100 years after remedial construction completion (see Figure 7-1).

Refer to Section 7.1.1.2 and Appendix A for discussion of the groundwater modeling performed to predict progress toward achieving MCLs under each remedial alternative. 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.

7.4.2.2 Alternative 3 Rating with Respect to this Criterion

Alternative 3 would satisfy the threshold criterion for compliance with ARARs, with the exception of meeting MCLs everywhere in groundwater. If meeting MCLs in groundwater is deemed technically impracticable, EPA may consider granting a TI waiver. Groundwater modeling predicts that the MCLs for benzene, benzo(a)pyrene, and arsenic will not be met throughout the plume 100 years after remedial construction completion.

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, the magnitude of residual risks associated with untreated waste/ treatment residuals left on-site after remediation is presented in terms of the degree to which PTW sources are remediated and the percent the plume is reduced.

Alternative 3 includes treatment of PTW that contributes significantly to deep groundwater contamination (i.e., in the RR DNAPL Area and the eastern portion of the MC DNAPL Area). However, approximately 88 percent (by volume) of the PTW is left in place as untreated waste; therefore, the volume of DNAPL-impacted soils and sediment that remain are 24,600 and 55,100 cy, respectively. The dissolved-phase plumes exceeding the MCL ARARs and drinking water RBCs are reduced (benzene by 37 percent, naphthalene by 26 percent, benzo[a]pyrene by 13 percent, and arsenic at 5 percent) from the Alternative 1 (No Action) baseline volume.

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, amended sand, and RCM caps), ENR, institutional controls, and monitoring.

Adequacy and reliability of controls can be assessed by examining the complexity and efficacy of requirements for long-term operation, maintenance and monitoring of the alternative. The adequacy and reliability of each of these controls are discussed below.

Upland Cap. Same as Alternative 2.

DNAPL Collection Trenches. Properly designed DNAPL collection trenches would be adequate and reliable in limiting a small unknown volume of DNAPL migration from the upland portion of the Site to the lake, and in protecting the downgradient PRB treatment media from clogging with DNAPL. However, much of the mobile DNAPL at the Site is located in the QP-U area, which is downgradient of the collection trenches and PRB. DNAPL collection trenches cannot be placed within the habitat area because monitoring and maintenance activities associated with the trenches may cause damage to the habitat area, limiting its adequacy. Institutional controls limiting activities that could cause trench damage would be required. The OMMP would require ongoing monitoring and maintenance/repair. Institutional controls would be put in place to restrict access to the habitat area without permission from the EPA or designated persons.

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 in the Shallow Aquifer approaching the shoreline. The volume of contaminated groundwater expected to be treated by the PRB is unknown. Treatment material may become saturated or become fouled, and without frequent monitoring, the effectiveness of the PRB may be compromised. Treatability studies will be required to determine the effective treatment material specifications. The gate portion of the PRB would need to be placed in a location where treated groundwater would not become re-contaminated with DNAPL left in place. The PRB cannot be placed within the habitat area because monitoring and maintenance activities associated with the PRB may cause damage to the habitat area. Institutional controls will be put in place to restrict access to the habitat area without permission from the EPA or designated persons. Long-term monitoring would be necessary to evaluate PRB performance and determine whether media replacement or other maintenance is needed. For the purpose of the FS, it is assumed that the PRB media would be replaced every 22 years over a 100 year period, although it is expected that the PRB would be required in perpetuity.

Sediment Caps. Same as Alternative 2.

ENR. Same as Alternative 2.

Institutional Controls. Because the vast majority of PTWs are left in place and restoration of groundwater to meet MCLs and RBCs would not be achieved within 100 years, institutional controls would be required and relied upon in perpetuity. For Alternative 3, there would also be more reliance on institutional controls to protect the additional remedy components (PRBs, DNAPL trenches, and solidified soils).

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 the vast majority of PTW remains on-site untreated and the alternative relies heavily on capping and institutional controls to provide long-term protection.

7.4.4 *Reduction of Toxicity, Mobility, or Volume through Treatment*

7.4.4.1 Treatment Processes Used and Materials Treated

Alternative 3 incorporates additional technologies not associated with Alternative 2. They are: 1) collection trenches/PRB[60] to collect mobile DNAPL and to treat PAH-contaminated groundwater from the Shallow Aquifer as it migrates through the PRB; and 2) *in situ* solidification of the RR and MC-1 DNAPL Areas to treat PTWs that are a major source of groundwater contamination in the Deep Aquifer.

7.4.4.2 Amount of Hazardous Materials Destroyed or Treated

Under Alternative 3, approximately 1,300 gallons of DNAPL from collection trenches is treated off-site (incinerated) and approximately 44,700 gallons of DNAPL are treated by *in situ* solidification.[61] The amount of contaminated groundwater treated by sorption in the PRB is unknown. The amount of DNAPL treated by sorption onto the RCM and amended sand caps and reactive residual covers is unknown. Refer to Table 7-2 and Figure 7-2 for estimated DNAPL treatment volumes.

7.4.4.3 Degree of Expected Reductions in Toxicity, Mobility, and Volume

Alternative 3 would reduce the volume and toxicity of upland DNAPL, through incineration, by approximately 1,300 gallons or 0.3 percent of the total DNAPL on-site.

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[60] Assumes likely use of granulated activated carbon (GAC) as the treatment material.
[61] The vast majority of contaminant mass at the Site is present as DNAPL or DNAPL-impacted soil or sediment (i.e., PTWs). Therefore, this consideration is primarily evaluated based on the amount of PTWs (as volume of DNAPL contained in those PTWs) that is treated.

Alternative 3 would reduce the mobility of upland DNAPL, through *in situ* solidification, by approximately 44,700 gallons or 10 percent of the total DNAPL on-site; however, the toxicity and volume of the treated material remaining onsite would not be reduced.

Based on modeling, the mass reduction of benzene, naphthalene, benzo(a)pyrene, and arsenic plumes would be reduced by 26, 30, 16, and 1 percent, respectively. Mass flux for benzene, benzo(a)pyrene and naphthalene would be reduced by 57, 58, 56, and 3 percent, respectively (see Figure 7-3).

The effectiveness of the RCM and amended sand caps in Alternative 3 is the same as Alternative 2.

7.4.4.4 Degree to which Treatment is Irreversible

Treatment of DNAPL via *in situ* solidification would be expected to be essentially irreversible. Dissolved-phase COCs (benzene and volatile PAHs) that could otherwise leach can be assumed to be irreversibly treated by solidification.

Treatment of dissolved-phase contaminated groundwater migrating through the PRB containing GAC is expected to be irreversible by sorption onto the GAC. Treatment of DNAPL and dissolved constituents using RCM and amended sand caps containing organoclay would be irreversible by sorption of organic matter to the treatment material. At present, for both technologies, the quantities of contaminants that would be sorbed are unknown.

7.4.4.5 Type and Quantity of Residuals Remaining after Treatment

RCM and Amended Sand Capping. As in Alternative 2, a small amount of DNAPL would remain immobilized in the caps. Portions of the RCM and amended sand caps may be periodically replaced, and the DNAPL in those portions would likely be destroyed by incineration; refer to Section 7.3.4.5.

Upland DNAPL/Soil Solidification. DNAPL solidified in the soil matrix would remain on site, and mixed with the soil matrix, would comprise approximately 17,500 cy. The DNAPL within the solidified soil matrix that is bonded and the solidified matrix as a whole are not considered to be post-treatment residuals or untreated wastes; whereas contaminants that may leach and migrate out of the solidified matrix to groundwater would be considered untreated or residual post-treatment waste. The amount of residual dissolved-phase contamination that may leach is unknown.

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 (8,800 cubic feet per installation, with an expected replacement frequency of 22 years).

7.4.4.6 Whether the Alternative Would Satisfy the Statutory Preference for Treatment as a Principal Element

Alternative 3 does not satisfy the statutory preference for treatment as a primary component of the alternative because the majority of the contaminated materials remain on-site contained by the use of capping.

7.4.4.7 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 RCM and amended sand caps. Treatment of PTWs in the RR and MC DNAPL Areas would moderately reduce the volume of contaminated groundwater, and the PRB would significantly reduce the mass flux of organic COCs to sediments. However, only a small portion of PTWs would be treated.

7.4.5 *Short-Term Effectiveness*

Alternative 3 has many of the same activities and protective measures as Alternative 2. Alternative 3 also has remedial construction activities that go beyond those in Alternative 2 and would require similar protective measures as a result of: 1) *in situ* solidification of 3,600 cy DNAPL-impacted soils and 2) construction of DNAPL collection trenches and the funnel and gate systems (PRB).

7.4.5.1 Protection of Community during Remedial Actions

For Alternative 3, potential exposure to hazardous substances to the neighboring community may result from:

1) Inhalation exposure to vapors from during dredging of 3,200 cy of potentially contaminated sediment;
2) Inhalation exposure to dust and vapors from excavation of 500 cy of DNAPL-impacted soil from construction of DNAPL collection trenches and the funnel and gate system;
3) Inhalation exposure to dust and vapors from *in situ* solidification of 3,600 cy of DNAPL-impacted soil;
4) Inhalation exposure to dust or air emissions from handling and stockpiles for transport off-site, by truck, of 3,700 cy of potentially contaminated soils/sediment;
5) Inhalation exposure of dust generated from the import and handling of clean material to cap up to 22 acres of soil, although a smaller area may be capped, which would be determined during remedial design; and
6) Inhalation exposure of the same amount of dust generated as with all other alternatives, from the import and handling of clean material to cap/cover 29.4 acres of sediment.

No unacceptable health risks to the community are expected even considering the slightly larger amounts of soil excavated and sediments containing hazardous materials dredged. This determination is based on the availability and use of BMPs and the amount of hazardous material handled on-site. BMPs and good housekeeping practices are the same as Alternative 2. Use of BMPs can mitigate inhalation exposure by active management of potential emissions by covering stockpiles and truck loads and/or keeping areas prone to generating emissions wet. *In situ* solidification is not expected to generate any appreciable amount of dust or air emissions. Approximately 3,700 cy of hazardous substances would be stockpiled on-site and then transported off-site for disposal.

Impacts to "quality of life" is assumed to be a concern of the neighboring community.

7.4.5.2 Protection of Workers during Remedial Actions

For Alternative 3, potential risks to site workers include the same exposure pathways as those associated with the neighboring community. However, additional exposures to workers can result from their close proximity to sources of exposure. These additional exposure pathways not only include inhalation but also dermal exposure pathways. On-site workers may be exposed to greater COC concentrations or frequency of dermal exposure, which may not be applicable to the nearby community (e.g., dermal contact with contaminated soil.) Potential exposure to hazardous substances to on-site workers may result from:

1) Inhalation and dermal exposure to potentially contaminated dust and vapors from excavation of 500 cy of DNAPL-impacted soil from construction of DNAPL collection trenches and the funnel and gate system;

2) Inhalation and dermal exposure to 3,600 cy of potentially contaminated soil, dust and vapors from *in situ* solidification of DNAPL-impacted soil;

3) Inhalation and dermal exposure to vapors and contaminated sediments during dredging of 3,200 cy of potentially contaminated sediment;

4) Inhalation and dermal exposure to dust or air emissions from handling and stockpiles for transport off-site, by truck, of 3,700 cy of potentially contaminated soils/sediment; and

5) Inhalation of the same amount of dust generated as with all other alternatives, from the import and handling of clean or reactive material to cap/cover 29.4 acres of sediment.

No unacceptable health risks to on-site workers are expected even though exposures may go beyond those expected for the neighboring community. The addition of dermal exposure to workers, of greater COC concentrations or frequency, can be prevented by use of protective clothing and gear, adherence to Site-specific health and safety plans and construction quality assurance plans, plus BMPs. Protective practices put in place to protect the neighboring community also contribute to prevention of worker exposure to hazardous substances, such as use of BMPs to mitigate inhalation exposure by active management of potential emissions by covering stockpiles and truck loads and/or keeping areas prone to generating emissions wet.

7.4.5.3 Environmental Impacts

While there are some additional upland construction activities associated with Alternative 3 beyond those expected with Alternative 2, the impact to the environment is expected to be about the same as Alternative 2. Construction practices to prevent uplands activities from impacting the aquatic environment will be monitored and enforced by on-site EPA personnel. Dredging of potentially contaminated sediments is expected to increase by approximately 400 cy.

7.4.5.4 Time until Remedial Action Objectives are Achieved

Remedial construction and establishment of institutional controls would be expected to be completed approximately 1.4 years from initiation of remedial construction (not including remedial design; see Figure 7-5). Similar with Alternative 2, the RAO for restoring groundwater to its highest beneficial use is not expected to be achieved within 100 years. The RAOs to reduce risks to humans and wildlife from consumption of fish/shellfish containing unacceptable levels of cPAHs are also not expected to be met immediately, although caps and ENR will provide for a “clean” sediment surface and will reduce aquatic biota concentrations. However, seafood and aquatic wildlife that have already accumulated cPAHs will not be safe to consume. All other RAOs involving reduction of risk via direct contact with contaminated media would be met at the end of the construction period.

7.4.5.5 Alternative 3 Rating with Respect to this Criterion

Alternative 3 is rated “high” with respect to short-term effectiveness. There is a little increase in the amount of potentially contaminated sediments to be dredged and handled for off-site disposal and a modest increase in the amount of DNAPL-impacted soils. No unacceptable risk is expected to the community or workers because of the use of protective equipment and practices. Impacts to the environment are the same as Alternative 2.

7.4.6 *Implementability*

7.4.6.1 Technical Feasibility

Alternative 3 incorporates three additional construction elements, each involving an additional remedial technology, beyond the three used in Alternative 2. They are: 1) construction and maintenance of DNAPL collection trenches; 2) construction and maintenance of PRB systems; and 3) implementation of *in-situ* solidification. As a result, Alternative 3 would be more complex to implement than Alternative 2. However, the additional construction elements use proven technologies, and their construction is technically feasible. As discussed in Section 7.3.6.1, there are concerns regarding the long-term maintenance of RCM caps. While PRBs are considered a proven technology for metals, there is less history regarding the effectiveness of using GAC in PRBs for organic COCs. Both PRB and solidification technologies require bench and pilot testing, but this is not considered to be an implementability concern. Compared to Alternative 2, Alternative 3 incorporates two additional remedial technologies (PRBs and collection trenches) that require ongoing maintenance and monitoring in perpetuity.

7.4.6.2 Administrative Feasibility

Alternative 3 may also provide more administrative feasibility issues than Alternative 2 because of multiple and different types of expertise and construction contracts to be developed and issued for bids and reviewed and negotiated. However, implementation of Alternative 3 is expected to be administratively feasible.

7.4.6.3 Availability of Services and Materials

Same as Alternative 2.

7.4.6.4 Alternative 3 Rating with Respect to this Criterion

Alternative 3 is rated “high” with respect to implementability because it involves no dredging and presents relatively few technical challenges. Necessary engineering and construction services are readily available. Sediment caps, DNAPL collection trenches, and PRBs will require ongoing maintenance and monitoring.

7.4.7 *Cost*

The estimated present worth cost of Alternative 3 is $35 million, including a projected $25 million for capital construction and $10 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 PTWs to reduce the groundwater contaminant plume volume, Alternative 4 removes potentially mobile PTWs in the QP-U and QP-S DNAPL Areas and selected TD DNAPL Areas. Removal of mobile PTWs in the QP DNAPL Areas eliminates the potential for PTWs to migrate into and within lake sediments. The purpose of removing PTW in selected TD DNAPL Area (DA-1 and DA-2) is to address Washington Department of Natural Resource concerns regarding the placement of sediment caps in State-Owned Aquatic Lands. Other PTW in lake sediments will be capped as in Alternative 3. Refer to Section 6.3.4 for a detailed description.

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 (Section 7.5.1.1) and the environment (Section 7.5.1.2) as follows:

7.5.1.1 RAOs for Protection of Human Health

- **HH1: Restore Groundwater to its Highest Beneficial Use by Meeting MCLs and RBC for Drinking Water.** Approximately 10 percent of the upland PTW, the predominant source of groundwater contamination, is removed in this alternative. In addition, treatment of shallow groundwater leaving the uplands and entering the lake using a PRB would restore an unknown amount of groundwater. However, deep upland PTW would not be addressed. Overall, the groundwater model predicts that the aggregate plume volume would be reduced by 15 percent (after 100 years) as compared to Alternative 1 (No Action). Human health risks would be addressed via institutional controls and monitoring in the same manner as Alternatives 2 and 3.

- **HH2: Reduce Recreational and Subsistence Ingestion of Seafood to Acceptable Levels.** Same as Alternative 3, except that QP-S sediments and selected T-Dock sediments would be dredged rather than capped (addressing approximately 88 percent of the aquatic PTWs). Human health risks would be addressed via institutional controls and monitoring in the same manner as Alternatives 2 and 3.

- **HH3: Reduce Recreational Beach Users Risk to Surface Sediment to Acceptable Levels.** Same as Alternative 3, except QP-S sediments would be dredged instead of capped.

- HH4: Reduce Risks to Recreational Beach Users From Exposure to Surface Water to Acceptable Levels. Same as Alternative 3, except QP-S sediments would be dredged instead of capped.

- **HH5: Reduce Risk to Future Residents from Exposure to Indoor Vapors to Acceptable Levels.** Same as Alternative 2, except vapor intrusion would be reduced by a nominal amount due to the excavation of PTWs in the QP-U DNAPL Area. Human health risk from inhalation of vapors, in enclosed spaces, from groundwater and/or soils contaminated with COCs would also be reduced and controlled by a combination of excavation, soil caps, and institutional controls. Excavation of the QP-U DNAPL Area would not reduce vapors sufficiently to reduce or change institutional or engineering controls for vapor intrusion as identified in Alternative 2.

- **HH6: Reduce Risk to Future Residents, Commercial Workers, and Excavation/Construction Workers from Soil to Acceptable Levels.** Same as Alternative 3, except that an estimated 15,600 cy of soil from the QP-U DNAPL Area would be excavated along with construction of the DNAPL collection trenches and the funnel and gate system, as opposed to an estimated 17,500 cy of soil being treated with *in situ* stabilization and approximately 2,900 cy of soil being excavated for the trenches and PRB.

7.5.1.2 RAOs for Protection of the Environment

- **EP1: Reduce Risk to Aquatic Plants and Fish from Surface Water to Acceptable Levels.** Same as Alternative 3, except that QP-S sediments and selected T-Dock sediments would be dredged rather than capped (addressing approximately 88 percent of the aquatic PTWs).

- **EP2: Reduce Risk to Terrestrial Plants, Birds, and Mammals from Contact with Soil to Acceptable Levels.** Same as Alternative 3.

- **EP3: Reduce Risk to Aquatic-dependent Birds, Mammals, and Benthic Community from Sediment to Acceptable Levels.** Same as Alternative 3, except that QP-S sediments and selected T-Dock sediments would be dredged rather than capped.

7.5.1.3 Alternative 4 Rating with Respect to this Criterion

Alternative 4 satisfies the threshold criterion for Overall Protection of Human Health and the Environment. The alternative is rated “moderate” for both Short-Term Effectiveness (Section 7.5.5) and Long-Term Effectiveness and Permanence (Section 7.5.3). The RAO to restore groundwater to its highest beneficial use by meeting MCL ARARs and RBCs for drinking water would not be met within 100 years of completion of remedial construction; however, protectiveness would be addressed via institutional controls and monitoring (Section 7.5.1.1).

7.5.2 *Compliance with ARARs*

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 Compliance with the MCL ARAR

For Alternative 4, groundwater volume exceeding MCLs is predicted to decrease by 20 percent for benzene, 6 percent for benzo(a)pyrene and 2 percent for arsenic relative to the No Action alternative 100 years after remedial construction completion (see Figure 7-1).

Refer to Section 7.1.1.2 and Appendix A for discussion of the groundwater modeling performed to predict progress toward achieving MCLs under each remedial alternative. One hundred years after remedial construction completion for Alternative 4, the groundwater volume exceeding MCLs in the aggregate was predicted to decrease by 19 percent relative to the No Action alternative.

7.5.2.2 Alternative 4 Rating with Respect to this Criterion

Alternative 4 would satisfy the threshold criterion for compliance with ARARs, with the exception of meeting MCLs everywhere in groundwater. If meeting MCLs in groundwater is deemed technically impracticable, EPA may consider granting a TI waiver. Groundwater modeling predicts that the MCLs for benzene, benzo(a)pyrene and arsenic will not be met throughout the plume 100 years after remedial construction completion.

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 untreated waste/treatment residuals left on-site after remediation is presented in terms of the degree to which sources are remediated and the percent the plume is reduced.

Alternative 4 includes removal of PTW from the TD, QP-S, and QP-U DNAPL Areas. These areas are targeted due to their proximity to Lake Washington and/or DNAPL mobilization potential. However, approximately 78 percent (by volume) of PTW is left in place as untreated waste; therefore DNAPL-impacted soils and sediment remain in place and untreated at 27,700 and 32,400 cy, respectively. The dissolved-phase plumes exceeding the MCL ARARs and drinking water RBC are reduced (benzene by 20 percent; naphthalene by 12 percent; benzo[a]pyrene by 6 percent; and arsenic by 2 percent) from the Alternative 1 (No Action) baseline volume.

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 RCM cap), reactive residuals cover, ENR, and institutional controls. The adequacy and reliability of each of these controls are discussed below.

Upland Cap. Same as Alternatives 2 and 3.

DNAPL Collection Trenches. Same as Alternative 3.

PRB (Funnel and Gate System). Same as Alternative 3.

Sediment Caps. Same as Alternatives 2 and 3, except for areas dredged in Alternative 4. Since the QP-S DNAPL Area is dredged, this alternative does not include an amended sand cap.

Reactive Residuals Cover. Similar to an RCM cap, a reactive residuals cover would be adequate and reliable in preventing direct contact with contaminated sediments, providing a clean bioturbation layer and in protecting surface water resources. Institutional controls will restrict/prohibit activities that may compromise the integrity of the covers. The OMMP will specify long-term monitoring required to evaluate whether the covers are functioning as required, and the remedial maintenance actions and repair actions that are taken if reactive sediments covers fail to perform as required.

Reactive residuals covers may lose their effectiveness when the amended/reactive material becomes saturated or damaged. Therefore, for continued effectiveness, such covers would need to be designed to include a mechanism to allow for replacement of reactive media as needed. Long-term monitoring would be necessary to determine if and when replacement or additional reactive materials are needed. Mixing reactive material with capping media is an evolving technology and is expected to be used successfully in the future. The sediment covers would be required to remain in place and effective in perpetuity.

ENR. Same as Alternatives 2 and 3.

Institutional Controls. Same as Alternative 3. Because the vast majority of PTWs are left in place and restoration of groundwater to meet MCLs and RBCs would not be achieved within 100 years of completion of remedial construction, institutional controls would be required and relied upon in perpetuity.

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 because removal of PTWs in the TD, QP-S, and QP-U DNAPL Areas eliminates the potential for PTWs to migrate into and within lake sediments. However, the vast majority of PTW remains on-site untreated and the alternative still relies heavily on capping and institutional controls to provide long-term protection.

7.5.4 *Reduction of Toxicity, Mobility, or Volume through Treatment*

7.5.4.1 Treatment Processes Used and Materials Treated

Treatment technologies used in Alternative 4 include 1) RCM caps to sorb DNAPL in the event that DNAPL is disturbed and migrates upward to the cap, 2) a PRB to treat contaminated groundwater moving toward the lake, 3) and reactive residuals covers over dredged areas to sorb any remaining PTW that may be left behind.

7.5.4.2 Amount of Hazardous Materials Destroyed or Treated

Under Alternative 4, approximately 1,300 gallons of DNAPL from collection trenches is treated (incinerated). The amount of contaminated groundwater treated by sorption in the PRB is unknown. The amount of DNAPL treated by sorption onto the RCM caps and reactive residual covers is also unknown. Refer to Table 7-2 and Figure 7-2 for estimated DNAPL treatment volumes.

7.5.4.3 Degree of Expected Reductions in Toxicity, Mobility, and Volume

Alternative 4 would reduce the volume and toxicity of upland DNAPL, through incineration, by approximately 1,300 gallons or 0.3 percent of the total DNAPL on-site.

The aquatic RCM caps and residual covers would be expected to be effective at preventing DNAPL migration from underlying sediments into the surface waters of Lake Washington. The RCM caps should also be highly effective in treating and reducing the volume of dissolved-phase contaminants flowing into the lake; however, the volume of dissolved-phase contaminants treated by the caps and covers is unknown.

Based on modeling, the mass reduction of benzene, naphthalene, benzo(a)pyrene, and arsenic plumes in groundwater would be 40, 20, 10, and less than zero percent, respectively. The mass flux reduction (due to the PRB) for benzene, naphthalene, benzo(a)pyrene, and arsenic would be reduced by 74, 61, 83, and less than zero percent, respectively (see Figure 7-3).

7.5.4.4 Degree to which Treatment is Irreversible

Treatment of DNAPL from collection trenches that is incinerated is irreversible. Treatment of dissolved-phase contaminated groundwater migrating through the PRB containing GAC is expected to be irreversible by sorption onto the GAC. Treatment of DNAPL and dissolved constituents using RCM caps and residual covers containing organoclay would be irreversible by sorption of organic matter to the treatment material. At present, for both technologies, the quantities that would be sorbed are unknown.

7.5.4.5 Type and Quantity of Residuals Remaining after Treatment

The type and quantity of residuals remaining after treatment would be the same as Alternative 3, except there would be no solidified materials onsite.

7.5.4.6 Whether the Alternative Would Satisfy the Statutory Preference for Treatment as a Principal Element

Alternative 4 does not satisfy the statutory preference for treatment as a primary component of the alternative because the majority of the alternative is containment.

7.5.4.7 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 would be reduced by RCM 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 PTWs would be treated.

7.5.5 *Short-Term Effectiveness*

Alternative 4 has some of the same activities as Alternative 3, but also includes remedial construction activities that go beyond or are different than Alternative 3. Alternative 4 dredges and excavates some of the DNAPL-impacted sediment and soil, respectively instead of capping all DNAPL-impacted contaminated soils and sediments.

7.5.5.1 Protection of Community during Remedial Actions

For Alternative 4, potential exposure to hazardous substances to the neighboring community may result from:

1) Inhalation exposure to vapors from during dredging of 25,900 cy of potentially contaminated sediment;

2) Inhalation exposure to dust and vapors from excavation of 2,800 cy of DNAPL-impacted soil;

3) Inhalation exposure to dust or air emissions from handling and stockpiles for transport off-site, by truck, of 28,700 cy of potentially contaminated soils/sediment;

4) Inhalation exposure to dust generated from the import and handling of clean material to cap up to 22 acres of soil, although a smaller area may be capped, which would be determined during remedial design; and

5) Inhalation exposure to the same amount of dust generated as with all other alternatives, from the import and handling of clean material to cap/cover 29.4 acres of sediment.

No unacceptable health risks to the community are expected even considering the larger amounts of soil excavated and sediments containing hazardous materials dredged. This determination is based on the availability and use of BMPs and the amount of hazardous material handled on-site. BMPs and good housekeeping practices are the same as Alternative 3. Use of BMPs can mitigate inhalation exposure by active management of potential emissions by covering stockpiles and truck loads and/or keeping areas prone to generating emissions wet. Even though significantly larger volumes of contaminated sediments are dredged compared to previous alternatives, the frequency of failure of BMPs and protective measures to mitigate exposure is not expected to increase compared to Alternative 3. Failures that may cause increased exposure are the same as Alternative 3 and by their nature can quickly be determined and repaired. Special repair equipment or machine parts are not a factor for Alternative 4.

Impacts to "quality of life" is assumed to be a concern of the neighboring community.

7.5.5.2 Protection of Workers during Remedial Actions

For Alternative 4, potential exposure to hazardous substances to on-site workers may result from:

1) Inhalation and dermal exposure to vapors and/or contaminated sediments from during dredging of 25,900 cy of potentially contaminated sediment;

2) Inhalation and dermal exposure to dust and vapors from excavation of 2,800 cy of DNAPL-impacted soil;

3) Inhalation and dermal exposure to dust or air emissions may also occur from handling and stockpiles for transport off-site, by truck, of 28,700 cy of potentially contaminated soils/sediment;

4) Inhalation exposure to vapors from during dredging of 25,900 cy of potentially contaminated sediment;

5) Inhalation and dermal exposure to dust and vapors from excavation of 2,800 cy of DNAPL-impacted soil;

6) Inhalation and dermal exposure to dust or air emissions from handling and stockpiles for transport off-site, by truck, of 28,700 cy of potentially contaminated soils/sediment; and

7) Inhalation of the same amount of dust generated as with all other alternatives, from the import and handling of clean or reactive material to cap/cover 29.4 acres of sediment.

No unacceptable health risks to on-site workers are expected even though exposures may go beyond those expected for the neighboring community. The addition of dermal exposure to workers, of greater COC concentrations or frequency, can be prevented by use of protective clothing and gear, adherence to Site-specific health and safety plans and construction quality assurance plans, plus BMPs. Protective practices put in place to protect the neighboring community also contribute to prevention of worker exposure to hazardous substances, such as use of BMPs to mitigate inhalation exposure by active management of potential emissions by covering stockpiles, truck loads and/or keeping areas prone to generating emissions wet.

7.5.5.3 Environmental Impacts

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 PTW soils along the shoreline and PTW sediments would have the potential to mobilize DNAPL and result in significant short-term environmental impacts to the aquatic environment if not adequately controlled. Potential short-term impacts of sediment dredging and capping are depicted on Figure 7-4, and are summarized below.

- **Excavation/Dredging.** As discussed in Appendix C, Section C5.3.2, detailed studies performed at a range of environmental dredging sites, which included silt curtains or similar technologies, have found that 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). However, the environmental hydraulic dredging proposed for the aquatic offshore DNAPL areas would provide a high level of control and residuals would be expected to be minimal. These dredges have greater control of resuspension than conventional hydraulic or mechanical dredges. In addition, 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. 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. Additional characterization during remedial design may be needed to reduce the potential for installing sheet-pile in areas with DNAPL. In areas where dredging occurs, the fish habitat and benthic community would be significantly altered and/or eliminated in the short term; however, acceptable concentrations are assumed to be managed through application of residual covers. Assuming concentrations are acceptable, recolonization would be expected within several months (McCabe et al. 1998).

- **Capping and ENR.** As for Alternatives 2 and 3, capping and ENR will cause short-term impacts to the water column due to the material being placed through the water column and also due to capping material coming in contact with contaminated surface sediment and possibly causing resuspension. In areas where capping or ENR occurs, the benthic community would be significantly altered and/or eliminated in the short term. Assuming concentrations are acceptable, recolonization would be expected within several months (McCabe et al. 1998).

Because Alternative 4 would include a moderate amount of PTW shoreline soil and PTW 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

Remedial construction and establishment of institutional controls would be expected to be completed roughly 2 to 3 years from initiation of remedial construction (not including remedial design); however, not all RAOs (refer to Section 7.5.1) would be achieved at the end of the construction period (Figure 7-5). The RAO to restore groundwater to its highest beneficial use by meeting MCLs and RBCs for drinking water would not be met within 100 years. The RAOs to reduce risks to humans and wildlife from consumption of fish/shellfish containing unacceptable levels of cPAHs is also not expected to be met immediately, although dredging, caps and ENR will provide for a “clean” sediment surface and will reduce aquatic biota concentrations. However, seafood and aquatic wildlife that have already accumulated cPAHs will not be safe to consume. All other RAOs involving reduction of risk via direct contact with contaminated media would be met at the end of the construction period.

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. Short-term risks to the community are expected to be managed with proper planning, communication, and BMPs. Negative short-term environmental impacts are expected to the benthic community but recovery is expected.

7.5.6 *Implementability*

7.5.6.1 Technical Feasibility

Alternative 4 incorporates two additional construction elements beyond the six used in Alternative 3, for a total of eight construction elements. The additional construction elements are: 1) removal of a limited amount of PTW soil by a combination of upland-based excavation equipment and mechanical dredging, along the shoreline; and 2) removal of a limited amount of PTW sediment by a combination of mechanical and hydraulic dredging. These additional remedial technologies are well understood technologies, have been widely used over a number of years and are considered to be technically feasible for the Quendall site. These eight construction elements use proven technologies, and their construction is technically feasible.

Excavation and dredging DNAPL-impacted soil and sediments can be operationally challenging not because of the technology itself but because of the DNAPL-impacted media being removed. Dredging and excavation pose technical challenges beyond those associated with some other remedial technologies such as installation of engineered caps. However, dredging and excavation can be generally successful in eliminating residuals, to the extent possible, when using expert operators, proper equipment and plans, including BMPs and isolation barriers to the maximum extent. Generation of residuals does not make dredging or excavation technically infeasibility. Residuals can be mitigated through the use of residual covers over dredged surfaces.

Of the two methods of dredging proposed in Alternative 4, environmental hydraulic dredging is used on a smaller scale and is simpler to implement 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.

However, Alternative 4 only uses RCM caps in 2.0 acres compared to 4.9 acres in Alternatives 2 and 3. RCM caps pose more uncertainties and technical challenges due to cap maintenance and repair than hydraulic dredging. As in Alternative 3, Alternative 4 poses challenges to project sequencing and contractor coordination because of the increased number of construction elements, such as upland excavation, two separate sediment-dredging methods and the need to provide access for mobilization/demobilization and staging. As in Alternative 3, the sediment capping technologies, PRBs, and DNAPL collection trenches will require maintenance and monitoring in perpetuity.

7.5.6.2 Administrative Feasibility

Same as Alternative 3.

7.5.6.3 Availability of Services and Materials

Same as Alternative 3.

7.5.6.4 Alternative 4 Rating with Respect to this Criterion

Implementability for Alternative 4 is “moderate”. The number of construction elements is greater by two than in Alternative 3, and mechanical dredging in the nearshore (DA-6) in particular has implementability concerns associated with it. However, Alternative 4 reduces the acreage of sediment covered by a RCM cap by instead hydraulically dredging that area, thus reducing the extent of ongoing maintenance and repair or replacement of RCM caps in perpetuity.

7.5.7 *Cost*

The estimated present worth cost of Alternative 4 is $46 million, including a projected $41 million for capital construction and $5.2 million (present worth) for OM&M.

7.6 Detailed Evaluation of Alternative 4a

Alternative 4a includes (1) *in situ* solidification of PTWs in the RR and MC-1 DNAPL Areas to address the deepest occurrences of DNAPL, which are a major source of contamination to the Deep Aquifer, (2) *in situ* solidification of PTW in the QP-U DNAPL Area to address large quantities of DNAPL that could potentially migrate into adjacent Lake Washington, (3) a DNAPL collection trench system to remove mobile PTWs from the shallow subsurface to further reduce the potential migration of DNAPL from the uplands to the lake sediments, (4) a PRB to treat contaminated groundwater in the upland Shallow Aquifer as it migrates west toward the shoreline, and (5) dredging of the TD DNAPL Area (DA-1 and DA-2) to address DNAPL in shallow offshore sediments. The remaining aquatic areas are addressed via the same RCM, amended sand, and engineered sand caps and ENR as Alternatives 2 and 3. Refer to Section 6.3.5 for a detailed description.

7.6.1 *Overall Protection of Human Health and the Environment*

Alternative 4a would eliminate, reduce, or control the risks associated with the exposure pathways delineated in the RAOs for protection of human health (Section 7.6.1.1) and the environment (Section 7.6.1.2) as follows:

7.6.1.1 RAOs for Protection of Human Health

- **HH1: Restore Groundwater to its Highest Beneficial Use by Meeting MCLs and RBC for Drinking Water.** Approximately 21 percent of the upland PTW (including deep PTW, a major contributor to groundwater contamination) is addressed in this alternative. In addition, treatment of shallow groundwater leaving the uplands and entering the lake using a PRB would restore an unknown amount of groundwater. Overall, the groundwater model predicts that the aggregate plume volume would be reduced by approximately 30 percent (after 100 years) as compared to Alternative 1 (No Action). Human health risks would be addressed via institutional controls and monitoring in the same manner as Alternatives 2, 3, and 4.

- **HH2: Reduce Recreational and Subsistence Ingestion of Seafood to Acceptable Levels.** Same as Alternative 4, except the QP-S Area is capped with an RCM cap rather than dredged.

- **HH3: Reduce Recreational Beach Users Risk to Surface Sediment to Acceptable Levels.** Same as Alternative 4, except the QP-S Area is capped with an amended sand cap rather than dredged.

- **HH4: Reduce Recreational Beach Users Risk to Surface Water to Acceptable Levels.** Same as Alternative 4, except the QP-S Area is capped with an amended sand cap rather than dredged.

- **HH5: Reduce Risk to Indoor Vapors to Acceptable Levels.** Same as Alternative 3, except vapor intrusion would be reduced by a nominal amount due to additional *in situ* solidification of the PTWs in the QP-U DNAPL Areas. Human health risk from inhalation of vapors, in enclosed spaces, from groundwater and/or soils contaminated with COCs throughout the Site would also be reduced and controlled to acceptable levels by soil caps and institutional controls. Treatment of the MC-1 DNAPL Area, which underlies the potential future location of mixed use buildings, would not reduce exposure to vapors sufficiently to reduce or change institutional controls, engineering controls or capping requirements for vapor intrusion as identified in Alternative 2.[62]

- **HH6: Reduce Risk to Future Residents, Commercial Workers, and Excavation/Construction Workers from Soil to Acceptable Levels.** Same as Alternative 3, except the QP-U DNAPL area will also be treated. The treated areas may not require a cap. Human health risk from direct contact or incidental ingestion of COCs in soil would be reduced and controlled to acceptable levels through a combination of a soil cap and institutional controls. A total of approximately 31,800 cy of soil would be treated with *in situ* solidification and approximately 2,900 cy of soil would be excavated during construction of the DNAPL collection trenches and the funnel and gate systems. It is assumed that excavated PTWs and associated contaminated soil will be disposed at a RCRA Subtitle C Landfill.

7.6.1.2 RAOs for Protection of the Environment

- **EP1: Reduce Risk to Aquatic Plants and Fish from Surface Water to Acceptable Levels.** Same as Alternative 4, except the QP-S DNAPL Area is capped with an amended sand cap rather than dredged.

- EP2: Reduce Risk to Terrestrial Plants, Birds, and Mammals from Contact with Soil to Acceptable Levels. Same as Alternative 4.

- EP3: Reduce Risk to Aquatic-dependent Birds, Mammals, and Benthic Community from Sediment to Acceptable Levels. Same as Alternative 4, except the QP-S DNAPL Area is capped with an amended sand cap rather than dredged.

7.6.1.3 Alternative 4a Rating with Respect to this Criterion

Alternative 4a satisfies the threshold criterion for Overall Protection of Human Health and the Environment. The alternative is rated “high” for Short-Term Effectiveness (Section 7.6.5) and rated “moderate” for Long-Term Effectiveness and Permanence (Section 7.6.3). The RAO to restore groundwater to its highest beneficial use by meeting MCL ARARs and RBCs for drinking water would not be met within 100 years of completion of remedial construction; however, protectiveness would be addressed via institutional controls and monitoring (Section 7.6.1.1).

[62] The QP-U DNAPL Area is located wholly within the habitat area, where no future building would be allowed.

7.6.2 *Compliance with ARARs*

Alternative 4a 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 Compliance with the MCL ARAR

For Alternative 4a, groundwater volume exceeding MCLs is predicted to decrease by 37 percent for benzene, 13 percent for benzo(a)pyrene and 5 percent for arsenic, relative to the No Action alternative, 100 years after remedial construction completion (see Figure 7-1).

Refer to Section 7.1.1.2 and Appendix A for discussion of the groundwater modeling performed to predict progress toward achieving MCLs under each remedial alternative. One hundred years after remedial construction completion for Alternative 4a, the groundwater volume exceeding MCLs in the aggregate was predicted to decrease by 35 percent relative to the No Action alternative.

7.6.2.2 Alternative 4a Rating with Respect to this Criterion

Alternative 4a would satisfy the threshold criterion for compliance with ARARs, with the exception of meeting MCLs everywhere in groundwater. If meeting MCLs in groundwater is deemed technically impracticable, EPA may consider granting a TI waiver. Groundwater modeling predicts that the MCLs for benzene, benzo(a)pyrene, and arsenic will not be met throughout the plume 100 years after remedial construction completion.

7.6.3 *Long-Term Effectiveness and Permanence*

The long-term effectiveness and permanence of Alternative 4a 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, the magnitude of residual risks associated with untreated waste/ treatment residuals left on-site after remediation is presented in terms of the degree to which PTW sources are remediated and the percent the plume is reduced.

Alternative 4a includes treatment of PTW that contributes the most to deep groundwater contamination (i.e., in the RR DNAPL Area and the eastern portion of the MC DNAPL Area). It also includes removal of PTW from the TD DNAPL Area, and treatment of PTW in the QP-U DNAPL Areas. These areas are targeted primarily due to their close proximity to Lake Washington and/or higher DNAPL mobilization potential. However, approximately 74 percent (by volume) of the PTW is left in place as untreated waste; therefore, DNAPL-impacted soils and sediment remain in place at 24,100 and 43,400 cy, respectively. The dissolved-phase plumes exceeding the MCL ARARs and drinking water RBCs are reduced (benzene by 37 percent, naphthalene by 26 percent, benzo[a]pyrene by 13 percent, and arsenic by 5 percent) from the Alternative 1 (No Action) baseline volume.

7.6.3.2 Adequacy and Reliability of Controls

Controls in Alternative 4a include an upland cap, DNAPL collection trenches, a PRB (funnel and gate system), sediment caps (engineered sand, amended sand, and RCM caps), ENR, institutional controls, and monitoring.

Adequacy and reliability of controls can be assessed by examining the complexity and efficacy of requirements for long-term operation, maintenance and monitoring of the alternative. The adequacy and reliability of each of these controls are discussed below.

Upland Cap. Same as Alternatives 2, 3, and 4.

DNAPL Collection Trenches. Same as Alternatives 3 and 4.

PRB (Funnel and Gate System). Same as Alternatives 3 and 4.

Sediment Caps. Same as Alternative 4, except an amended sand cap is placed in the QP-S DNAPL Area in lieu of dredging.

Reactive Residuals Cover. Same as Alternative 4 except that only the TD DNAPL Area receives a reactive residuals cover, since the QP-S DNAPL Area is not dredged in this alternative.

ENR. Same as Alternatives 2, 3, and 4.

Institutional Controls. Same as Alternative 3. Because the vast majority of PTWs are left in place, and restoration of groundwater to meet MCLs and RBCs would not be achieved within 100 years following remedial construction, institutional controls would be required and relied upon in perpetuity. However, for Alternative 4a, there are more remedy components than Alternative 3 (sediment dredging).

7.6.3.3 Alternative 4a Rating with Respect to this Criterion

Alternative 4a is rated “moderate” with respect to long-term effectiveness and permanence because the potential for PTWs to migrate into and within lake sediments is greatly reduced through removal of PTWs in the TD DNAPL Area and solidification of PTWs in the QP-U DNAPL Area. However, the vast majority of PTW remains on-site untreated and the alternative relies heavily on capping and institutional controls to provide long-term protection.

7.6.4 *Reduction of Toxicity, Mobility, or Volume through Treatment*

7.6.4.1 Treatment Processes Used and Materials Treated

Treatment technologies used in Alternative 4a include: 1) *in situ* solidification of the RR and MC-1 DNAPL Areas to treat PTWs that are a major source of groundwater contamination in the Deep Aquifer, 2) *in situ* solidification of the QP-U DNAPL Area to treat PTWs that may potentially migrate into adjacent Lake Washington, 3) RCM and amended sand caps to sorb DNAPL in the event that DNAPL is disturbed and migrates upward to the cap, 4) a PRB to treat contaminated groundwater moving toward the lake, 5) and reactive residuals covers over selected TD DNAPL Area dredged areas to sorb any remaining PTW that may be left behind.

7.6.4.2 Amount of Hazardous Materials Destroyed or Treated

Under Alternative 4a, approximately 1,300 gallons of DNAPL from collection trenches is treated off-site (incinerated) and approximately 73,000 gallons of DNAPL are treated by *in situ* solidification.[63] The amount of contaminated groundwater treated by sorption in the PRB is unknown. The amount of DNAPL treated by sorption onto the RCM and amended sand caps and reactive residual covers is also unknown. Refer to Table 7-2 and Figure 7-2 for estimated DNAPL treatment volumes.

7.6.4.3 Degree of Expected Reductions in Toxicity, Mobility, and Volume

Alternative 4a would reduce the volume and toxicity of upland DNAPL, through incineration, by approximately 1,300 gallons or 0.3 percent of the total DNAPL on-site.

Alternative 4a would reduce the mobility of upland DNAPL, through *in situ* solidification, by approximately 73,000 gallons or 16 percent of the total DNAPL on-site; however, the toxicity and volume of the treated material remaining onsite would not be reduced. The effectiveness of the RCM and amended sand caps and residual covers in Alternative 4a is the same as Alternative 4.

Based on modeling, the mass reduction of benzene, naphthalene, benzo(a)pyrene, and arsenic plumes would be reduced by 26, 30, 16, and 1 percent, respectively. Mass flux for benzene, benzo(a)pyrene and naphthalene would be reduced by 80, 81, 89, and 5 percent, respectively (see Figure 7-3).[64]

7.6.4.4 Degree to which Treatment is Irreversible

The vast majority of DNAPL in *in situ* solidification is expected to be treated and solidification treatment would be expected to be essentially irreversible. Dissolved-phase COCs (benzene and volatile PAHs) that may leach from the solidified block can be assumed to not be irreversibly treated.

Like Alternatives 3 and 4, treatment of dissolved-phase contaminated groundwater migrating through the PRB is expected to be irreversible, as is treatment of DNAPL using RCM caps and amended sediment caps. At present, for both technologies, the quantities of contaminants that would be sorbed are unknown.

7.6.4.5 Type and Quantity of Residuals Remaining after Treatment

The type and quantity of residuals remaining after treatment would be the same as Alternative 3, except the DNAPL in the stabilized matrix would comprise approximately 31,800 cy.

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[63] The vast majority of contaminant mass at the Site is present as DNAPL or DNAPL-impacted soil or sediment (i.e., PTWs). Therefore, this consideration is primarily evaluated based on the amount of PTWs (as volume of DNAPL contained in those PTWs) that is treated.

[64] Mass flux for Alternative 4a was not modeled directly; however, its performance is expected to be similar to Alternative 5 because it contains similar remedial components in the uplands near the shoreline.

7.6.4.6 Whether the Alternative Would Satisfy the Statutory Preference for Treatment as a Principal Element

Alternative 4a does not satisfy the statutory preference for treatment as a primary component of the alternative because the majority of the alternative is containment.

7.6.4.7 Alternative 4a Rating with Respect to this Criterion

Alternative 4a is rated "low" with respect to reduction of toxicity, mobility, or volume through treatment. DNAPL mobility in sediments would be reduced by the RCM cap and amended sand cap. Treatment of PTWs in the RR, MC, and QP-U DNAPL Areas would moderately reduce the volume of contaminated groundwater, and the PRB would significantly reduce the mass flux of organic COCs to sediments. However, only a small portion of PTWs would be treated.

7.6.5 *Short-Term Effectiveness*

7.6.5.1 Protection of Community during Remedial Actions

For Alternative 4a, potential exposure to hazardous substances to the neighboring community may result from:

1) Inhalation exposure to vapors from during dredging of 14,900 cy of potentially contaminated sediment;
2) Inhalation exposure to dust and vapors from excavation of 500 cy of DNAPL-impacted soil;
3) Inhalation exposure to dust and vapors from *in situ* solidification of 5,900 cy of DNAPL-impacted soil;
4) Inhalation exposure to dust or air emissions from handling and stockpiles for transport off-site, by truck, of 15,400 cy of potentially contaminated soils/sediment;
5) Inhalation exposure to dust generated from the import and handling of clean material to cap up to 22 acres of soil, although a smaller area may be capped, which would be determined during remedial design; and
6) Inhalation exposure to the same amount of dust generated as with all other alternatives, from the import and handling of clean material to cap/cover 29.4 acres of sediment.

Even though more DNAPL-impacted soil is solidified than in Alternative 3, solidification is expected not to generate as much dust as in Alternative 4 where DNAPL-impacted soil is excavated. A significantly smaller volume of contaminated sediments is dredged than in Alternative 4 and then transported off-site for disposal.

No unacceptable health risks to the community are expected. This determination is based on the availability and use of BMPs and the amount of hazardous material handled on-site. BMPs and good housekeeping practices are the same as in Alternatives 3 and 4. Use of BMPs can mitigate inhalation exposure by active management of potential emissions by covering stockpiles and truck loads and/or keeping areas prone to generating emissions wet. The frequency of failure of BMPs and protective measures to mitigate exposure is not expected to increase compared to Alternative 3. Failures that may cause increased exposure are the same as Alternative 3 and, by their nature, can quickly be determined and repaired. Special repair equipment or machine parts are not a factor for Alternative 4a.

Impacts to “quality of life” is assumed to be a concern of the neighboring community.

7.6.5.2 Protection of Workers during Remedial Actions

For Alternative 4a, potential exposure to hazardous substances to on-site workers may result from:

1) Inhalation and dermal exposure to vapors and/or contaminated sediments from during dredging of 14,900 cy of potentially contaminated sediment;
2) Inhalation and dermal exposure to dust and vapors from excavation of 500 cy of DNAPL-impacted soil;
3) Inhalation and dermal exposure to dust or air emissions may also occur from handling and stockpiles for transport off-site, by truck, of 15,400 cy of potentially contaminated soils/sediment;
4) Inhalation exposure to vapors from during dredging of 14,900 cy of potentially contaminated sediment; and
5) Inhalation of the same amount of dust generated as with all other alternatives, from the import and handling of clean or reactive material to cap/cover 29.4 acres of sediment.

No unacceptable health risks to on-site workers are expected even though exposures may go beyond those expected for the neighboring community. The addition of dermal exposure to workers, of greater COC concentrations or frequency, can be prevented by use of protective clothing and gear, adherence to Site-specific health and safety plans and construction quality assurance plans, plus BMPs. Protective practices put in place to protect the neighboring community also contribute to prevention of worker exposure to hazardous substances, such as use of BMPs to mitigate inhalation exposure by active management of potential emissions by covering stockpiles and truck loads and/or keeping areas prone to generating emissions wet.

7.6.5.3 Environmental Impacts

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.

While there are some additional upland construction activities associated with Alternative 4a beyond those expected with Alternative 3, the impact to the environment is expected to be about the same as Alternative 3. Construction practices to prevent uplands activities from impacting the aquatic environment will be monitored and enforced by on-site EPA personnel. Dredging of potentially contaminated sediments is expected to increase by approximately 11,700 cy.

7.6.5.4 Time until Remedial Action Objectives are Achieved

Remedial construction and establishment of institutional controls would be expected to be completed roughly 2 to 3 years from initiation of remedial construction (not including remedial design); however, not all RAOs (refer to Section 7.5.1) would be achieved at the end of the construction period (Figure 7-5). The RAO to restore groundwater to its highest beneficial use by meeting MCLs and RBCs for drinking water would not be met within 100 years. The RAOs to reduce risks to humans and wildlife from consumption of fish/shellfish containing unacceptable levels of cPAHs is also not expected to be met immediately, although dredging, caps and ENR will provide for a "clean" sediment surface and will reduce aquatic biota concentrations. However, seafood and aquatic wildlife that have already accumulated cPAHs will not be safe to consume. All other RAOs involving reduction of risk via direct contact with contaminated media would be met at the end of the construction period.

7.6.5.5 Alternative 4a Rating with Respect to this Criterion

Alternative 4a is rated "high" with respect to short-term effectiveness because it would involve relatively modest construction activities. Alternatives 3 and 4 were respectively rated "high" and "moderate" for this criterion. The amount of soils excavated and disposed of in this alternative is the same as Alternative 3 and much less than Alternative 4. The amount of soils solidified in-situ is greater than Alternative 3, but solidification is expected not to generate as much dust as excavation. The amount of potentially contaminated sediments to be hydraulically dredged and handled for off-site disposal is the same as Alternative 4, but the mechanical dredging component of Alternative 4 is not included in this alternative.

7.6.6 *Implementability*

7.6.6.1 Technical Feasibility

The technical feasibility of *in situ* solidification of PTW soils, DNAPL trenches, the funnel and gate systems, and upland capping are the same as Alternative 3. Similar to Alternative 4, sediments in the TD DNAPL area (DA-1 and DA-2) would be hydraulically dredged, thereby reducing the RCM capping acreage relative to Alternatives 2 and 3. As noted in Section 7.5.6.1, RCM caps pose more uncertainties and technical challenges due to long-term cap maintenance and repair than hydraulic dredging. Similar to Alternatives 2 and 3, an amended sand cap would be placed in the QP-S DNAPL area (DA-6), which has fewer implementability concerns than the mechanical dredging of these sediments in Alternative 4. Other areas of impacted sediments are addressed in the same manner as in Alternatives 2, 3, and 4.

7.6.6.2 Administrative Feasibility

The administrative feasibility of *in situ* solidification of PTW soils, DNAPL trenches, the funnel and gate systems, and upland capping are the same as Alternative 3. The administrative feasibility of the aquatic remedies is the same as Alternative 4 for hydraulic dredging, RCM caps, and ENR.

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 4a Rating with Respect to this Criterion

Alternative 4a is rated "high" with respect to implementability because it involves no mechanical dredging of DNAPL-contaminated sediments and presents relatively few technical challenges. Necessary engineering and construction services are readily available. Sediment caps, DNAPL collection trenches, and PRBs will require ongoing maintenance and monitoring.

7.6.7 *Cost*

The estimated present worth cost of Alternative 4a is $39 million, including a projected $33 million for capital construction and $5.6 million (present worth) for OM&M.

7.7 Detailed Evaluation of Alternative 5

Alternative 5 incorporates the same upland remedial technologies as Alternative 3[65] to treat groundwater and restore a portion of the Deep Aquifer, and the same aquatic remedial technologies as Alternative 4 to remove PTWs 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 (the same area targeted for excavation in Alternative 4), and areas containing at least 4-feet cumulative thickness of DNAPL-impacted soil. Refer to Section 6.3.5 for a detailed description.

7.7.1 *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 (Section 7.6.1.1) and the environment (Section 7.6.1.2) as follows:

7.7.1.1 RAOs for Protection of Human Health

- **HH1: Restore Groundwater to its Highest Beneficial Use by Meeting MCLs and RBC for Drinking Water.** Approximately 57 percent of the upland PTW (including deep PTW, a major contributor to groundwater contamination) is treated or removed in this alternative. In addition, treatment of shallow groundwater leaving the uplands and entering the lake using a PRB would restore an unknown amount of groundwater. However, remaining upland PTW would continue to act as a source of groundwater contamination, likely for hundreds of years. Overall, the groundwater model predicts that the aggregate plume volume would be reduced by 31 percent (after 100 years) as compared to Alternative 1 (No Action). Human health risks would be addressed via institutional controls and monitoring in the same manner as Alternatives 2, 3, and 4.

[65] 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.

- **HH2: Reduce Recreational and Subsistence Ingestion of Seafood to Acceptable Levels.** Same as Alternative 4.

- **HH3: Reduce Recreational Beach Users Risk to Surface Sediment to Acceptable Levels.** Same as Alternative 4.

- **HH4: Reduce Recreational Beach Users Risk to Surface Water to Acceptable Levels.** Same as Alternative 4.

- **HH5: Reduce Risk to Indoor Vapors to Acceptable Levels.** Same as Alternative 3, except vapor intrusion concerns would be additionally reduced by *in situ* solidification treatment of the PTW with cumulative thicknesses of 4 feet or more. Human health risk from inhalation of vapors, in enclosed spaces, from groundwater and/or soils contaminated with COCs throughout the Site would also be reduced and controlled to acceptable levels by soil caps and institutional controls. Treatment of DNAPL with cumulative thicknesses of 4 feet or more may not reduce exposure to vapors sufficiently to reduce or change institutional controls, engineering controls or capping requirements for vapor intrusion as identified in Alternative 3.

- **HH6: Reduce Risk to Soil to Acceptable Levels.** Same as Alternative 3, except a larger area of the uplands will be treated or excavated. This area would be noted on the appropriate institutional controls and may not require a cap. Otherwise, human health risk from direct contact or incidental ingestion of COCs in soil would be reduced and controlled to acceptable levels through a combination of a soil cap and institutional controls. A total of approximately 78,900 cy of soil would be treated with *in situ* solidification and approximately 2,100 cy of soil would be excavated during construction of the DNAPL collection trenches and the funnel and gate systems.

7.7.1.2 RAOs for Protection of the Environment

- **EP1: Reduce Risk to Aquatic Plants and Fish from Surface Water to Acceptable Levels.** Same as Alternative 4.

- **EP2: Reduce Risk to Terrestrial Plants, Birds, and Mammals from Contact with Soil to Acceptable Levels.** Same as Alternative 4.

- **EP3: Reduce Risk to Aquatic-dependent Birds, Mammals, and Benthic Community from Sediment to Acceptable Levels.** Same as Alternative 4.

7.7.1.3 Alternative 5 Rating with Respect to this Criterion

Alternative 5 satisfies the threshold criterion for Overall Protection of Human Health and the Environment. The alternative is rated “moderate” for both Short-Term Effectiveness (Section 7.7.5) and Long-Term Effectiveness and Permanence (Section 7.7.3). The RAO to restore groundwater to its highest beneficial use by meeting MCL ARARs and RBCs for drinking water would not be met within 100 years of completion of remedial construction; however, protectiveness would be addressed via institutional controls and monitoring (Section 7.7.1.1).

7.7.2 *Compliance with ARARs*

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. Approximately 62 percent of the PTW that causes the groundwater contamination is removed or treated in this alternative. The extent to which MCLs would be achieved in this alternative is discussed below.

7.7.2.1 Compliance with the MCL ARAR

For Alternative 5, the groundwater volume exceeding MCLs is predicted to decrease by 40 percent for benzene, 31 percent for benzo[a]pyrene and 8 percent for arsenic relative to the No Action alternative 100 years after remedial construction completion (see Figure 7-1).

Refer to Section 7.1.1.2 and Appendix A for discussion of the groundwater modeling performed to predict progress toward achieving MCLs under each remedial alternative. 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.

7.7.2.2 Alternative 5 Rating with Respect to this Criterion

Alternative 5 would satisfy the threshold criterion for compliance with ARARs, with the exception of meeting MCLs everywhere in groundwater. If meeting MCLs in groundwater is deemed technically impracticable, EPA may consider granting a TI waiver. Groundwater modeling predicts that the MCLs for benzene, benzo(a)pyrene, and arsenic will not be met throughout the plume 100 years after remedial construction completion.

7.7.3 *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.

7.7.3.1 Magnitude of Residual Risks

In this subsection, residual risks associated with untreated waste/treatment residuals left on-site after remediation is presented in terms of the degree to which sources are remediated and the percent the plume is reduced.

Alternative 5 includes treatment of PTW that contributes the most to deep groundwater contamination (i.e., in the RR DNAPL Area and the eastern portion of the MC DNAPL Area). It also includes removal of PTW from the QP-S and TD DNAPL Areas, and treatment of PTW in the QP-U DNAPL Areas. These areas are targeted primarily due to their close proximity to Lake Washington and/or higher DNAPL mobilization potential. Approximately 38 percent (by volume) of PTW is left in place as untreated waste; therefore DNAPL-impacted soils and sediment remain in place and untreated at 13,100 and 32,400 cy, respectively. The dissolved-phase plumes exceeding the MCL ARARs and drinking water RBCs are reduced (benzene by 40 percent, naphthalene by 29 percent, benzo[a]pyrene by 31 percent, and arsenic by 8 percent) from the Alternative 1 (No Action) baseline volume.

7.7.3.2 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 RCM cap), reactive residuals cover, ENR, and institutional controls. The adequacy and reliability of each of these controls are discussed below.

Upland Cap. Same as Alternatives 2, 3, and 4.

PRB (Funnel and Gate System). Same as Alternatives 3 and 4.

Sediment Caps. Same as Alternative 4.

Reactive Residuals Cover. Same as Alternative 4.

ENR. Same as Alternatives 2, 3, and 4.

Institutional Controls. Same as Alternatives 3 and 4. Because most of the PTWs are left in place and restoration of groundwater to meet MCLs and RBCs would not be achieved within 100 years following remedial construction, institutional controls would be required and relied upon in perpetuity.

7.7.3.3 Alternative 5 Rating with Respect to this Criterion

Alternative 5 is rated “moderate” with respect to long-term effectiveness and permanence because, while it treats or removes more than half of the PTW at the Site, the alternative still relies heavily on capping and institutional controls to provide long-term protection.

7.7.4 *Reduction of Toxicity, Mobility, or Volume through Treatment*

7.7.4.1 Treatment Processes Used and Materials Treated

Treatment processes used in Alternative 5 would include RCM capping, reactive residuals cover, upland DNAPL/soil *in situ* solidification, and PRB treatment of groundwater. Refer to Table 7-2 and Figure 7-2 for estimated DNAPL treatment volumes. Under this alternative, approximately 47 percent of DNAPL would be treated.

7.7.4.2 Amount of Hazardous Materials Destroyed or Treated

Under Alternative 5, approximately 210,800 gallons of DNAPL is treated by *in situ* solidification. The amount of contaminated groundwater treated by sorption in the PRB is unknown. The amount of DNAPL treated by sorption onto the RCM caps and reactive residual covers is also unknown. Refer to Table 7-2 and Figure 7-2 for estimated DNAPL treatment volumes.

7.7.4.3 Degree of Expected Reductions in Toxicity, Mobility, and Volume

Alternative 5 would reduce the mobility of upland DNAPL, through *in situ* solidification, by approximately 210,800 gallons or 47 percent of the total DNAPL on-site; however, the toxicity and volume of the treated material remaining onsite would not be reduced. The effectiveness of the RCM caps and residual covers in Alternative 5 is the same as Alternative 4.

Based on modeling, the mass reduction of benzene, naphthalene, benzo(a)pyrene, and arsenic plumes in groundwater would be 51, 52, 49, and 5 percent, respectively. The mass flux reduction (due to the *in situ* solidification and PRB) for benzene, naphthalene, benzo(a)pyrene, and arsenic would be reduced by 80, 81, 89, and 5 percent, respectively (see Figure 7-3).

7.7.4.4 Degree to which Treatment is Irreversible

The vast majority of DNAPL in *in situ* solidification is expected to be treated and solidification treatment would be expected to be essentially irreversible. Dissolved-phase COCs (benzene and volatile PAHs) that may leach from the solidified block can be assumed to not be irreversibly treated.

Like Alternatives 3 and 4, treatment of dissolved-phase contaminated groundwater migrating through the PRB is expected to be irreversible, as is treatment of DNAPL using reactive amended caps and residual covers. At present, for both technologies, the quantities of contaminants that would be sorbed are unknown.

7.7.4.5 Type and Quantity of Residuals Remaining after Treatment

DNAPL treated by *in situ* solidification would remain onsite, and mixed with the soil matrix would comprise approximately 78,900 cy. As with Alternative 3, the solidified matrix is not considered to be post-treatment residual or untreated waste; whereas contaminants that may leach and migrate out of the solidified matrix to groundwater would be considered untreated or residual post-treatment waste. The amount of residual dissolved-phase contamination that may leach is unknown.

Alternative 5 would include the same residuals from aquatic remedial technologies as Alternative 4.

7.7.4.6 Whether the Alternative Would Satisfy the Statutory Preference for Treatment as a Principal Element

Alternative 5 does not satisfy the statutory preference for treatment as a primary component of the alternative because approximately 47 percent of the PTW is treated and the majority of the alternative is containment.

7.7.4.7 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 would be reduced by a combination of dredging/residual covers and RCM caps. Treatment of upland PTWs greater than 4 feet in cumulative thickness would moderately reduce the volume of contaminated groundwater, and the PRB would significantly reduce the mass flux of organic COCs to sediments.

7.7.5 *Short-Term Effectiveness*

Alternative 5 has many of the same activities as Alternatives 3 and 4. Generally, the focus of Alternative 5 is in-situ solidification of some of the DNAPL-impacted soil at Quendall and does not involve excavation directly as a remedial action for DNAPL-impacted soil. The same volume of contaminated sediment is dredged as in Alternative 4.

7.7.5.1 Protection of Community during Remedial Actions

For Alternative 5, potential exposure to hazardous substances to the neighboring community may result from:

1) Inhalation exposure to vapors from during dredging of 25,900 cy of potentially contaminated sediment;

2) Inhalation exposure to dust and vapors from excavation of 400 cy of DNAPL-impacted soil;

3) Inhalation exposure to dust and vapors from in-situ solidification of 17,000 cy of DNAPL-impacted soil;

4) Inhalation exposure to dust or air emissions from handling and stockpiles for transport off-site, by truck, of 26,300 cy of potentially contaminated soils/sediment;

5) Inhalation of dust generated from the import and handling of clean material to cap up to 22 acres of soil, although a smaller area may be capped, which would be determined during remedial design; and

6) Inhalation of the same amount of dust generated as with all other alternatives, from the import and handling of clean material to cap/cover 29.4 acres of sediment.

Less contaminated soil will be transported off-site for disposal than with Alternative 3 because DNAPL collection trenches would not be constructed. The same amount, 25,900 cy of contaminated sediment will be dredged and handled for off-site disposal as with Alternative 4. Implementation of Alternative 5 will not pose an increased chance of exposure because there is no increase in the amount of dredging, and in-situ solidification generates less dust and air quality issues than excavation. Protective measures are the same as in Alternatives 3 and 4. Alternative 5 is not expected to cause unacceptable risks to the community.

Impacts to “quality of life” is assumed to be a concern of the neighboring community.

7.7.5.2 Protection of Workers during Remedial Actions

For Alternative 5, potential exposure to hazardous substances to on-site workers may result from:

1) Inhalation and dermal exposure to vapors and contaminated sediments during dredging of 25,900 cy of potentially contaminated sediment;

2) Inhalation and dermal exposure to dust and vapors from excavation of 400 cy of DNAPL-impacted soil;

3) Inhalation and dermal exposure to dust and vapors from in-situ solidification of 17,000 cy of DNAPL-impacted soil;

4) Inhalation and dermal exposure to dust or air emissions from handling and stockpiles for transport off-site, by truck, of 26,300 cy of potentially contaminated soils/sediment; and

5) Inhalation of the same amount of dust generated as with all other alternatives, from the import and handling of clean or reactive material to cap/cover 29.4 acres of sediment.

Alternative 5 would require the same measures to protect workers to those defined under Alternatives 3 and 4. No unacceptable health risks to on-site workers are expected even though exposures may go beyond those expected for the neighboring community. For Alternative 5 the potential risk to on-site workers may be less than with Alternative 4. Less dust is generated and fewer potential air quality issues are expected using in-situ solidification instead of excavation for remediating upland DNAPL-impacted soils. There is no increase in the amount of contaminated sediments dredged, and there is a decrease in the amount of hazardous materials to be handled and transported off-site.

7.7.5.3 Environmental Impacts

Environmental impacts associated with Alternative 5 are not expected to be any greater than with Alternative 4. On the contrary, environmental impacts are likely to be less because activities associated with in-situ solidification of soils in the QP-U DNAPL Area are expected to be easier to manage than excavation in terms of impacts to the aquatic environment.

7.7.5.4 Time until Remedial Action Objectives are Achieved

Remedial construction and establishment of institutional controls would be expected to be completed in about 2.3 years from initiation of remedial construction (not including remedial design), slightly more quickly than with Alternative 4 (Figure 7-5). Not all RAOs would be achieved at the end of the construction period. The RAO to restore groundwater to its highest beneficial use by meeting MCLs and RBCs for drinking water would not be met within 100 years. The RAOs to reduce risks to humans and wildlife from consumption of fish/shellfish containing unacceptable levels of cPAHs is also not expected to be met immediately, although dredging, caps and ENR will provide for a “clean” sediment surface and will reduce aquatic biota concentrations. However, seafood and aquatic wildlife that have already accumulated cPAHs will not be safe to consume. All other RAOs involving reduction of risk via direct contact with contaminated media would be met at the end of the construction period.

7.7.5.5 Alternative 5 Rating with Respect to this Criterion

Same as Alternative 4, Alternative 5 is rated “moderate” with respect to short-term effectiveness.

7.7.6 *Implementability*

7.7.6.1 Technical Feasibility

Alternative 5 consists of one fewer construction element than Alternative 4, for a total of seven construction elements. Alternative 5 replaces excavation of 2,800 cy upland DNAPL-impacted soil (QP-U) and DNAPL collection trenches with *in situ* solidification of 17,000 cy of DNAPL-impacted soil. Solidification, like excavation, is a proven remedial technology that has been widely used over a number of years and is considered to be technically feasible for the Quendall site. Alternative 5 incorporates the same remedial technologies containing reactive media (PRBs and RCM caps), and raises the same repair and replacement concerns as in Alternative 4. PRBs and RCM caps as used in Alternative 5 and previous alternatives require maintenance and possible replacement, in perpetuity, but Alternative 5 does not include DNAPL collection trenches.

7.7.6.2 Administrative Feasibility

The administrative feasibility is the same as in Alternatives 3and 4.

7.7.6.3 Availability of Services and Materials

Necessary engineering and construction services and remedial materials are readily available.

7.7.6.4 Alternative 5 Rating with Respect to this Criterion

Implementability for Alternative 5 is “moderate” even though there are a number of construction elements, however, there is one fewer remedial technology that requires ongoing operation and maintenance, in perpetuity.

7.7.7 *Cost*

The estimated present worth cost of Alternative 5 is $48 million, including a projected $43 million for capital construction and $4.5 million (present worth) for OM&M.

7.8 Detailed Evaluation of Alternative 6

Alternative 6 is similar to Alternative 5 but provides additional treatment of PTW by expanding the solidification area to include upland DNAPL-impacted soil that exceeds 2 feet of cumulative thickness (as opposed to solidifying DNAPL-impacted soil that exceeds 4 feet of cumulative thickness in Alternative 5). Like Alternative 4, Alternative 6 includes excavation of PTWs in the QP-U area, which contains large amounts of potentially mobile DNAPL adjacent to Lake Washington. Refer to Section 6.3.6 for a detailed description.

7.8.1 *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 (Section 7.7.1.1) and the environment (Section 7.7.1.2) as follows:

7.8.1.1 RAOs for Protection of Human Health

- **HH1: Restore Groundwater to its Highest Beneficial Use by Meeting MCLs and RBC for Drinking Water.** Approximately 91 percent of the upland PTW (including deep PTW, a major contributor to groundwater contamination) is treated or removed in this alternative. In addition, treatment of shallow groundwater leaving the uplands and being sorbed by a PRB before entering the lake would restore an unknown amount of groundwater. However, remaining upland PTW would continue to act as a source of groundwater contamination, likely for hundreds of years. Overall, the groundwater model predicts that the aggregate plume volume would be reduced by 43 percent (after 100 years) as compared to Alternative 1 (No Action). Human health risks would be addressed via institutional controls and monitoring in the same manner as Alternatives 2, 3, 4, and 5.

- **HH2: Reduce Recreational and Subsistence Ingestion of Seafood to Acceptable Levels.** Same as Alternatives 4 and 5.

- **HH3: Reduce Recreational Beach Users Risk to Surface Sediment to Acceptable Levels**. Same as Alternatives 4 and 5.

- **HH4: Reduce Recreational Beach Users Risk to Surface Water to Acceptable Levels.** Same as Alternatives 4 and 5.

- **HH5: Reduce Risk to Indoor Vapors to Acceptable Levels.** Same as Alternative 5, except vapor intrusion concerns would be additionally reduced by *in situ* solidification treatment of the PTW with cumulative thicknesses of 2 feet or more. Human health risk from inhalation of vapors, in enclosed spaces, from groundwater and/or soils contaminated with COCs throughout the Site would also be reduced and controlled to acceptable levels by soil caps and institutional controls. Treatment of DNAPL with cumulative thicknesses of 2 feet or more may not reduce exposure to vapors sufficiently to reduce or change institutional controls, engineering controls or capping requirements for vapor intrusion as identified in Alternatives 3 and 5.

- **HH6: Reduce Risk to Soil to Acceptable Levels.** Same as Alternative 5, except a larger area of the uplands will be treated or excavated. This area would be noted on the appropriate institutional controls and may not require a cap. Human health risk from direct contact or incidental ingestion of COCs in soil would be reduced and controlled to acceptable levels through a combination of a soil cap and institutional controls. A total of approximately 142,500 cy of DNAPL and soil would be treated with *in situ* solidification and approximately 14,800 cy of soil would be excavated in the QP-U area and during construction of the funnel and gate systems.

7.8.1.2 7.7.1.2 RAOs for Protection of the Environment

- **EP1: Reduce Risk to Aquatic Plants and Fish from Surface Water to Acceptable Levels.** Same as Alternatives 4 and 5.

- **EP2: Reduce Risk to Terrestrial Plants, Birds, and Mammals from Contact with Soil to Acceptable Levels.** Same as Alternatives 4 and 5.

- **EP3: Reduce Risk to Aquatic-dependent Birds, Mammals, and Benthic Community from Sediment to Acceptable Levels.** Same as Alternatives 4 and 5.

7.8.1.3 Alternative 6 Rating with Respect to this Criterion

Alternative 6 satisfies the threshold criterion for Overall Protection of Human Health and the Environment. The alternative is rated “moderate” for both Short-Term Effectiveness (Section 7.8.5) and Long-Term Effectiveness and Permanence (Section 7.8.3). The RAO to restore groundwater to its highest beneficial use by meeting MCL ARARs and RBCs for drinking water would not be met within 100 years of completion of remedial construction; however, protectiveness would be addressed via institutional controls and monitoring (Section 7.8.1.1).

7.8.2 *Compliance with ARARs*

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. Approximately 91 percent of the PTW that causes the groundwater contamination is removed or treated in this alternative. The extent to which MCLs would be achieved in this alternative is discussed below.

7.8.2.1 Compliance with the MCL ARAR

For Alternative 6, groundwater volume exceeding MCLs is predicted to decrease by 56 percent for benzene, 47 percent for benzo[a]pyrene and 12 percent for arsenic relative to the No Action alternative 100 years after remedial construction completion (see Figure 7-1).

Refer to Section 7.1.1.2 and Appendix A for discussion of the groundwater modeling performed to predict progress toward achieving MCLs under each remedial alternative. 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.

7.8.2.2 Alternative 6 Rating with Respect to this Criterion

Alternative 6 would satisfy the threshold criterion for compliance with ARARs, with the exception of meeting MCLs everywhere in groundwater. If meeting MCLs in groundwater is deemed technically impracticable, EPA may consider granting a TI waiver. Groundwater modeling predicts that the MCLs for benzene, benzo(a)pyrene, and arsenic will not be met throughout the plume 100 years after remedial construction completion.

7.8.3 *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.

7.8.3.1 Magnitude of Residual Risks

In this subsection, residual risks associated with untreated waste/treatment residuals left on-site after remediation is presented in terms of the degree to which sources are remediated and the percent the plume is reduced.

Alternative 6 includes treatment of PTW that contributes the most to deep groundwater contamination (i.e., in the RR DNAPL Area and the eastern portion of the MC DNAPL Area). It also includes removal of PTW from the TD, QP-S, and QP-U DNAPL Areas. These areas are targeted primarily due to their close proximity to Lake Washington and/or higher DNAPL mobilization potential. Approximately 9 percent (by volume) of PTW is left in place as untreated waste; therefore DNAPL-impacted soils and sediment remain in place and untreated at 2,700 and 32,400 cy, respectively. The dissolved-phase plumes exceeding the MCL ARARs and drinking water RBCs are reduced (benzene at 56 percent, naphthalene at 41 percent, benzo[a]pyrene at 47 percent, and arsenic at 12 percent) from the Alternative 1 (No Action) baseline volume. Unacceptable risks remain in place should exposure occur.

7.8.3.2 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. Same as Alternatives 2, 3, 4, and 5.

PRB (Funnel and Gate System). Same as Alternatives 3, 4, and 5.

Sediment Caps. Same as Alternatives 4 and 5.

Reactive Residuals Cover. Same as Alternatives 4 and 5.

ENR. Same as Alternatives 2, 3, 4, and 5.

Institutional Controls. Same as Alternatives 3, 4, and 5. Because some PTWs are left in place, and restoration of groundwater to meet MCLs and RBCs would not be achieved, they would be required and relied upon in perpetuity.

7.8.3.3 Alternative 6 Rating with Respect to this Criterion

Alternative 6 is rated "moderate" with respect to long-term effectiveness and permanence while it treats or removes a significant amount of the PTW at the Site, the alternative still relies heavily on capping and institutional controls to provide long-term protection.

7.8.4 *Reduction of Toxicity, Mobility, or Volume Through Treatment*

7.8.4.1 Treatment Processes Used and Materials Treated

Treatment processes used in Alternative 6 include RCM capping, reactive residuals cover, upland DNAPL/soil *in situ* solidification, and PRB treatment of groundwater. Refer to Table 7-2 and Figure 7-2 for estimated DNAPL treatment volumes. Under this alternative, approximately 70 percent of DNAPL would be treated.

7.8.4.2 Amount of Hazardous Materials Destroyed or Treated

Under Alternative 6, approximately 311,000 gallons of DNAPL is treated by *in situ* solidification. The amount of contaminated groundwater treated by sorption in the PRB is unknown. The amount of DNAPL treated by sorption onto the RCM caps and reactive residual covers is also unknown. Refer to Table 7-2 and Figure 7-2 for estimated DNAPL treatment volumes.

7.8.4.3 Degree of Expected Reductions in Toxicity, Mobility, and Volume

Alternative 6 would reduce the mobility of upland DNAPL, through *in situ* solidification, by approximately 311,000 gallons or 70 percent of the total DNAPL on-site; however, the toxicity and volume of the treated material would not be reduced. The effectiveness of the RCM caps and residual covers in Alternative 6 is the same as Alternatives 4 and 5.

Based on modeling, the mass reduction of benzene, naphthalene, benzo(a)pyrene, and arsenic plumes in groundwater would be 69, 74, 75, and 12 percent, respectively. The mass flux reduction (due to the *in situ* solidification and PRB) for benzene, naphthalene, benzo(a)pyrene, and arsenic would be reduced by 86, 89, 94, and 5 percent, respectively (see Figure 7-3). However, the PRB can only be completely effective if long-term monitoring and maintenance is successfully implemented and institutional controls are observed in perpetuity.

7.8.4.4 Degree to which Treatment is Irreversible

The vast majority of DNAPL in *in situ* solidification is expected to be treated and solidification treatment would be expected to be essentially irreversible. Dissolved-phase COCs (benzene and volatile PAHs) that may leach from the solidified block can be assumed to not be irreversibly treated.

Like Alternatives 4 and 5, treatment of dissolved-phase contaminated groundwater migrating through the PRB is expected to be irreversible as is treatment of DNAPL and dissolved constituents using RCM caps and residual covers. At present, for both technologies, the quantities of contaminants that would be sorbed are unknown.

7.8.4.5 Type and Quantity of Residuals Remaining after Treatment

DNAPL treated by *in situ* solidification would remain onsite, and mixed with the soil matrix would comprise approximately 142,500 cy. As with Alternative 3, the solidified matrix is not considered to be post-treatment residual or untreated waste; whereas contaminants that may leach and migrate out of the solidified matrix to groundwater would be considered untreated or residual post-treatment waste. The amount of residual dissolved-phase contamination that may leach is unknown.

Alternative 6 would include the same residuals from aquatic remedial technologies as Alternatives 4 and 5.

7.8.4.6 Whether the Alternative Would Satisfy the Statutory Preference for Treatment as a Principal Element

Alternative 6 does satisfy the statutory preference for treatment as a primary component of the alternative because 68 percent of the PTW is treated.

7.8.4.7 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 would be reduced by a combination of dredging/residual covers and RCM caps. Treatment of upland PTWs greater than 2 feet in cumulative thickness would moderately reduce the volume of contaminated groundwater, and the PRB would significantly reduce the mass flux of organic COCs to sediments.

7.8.5 *Short-Term Effectiveness*

Alternative 6 has the same activities as Alternative 5, but includes excavation and solidification of larger volumes of DNAPL-impacted soil. The same volume of contaminated sediment is dredged as in Alternatives 4 and 5.

7.8.5.1 Protection of Community during Remedial Actions

For Alternative 6, potential exposure to hazardous substances to the neighboring community may result from:

1) Inhalation exposure to vapors from during dredging of 25,900 cy of potentially contaminated sediment;

2) Inhalation exposure to dust and vapors from excavation of 2,700 cy of DNAPL-impacted soil;

3) Inhalation exposure to dust and vapors from *in situ* solidification of 25,100 cy of DNAPL-impacted soil;

4) Inhalation exposure to dust or air emissions may also occur from handling and stockpiles for transport off-site, by truck, of 28,600 cy of potentially contaminated soils/sediment;

5) Inhalation of dust generated from the import and handling of clean material to cap up to 22 acres of soil, although a smaller area may be capped, which would be determined during remedial design; and

6) Inhalation of the same amount of dust generated as with all other alternatives, from the import and handling of clean material to cap/cover 29.4 acres of sediment.

Alternative 6 would solidify 8,100 cy more of DNAPL-impacted soils than Alternative 5. In Alternative 6, an additional 2,300 cy of DNAPL-impacted soil would be excavated and transported off-site than with Alternative 5, but it is close to the same amount as in Alternative 4. The same amount, 25,900 cy, of contaminated sediment will be dredged and handled for off-site disposal as with Alternatives 4 and 5.

Implementation of Alternative 6 will not pose a significantly increased chance of exposure because there is no significant increase in the amount of hazardous material handled than in previous alternatives. Alternative 6 is not expected to cause unacceptable risks to the community.

Impacts to “quality of life” is assumed to be a concern of the neighboring community.

7.8.5.2 Protection of Workers during Remedial Actions

For Alternative 6, potential exposure to hazardous substances to on-site workers may result from:

1) Inhalation and dermal exposure to vapors and contaminated sediments during dredging of 25,900 cy of potentially contaminated sediment;

2) Inhalation and dermal exposure to dust and vapors from excavation of 2,700 cy of DNAPL-impacted soil;

3) Inhalation and dermal exposure to dust and vapors from *in situ* solidification of 25,100 cy of DNAPL-impacted soil;

4) Inhalation and dermal exposure to dust or air emissions may also occur from handling and stockpiles for transport off-site, by truck, of 28,600 cy of potentially contaminated soils/sediment; and

5) Inhalation of the same amount of dust generated as with all other alternatives, from the import and handling of clean or reactive material to cap/cover 29.4 acres of sediment.

Alternative 6 would require the same measures to protect workers to those defined under Alternatives 3, 4 and 5. No unacceptable health risks to on-site workers are expected even though exposures may go beyond those expected for the neighboring community.

For Alternative 6, the potential risk to on-site workers may be only marginally greater than with Alternative 4. Although a large volume of soil is solidified in-situ in Alternative 6 (versus none in Alternative 4), dust generation and air quality issues in general are not a major concern with this technology. There is no increase in the amount of contaminated sediments dredged or in the amount of hazardous materials to be handled and transported off-site.

7.8.5.3 Environmental Impacts

Environmental impacts associated Alternative 6 are expected to be similar to those with Alternative 4.

7.8.5.4 Time until Remedial Action Objectives are Achieved

Remedial construction and establishment of institutional controls would be expected to be completed in about 3.2 years from initiation of remedial construction (not including remedial design), slightly longer than Alternative 4 and 5 (Figure 7-5). Not all RAOs would be achieved at the end of the construction period. The RAO to restore groundwater to its highest beneficial use by meeting MCLs and RBCs for drinking water would not be met within 100 years. The RAOs to reduce risks to humans and wildlife from consumption of fish/shellfish containing unacceptable levels of cPAHs is also not expected to be met immediately, although dredging, caps and ENR will provide for a “clean” sediment surface and will reduce aquatic biota concentrations. However, seafood and aquatic wildlife that have already accumulated cPAHs will not be safe to consume. All other RAOs involving reduction of risk via direct contact with contaminated media would be met at the end of the construction period.

7.8.5.5 Alternative 6 Rating with Respect to this Criterion

Alternative 6 is rated the same as Alternatives 4 and 5, as “moderate”.

7.8.6 *Implementability*

7.8.6.1 Technical Feasibility

Alternative 6 has one additional construction element than Alternative 5 for a total of eight construction elements. Similar to previous alternatives, Alternative 6 relies on the use of multiple construction elements. The difference between Alternative 5 and 6 is that under Alternative 6, 2,700 cy of upland DNAPL-impacted soil (QP-U) is excavated rather than solidified. Alternative 6 solidifies a total of 25,100 cy of DNAPL-impacted soil compared to the total of 17,000 cy for Alternative 5. Solidification and excavation are proven remedial technologies that have been widely used over a number of years and are considered to be technically feasible for the Quendall site. Alternative 6 incorporates the same remedial technologies containing reactive media (PRBs and RCM caps), and raises the same repair and replacement concerns as in Alternatives 4 and 5. PRBs and RCM caps used in Alternative 6 and previous alternatives require repair or replacement, in perpetuity.

7.8.6.2 Administrative Feasibility

The administrative feasibility of Alternative 6 is the same as for Alternative 5.

7.8.6.3 Availability of Services and Materials

Availability of services and materials is the same as Alternative 5.

7.8.6.4 Alternative 6 Rating with Respect to this Criterion

Implementability for Alternative 6 is "moderate." Even though there are a high number of construction elements, there are fewer remedial technologies that require ongoing maintenance and repair and replacement, in perpetuity.

7.8.7 *Cost*

The estimated present worth cost of Alternative 6 is $62 million, including a projected $58 million for capital construction and $4.5 million (present worth) for OM&M.

7.9 Detailed Evaluation of Alternative 7

Alternative 7 involves solidification of all known upland PTWs and removal and on-site treatment of all known sediment PTWs. The purpose of treating or removing all PTW is to eliminate sources of groundwater contamination to a greater extent than other previous alternatives. Because all known PTWs are being addressed, upland DNAPL collection trenches and the PRB are not included in this alternative. Containment measures described in Alternative 2, except RCM caps, are also included in this alternative to maintain protectiveness and provide additional source control. Residual covers will be placed over all dredged sediment areas. Refer to Section 6.3.7 for a detailed description.

7.9.1 *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:

7.9.1.1 RAOs for Protection of Human Health

- **HH1: Restore Groundwater to its Highest Beneficial Use by Meeting MCLs and RBC for Drinking Water.** Under Alternative 7, treatment of all upland PTW would significantly reduce the source of groundwater contamination over time and contribute to groundwater restoration. Overall, the groundwater model predicts that the aggregate plume volume would be reduced by 80 percent (after 100 years) as compared to Alternative 1 (No Action). It further predicts that remediation in Alternative 7 would restore groundwater to a large degree for benzene and benzo(a)pyrene, but to only a small degree for arsenic. The likelihood of complete restoration is uncertain due to a number of factors, including conservative modeling assumptions, the complexity of the source, the potential for leaching from the solidified mass, and the potential for leaving unidentified PTW behind (see Section 7.1.1.2). Human health risks would be addressed in the same manner as previous alternatives until COCs are reduced to acceptable levels.

- **HH2: Reduce Recreational and Subsistence Ingestion of Seafood to Acceptable Levels.** Same as Alternative 6, except that areas with RCM caps would be replaced with residual covers.

- **HH3: Reduce Recreational Beach Users Risk to Surface Sediment to Acceptable Levels.** Same as Alternative 6, except that areas with RCM caps would be replaced with residual covers.

- **HH4: Reduce Recreational Beach Users Risk to Surface Water to Acceptable Levels.** Same as Alternative 6, except that areas with RCM caps would be replaced with residual covers.

- **HH5: Reduce Risk to Indoor Vapors to Acceptable Levels.** Human health risk from inhalation of vapors, in enclosed spaces, from groundwater and/or soils contaminated with COCs would be greatly reduced, especially in buildings constructed over areas of the Site treated by *in situ* solidification. Institutional controls would still include an assessment of occupied enclosed spaces for potential vapor intrusion risks and, if necessary, engineering controls to eliminate exposure to vapors.

- **HH6: Reduce Risk to Future Residents, Commercial Workers, and Excavation/Construction Workers from Soil to Acceptable Levels.** Human health risk from direct contact or incidental ingestion of COCs in soil would be greatly reduced by addressing all upland PTWs via *in situ* solidification. Exposure to any remaining unacceptable levels of COCs would be reduced and controlled to acceptable levels through a combination of a soil cap and institutional controls. A total of approximately 241,300 cy of DNAPL and soil would be treated with *in situ* solidification.

7.9.1.2 7.8.1.2 RAOs for Protection of the Environment

- **EP1: Reduce Risk to Aquatic Plants and Fish from Surface Water to Acceptable Levels.** Same as Alternative 6; except that areas with reactive amended caps would be replaced with residual covers.

- **EP2: Reduce Risk to Terrestrial Plants, Birds, and Mammals from Contact with Soil to Acceptable Levels.** Same as Alternative 6.

- **EP3: Reduce Risk to Aquatic-dependent Birds, Mammals, and Benthic Community from Sediment to Acceptable Levels.** Same as Alternative 6; except that areas with reactive amended caps would be replaced with residual covers.

7.9.1.3 Alternative 7 Rating with Respect to this Criterion

Alternative 7 satisfies the threshold criterion for Overall Protection of Human Health and the Environment. It is rated “moderate” for Short-Term Effectiveness (Section 7.9.5) because of the extensive upland and in-water construction activities occurring over a multi-year period; however, the alternative is rated “high” for Long-Term Effectiveness and Permanence (Section 7.9.3) because all PTWs are removed or treated. Addressing all PTWs will have a greater contribution to groundwater restoration. To the extent required, protectiveness would be addressed via institutional controls and monitoring (Section 7.9.1.1).

7.9.2 *Compliance with ARARs*

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.

7.9.2.1 Compliance with the MCL ARAR

For Alternative 7, groundwater volume exceeding MCLs is predicted to decrease by 97 percent for benzene, 78 percent for benzo[a]pyrene, and 21 percent for arsenic relative to the No Action alternative 100 years after remedial construction completion (see Figure 7-1).

Refer to Section 7.1.1.2 and Appendix A for discussion of the groundwater modeling performed to predict progress toward achieving MCLs under each remedial alternative. 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. Since all identified PTW sources to groundwater are addressed, this alternative has a greater effect on plume reduction than Alternatives 2 through 6.

7.9.2.2 Alternative 7 Rating with Respect to this Criterion

Alternative 7 would satisfy the threshold criterion for compliance with ARARs, with the exception of meeting MCLs everywhere in groundwater. If meeting MCLs in groundwater is deemed technically impracticable, EPA may consider granting a TI waiver. Groundwater modeling predicts that the MCLs for benzene, benzo(a)pyrene, and arsenic will not be met throughout the plume 100 years after remedial construction completion.

7.9.3 *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.

7.9.3.1 Magnitude of Residual Risks

In this subsection, residual risks associated with untreated waste/treatment residuals left on-site after remediation is presented in terms of the degree to which sources are remediated and the percent the plume is reduced.

For Alternative 7, none of the PTW is left in place as untreated waste. The dissolved-phase plumes exceeding the MCL ARARs and drinking water RBC are reduced (benzene by 97 percent, naphthalene by 89 percent, benzo[a]pyrene by 78 percent, and arsenic by 21 percent) from the Alternative 1 (No Action) baseline volume.

7.9.3.2 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. An upland cap may not be needed once all PTW has been addressed.

Engineered Sand Caps. Same as Alternative 6, except some institutional controls may not be needed in perpetuity because of significant contaminant mass flux reduction because all PTW is being addressed.

Reactive Residuals Cover. Same as Alternative 6 except all PTW is dredged, therefore the areal extent of reactive residual covers is extended.

ENR. Same as Alternative 6.

Institutional Controls. Same as Alternative 6. Because all of the PTWs identified during site investigations are treated or removed, and there are fewer engineering controls needed to protect contained contamination, there is less reliance on institutional controls for Alternative 7 than for Alternatives 2 through 6. In addition, some institutional controls may not be needed in perpetuity (e.g., the engineered sand cap for upwelling contaminated groundwater).

7.9.3.3 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 PTWs.

7.9.4 *Reduction of Toxicity, Mobility, or Volume through Treatment*

7.9.4.1 Treatment Processes Used and Materials Treated

Treatment processes used in Alternative 7 include a reactive residuals cover and upland DNAPL/soil *in situ* solidification. Refer to Table 7-2 and Figure 7-2 for estimated DNAPL treatment volumes. Under this alternative, approximately 85 percent of DNAPL would be treated.

7.9.4.2 Amount of Hazardous Materials Destroyed or Treated

Under Alternative 7, approximately 377,500 gallons of DNAPL is treated by *in situ* solidification. The amount of DNAPL treated by sorption onto the reactive residual covers is unknown. Refer to Table 7-2 and Figure 7-2 for estimated DNAPL treatment volumes.

7.9.4.3 Degree of Expected Reductions in Toxicity, Mobility, and Volume

Alternative 7 would reduce the mobility of upland DNAPL, through *in situ* solidification, by approximately 377,500 gallons or 85 percent of the total DNAPL on-site; however, the toxicity and volume of the treated material would not be reduced. The remaining 15 percent would be removed from the aquatic environment via dredging and landfilled.

The reactive residual covers would be expected to be 100 percent effective at controlling DNAPL mobility from underlying sediments into the surface waters of Lake Washington; however, only a negligible amount of DNAPL is expected to be in contact with the caps and covers. The residual covers should also be 100 percent effective in treating and reducing the volume of dissolved-phase contaminants flowing into the lake; however, the volume of dissolved-phase contaminants treated by the caps and covers is unknown. The reactive residual covers can only be completely effective if long-term monitoring and maintenance is successfully implemented and institutional controls are observed in perpetuity.

Based on modeling, the mass reduction of benzene, naphthalene, benzo(a)pyrene, and arsenic plumes in groundwater would be 100, 100, 98, and 24 percent, respectively. The mass flux reduction (due to the *in situ* solidification) for benzene, naphthalene, benzo(a)pyrene, and arsenic would be reduced by 100, 100, 99, and 6 percent, respectively (see Figure 7-3).

7.9.4.4 Degree to which Treatment is Irreversible

In situ solidification is expected to treat the vast majority of DNAPL and solidification treatment would be expected to be essentially irreversible. Dissolved-phase COCs (benzene and volatile PAHs) that may leach from the solidified block can be assumed to not be irreversibly treated.

Treatment of DNAPL and dissolved constituents using reactive residual covers containing organoclay would be irreversible by sorption of organic matter to the treatment material. At present, the quantities that would be sorbed are unknown.

7.9.4.5 Type and Quantity of Residuals Remaining after Treatment

DNAPL treated by *in situ* solidification would remain onsite, and mixed with the soil matrix would comprise approximately 241,300 cy. As with Alternative 3, the solidified matrix is not considered to be post-treatment residual or untreated waste; whereas contaminants that may leach and migrate out of the solidified matrix to groundwater would be considered untreated or residual post-treatment waste. The amount of residual dissolved-phase contamination that may leach is unknown.

Alternative 7 would differ from Alternative 6 in there are fewer residuals in both the upland and aquatic areas due to more extensive solidification and dredging in these areas.

7.9.4.6 Whether the Alternative Would Satisfy the Statutory Preference for Treatment as a Principal Element

Alternative 7 satisfies the statutory preference for treatment as a primary component of the alternative because the majority of the alternative includes treatment.

7.9.4.7 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 PTWs would be treated. The volume of contaminated groundwater and mass flux of organic COCs to sediments would be greatly reduced over time.

7.9.5 *Short-Term Effectiveness*

Alternative 7 has generally the same activities as Alternative 6, but does not involve excavation of DNAPL-impacted soil. Instead, all DNAPL-impacted soil is solidified. All DNAPL-impacted sediment is dredged; twice the amount as in Alternative 6.

7.9.5.1 Protection of Community during Remedial Actions

For Alternative 7, potential exposure to hazardous substances to the neighboring community may result from:

1) Inhalation exposure to vapors from during dredging of 58,300 cy of potentially contaminated sediment;

2) Inhalation exposure to dust and vapors from *in situ* solidification of 30,500 cy of DNAPL-impacted soil;

3) Inhalation exposure to dust or air emissions from handling and stockpiles for transport off-site, by truck, of 58,300 cy of potentially contaminated soils/sediment;

4) Inhalation of dust generated from the import and handling of clean material to cap up to 22 acres of soil, although a smaller area may be capped, which would be determined during remedial design; and

5) Inhalation of the same amount of dust generated as with all other alternatives, from the import and handling of clean material to cap/cover 29.4 acres of sediment.

In Alternative 7 an additional 5,400 cy of DNAPL-impacted soils are solidified than with Alternative 6, but Alternative 7 does not include excavation of DNAPL-impacted soils as Alternative 6 does. Approximately twice the amount (32,400 cy more) of contaminated sediments are dredged and transported off-site with Alternative 7 than with Alternative 6.

Implementation of Alternative 7 may cause an increased concern regarding air quality because of the increased amount of contaminated sediments to be dredged compared with Alternatives 3, 4, and 6. However, the areas that will be dredged in Alternative 7 that will not be dredged in Alternative 2 and 3 contain much lower volumes of DNAPL and lower concentrations of contaminated sediments; therefore, the likelihood that an increase in risk due to air quality exceedance is low. Also, in Alternative 7, concerns about the generation of dust are low compared to previous alternatives where excavation of DNAPL-impacted soil is included such as in Alternative 6. Solidification is not expected to generate as much dust as excavation and is expected not to be a concern for the nearby community. Alternative 7 would require similar protective measures as those defined under Alternatives 5 and 6. Alternative 7 is not expected to cause unacceptable risks to the community.

Impacts to “quality of life” are assumed to be a concern of the neighboring community.

7.9.5.2 Protection of Workers during Remedial Actions

For Alternative 7, potential on-site worker exposure to hazardous substances may result from:

1) Inhalation and dermal exposure to vapors and contaminated sediment from during dredging of 58,300 cy of potentially contaminated sediment;

2) Inhalation and dermal exposure to dust and vapors from *in situ* solidification of 30,500 cy of DNAPL-impacted soil;

3) Inhalation and dermal exposure to dust or air emissions may also occur from handling and stockpiles for transport off-site, by truck, of 58,300 cy of potentially contaminated soils/sediment; and

4) Inhalation of the same amount of dust generated as with all other alternatives, from the import and handling of clean or reactive material to cap/cover 29.4 acres of sediment.

Alternative 7 would require the same measures to protect workers as those defined under Alternatives 3, 4, 5, and 6. No unacceptable health risks to on-site workers are expected even though exposures may go beyond those expected for the neighboring community. For Alternative 7 the potential risk to on-site workers is expected to be similar to Alternatives 5 and 6. There is an increase in the amount of DNAPL-impacted soils to be solidified, but there will not be concerns about dust generated from excavation as in Alternative 6. There is a significant increase in the amount of dredging of contaminated sediments that greatly increases concerns about exposure; however, the areas contributing to the increase in dredging volumes contain much lower volumes of DNAPL and lower contaminant concentrations in impacted sediments. Actual risk due to air quality concerns is not expected to increase beyond that of Alternatives 4, 5, and 6.

7.9.5.3 Environmental Impacts

Alternative 7 requires dredging approximately twice the volume of contaminated sediments as Alternative 6. Alternative 7 involves the same amount of capping as Alternative 6. However, the assumed increase in adverse impact to aquatic habitat caused by dredging is off-set by impacts caused by capping in previous alternatives. For example, Alternative 6 involves using RCM caps over 2.0 acres, versus none in Alternative 7. The area of sediments either dredged and/or capped/covered is the same throughout all the alternatives; however, dredging can result in the generation of contaminated residuals. Alternative 7 is estimated to require a residuals cover over 6.4 acres, nearly twice as much area as Alternative 6 (3.5 acres). However, the use of a residuals cover, which will mitigate the impact of residuals, will less adversely impact the aquatic environment than RCM caps used in previous alternatives.

Impacts to the environment from upland activities are expected to decrease compared to Alternative 6 because, although there is increased in-situ soil solidification, excavation of DNAPL-impacted and contaminated soil is not a part of Alternative 7.

7.9.5.4 Time until Remedial Action Objectives are Achieved

Remedial construction and establishment of institutional controls would be expected to be completed in about 4 years from initiation of remedial construction (not including remedial design), which is longer by a half of a year, than Alternative 6 (Figure 7-5). Not all RAOs would be achieved at the end of the construction period.

The RAO to restore groundwater to its highest beneficial use by meeting MCLs and RBCs for drinking water would likely not be met within 100 years. However, MCLs are expected to be achieved over a larger area than Alternatives 2 through 6. The RAOs to reduce risks to humans and wildlife from consumption of fish/shellfish containing unacceptable levels of cPAHs is also not expected to be met immediately, although dredging, caps and ENR will provide for a “clean” sediment surface and will reduce aquatic biota concentrations. However, seafood and aquatic wildlife that have already accumulated cPAHs will not be safe to consume. All other RAOs involving reduction of risk via direct contact with contaminated media would be met at the end of the construction period.

7.9.5.5 Alternative 7 Rating with Respect to this Criterion

Alternative 7 is rated “moderate” with respect to short-term effectiveness. There is a large increase in the amount of potentially contaminated sediments to be dredged and handled for off-site disposal; however, there are no DNAPL-impacted soils to be excavated and disposed off-site. No unacceptable risk is expected to the community or workers because of the use of protective equipment and practices. Greater adverse impacts are expected in the aquatic environment compared to Alternative 6 because of the greater extent of dredging and the generation of contaminated residuals associated with Alternative 7; however, habitat recovery is expected to occur relatively quickly. EPA believes Alternative 7 should be rated ‘moderate’ to differentiate this alternative from Alternatives 8 through 10, which have substantially greater short-term impacts, particularly in the upland area.

7.9.6 *Implementability*

7.9.6.1 Technical Feasibility

Alternative 7 consists of fewer construction elements and remedial technologies than most previous alternatives. Alternative 7 consists of: 1) placing and repair/placement of engineered sand caps and ENR cover; 2) dredging and off-site disposal of all DNAPL-impacted sediments (58,300 cy of sediment); and 3) *in situ* solidification of all DNAPL-impacted soil (30,500 cy) and additional clean and contaminated soil in the DNAPL “footprint” (totaling 241,300 cy). All are proven and reliable technologies to implement and operate, and previously noted concerns with respect to long-term maintenance and monitoring of RCM caps, PRBs, and DNAPL collection trenches do not apply to Alternative 7. However, the large scale and volume of materials removed or treated compared to previous alternatives would introduce additional technical and logistical challenges. Dredging of 58,000 cy of sediment in DNAPL-impacted areas would involve significant challenges in controlling potential water quality impacts during construction. Dredging can generate contaminated residuals, but with the use of expert operators and “tried and true” dredging practices, the generation of residuals can be minimized and remediated with the application of a residuals cover. The installation and removal of in-water containment sheet pile will add to the technical and logistical challenges of this alternative.

7.9.6.2 Administrative Feasibility

Compared to Alternatives 2 through 6, Alternative 7 is expected to have fewer administrative feasibility challenges associated with sediment capping. However, because of the much larger extent of dredging, substantial coordination with regulatory agencies would be required to address potential water quality impacts. Alternative 7 may also require more administrative coordination based on its longer construction duration.

7.9.6.3 Availability of Services and Materials

Necessary engineering and construction services are readily available.

7.9.6.4 Alternative 7 Rating with Respect to this Criterion

Alternative 7 is rated “moderate” with respect to implementability. The much larger scale and volume of materials removed or treated compared to previous alternatives would introduce additional implementability challenges. However, Alternative 7 involves fewer construction elements than most of the previous alternatives. The technologies are well understood and have been used for many years. Environmental dredging is a more recent technique but as experience with environmental dredging has increased, better practices have developed to minimize the generation of contaminated residuals and the management of such residuals, as evidenced in recent local dredging projects, such as the

Boeing project in the Duwamish River. Engineered caps are relatively easy to repair or replace compared to RCM caps. Monitoring is expected to be relatively simple to implement given that DNAPL-impacted media will be treated or removed, unlike other alternatives that leave more DNAPL-impacted media in place in perpetuity. Lengthy construction schedules may results in more schedule modifications than previous alternatives. However, alternatives with more construction elements could also result in schedule complications because of more complicated coordination of multiple remedial activities sometimes in a short period of time.

7.9.7 *Cost*

The estimated present worth cost of Alternative 7 is $82 million, including a projected $79 million for capital construction and $2.9 million (present worth) for OM&M.

7.10 Detailed Evaluation of Alternative 8

Alternative 8 involves removal and on-site treatment of upland and sediment PTWs. The upland remedy components differ from Alternative 7 in that PTWs are removed and thermally treated *ex situ* on-site instead of treated with *in situ* stabilization. As with Alternative 7, because all known PTWs are being addressed, upland DNAPL collection trenches and the PRB are not included in this alternative. The aquatic remedy components are identical to Alternative 7. Containment measures described in Alternative 2, except RCM capping[66], are also included in this alternative to maintain protectiveness and provide additional source control. Refer to Section 6.3.8 for a detailed description.

7.10.1 *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:

7.10.1.1 RAOs for Protection of Human Health

- **HH1: Restore Groundwater to its Highest Beneficial Use by Meeting MCLs and RBC for Drinking Water.** Under Alternative 8, removal of all upland PTW would provide a greater contribution to groundwater restoration. Overall, the groundwater model predicts that the aggregate plume volume would be reduced by 81 percent (after 100 years) as compared to Alternative 1 (No Action). It further predicts that the MCL for benzene would be achieved throughout the aquifers after 100 years, but not the MCLs for arsenic or benzo(a)pyrene. The likelihood of complete restoration is uncertain due to a number of factors, including conservative modeling assumptions, the complexity of the source, and the potential for leaving unidentified PTW behind (see Section 7.1.1.2). Human health risks would be addressed in the same manner as Alternative 2 until COCs are reduced to acceptable levels.

[66] RCM capping is not included in Alternative 8 because sediment PTWs are removed.

- **HH2: Reduce Recreational and Subsistence Ingestion of Seafood to Acceptable Levels.** Same as Alternative 7.
- **HH3: Reduce Recreational Beach Users Risk to Surface Sediment to Acceptable Levels.** Same as Alternative 7.
- **HH4: Reduce Recreational Beach Users Risk to Surface Water to Acceptable Levels.** Same as Alternative 7.
- **HH5: Reduce Risk to Indoor Vapors to Acceptable Levels.** Same as Alternative 7.
- **HH6: Reduce Risk to Future Residents, Commercial Workers, and Excavation/Construction Workers from Soil to Acceptable Levels.** Same as Alternative 7. A total of approximately 210,100 cy of DNAPL and soil would be excavated and thermally treated on site.

7.10.1.2 RAOs for Protection of the Environment

- **EP1: Reduce Risk to Aquatic Plants and Fish from Surface Water to Acceptable Levels.** Same as Alternative 7.
- **EP2: Reduce Risk to Terrestrial Plants, Birds, and Mammals from Contact with Soil to Acceptable Levels.** Same as Alternative 7.
- **EP3: Reduce Risk to Aquatic-dependent Birds, Mammals, and Benthic Community from Sediment to Acceptable Levels.** Same as Alternative 7.

7.10.1.3 Alternative 8 Rating with Respect to this Criterion

Alternative 8 satisfies the threshold criterion for Overall Protection of Human Health and the Environment. While it is rated “low” for Short-Term Effectiveness (Section 7.10.5) because of the extensive upland and in-water construction activities occurring over a multi-year period, the alternative is rated “high” for Long-Term Effectiveness and Permanence (Section 7.10.3) because all PTWs are removed or treated. Addressing all PTWs will provide a greater contribution to groundwater restoration. To the extent required, protectiveness would be addressed via institutional controls and monitoring (Section 7.10.1.1).

7.10.2 *Compliance with ARARs*

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.

7.10.2.1 Compliance with the MCL ARAR

For Alternative 8, groundwater volume exceeding MCLs is predicted to decrease by 100 percent for benzene, 33 percent for benzo[a]pyrene, and 11 percent for arsenic relative to the No Action alternative 100 years after remedial construction completion (see Figure 7-1).

Refer to Section 7.1.1.2 and Appendix A for discussion of the groundwater modeling performed to predict progress toward achieving MCLs under each remedial alternative. 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. Since all identified PTW sources are addressed, this alternative has a greater effect on plume reduction than Alternatives 2 through 6, which leave known quantities of PTW behind.

7.10.2.2 Alternative 8 Rating with Respect to this Criterion

Alternative 8 would satisfy the threshold criterion for compliance with ARARs, with the exception of meeting MCLs everywhere in groundwater. If meeting MCLs in groundwater is deemed technically impracticable, EPA may consider granting a TI waiver. Groundwater modeling predicts that the MCLs for benzo(a)pyrene and arsenic will not be met throughout the plume 100 years after remedial construction completion.

7.10.3 *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.

7.10.3.1 Magnitude of Residual Risks

In this subsection, residual risks associated with untreated waste/treatment residuals left on-site after remediation is presented in terms of the degree to which sources are remediated and the percent the plume is reduced.

For Alternative 8, none of the PTW is left in place as untreated waste. The dissolved-phase plumes exceeding the MCL ARARs and drinking water RBC are reduced (benzene by 100 percent, naphthalene by 100 percent, benzo[a]pyrene by 33 percent, and arsenic by 11 percent) from the Alternative 1 (No Action) baseline volume.

7.10.3.2 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. Same as Alternative 7.

Engineered Sand Caps. Same as Alternative 7.

Reactive Residuals Cover. Same as Alternative 7.

ENR. Same as Alternative 7.

Institutional Controls. Same as Alternative 7. Because all of the PTWs identified during site investigations are treated or removed, and there are fewer engineering controls needed to protect contained contamination, there is less reliance on institutional controls for Alternative 8 than for Alternatives 2 through 6. In addition, some institutional controls may not be needed in perpetuity (e.g., the engineered sand cap for upwelling contaminated groundwater).

7.10.3.3 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 PTWs.

7.10.4 *Reduction of Toxicity, Mobility, or Volume Through Treatment*

7.10.4.1 Treatment Processes Used and Materials Treated

Treatment processes used in Alternative 8 include a reactive residuals cover (same as Alternative 7) and on-site thermal treatment for all PTW soil and sediment (different than Alternative 7, which uses *in situ* solidification for upland PTW treatment). Refer to Table 7-2 and Figure 7-2 for estimated DNAPL treatment volumes.

7.10.4.2 Amount of Hazardous Materials Destroyed or Treated

Under Alternative 8, approximately 445,100 gallons of DNAPL is treated by on-site thermal treatment. The amount of contaminated groundwater treated by sorption onto reactive residual covers is unknown but expected to be minimal. The intent of this alternative is to treat all PTWs at the Site. However it is likely that some residual contamination could remain given the complexity of the Site and volume of treatment involved under this alternative.

7.10.4.3 Degree of Expected Reductions in Toxicity, Mobility, and Volume

Alternative 8 would reduce the toxicity, mobility, and volume of upland DNAPL that is treated. Thermal treatment effectiveness for arsenic is uncertain. Pilot-scale testing would be completed to optimize treatment parameters such as 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 treatment would remove DNAPL but that the treated soil may still exceed PRGs and require containment (such as capping).

Based on modeling, the mass reduction of benzene, naphthalene, benzo(a)pyrene, and arsenic plumes in groundwater would be 100, 100, 92, and 13 percent, respectively. The mass flux reduction for benzene, naphthalene, benzo(a)pyrene, and arsenic would be reduced by 100, 100, 99, and 6 percent, respectively (see Figure 7-3).

The degree of expected reductions in toxicity, mobility, and volume from the reactive residual covers is the same as for Alternative 7.

7.10.4.4 Degree to which Treatment is Irreversible

Organic contaminant thermal treatment is irreversible.

Treatment of DNAPL and dissolved constituents using reactive residual covers containing organoclay would be irreversible by sorption of organic matter to the treatment material. At present, the quantities that would be sorbed are unknown.

7.10.4.5 Type and Quantity of Residuals Remaining after Treatment

DNAPL-impacted soil and sediment treated thermally would remain onsite, and mixed with the soil/sediment matrix would comprise approximately 268,400 cy. Residual contaminant concentrations in soil would be expected to be low but may exceed PRGs depending on the effectiveness of treatment.

7.10.4.6 Whether the Alternative Would Satisfy the Statutory Preference for Treatment as a Principal Element

Alternative 9 satisfies the statutory preference for treatment as a primary component of the alternative because the majority of the alternative includes treatment.

7.10.4.7 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 PTWs 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.

7.10.5 *Short-Term Effectiveness*

Alternative 8 has some of the same activities as Alternative 7. Alternative 8 does not involve solidification of DNAPL-impacted soil, instead all DNAPL-impacted soil is excavated and treated on-site. All DNAPL-impacted sediment is dredged and treated on-site.

7.10.5.1 Protection of Community during Remedial Actions

For Alternative 8, potential exposure to hazardous substances to the neighboring community may result from:

1) Inhalation exposure to vapors from during dredging of 58,300 cy of potentially contaminated sediment;
2) Inhalation exposure to dust and vapors from excavation of 30,500 cy of DNAPL-impacted soil;
3) Inhalation exposure to air emissions from on-site treatment of 88,800 cy of potentially contaminated soils/sediment;
4) Inhalation of dust generated from the import and handling of clean material to cap up to 22 acres of soil, although a smaller area may be capped, which would be determined during remedial design; and
5) Inhalation of the same amount of dust generated as with all other alternatives, from the import and handling of clean material to cap/cover 29.4 acres of sediment.

Alternative 8 involves excavation and on-site thermal treatment of 30,500 cy of DNAPL-impacted soils as opposed to Alternative 7, where the 30,500 cy would instead be solidified in-situ. The amount of DNAPL-impacted soil that is excavated and thermally treated on-site in Alternative 8 is over 10 times greater than the amount excavated and disposed off-site in Alternative 6 and previous alternatives (up to 2,800 cy for Alternative 4). Since all materials are treated on-site, no materials would be trucked off-site. Neighboring communities maybe exposed to increased amounts of dust caused by excavation of DNAPL-impacted soil; however, continuous ongoing EPA oversight and monitoring will mitigate the extent that exposure may occur.

Alternative 8 dredges and caps/covers the same acreage of contaminated sediments as in Alternative 7. The contaminated sediments will be thermally treated on-site instead of being trucked off-site for disposal. None of the previous alternatives thermally treat contaminated waste on-site. Air emissions are a concern for thermal treatment of contaminated soil and sediment; however, very stringent air standards exist for controlling air emissions from treatment facilities.

Implementation of Alternative 8 is not expected to increase any concern for air emissions from the dredging activity compared to Alternative 7 because the same amount of contaminated sediments are being dredged for both alternatives. As with Alternative 7, the increased volume of contaminated sediments dredged may cause an increased concern regarding air quality because of the increased amount dredged compared with Alternatives 3, 4, and 6. However, the areas that will be dredged in Alternative 7 and 8 that were not dredged in previous alternatives contain lower amounts of DNAPL and lower concentrations of contaminated sediments; therefore, the likelihood of an increase in risk due to air quality exceedance is low.

Alternative 8 is not expected to cause unacceptable risks to the community because of the availability of the protective procedures and enforceable requirements. Safe levels of exposure to hazardous substances will be identified from existing regulations or risk-based calculations and included in Site operation plans. Continuous monitoring for COCs for all appropriate on-site activities, such as thermal treatment and excavation will be required and overseen by EPA personnel.

Impacts to “quality of life” are assumed to be a concern of the neighboring community.

Alternative 8 would require protective measures in addition to those identified under Alternative 7 based on the addition of a large upland excavation component and on-site thermal treatment facility.

7.10.5.2 Protection of Workers during Remedial Actions

For Alternative 8, potential exposure to hazardous substances to on-site workers may result from:

1) Inhalation and dermal exposure to vapors and contaminated sediment during dredging of 58,300 cy of potentially contaminated sediment;

2) Inhalation and dermal exposure to dust and vapors from excavation of 30,500 cy of DNAPL-impacted soil;

3) Inhalation and dermal exposure to dust or air emissions from handling and stockpiles for on-site thermal treatment, of 268,400 cy of potentially contaminated soils/sediment (88,800 cy of DNAPL-impacted soils/sediment);

4) Inhalation exposure to air emissions from on-site treatment of 268,400 cy of soils/sediment (88,800 cy of DNAPL-impacted soils/sediment); and

5) Inhalation of the same amount of dust generated as with all other alternatives, from the import and handling of clean or reactive material to cap/cover 29.4 acres of sediment.

Alternative 8 includes on-site treatment of contaminated media. The addition of thermal treatment will involve more handling and stockpiling of contaminated soils and sediment than previous alternatives; however, worker exposure can be mitigated by use of protective clothes/gear, engineering controls, and use of BMPS, as will be specified in the site safety plan and enforced by EPA. Construction Quality Assurance and Control Plans will be required. One focus of these plans is the prevention of worker exposure to contaminated media by direct contact or by the inhalation route.

On-site workers may also be exposed to increased amounts of dust caused by the excavation of DNAPL-impacted soil; however, the use of appropriate protective clothing, equipment, such as dust masks, and BMPs would be expected to mitigate potential risks associated with dust containing contaminated soil.

Similar measures to protect workers in Alternatives 6 and 7 will also be used with Alternative 8.

7.10.5.3 Environmental Impacts

The environmental impacts of Alternative 8 would be similar to Alternative 7. The use of on-site thermal treatment is not expected to pose an additional threat to the upland and aquatic environments. Air emissions and the potential increase of on-site handling of contaminated media can be controlled and managed so not to pose an adverse impact to the upland and aquatic environments.

7.10.5.4 Time until Remedial Action Objectives are Achieved

Remedial construction and establishment of institutional controls would be expected to be completed in about 4.5 years from initiation of remedial construction (not including remedial design), longer by a half of a year, than Alternative 7 (Figure 7-5). Not all RAOs would be achieved at the end of the construction period. The RAO to restore groundwater to its highest beneficial use by meeting MCLs and RBCs for drinking water would likely not be met within 100 years. However, MCLs are expected to be achieved for more COCs and over a larger area than Alternatives 2 through 7. The RAOs to reduce risks to humans and wildlife from consumption of fish/shellfish containing unacceptable levels of cPAHs is also not expected to be met immediately, although dredging, caps and ENR will provide for a “clean” sediment surface and will reduce aquatic biota concentrations. However, seafood and aquatic wildlife that have already accumulated cPAHs will not be safe to consume. All other RAOs involving reduction of risk via direct contact with contaminated media would be met at the end of the construction period.

7.10.5.5 Alternative 8 Rating with Respect to this Criterion

Alternative 8 is rated “low” with respect to short-term effectiveness. There is no change in the amount of potentially contaminated sediments to be dredged, but the amount of soil excavated in this alternative is over 10 times greater than in any previous alternative. As a result, neighboring communities maybe exposed to increased amounts of dust. On-site Air emissions associated with thermal treatment may also cause higher concern for worker exposure because of assumed increased handling and stockpiling of contaminated media. No unacceptable risk is expected to the community or workers because of the use of protective equipment and practices. Impacts to the aquatic environment are expected to be similar to Alternative 7.

7.10.6 *Implementability*

7.10.6.1 Technical Feasibility

Alternative 8 includes many of the same remedial technologies that have been incorporated into previous alternatives, with the exception of on-site thermal treatment. Alternative 8 incorporates on-site thermal treatment as the disposal method instead of off-site disposal as used in previous alternatives. Specifically, Alternative 8 consists of: 1) placing and repair/replacement of engineered sand caps and ENR cover; 2) dredging all DNAPL-impacted sediments (58,300 cy); 3) excavation of 30,500 cy of DNAPL-impacted soil along with 179,600 cy of non-DNAPL-impacted soil; and 4) on-site thermal treatment and backfill of 268,400 cy of contaminated soil and sediment (88,800 cy of DNAPL-impacted soils/sediment). An upland soil cap may not be required depending on the post-treatment sampling results of the thermally treated soil and sediment.

Alternative 8 incorporates relatively few construction elements. They are proven and commonly used technologies such as excavation, dredging and thermal treatment.

Excavation as conducted in Alternative 8, may present some implementability challenges just due to the size of the area to be excavated, in the dry, requiring extensive shoring and dewatering systems.

Thermal treatment can pose implementability concerns. Thermal treatment is technically feasible for treatment of organic compounds; however, thermal treatment requires extensive monitoring throughout its operation. On-site thermal treatment would require air emission controls and monitoring which are routine but require a series of test runs to adjust operational specifications to target for the COCs being treated at concentrations found in excavated media.

Thermal treatment is not successful with metals such as arsenic. An upland cap may be required if post-excavation sampling indicates exceedance of arsenic cleanup numbers. However, it is expected that arsenic in groundwater is largely present due to the high organic content of the soils such as DNAPL. Once the DNAPL is treated in soil, the arsenic concentrations may be reduced in the Shallow Aquifer more than modeling predicts.

Implementation of dredging in Alternative 8 is the same as in Alternative 7.

7.10.6.2 Administrative Feasibility

The administrative feasibility of the excavation and dredging components of Alternative 8 would be similar to other alternatives that use these technologies. The same monitoring and enforcement of air emissions are expected to not cause any significant administrative issues when compared to other alternatives. EPA will conduct the oversight and ensure that all substantive requirement are met eliminating much of the coordination with other agencies that would otherwise be required. Permits are not required for Superfund work but the substantive requirements of the permit programs must be met.

7.10.6.3 Availability of Services and Materials

The local availability of vendors and equipment for on-site thermal treatment may be limited, although thermal treatment is frequently used in the Northwest. Some specialized equipment and custom materials (e.g., sheet piles for excavation) would be required and are not expected to pose any significant or inordinate problems with lead time or transportation.

7.10.6.4 Alternative 8 Rating with Respect to this Criterion

Alternative 8 is rated "low" with respect to implementability. Use of on-site thermal treatment and extensive shoring and dewatering efforts are expected to pose technical challenges, such as continuous 24-hour operation of thermal equipment and dewatering pumps.

7.10.7 *Cost*

The estimated present worth cost of Alternative 8 is $146 million, including a projected $143 million for capital construction and $2.9 million (present worth) for OM&M.

7.11 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 PTWs 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 PTWs and to restore groundwater to its highest beneficial use (drinking water) to the maximum extent possible within the shortest timeframe.

7.11.1 *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:

7.11.1.1 RAOs for Protection of Human Health

- **HH1: Restore Groundwater to its Highest Beneficial Use by Meeting MCLs and RBC for Drinking Water.** Under Alternative 9, removal of all shallow contaminated soils and *in situ* treatment of all deep contaminated soils would provide a greater contribution to groundwater restoration. Overall, the groundwater model predicts that the aggregate plume volume would be reduced by 77 percent (after 100 years) as compared to Alternative 1 (No Action). It further predicts that remediation in Alternative 9 would restore groundwater to a large degree for benzene and benzo(a)pyrene, but to only a small degree for arsenic. The likelihood of complete restoration is uncertain due to a number of factors, including conservative modeling assumptions, the complexity of the source, the potential for leaching from the solidified mass, and the potential for leaving unidentified PTW behind (see Section 7.1.1.2). Human health risks would be addressed in the same manner as Alternative 2 until COCs are reduced to acceptable levels.

- **HH2: Reduce Recreational and Subsistence Ingestion of Seafood to Acceptable Levels.** Same as Alternative 8, except the extent of dredging goes beyond DNAPL areas to include the additional nearshore area where sediment is potentially contributing to MCL exceedances.

- **HH3: Reduce Recreational Beach Users Risk to Surface Sediment to Acceptable Levels.** Same as Alternative 8, except the extent of dredging goes beyond DNAPL areas to include the additional nearshore area where sediment is potentially contributing to MCL exceedances.

- **HH4: Reduce Recreational Beach Users Risk to Surface Water to Acceptable Levels.** Same as Alternative 8, except the extent of dredging goes beyond DNAPL areas to include the additional nearshore area where sediment is potentially contributing to MCL exceedances.

- **HH5: Reduce Risk to Indoor Vapors to Acceptable Levels.** Human health risk from inhalation of vapors, in enclosed spaces, from groundwater and/or soils contaminated with COCs would be mitigated by excavation or treatment of all contaminated soil.

- **HH6: Reduce Risk to Future Residents, Commercial Workers, and Excavation/Construction Workers from Soil to Acceptable Levels.** Human health risk from direct contact or incidental ingestion of COCs in soil would be mitigated by addressing all contaminated soil. A total of approximately 362,900 cy of DNAPL and soil would be treated with *in situ* solidification and approximately 342,500 cy of DNAPL and soil would be excavated and thermally treated on-site.

7.11.1.2 RAOs for Protection of the Environment

- **EP1: Reduce Risk to Aquatic Plants and Fish from Surface Water to Acceptable Levels.** Same as Alternative 8, except the extent of dredging goes beyond DNAPL areas to include the additional nearshore area where sediment is potentially contributing to MCL exceedances.

- **EP2: Reduce Risk to Terrestrial Plants, Birds, and Mammals from Contact with Soil to Acceptable Levels.** Same as Alternative 8.

- **EP3: Reduce Risk to Aquatic-dependent Birds, Mammals, and Benthic Community from Sediment to Acceptable Levels.** Same as Alternative 8, except the extent of dredging goes beyond DNAPL areas to include the additional nearshore area where sediment is potentially contributing to MCL exceedances.

7.11.1.3 Alternative 9 Rating with Respect to this Criterion

Alternative 9 satisfies the threshold criterion for Overall Protection of Human Health and the Environment. It is rated “low” for Short-Term Effectiveness (Section 7.11.5) because of the extensive upland and in-water construction activities occurring over a multi-year period; however, the alternative is rated “high” for Long-Term Effectiveness and Permanence (Section 7.11.3) because all PTWs and all contaminated soils are removed or treated. This will provide a greater contribution to groundwater restoration. To the extent required, protectiveness would be addressed via institutional controls and monitoring (Section 7.11.1.1).

7.11.2 *Compliance with ARARs*

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 plume. The extent to which MCLs would be achieved in this alternative is discussed below.

7.11.2.1 Compliance with the MCL ARAR

For Alternative 9, groundwater volume exceeding MCLs is predicted to decrease by 97 percent for benzene, 81 percent for benzo[a]pyrene, and 21 percent for arsenic relative to the No Action alternative 100 years after remedial construction completion (see Figure 7-1).

Refer to Section 7.1.1.2 and Appendix A for discussion of the groundwater modeling performed to predict progress toward achieving MCLs under each remedial alternative. 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. Since all identified PTW sources are addressed, this alternative has a greater effect on plume reduction than Alternatives 2 through 6, which leave known quantities of PTW behind.

7.11.2.2 Alternative 9 Rating with Respect to this Criterion

Alternative 9 would satisfy the threshold criterion for compliance with ARARs, with the exception of meeting MCLs everywhere in groundwater. If meeting MCLs in groundwater is deemed technically impracticable, EPA may consider granting a TI waiver. Groundwater modeling predicts that the MCLs for benzene, benzo(a)pyrene, and arsenic will not be met throughout the plume 100 years after remedial construction completion.

7.11.3 *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.

7.11.3.1 Magnitude of Residual Risks

In this subsection, residual risks associated with untreated waste/treatment residuals left on-site after remediation is presented in terms of the degree to which sources are remediated and the percent the plume is reduced.

For Alternative 9, none of the PTW is left in place as untreated waste. The dissolved-phase plumes exceeding the MCL ARARs and drinking water RBC are reduced (benzene at 97 percent, naphthalene at 86 percent, benzo[a]pyrene at 81 percent, and arsenic at 21 percent) from the Alternative 1 (No Action) baseline volume.

7.11.3.2 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. An upland cap may not be needed once all PTW and soil contributing to MCL exceedances has been addressed.

Engineered Sand Caps. Same as Alternatives 7 and 8, except some institutional controls may not be needed in perpetuity because of significant contaminant mass flux reduction because all PTW and sediment contributing to MCL exceedances is being addressed.

Reactive Residuals Cover. Same as Alternatives 7 and 8 except all PTW and sediment contributing to MCL exceedances is dredged, therefore the areal extent of reactive residual covers is extended.

ENR. Same as Alternatives 7 and 8.

Institutional Controls. Same as Alternatives 7 and 8 except some institutional controls may not be needed in perpetuity.

7.11.3.3 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 PTWs.

7.11.4 *Reduction of Toxicity, Mobility, or Volume through Treatment*

7.11.4.1 Treatment Processes Used and Materials Treated

Treatment processes used in Alternative 9 include a reactive residuals cover, upland DNAPL/soil *in situ* stabilization, and on-site thermal treatment. Refer to Table 7-2 and Figure 7-2 for estimated DNAPL treatment volumes. This alternative would treat all PTWs at the Site.

7.11.4.2 Amount of Hazardous Materials Destroyed or Treated

Under Alternative 9, approximately 104,400 gallons of DNAPL are treated by *in situ* stabilization; approximately 340,700 gallons of DNAPL are removed and thermally treated onsite. The amount of contaminated groundwater treated due to dewatering for excavation is unknown but is expected to be significant. The amount of contaminated groundwater treated by sorption onto reactive residual covers is unknown but expected to be minimal.

7.11.4.3 Degree of Expected Reductions in Toxicity, Mobility, and Volume

Alternative 9 would reduce the mobility of upland DNAPL, through *in situ* stabilization, by approximately 104,400 gallons or 23 percent of the total DNAPL on-site; however, the toxicity and volume of the treated material would not be reduced. The remaining 77 percent would be removed from the upland and aquatic environment via excavation and dredging and would be treated thermally on-site, which would reduce the toxicity, mobility, and volume of the DNAPL.

DNAPL/soil thermal treatment would reduce the volume and mobility of contaminated groundwater. Based on modeling, the mass reduction of benzene, naphthalene, benzo(a)pyrene, and arsenic plumes in groundwater would be 99, 100, 99, and 29 percent, respectively. The mass flux reduction for benzene, naphthalene, benzo(a)pyrene, and arsenic would be reduced by 100, 100, 100, and 62 percent, respectively (see Figure 7-3).

The degree of expected reductions in toxicity, mobility, and volume from the reactive residual covers is the same as for Alternative 8, except the area would be larger.

7.11.4.4 Degree to which Treatment is Irreversible

The vast majority of DNAPL in the solidified soil is expected to be treated and solidification treatment would be expected to be essentially irreversible. Thermal treatment is irreversible as well. Dissolved-phase COCs (benzene and volatile PAHs) that may leach from the solidified block can be assumed to not be irreversibly treated.

Treatment of DNAPL and dissolved constituents using reactive residual covers containing organoclay would be irreversible by sorption of organic matter to the treatment material. At present, the quantities that would be sorbed are unknown.

7.11.4.5 Type and Quantity of Residuals Remaining after Treatment

DNAPL-impacted soil and sediment thermally treated would remain onsite, and mixed with the soil/sediment matrix would comprise approximately 515,600 cy. DNAPL treated by ISS would remain onsite, and mixed with the soil matrix would comprise approximately 362,900 cy. The solidified matrix is not considered to be post-treatment residual or untreated waste; whereas contaminants that may leach and migrate out of the solidified matrix to groundwater would be considered untreated or residual post-treatment waste. The amount of residual dissolved-phase contamination that may leach is unknown.

7.11.4.6 Whether the Alternative Would Satisfy the Statutory Preference for Treatment as a Principal Element

Alternative 9 satisfies the statutory preference for treatment as a primary component of the alternative because the majority of the alternative includes treatment.

7.11.4.7 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 PTWs.

7.11.5 *Short-Term Effectiveness*

Alternative 9 has many of the same activities as Alternatives 7 and 8. Alternative 9 involves a combination of solidification and excavation and on-site thermal treatment of DNAPL-impacted and contaminated soil. All DNAPL-impacted sediment is dredged and treated on-site.

7.11.5.1 Protection of Community during Remedial Actions

For Alternative 9, potential exposure to hazardous substances to the neighboring community may result from:

1) Inhalation exposure to vapors from during dredging of 173,100 cy of potentially contaminated sediment;

2) Inhalation exposure to dust and vapors from excavation of 22,000 cy of DNAPL-impacted soil;

3) Inhalation exposure to dust or air emissions from handling and stockpiles for on-site thermal treatment, of 515,600 cy of potentially contaminated soils/sediment (80,300 cy of DNAPL-impacted soils/sediment);

4) Inhalation exposure to dust and vapors from *in situ* solidification of 8,400 cy of DNAPL-impacted soil; and

5) Inhalation of the same amount of dust generated as with all other alternatives, from the import and handling of clean or reactive material to cap/cover 29.4 acres of sediment.

Alternative 9 involves excavation of 22,000 cy of shallow DNAPL-impacted soils, as opposed to 30,500 cy of shallow and deep DNAPL-impacted soils with Alternative 8. Therefore, in Alternative 9, less DNAPL-impacted soil will be excavated than in Alternative 8, and a small amount of DNAPL-impacted soil will be solidified unlike in Alternative 8. Potential risk from dust generated from excavation is expected to about the same as Alternative 8.

Alternative 9 involves dredging of 173,100 cy of sediment; however approximately 58,300 cy represent DNAPL-impacted sediment; therefore, the amount of DNAPL-impacted sediment dredged for Alternative 9 is the same as for Alternatives 7 and 8. The additional contaminated sediment dredged as part of Alternative 9 is not impacted by DNAPL and is expected to have much lower contaminant concentrations.

Implementation of Alternative 9 will include on-site thermal treatment of less DNAPL-impacted soil and the same DNAPL-impacted sediment as Alternative 8, but the overall volume of thermally-treated soil and sediment is approximately 515,600 cy, as compared to 268,400 cy for Alternative 8. However, the additional soils and sediment treated would have much lower levels of contamination than the DNAPL-impacted soils and sediment, so there would be less concern for air emissions from the incremental thermal treatment exceeding safe levels.

Alternative 9 is not expected to cause unacceptable risks to the community because of the availability of the protective procedures and enforceable requirements. Safe levels of exposure to hazardous substances will be identified from existing regulations or risk-based calculations and included in Site operation plans. Continuous monitoring for COCs for all appropriate on-site activities, such as thermal treatment and excavation will be required and overseen by EPA personnel.

Impacts to “quality of life” are assumed to be a concern of the neighboring community.

Alternative 9 would require similar protective measures as those identified under Alternatives 7 and 8.

7.11.5.2 Protection of Workers during Remedial Actions

For Alternative 9, potential exposure to hazardous substances to on-site workers may result from:

1) Inhalation exposure to vapors from during dredging of 173,100 cy of potentially contaminated sediment;

2) Inhalation and dermal exposure to dust and vapors from excavation of 22,000 cy of DNAPL-impacted soil;

3) Inhalation and dermal exposure to dust or air emissions from handling and stockpiles for on-site thermal treatment, of 515,600 cy of potentially contaminated soils/sediment (80,300 cy of DNAPL-impacted soils/sediment);

4) Inhalation and dermal exposure to dust and vapors from *in situ* solidification of 8,400 cy of DNAPL-impacted soil; and

5) Inhalation of the same amount of dust generated as with all other alternatives, from the import and handling of clean or reactive material to cap/cover 29.4 acres of sediment.

Alternative 9 involves a combination of *in situ* solidification and excavation of the same DNAPL-impacted soils as Alternatives 7 and 8, with the majority being excavated. Potential risk to workers from dust and vapors generated from excavation is expected to about the same as Alternative 8. The use of appropriate protective clothing, equipment, such as dust masks, and BMPs would be expected to mitigate potential risks associated with dust containing contaminated soil.

The overall volume of thermally-treated soil and sediment is approximately 515,600 cy, as compared to 268,400 cy for Alternative 8. However, the additional soils and sediment treated would have much lower levels of contamination than the DNAPL-impacted soils and sediment treated in Alternative 8, so there would be less concern for air emissions exceeding safe levels. Worker exposure can be mitigated by use of protective clothes/gear, engineering controls, and use of BMPS, as will be specified in the site safety plan and enforced by EPA. Construction Quality Assurance and Control Plans will be required. One focus of these plans is the prevention of worker exposure to contaminated media by direct contact or by the inhalation route.

Similar measures to protect workers in Alternatives 7 and 8 will also be used with Alternative 9.

7.11.5.3 Environmental Impacts

The environmental impacts of Alternative 9 would be similar to Alternatives 7 and 8, except a larger portion of the nearshore aquatic habitat would be dredged as opposed to capped. The area of sediments either dredged and/or capped/covered is the same throughout all the alternatives; however, dredging can result in the generation of contaminated residuals. Alternative 9 is estimated to require a residuals cover over 8.0 acres, marginally greater than Alternatives 7 and 8 (6.4 acres). The use of a residuals cover, which will mitigate the impact of residuals, will less adversely impact the aquatic environment than RCM caps used in Alternatives 2 through 6.

Impacts to the environment from the uplands is expected to increase as compared to Alternative 8 because a larger area would be subject to excavation/solidification.

7.11.5.4 Time until Remedial Action Objectives are Achieved

Remedial construction and establishment of institutional controls would be expected to be completed in about 11 years from initiation of remedial construction, longer than

Alternative 8 by approximately 7 years (Figure 7-5). The RAO to restore groundwater to its highest beneficial use by meeting MCLs and RBCs for drinking water would likely not be met within 100 years. However, MCLs are expected to be achieved over a larger area than Alternatives 2 through 6. The RAOs to reduce risks to humans and wildlife from consumption of fish/shellfish containing unacceptable levels of cPAHs is also not expected to be met immediately, although dredging, caps and ENR will provide for a “clean” sediment surface and will reduce aquatic biota concentrations. However, seafood and aquatic wildlife that have already accumulated cPAHs will not be safe to consume. All other RAOs involving reduction of risk via direct contact with contaminated media would be met at the end of the construction period.

7.11.5.5 Alternative 9 Rating with Respect to this Criterion

Alternative 9 is rated “low” with respect to short-term effectiveness. A portion of the upland DNAPL-impacted soil will be treated with in situ solidification; but the majority of the DNAPL-impacted soil will be excavated, similar to Alternative 8. There is no change in the amount of DNAPL-impacted sediment to be dredged. However, much larger volumes of potentially contaminated soil and sediment will be handled, stockpiled and will undergo on-site thermal treatment, which may cause of higher concern for worker exposure. No unacceptable risk is expected to the community or workers because of the use of protective equipment and practices. Impacts to the aquatic environment are expected to be similar to Alternatives 7 and 8, except a larger portion of the nearshore aquatic environment is dredged and a smaller portion is subject to an engineered sand cap.

7.11.6 *Implementability*

7.11.6.1 Technical Feasibility

Alternative 9 only includes many of the same remedial technologies that have been incorporated into Alternatives 7 and 8, including on-site thermal treatment. Specifically, Alternative 9 consists of: 1) placing and repair/placement of engineered sand caps and ENR cover; 2) dredging 58,300 cy of DNAPL-impacted sediments along with 114,800 cy of potentially contaminated sediment; 3) solidification of 8,400 cy of DNAPL-impacted soils; 4) excavation of 22,000 cy of DNAPL-impacted soil along with 320,500 cy of potentially contaminated soil; and 5) on-site thermal treatment and backfill of 515,600 cy of partially contaminated soil and sediment. An upland soil cap may not be required depending on the post-treatment sampling results of the thermally treated soil and sediment to be used as backfill. Alternative 9 incorporates a number of construction elements; however, they are proven and commonly used technologies such as solidification, excavation, dredging, and thermal treatment. Excavation as conducted in Alternative 9, may present some implementability challenges just due to the size of the area to be excavated, in the dry, requiring extensive shoring and dewatering systems. Thermal treatment is also anticipated to pose technical feasibility challenges as explained in Alternative 8.

7.11.6.2 Administrative Feasibility

Same as Alternatives 7 and 8.

7.11.6.3 Availability of Services and Materials

Same as Alternatives 7 and 8, except for more extensive sheet piles for excavation shoring.

7.11.6.4 Alternative 9 Rating with Respect to this Criterion

Alternative 9 is rated “low” with respect to implementability because of the extensive amount of partially contaminated soil and sediment that will be thermally treated and dewatered on-site.

7.11.7 *Cost*

The estimated present worth cost of Alternative 9 is $280 million, including a projected $277 million for capital construction and $2.9 million (present worth) for OM&M.

7.12 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 PTWs 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. The purpose of Alternative 10 is to remove PTWs and to restore groundwater to the maximum extent possible within the shortest timeframe.

7.12.1 *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:

7.12.1.1 RAOs for Protection of Human Health

- **HH1: Restore Groundwater to its Highest Beneficial Use by Meeting MCLs and RBC for Drinking Water.** Under Alternative 10, removal of all contaminated soils would greatly contribute to groundwater restoration. Overall, the groundwater model predicts that the aggregate plume volume would be reduced by 93 percent (after 100 years) as compared to Alternative 1 (No Action). It further predicts that the MCLs for benzene and benzo(a)pyrene would be achieved throughout the aquifers after 100 years, but not the MCL for arsenic. The likelihood of complete restoration is uncertain due to a number of factors, including conservative modeling assumptions, the complexity of the source, and the potential for leaving unidentified PTW behind (see Section 7.1.1.2). Human health risks would be addressed in the same manner as Alternative 2 until COCs are reduced to acceptable levels.

- **HH2: Reduce Recreational and Subsistence Ingestion of Seafood to Acceptable Levels.** Same as Alternative 9.

- **HH3: Reduce Recreational Beach Users Risk to Surface Sediment to Acceptable Levels.** Same as Alternative 9.

- **HH4: Reduce Recreational Beach Users Risk to Surface Water to Acceptable Levels.** Same as Alternative 9.

- **HH5: Reduce Risk to Indoor Vapors to Acceptable Levels.** Human health risk from inhalation of vapors, in enclosed spaces, from groundwater and/or soils contaminated with COCs would be mitigated by excavation of all contaminated soil.

- **HH6: Reduce Risk to Future Residents, Commercial Workers, and Excavation/Construction Workers from Soil to Acceptable Levels.** Human health risk from direct contact or incidental ingestion of COCs in soil would be mitigated by addressing all contaminated soil. A total of approximately 705,400 cy of DNAPL and soil would be excavated and thermally treated on-site.

7.12.1.2 RAOs for Protection of the Environment

- **EP1: Reduce Risk to Aquatic Plants and Fish from Surface Water to Acceptable Levels.** Same as Alternative 9.

- **EP2: Reduce Risk to Terrestrial Plants, Birds, and Mammals from Contact with Soil to Acceptable Levels.** Same as Alternative 9.

- **EP3: Reduce Risk to Aquatic-dependent Birds, Mammals, and Benthic Community from Sediment to Acceptable Levels.** Same as Alternative 9.

7.12.1.3 Alternative 10 Rating with Respect to this Criterion

Alternative 10 satisfies the threshold criterion for Overall Protection of Human Health and the Environment. It is rated “low” for Short-Term Effectiveness (Section 7.12.5) because of the extensive upland and in-water construction activities occurring over a multi-year period; however, the alternative is rated “high” for Long-Term Effectiveness and Permanence (Section 7.12.3) because all PTWs and all contaminated soils are removed or treated. This will greatly contribute to groundwater restoration. To the extent required, protectiveness would be addressed via institutional controls and monitoring (Section 7.12.1.1).

7.12.2 *Compliance with ARARs*

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.

7.12.2.1 Compliance with MCL ARAR

For Alternative 10, groundwater volume exceeding MCLs is predicted to decrease by 100 percent for benzene and benzo[a]pyrene, and 65 percent for arsenic relative to the No Action alternative 100 years after remedial construction completion (see Figure 7-1).

Refer to Section 7.1.1.2 and Appendix A for discussion of the groundwater modeling performed to predict progress toward achieving MCLs under each remedial alternative. One hundred years after remedial construction completion for Alternative 10, the groundwater volume exceeding MCLs in the aggregate 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. This alternative has the greatest effect on plume reduction of all the alternatives due to the large quantity of contaminated material treated.

7.12.2.2 Alternative 10 Rating with Respect to this Criterion

Alternative 10 would satisfy the threshold criterion for compliance with ARARs, with the exception of meeting MCLs everywhere in groundwater. If meeting MCLs in groundwater is deemed technically impracticable, EPA may consider granting a TI waiver.". Groundwater modeling predicts that the MCL for arsenic will not be met throughout the plume 100 years after remedial construction completion.

7.12.3 *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.

7.12.3.1 Magnitude of Residual Risks

In this subsection, residual risks associated with untreated waste/treatment residuals left on-site after remediation is presented in terms of the degree to which sources are remediated and the percent the plume is reduced.

For Alternative 10, none of the PTW is left in place as untreated waste. The dissolved-phase plumes exceeding the MCL ARARs and drinking water RBC are reduced (benzene, naphthalene, and benzo[a]pyrene at 100 percent, and arsenic at 65 percent) from the Alternative 1 (No Action) baseline volume. Unacceptable risks remain in place should exposure occur, until COCs are returned to acceptable levels.

7.12.3.2 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. An upland cap may not be needed once all PTW and soil contributing to MCL exceedances has been addressed.

Engineered Sand Caps. Same as Alternative 9.

Reactive Residuals Cover. Same as Alternative 9.

ENR. Same as Alternative 9.

Institutional Controls. Same as Alternative 9, except some institutional controls (related to activities that may be restricted in *in situ* solidification areas) would not be needed.

7.12.3.3 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 PTWs.

7.12.4 *Reduction of Toxicity, Mobility, or Volume through Treatment*

7.12.4.1 Treatment Processes Used and Materials Treated

Treatment processes used in Alternative 10 include a reactive residuals cover, on-site thermal treatment, and treatment of extracted groundwater. This alternative would treat all PTWs at the Site. Refer to Table 7-2 and Figure 7-2 for estimated DNAPL treatment volumes.

7.12.4.2 Amount of Hazardous Materials Destroyed or Treated

Under Alternative 10, approximately 445,100 gallons of DNAPL are removed and thermally treated onsite. The intent of this alternative is to treat all PTWs at the Site, as well as soils contaminated with recalcitrant compounds. The amount of soil contaminants treated is unknown, but the mass in contaminated soil is expected to be negligible compared to the DNAPL.

Alternative 10 also includes a groundwater treatment system that 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. The amount of groundwater contaminants treated due to dewatering for excavation is unknown. The amount of groundwater contaminants treated during ongoing pump and treat operations is also unknown.

7.12.4.3 Degree of Expected Reductions in Toxicity, Mobility, and Volume

Alternative 10 would reduce the toxicity, mobility, and volume of DNAPL via on-site thermal treatment, which volatilizes the organic compounds.

DNAPL/soil thermal treatment and groundwater extraction would reduce the volume and mobility of contaminated groundwater. Groundwater treatment via GAC would also reduce the mobility of organic contaminants as they would be sorbed to the GAC; however, GAC has limited effectiveness for treating arsenic.

Based on modeling, the mass reduction of benzene and naphthalene would be 100 percent, for benzo(a)pyrene would be 99 percent, and for arsenic would be 53 percent. Mass flux for the organic COCs was projected to be negligible (essentially 100 percent reduction), whereas projected reduction in arsenic mass flux was approximately 86 percent relative to the No Action alternative (see Figure 7-3).

The degree of expected reductions in toxicity, mobility, and volume from the reactive residual covers is the same as for Alternative 9.

7.12.4.4 Degree to which Treatment is Irreversible

Organic contaminant thermal treatment is irreversible. Treatment of organic contaminants in groundwater using GAC would also be irreversible.

Treatment of DNAPL and dissolved constituents in the aquatic environment using reactive residual covers containing organoclay would be irreversible by sorption of organic matter to the treatment material. At present, the quantities that would be sorbed are unknown.

7.12.4.5 Type and Quantity of Residuals Remaining after Treatment

DNAPL-impacted soil and sediment thermally treated on-site would remain onsite, and mixed with the soil/sediment matrix would comprise approximately 878,500 cy.

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.

7.12.4.6 Whether the Alternative Would Satisfy the Statutory Preference for Treatment as a Principal Element

Alternative 10 satisfies the statutory preference for treatment as a primary component of the alternative because the majority of the alternative includes treatment.

7.12.4.7 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 PTWs.

7.12.5 *Short-Term Effectiveness*

Alternative 10 is similar to Alternative 9 except all upland contaminated soil is excavated and treated on-site, whereas for Alternative 9, deeper DNAPL-impacted and contaminated soils are treated with in-situ stabilization. The offshore remedy components for Alternative 10 are identical to Alternative 9.

7.12.5.1 Protection of Community during Remedial Actions

For Alternative 10, potential exposure to hazardous substances to the neighboring community may result from:

1) Inhalation exposure to vapors from during dredging of 173,100 cy of potentially contaminated sediment;

2) Inhalation exposure to dust and vapors from excavation of 30,500 cy of DNAPL-impacted soil;

3) Inhalation exposure to dust or air emissions from handling and stockpiles for on-site thermal treatment, of 878,500 cy of potentially contaminated soils/sediment (88,800 cy of DNAPL-impacted soils/sediment); and

4) Inhalation of vapors or air emissions from an onsite groundwater pumping and treatment system; and

5) Inhalation of the same amount of dust generated as with all other alternatives, from the import and handling of clean or reactive material to cap/cover 29.4 acres of sediment.

Alternative 10 involves excavation 30,500 cy of DNAPL-impacted soils as opposed to 22,000 cy of shallow DNAPL-impacted soils with Alternative 9. Therefore, in Alternative 10, more DNAPL-impacted soil would be excavated in Alternative 9 (and no

DNAPL-impacted soil will be solidified as in Alternative 9). Potential risk from dust generated from excavation is expected to be about the same as Alternative 9.

Alternative 10 involves the same dredging of 173,100 cy of sediment (including 58,300 cy of DNAPL-impacted sediment) as Alternative 9. Therefore, potential exposures to vapors during dredging are identical to Alternative 9.

Alternative 10 also includes construction and operation of a groundwater pumping and treatment system. These systems are commonly used, and are not expected to pose any risks to the community.

Implementation of Alternative 10 will include on-site thermal treatment of more DNAPL-impacted soils and the same DNAPL-impacted sediment as Alternative 9, but the overall volume of thermally-treated soil and sediment is approximately 878,500 cy, as compared to 515,600 cy for Alternative 9. However, the additional soils and sediment treated would have much lower levels of contamination than the DNAPL-impacted soils and sediment, so there would be less concern for air emissions from the incremental thermal treatment exceeding safe levels.

Alternative 10 is not expected to cause unacceptable risks to the community because of the availability of the protective procedures and enforceable requirements. Safe levels of exposure to hazardous substances will be identified from existing regulations or risk-based calculations and included in Site operation plans. Continuous monitoring for COCs for all appropriate on-site activities, such as thermal treatment and excavation will be required and overseen by EPA personnel.

Impacts to “quality of life” are assumed to be a concern of the neighboring community.

Alternative 10 would require similar protective measures as those identified under Alternatives 7 through 9.

7.12.5.2 Protection of Workers during Remedial Actions

For Alternative 10, potential exposure to hazardous substances to on-site workers may result from:

1) Inhalation exposure to vapors from during dredging of 173,100 cy of potentially contaminated sediment;
2) Inhalation and dermal exposure to dust and vapors from excavation of 30,500 cy of DNAPL-impacted soil;
3) Inhalation and dermal exposure to dust or air emissions from handling and stockpiles for on-site thermal treatment, of 878,500 cy of potentially contaminated soils/sediment (88,800 cy of DNAPL-impacted soils/sediment);
4) Inhalation of vapors or air emissions from an onsite groundwater pumping and treatment system; and
5) Inhalation of the same amount of dust generated as with all other alternatives, from the import and handling of clean or reactive material to cap/cover 29.4 acres of sediment.

Alternative 10 involves excavation and dredging of the same DNAPL-impacted soils and sediment as Alternative 8. Potential risk to workers from dust and vapors generated from excavation is expected to about the same as Alternatives 8 and 9. The use of appropriate protective clothing, equipment, such as dust masks, and BMPs would be expected to mitigate potential risks associated with dust containing contaminated soil.

Alternative 10 also includes construction and operation of a groundwater pumping and treatment system. These systems are commonly used, and are not expected to pose any unacceptable risks to the workers that could not be mitigated by protective gear and protocols.

The overall volume of thermally-treated soil and sediment is approximately 878,500 cy, as compared to 515,600 cy for Alternative 9. However, the additional soils and sediment treated would have much lower levels of contamination than the DNAPL-impacted soils and sediment, so there would be less concern for air emissions from the incremental thermal treatment exceeding safe levels. Worker exposure can be mitigated by use of protective clothes/gear, engineering controls, and use of BMPS, as will be specified in the site safety plan and enforced by EPA. Construction Quality Assurance and Control Plans will be required. One focus of these plans is the prevention of worker exposure to contaminated media by direct contact or by the inhalation route.

Similar measures to protect workers in Alternatives 7 through 9 will also be used with Alternative 10.

7.12.5.3 Environmental Impacts

The environmental impacts of Alternative 10 would similar to Alternative 9.

7.12.5.4 Time until Remedial Action Objectives are Achieved

Remedial construction and establishment of institutional controls would be expected to be completed in about 12 to 13 years from initiation of remedial construction, two years longer than Alternative 9 (Figure 7-5). Not all RAOs would be achieved at the end of the construction period. The RAO to restore groundwater to its highest beneficial use by meeting MCLs and RBCs for drinking water would likely not be met within 100 years. However, MCLs are expected to be achieved for more COCs and over a larger area than Alternatives 2 through 9. The RAOs to reduce risks to humans and wildlife from consumption of fish/shellfish containing unacceptable levels of cPAHs is also not expected to be met immediately, although dredging, caps and ENR will provide for a “clean” sediment surface and will reduce aquatic biota concentrations. However, seafood and aquatic wildlife that have already accumulated cPAHs will not be safe to consume. All other RAOs involving reduction of risk via direct contact with contaminated media would be met at the end of the construction period.

7.12.5.5 Alternative 10 Rating with Respect to this Criterion

Alternative 10 is rated “low” with respect to short-term effectiveness. There is no change in the amount of DNAPL-impacted soil and sediment to be excavated or dredged as compared with Alternative 8; however, much larger volumes of potentially contaminated soil and sediment will be handled and stockpiled and will undergo on-site thermal treatment, which may cause higher concern for worker exposure. No unacceptable risk is expected to the community or workers because of the use of protective equipment and practices. Impacts to the aquatic environment will be similar to Alternative 9.

7.12.6 *Implementability*

7.12.6.1 Technical Feasibility

Alternative 10 includes the same remedial technologies that have been incorporated into Alternatives 9, with the exception of solidification of DNAPL-impacted soil. Specifically, Alternative 10 consists of: 1) placing and repair/placement of engineered sand caps and ENR cover; 2) dredging of 58,300 cy of DNAPL-impacted sediments along with 114,800 cy of potentially contaminated sediment; 3) excavation of 30,500 cy of DNAPL-impacted soil along with 674,900 cy of potentially contaminated soil; and 4) on-site thermal treatment and backfill of 878,500 cy of partially contaminated soil and sediment. An upland soil cap may not be required depending on the post-treatment sampling results of the thermally treated soil and sediment.

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.

Technical feasibility concerns for Alternative 10 are the same as Alternative 9 with the exception of on-site solidification.

7.12.6.2 Administrative Feasibility

Same as in Alternative 9.

7.12.6.3 Availability of Services and Materials

Same as Alternative 9.

7.12.6.4 Alternative 10 Rating with Respect to this Criterion

Alternative 10 is rated “low” with respect to implementability because of the extensive amount of partially contaminated soil and sediment that will be thermally treated and dewatered on-site and the transport of custom made sheet pile to be used as shoring for excavation.

7.12.7 *Cost*

The estimated present worth cost of Alternative 10 is $425 million, including a projected $397 million for capital construction and $28 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.

Consistent with 40 CFR300.430, each alternative is first evaluated using the threshold criteria of:

- Overall Protectiveness of Human Health and the Environment; and
- Compliance with ARARs (defined in Section 7.1.1).

The alternatives that meet the threshold criteria are evaluated further using the NCP balancing criteria of:

- 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 all of the balancing criteria except cost, each alternative is evaluated using a qualitative scale to rate the relative degree (i.e., low, moderate, high) to which the alternative meets the criteria requirements. For cost, the evaluation is based on estimated capital and long-term (OM&M) costs[67]. A summary of the comparative rating of the alternatives is provided in Table 8-1.

8.1 Threshold Criteria Comparison

This section presents a comparative analysis of the two NCP threshold criteria: Overall Protection of Human Health and the Environment (Section 8.1.1) and Compliance with ARARs (Section 8.1.2).

8.1.1 *Overall Protection of Human Health and the Environment*

This threshold 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 comply with ARARs. This threshold criterion also evaluates whether the alternative achieves the RAOs for protection of human health and the environment.

[67] 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.

A comparison of the alternatives is summarized for RAOs pertaining to protection of human health (Section 8.1.1.1) and protection of the environment (Section 8.1.1.2), followed by a comparison relative to overall protection of human health and the environment (Section 8.1.1.3).

An alternative's **protectiveness** is described by the adequacy of how the risks associated with the exposure pathways are eliminated, reduced, or controlled through treatment, engineering, or institutional controls. However, the **Overall Protection of Human Health and the Environment** threshold criterion draws on the assessments conducted under other evaluation criteria, especially long-term effectiveness and permanence and short-term effectiveness (EPA, 1988). As described in Section 7.1.1.1, the Overall Protection of Human Health and the Environment criterion was rated as "No," or "Yes," based on consideration of whether:

1) All exposure pathways are mitigated (i.e., the alternative is protective);
2) The alternative provides long-term effectiveness and permanence; and
3) The alternative does not pose a high short-term risk.

8.1.1.1 RAOs for Protection of Human Health

Alternative 1 does not achieve any of the RAOs for protection of human health. Alternatives 2 through 6 will achieve the RAOs for human health that focus on protection of beach users, subsistence fishers, upland residents, commercial workers, and construction workers. However, the RAO to restore groundwater to its highest beneficial use (drinking water) by meeting MCLs cannot be achieved by Alternatives 2 through 6 because PTWs that cause the groundwater contamination remain in place to varying degrees. Alternatives 7 through 10, which treat or remove all known PTWs that are sources to groundwater contamination[68], have a greater effect on plume reduction than other alternatives; however, groundwater modeling predicts that the RAO to restore groundwater to its highest beneficial use (drinking water) by meeting MCLs would not be achieved for all COCs by Alternatives 7 through 10. Groundwater modeling predicts that groundwater concentrations will meet MCLs for benzene within 100 years under Alternatives 8 and 10 and will meet MCLs for benzo[a]pyrene under Alternative 10. For all alternatives, institutional controls that specifically address use of drinking water may be required in perpetuity.

There would be a heavier reliance on institutional controls to restrict activities that may compromise the integrity of the soil cap for Alternatives 2 through 6; whereas a thinner or smaller soil cap may be acceptable for Alternatives 7 through 10, in which all PTWs are removed or treated. Alternatives 2 through 10 would all initially rely on institutional controls to control exposure to contaminated sediment and surface water by restricting activities that could cause damage to sediment caps designed to mitigate the release of contamination into surface water. However, Alternatives 7 through 10 would rely less on

[68] All "known PTWs" refers to PTWs identified during site investigations supporting the FS. It is anticipated that the lateral and vertical extent of PTWs in both the upland and aquatic areas of the Site would be based on a field performance standard that would be developed during remedial design. It is also anticipated that small volumes and masses of DNAPL residuals could be inadvertently missed during remedial implementation.

caps, which may not be required in perpetuity, because all known PTWs are removed from the aquatic environment.

8.1.1.2 RAOs for Protection of the Environment

Alternative 1 does not achieve any of the RAOs for protection of the environment. Alternatives 2 through 10 will achieve the RAOs for the environment that focus on protection of upland wildlife and plants, as well as aquatic benthos, fish, plants, and aquatic-dependent wildlife. There would be a heavier reliance on institutional controls to restrict activities that may compromise the integrity of the soil cap for Alternatives 2 through 6; whereas a thinner or smaller soil cap may be acceptable for Alternatives 7 through 10, in which all known PTWs are removed or treated. Alternatives 2 through 10 would all rely on institutional controls to control exposure to contaminated sediment and surface water by restricting activities that could cause damage to sediments caps designed to mitigate the release of contamination into surface water. However, there would be a lesser reliance on caps in perpetuity for Alternatives 7 through 10 because all known PTWs are removed from the aquatic environment.

8.1.1.3 Overall Protection of Human Health and the Environment Summary

Alternative 1 would not meet this threshold criterion. Alternatives 2 through 10 would meet this threshold criterion. Alternatives 2 through 6 leave varying amounts of known and accessible PTWs in place and rely heavily on engineering and institutional controls to be protective. Alternatives 7 through 10 would also require engineering and institutional controls to be protective, but they may be more limited than those associated with Alternatives 2 through 6.

8.1.2 *Compliance with ARARs*

This threshold 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. The degree to which MCLs would be achieved varies based on the PTWs addressed for each alternative.

As described in Section 7.1.1.2, the Compliance with ARARs criterion was rated as “No” or “Yes”, with justification as appropriate.

8.1.2.1 Compliance with the MCL ARAR

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. It was predicted to achieve its MCL after 28 years for Alternative 8, and after 14 years for Alternative 10.
- Benzo(a)pyrene was predicted to exceed its MCL in groundwater after 100 years for all alternatives except for Alternative 10. For Alternative 10, the groundwater

model predicted that the benzo(a)pyrene MCL would be achieved when construction is complete.

- Arsenic was predicted to exceed its MCL in groundwater 100 years following implementation of all alternatives.

Alternative 2 slightly reduced the estimated volume of groundwater exceeding MCLs after 100 years (by 13 percent for the aggregate plume). 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 (ranging from 33 to 50 percent aggregate reduction) and more greatly reduced by implementing Alternatives 7 through 10 (ranging from 79 to 93 percent aggregate reduction).

8.1.2.2 Compliance with ARARs Summary

Alternative 1 does not satisfy the threshold criterion for compliance with ARARs. Alternatives 2 through 10 would satisfy the threshold criterion for compliance with ARARs, with the exception of meeting MCLs everywhere in groundwater. If meeting MCLs in groundwater is deemed technically impracticable, EPA may consider granting a TI waiver.

8.1.3 *Threshold Criteria Summary*

Overall protection of human health and the environment and compliance with ARARs serve as threshold determinations in that they must be met by any alternative for it to be eligible for selection (EPA, 1988).

As described above, Alternative 1 does not meet either threshold criterion and, therefore, is not carried forward in the Balancing Criteria comparison. Alternatives 2 through 10 satisfy the overall protection of human health and the environment criterion, and would meet all ARARs if a TI waiver is granted for COCs in groundwater that do not achieve MCLs. Therefore, Alternatives 2 through 10 are carried forward in the Balancing Criteria comparison. Section 7 includes the detailed analysis used to evaluate these threshold criteria that drew on evaluation of the balancing criteria and interpretation of groundwater modeling results.

8.2 Balancing Criteria Comparison

This section includes a comparison of Alternatives 2 through 10 with respect to the five balancing criteria (long-term effectiveness and permanence; reduction of toxicity, mobility, and volume through treatment; short-term effectiveness; implementability; and cost).

8.2.1 *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 untreated waste and treatment residuals left onsite after remediation. It is presented in terms of the degree to which PTW sources are remediated and the extent to which (percent reduction relative to Alternative 1) the contaminated groundwater plume is reduced. It also considers to what degree DNAPL areas that are targeted based on location, mobility potential, or depth are treated or removed. The adequacy and reliability of controls were evaluated by examining the complexity and efficacy of requirements for long-term operation, maintenance and monitoring of the alternative. The comparison of alternatives on these general criteria is described below.

8.2.1.1 Magnitude of Residual Risk

Assessment of 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 (Table 7-2 and Figure 7-2) and the areas of higher-risk DNAPL removed or treated. A secondary factor that was considered is the effectiveness of groundwater treatment among the alternatives based on the predicted reduction in contaminant plume volumes 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 is contained in the PTWs.

The primary differences in which Alternatives 2 through 10 would remove or treat PTWs at the Site are summarized as follows:

- Alternative 2 would not remove or treat DNAPL.
- Alternative 3 would remove or treat 12 percent of the DNAPL volume, including deeper DNAPL (RR DNAPL Area and the eastern portion of the MC DNAPL Area).
- Alternative 4 would remove or treat 22 percent of DNAPL volume, including targeted DNAPL areas based on proximity to Lake Washington and/or DNAPL mobilization potential (TD, QP-U, and QP-S DNAPL areas).
- Alternative 4a would remove or treat 16 percent of DNAPL volume, including deeper DNAPL (RR DNAPL Area and the eastern portion of the MC DNAPL Area) and two of the three DNAPL areas targeted based on proximity to Lake Washington and mobilization potential (TD and QP-U DNAPL Areas).
- Alternatives 5 and 6 would remove or treat progressively greater volumes of DNAPL (62 percent and 91 percent, respectively), including deeper DNAPL (RR DNAPL Area and the eastern portion of the MC DNAPL Area) and DNAPL areas based on proximity to Lake Washington and mobilization potential (TD, QP-S, and QP-U DNAPL Areas).
- Alternatives 7 through 10 would remove or treat all known DNAPL. Alternatives 9 and 10 would further remove or treat additional contaminated Shallow Aquifer materials (outside known DNAPL areas) in the upland and contaminated sediment in the nearshore area.

The primary differences in which Alternatives 2 through 10 would treat groundwater at the Site are summarized as follows:

- Alternative 2 would not substantially reduce the size of the groundwater plume.

- Alternatives 3, 4a, 5, and 6 would provide moderate reductions in the size of the groundwater benzene and naphthalene plume. Alternatives 3, 4a, 5, and 6 are predicted to reduce the benzene plume by 37, 37, 40, and 56 percent, respectively, 100 years after implementation of the alternative. These alternatives are also predicted to reduce the naphthalene plume by 12, 12, 29, and 41 percent, respectively. Alternatives 5 and 6 provide slightly greater reduction in the size of these plumes because more upland PTWs are treated under these alternatives.

- Alternative 4 provides somewhat smaller reductions in contaminant plume than Alternatives 3, 4a, 5, and 6 because deep DNAPL in the eastern portion of the Site, which is predicted to contribute most greatly to the groundwater plume in the Deeper Aquifer, is not treated under this alternative. Plume reductions under Alternative 4 are 20 and 12 percent for benzene and naphthalene, respectively.

- Alternatives 7 through 10 would substantially reduce the volume of organic COCs in groundwater. Alternatives 7 and 9 are predicted to reduce benzene by 97 percent; and naphthalene by 89 and 86 percent, respectively. Alternatives 8 and 10 would each reduce benzene and naphthalene by 100 percent. Alternative 10 would also reduce the benzo(a)pyrene plume by 100 percent.

- In regards to arsenic, Alternatives 2 through 6 are predicted to result in a relatively small plume reduction, ranging from 1 to 8 percent. Alternatives 7 through 9 are also predicted to result in a relatively modest plume reduction, ranging from 11 to 21 percent. Alternative 10 would reduce the arsenic plume volume by 65 percent primarily because this alternative includes removal of the Shallow Aquifer materials with arsenic exceeding MCLs; the remaining 35 percent represents arsenic in the Deep Aquifer. EPA believes that if the PTW source is removed, the reducing conditions would be moderated and arsenic plume attenuation would be greater than predicted by the groundwater model.

For all alternatives, unacceptable risks would remain in place should exposure occur, until COCs are returned to acceptable levels.

In summary, Alternatives 2 and 3 leave the majority of PTWs, including higher-risk PTWs, in place. Alternatives 4 through 6 treat or remove most or all of the deep DNAPL and DNAPL targeted based on proximity to Lake Washington and/or mobilization potential. Alternatives 7 through 10 would treat all known PTWs and would result in large reductions in organic COC plumes. Although Alternatives 9 and 10 treat or remove all contaminated materials, the effect on organic COC plume reduction would not be significantly greater than that of Alternatives 7 and 8. The groundwater model predicts that Alternative 10 provides a more substantial decrease in the volume of the arsenic plume as compared to Alternatives 7 through 9; however, EPA believes that arsenic would attenuate significantly in all four alternatives following PTW removal, though there is a higher degree of uncertainty around the fate and transport of arsenic (versus the organic COCs) following PTW removal.

8.2.1.2 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, and long-term monitoring. Differences in the reliability of controls include the following:

- Controls in upland areas are generally considered much more reliable than controls in aquatic areas because access and use of upland areas could be more easily controlled and controls in upland areas could be more easily enforced, and upland areas would be easier to access for monitoring and maintenance.
- Controls that rely on treatment (e.g., reactive sediment covers) to be effective are considered to have a greater risk of failure than controls that rely on providing a physical barrier, because 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. *In situ* reactive treatment technologies for sediment are fairly new, with limited long-term (i.e., past 10 years) field experience; therefore, there is more uncertainty regarding maintenance and replacement frequency, and how the maintenance/replacement impacts the environment, particularly the shallow aquatic environment (e.g., habitat disturbance, release of COCs).
- Technologies that rely on long-term monitoring to ensure the viability of controls (e.g., *in situ* stabilization, soil caps, reactive sediment covers, engineered sand caps, ENR) are considered to have a greater risk of failure than technologies that do not require long-term monitoring. Monitoring frequency and techniques can greatly increase the cost of long-term care of remedies and are absolutely necessary to ensure protectiveness. A balance needs to be found between monitoring magnitude and frequency and assurance of protectiveness; if controls fail, the degree of monitoring would affect the significance of the magnitude and/or duration of potential exposure.

Alternatives 2 through 10 would include similar types of engineering controls, including an upland cap, an engineered sand cap, and ENR placed over generally similar areas. The engineered sand cap area would be less for Alternatives 9 and 10 than Alternatives 2 through 8 due to dredging of contaminated sediments outside DNAPL areas. In dredging areas, the engineered sand cap would be eliminated; however, a reactive residuals cover would be placed following dredging. A thinner or smaller upland cap may be acceptable for Alternatives 7 through 10, which treat or remove all known PTWs.

Alternatives 2 through 6 rely more heavily on reactive sediment covers (e.g., RCM and/or amended sand caps). Alternatives 2 and 3 include RCM or amended sand caps over all offshore DNAPL areas. Alternatives 4, 5, and 6 include removal of sediment DNAPL in the TD and QP-U DNAPL Areas. RCM caps are placed over other DNAPL areas. Alternative 4a includes removal of sediment DNAPL in the TD DNAPL Area and an amended sand cap over the QP-U DNAPL Area. RCM caps are placed over other DNAPL areas.

All alternatives will require institutional controls. Alternatives 2 through 6 will require institutional controls in perpetuity. Alternatives 7 through 10 rely less on institutional controls because all known PTWs are removed or treated, and some institutional controls may not be needed in perpetuity. Alternative 10 requires the fewest institutional controls because all known PTWs and associated contaminated shallow aquifer materials would be removed.

8.2.1.3 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.

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

- Alternatives 2 and 3 would not substantially reduce the volume of contaminated materials. In particular, these alternatives would rely on passive controls with a risk of failure to address higher-risk PTWs. Therefore, these alternatives are rated low for this criterion.
- Alternatives 4, 4a, 5, and 6 would achieve a significantly larger reduction in the volume of contamination compared to Alternatives 2 and 3, and would also improve effectiveness by treating or removing deep DNAPL and all or most of the DNAPL areas targeted due to their proximity to Lake Washington and/or mobilization potential. However, a significant volume of PTWs and contaminated groundwater would remain on site. Therefore, 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 known PTWs. Alternatives 9 and 10 remove or treat additional contaminated soil and sediment, but the vast majority of the contaminant mass is present in the PTWs. With the exception of a smaller residual arsenic plume for Alternative 10, all of these alternatives provide for similar and substantial reductions in the volume of contaminated groundwater. These alternatives are all rated high for this criterion.

8.2.2 *Reduction of Toxicity, Mobility, or Volume through Treatment*

This NCP balancing criterion evaluates the degree to which each remedial alternative reduces toxicity, mobility, or volume through 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 PTWs, primarily using the estimated total volume of DNAPL treated as a metric.

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. Groundwater treatment metrics were considered secondary to the PTW treatment metric because the majority of contaminant mass at the Site, and the most toxic materials, are contained in the PTWs.

8.2.2.1 Treatment Processes Used and Materials Treated

The treatment processes used are as follows:

- Alternatives 3, 4a, 5, 6, 7 and 9 include upland DNAPL/soil *in situ* solidification, which immobilizes COCs;
- Alternatives 8, 9, and 10 include on-site *ex situ* thermal treatment of PTW soils and sediments, which volatilizes and destroys organic VOCs and some SVOCs;
- Alternatives 3, 4, and 4a include DNAPL collections trenches to collect mobile DNAPL for off-site incineration, which destroys organic COCs;
- Alternatives 3 through 6 include PRBs to treat contaminated groundwater, which immobilizes COCs through sorption;
- Alternatives 2 through 6 include RCM and/or amended sand caps in areas of the aquatic environment where PTWs are left in place, which immobilize organic COCs through sorption; and
- Alternatives 4 through 10 all include residuals covers in areas of the aquatic environment that have been dredged, which immobilize residual organic COCs through sorption.

8.2.2.2 Amount of Hazardous Materials Destroyed or Treated

The majority of hazardous material destruction or treatment would be accomplished by *in situ* solidification or on-site *ex situ* thermal treatment. The amount of DNAPL collected and treated in collection trenches (in Alternatives 3, 4, and 4a) is approximately 1,300 gallons, or less than 0.3 percent of the total DNAPL volume. The amount of DNAPL that may be sorbed onto the PRB, RCM and amended sand caps, and residual covers is unknown but expected to be minimal. The amount of hazardous materials destroyed or treated by each alternative is summarized as follows:

- For Alternatives 2 and 4, a negligible amount of DNAPL would be treated.
- For Alternative 4a, approximately 28,300 gallons of DNAPL would be treated by *in situ* solidification. Progressively larger volumes of DNAPL would be treated by *in situ* solidification under Alternative 3 (44,700 gallons), Alternative 5 (210,800 gallons), Alternative 6 (311,000 gallons), and Alternative 7 (377,500 gallons).
- For Alternative 9, all of the DNAPL (445,100 gallons) would be treated, approximately 104,400 gallons by *in situ* solidification and 340,700 gallons by on-site thermal treatment.
- For Alternatives 8 and 10, all of the DNAPL (445,100 gallons) would be subject to on-site thermal treatment.

Alternatives 9 and 10 would also treat contaminated soil that does not contain PTWs, but the mass of contaminants in the soil is expected to be negligible compared to PTWs. It is likely that some residual contamination would remain, given the complexity of the Site and the volumes of treatment for all of these alternatives. Alternatives 9 and 10 would rank slightly higher than Alternatives 7 and 8 because of the additional contaminants that may be treated beyond the known PTW and because a larger treatment area would increase the likelihood that all PTW is found.

8.2.2.3 Degree of Expected Reductions in Toxicity, Mobility, and Volume

Alternatives 3, 4a, 5, 6, and 7 would reduce the mobility of upland DNAPL through *in situ* solidification. Alternative 9 would also reduce the mobility of deeper DNAPL (generally deeper than 15 feet) through *in situ* solidification, and would reduce the toxicity, mobility, and volume of shallow DNAPL via on-site thermal treatment. Alternatives 8 and 10 would reduce the toxicity, mobility, and volume of all known DNAPL via on-site thermal treatment. The effectiveness of thermal treatment on arsenic is unknown; however, arsenic would be immobilized with *in situ* solidification. This FS assumes that thermal treatment would remove DNAPL, but the treated soil may still exceed PRGs.

The estimated percent reductions in groundwater contaminant mass and mass flux for Alternatives 2 through 10 are as follows:

Percent Contaminant Mass Reduction in Groundwater				
Alternative	**Benzene**	**Naphthalene**	**Benzo(a)pyrene**	**Arsenic**
2	10	8	1	<1
3	26	30	16	1
4	40	20	10	<0
4a	26	30	16	1
5	51	52	49	5
6	69	74	75	12
7	100	100	98	24
8	100	100	92	13
9	99	100	99	29
10	100	100	99	53

Percent Contaminant Mass Flux Reduction in Groundwater				
Alternative	**Benzene**	**Naphthalene**	**Benzo(a)pyrene**	**Arsenic**
2	27	31	27	5
3	57	58	56	3
4	74	61	83	<0
4a	80	81	89	5
5	80	81	89	5
6	86	89	94	5
7	100	100	99	6
8	100	100	99	6
9	100	100	100	62
10	100	100	100	86

Alternative 2 provides little reduction in contaminant toxicity, mobility, and volume. Alternatives 3, 4, and 4a provide improved reductions in organic contaminant toxicity, mobility, and volume through a combination of targeted PTW treatment/removal and shoreline PRBs. Alternatives 5 and 6 treat a greater volume of PTW compared to the earlier alternatives, which results in additional reductions in contaminant mass and mass flux.

Alternatives 7 through 10 would all be highly effective for treating organics. The groundwater model predicts more modest reductions for arsenic for all alternatives. Alternatives 9 and 10 would be more effective in that they would address areas with MCL exceedances for arsenic that are outside of the footprint of known PTWs.

8.2.2.4 Degree to which Treatment is Irreversible

When evaluating the degree to which treatment is irreversible, alternatives 8, 9, and 10, which employ thermal treatment to varying degrees, rank higher than Alternatives 3, 4a, 5, 6, and 7, which rely primarily on *in situ* stabilization for treatment. Thermal treatment is irreversible. While *in situ* solidification is also expected to be irreversible, dissolved-phase COCs that may leach from the solidified block can be assumed not to be irreversibly treated.

8.2.2.5 Type and Quantity of Residuals Remaining after Treatment

For Alternatives 3, 4a, 5, 6, 7, and 9, the solidified matrix is not considered to be post-treatment residual or untreated waste; whereas contaminants that may leach and migrate out of the solidified matrix to groundwater would be considered untreated or residual post-treatment waste. The amount of residual dissolved-phase contamination that may leach is unknown. For Alternatives 8, 9, and 10, thermally-treated DNAPL-impacted soil and sediment would remain onsite, and mixed with the soil/sediment matrix would comprise between approximately 268,400 cy for Alternative 8, 515,600 cy for Alternative 9, and 878,500 cy for Alternative 10. Residual contaminant concentrations in soil would be expected to be low but may exceed PRGs depending on the effectiveness of treatment. Alternative 9, which includes *in situ* stabilization of deeper Shallow Aquifer materials, may also contribute an unknown amount of residual dissolved-phase contamination.

8.2.2.6 Whether the Alternative Would Satisfy the Statutory Preference for Treatment as a Principal Element.

Alternatives 2 through 5 would not satisfy the statutory preference for treatment as a principal element, as the majority of the contaminant mass is not treated in these alternatives. Alternatives 6 through 10 all satisfy the statutory preference for treatment as a principal element, as the majority of the contaminant mass is treated in these alternatives.

8.2.2.7 Overall Reduction of Toxicity, Mobility, or Volume through Treatment Ranking

The alternatives employ two primary treatment methods for PTW:

- *In situ* solidification of upland PTWs (Alternatives 3, 4a, 5, 6, 7, and 9); and
- On-site thermal treatment of PTWs (Alternatives 8, 9, and 10).

For the purposes of this FS, treatment by thermal destruction technologies (incineration/ thermal treatment) 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 bind COCs.

Groundwater treatment would be achieved through treatment of PTWs 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).

Alternatives 2 through 10 were rated with respect to this criterion as follows:

- RCM and amended sand caps in Alternative 2 would provide negligible treatment of PTWs or groundwater. This alternative is rated low.
- Alternatives 3 and 4a would treat 10 and 6 percent of PTWs, respectively, via *in situ* solidification. By targeting deep PTWs for treatment and by using a PRB to treat groundwater near the shoreline, these alternatives would achieve modest reductions in groundwater volume and mass flux. However, these alternatives are rated low because only a small portion of PTWs would be addressed by treatment.

- Alternative 4 includes negligible treatment of PTWs, and would achieve only modest reductions in groundwater volume and mass flux by removing PTWs in the QP-U DNAPL Area and installing a PRB. This alternative is rated low.
- Alternatives 5 and 6 would treat approximately 47 and 70 percent of PTWs, respectively. These alternatives would also achieve more substantial reductions in groundwater volume and flux compared to the earlier alternatives. These alternatives are rated moderate.
- Alternative 7 would treat approximately 85 percent of PTWs through *in situ* solidification, while Alternative 8 would treat all PTWs through on-site thermal treatment. In addition, both alternatives would greatly reduce the volume and mass flux of contaminated groundwater. Both alternatives are rated high for this criterion. Alternative 8 satisfies this criterion to a higher degree than Alternative 7 due to more complete treatment of PTWs and the more permanent nature of treatment and reduction in contaminant volume.
- Alternatives 9 and 10 would treat all PTWs 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 thermal treatment, while Alternative 10 would use on-site thermal treatment. Alternative 10 also would achieve the greatest reduction in groundwater plume volume. These alternatives are rated high for this criterion.

8.2.3 *Short-Term Effectiveness*

This NCP balancing criterion is used to evaluate the effects and potential risks associated with remedial alternative implementation, considering the protection of the community, the protection of workers, 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. RAOs, with the exception of restoring groundwater to its highest beneficial use, would be achieved at the end of the construction period for all alternatives.

In general, short-term impacts increase with 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 BMPs, but the potential for increased exposures, or releases to the neighboring community, on-site workers, and the environment could occur due to failure of construction equipment and/or protective controls when remediating greater volumes of contaminated materials. In addition, several impacts would be challenging to control, including the following:

- Vapor and dust emissions, from disturbance of contaminated materials during excavation, dredging, and (to a lesser degree) *in situ* solidification. These could result in noxious odors and community exposure to volatile compounds.
- Vapor and dust emissions from handing, stockpiling, and transporting contaminated materials off-site (Alternatives 2 through 7).

- Alternatives involving on-site thermal treatment of contaminated materials (Alternatives 8, 9, and 10) also would have the potential for air emissions from on-site handling and treatment; however, these emissions would be more easily controlled by available process technologies employed in the treatment train.
- Water quality impacts from capping and dredging 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.
- "Quality of life" impacts to the community from construction noise, traffic, and aesthetics could result. However, these are not related to risks caused from potential exposure to contaminated media.

The estimated design and construction duration for each alternative is shown on Figure 7-5. The short-term effectiveness of Alternatives 2 through 10 is compared in Table 8-1 and summarized as follows:

- Alternative 2 has a construction duration of less than 1 year. This alternative would have the greatest short-term effectiveness and is rated high for this criterion. Alternative 2 would disturb a minimum of contaminated material, and would present the lowest risk to workers, the community, and the environment.
- Alternative 3 has a construction duration of approximately 1.5 years. This alternative 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 PTWs, and the construction of a PRB and DNAPL collection trenches. These activities all create the potential for exposure to dust and vapors for both the community and Site workers; however, no unacceptable risk is expected to the community or workers because of the use of protective equipment and practices. In addition, the total volume of soil disturbed in this alternative would be relatively modest. This alternative is also rated high for short-term effectiveness.
- Alternative 4, which has a construction duration of approximately 2.5 years, would have increased short-term impacts from dredging of PTWs in sediment. The greatest impacts would be expected in the aquatic environment; however, BMPs would be used to minimize water quality impacts and habitat recovery would be expected to occur relatively quickly following placement of the residuals cover over dredged areas. 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 4a, which also has a construction duration of approximately 2.5 years, would present a lower short-term risk than Alternative 4 because the QP-U DNAPL area is solidified rather than excavated, which is expected to cause fewer air emissions. In addition, a significantly smaller volume of contaminated sediments is dredged than in Alternative 4. This alternative is rated high for short-term effectiveness.

- Alternative 5, which has a construction duration of 2.5 years, has a similar 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 rather than excavation, resulting in fewer short-term impacts. This alternative is rated moderate for short-term effectiveness.

- Alternative 6 would have a slightly longer construction duration (3 years) than Alternatives 4, 4a, and 5. This alternative would have a similar potential as Alternatives 4 and 5 for water quality impacts through dredging, but slightly greater short-term impacts due to more extensive upland construction (primarily *in situ* solidification). This alternative is rated moderate for short-term effectiveness.

- Alternative 7 involves *in situ* stabilization of all known upland PTWs and dredging of all known aquatic PTWs, and would have a construction period of approximately 4.5 years. Dredged materials would be trucked offsite for disposal. Similar to Alternatives 3 through 6, these activities all create the potential for exposure to dust and vapors for both the community and Site workers; however, no unacceptable risk is expected to the community or workers because of the use of protective equipment and practices. The greatest impacts would be expected in the aquatic environment; however, BMPs would be used to minimize water quality impacts, and habitat recovery would be expected to occur relatively quickly following placement of the residuals cover over dredged areas. Although Alternative 7 would have greater short-term impacts than Alternatives 5 and 6 because of the substantially larger volume of dredging, EPA has rated this alternative as moderate for short-term effectiveness (the same as Alternatives 5 and 6) to differentiate it from Alternatives 8 through 10, which have even greater short-term impacts.

- Alternative 8 would have a longer construction period (approximately 5.5 years) than Alternative 7. It would include additional materials handling and stockpiling of PTW materials, as well as air emissions from on-site treatment; therefore, it would likely have higher short-term impacts than Alternative 7. Alternative 8 is rated low for short-term effectiveness.

- Alternatives 9 and 10 would have the greatest potential short-term impacts to workers, the community, and the environment, and would have very long construction durations (10 and 12 years, respectively). Therefore, they 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.

8.2.4 *Implementability*

This NCP balancing criterion is used to evaluate the relative implementability of Alternatives 2 through 10, 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 RCM and amended sand 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 there is increasing field experience with the installation of RCM and amended sand caps, there is no field information/experience regarding the maintenance/repair of such caps.

Differences in complexity include the following:

- Alternatives that involve RCM or amended sand caps (Alternatives 2 through 6) would require ongoing maintenance and monitoring in perpetuity.
- Alternatives that involve PRBs (Alternatives 3 through 6) would require bench and/or pilot testing of potential treatment media, though this is not considered to be an implementability concern. PRBs will also require ongoing maintenance and monitoring in perpetuity.
- Alternatives involving *in situ* solidification (Alternatives 3, 4a, 5, 6, 7, and 9) would require bench and/or pilot testing of potential amendment mixtures to determine proper mixes to optimize effectiveness, though this is not considered to be an implementability concern.
- Alternatives that involve more construction elements are generally more complex to implement.
- Alternatives that include mechanical dredging of DNAPL-containing sediments in the QP-S DNAPL area have increased complexity due to installation and removal of sheetpile shoring systems and removal of relatively deep sediments.
- 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. On-site thermal treatment would also require air emission controls and extensive monitoring.

All alternatives would require coordination with numerous federal and state regulatory agencies, during remedial design, to ensure that all ARARs (including ESA consultation and substantive compliance with Section 401 and 404 of the CWA), policies, and regulations are met. Coordination with these agencies, by EPA, has become routine in the Puget Sound area of Washington. Little coordination is expected during remedial action because reasons for coordination would be addressed during remedial design. 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 and/or more construction elements 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 has fewer construction elements (3) than the subsequent alternatives, would present no unusual construction challenges, and necessary engineering and construction services are available. However, there are concerns about the successful use of RCM caps, and the sediment capping technologies will require maintenance and monitoring. This alternative is rated high for implementability.
- Alternative 3 would involve slightly more technical complexity compared to Alternative 2 due to additional treatment and containment measures, including PRBs that will require maintenance and monitoring in perpetuity. This alternative is also rated high for implementability.
- Alternative 4 would have greater technical complexity compared to Alternative 3, with two additional construction elements including dredging of DNAPL-containing sediments. However, Alternative 4 reduces the acreage of sediment covered by RCM caps, which reduces long-term monitoring and maintenance obligations. This alternative is rated moderate for implementability.
- Alternative 4a reduces the acreage of sediment covered by RCM caps compared to Alternatives 2 and 3, which reduces long-term monitoring maintenance obligations. In addition, unlike Alternative 4, this alternative does not implement mechanical dredging of DNAPL-containing sediments in the nearshore area. This alternative is rated high for implementability
- Alternatives 5 and 6 are similar to Alternative 4 but would have more complicated upland remedial components due to more extensive solidification. These alternatives are rated moderate for implementability.
- Alternative 7 involves more extensive solidification and dredging than Alternative 6, but has significantly fewer construction elements and long-term maintenance and monitoring obligations. This alternative is rated moderate for implementability.
- 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 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.

8.2.5 *Cost*

Cost estimates were developed for each alternative per EPA guidance (EPA 2000b) 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 1.4 percent discount rate. See Appendix D for three versions of the cost estimates for each alternative: one based on NPV with a 7 percent discount rate; one based on NPV with a 1.4 percent discount rate; and one with no discount rate applied.

The estimated present worth cost for each alternative, in 2015 dollars and using a discount factor of 1.4 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 PTWs 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 ($20 million [M]) and total ($28M) costs of the alternatives. Capital costs are fairly evenly split between upland capping and sediment capping/ENR components. Estimated OM&M costs ($8.2M) are largely for the assumed periodic repair of the RCM and amended sand caps.

- Alternative 3 would have somewhat higher capital ($25M) and OM&M ($10M) costs than Alternative 2 due to the *in situ* solidification of deep PTWs and installation of the DNAPL collection trenches and a PRB. These measures result in a somewhat higher total cost ($35M).

- Alternative 4 would have much higher capital ($41M) and total ($46M) costs than Alternative 3, primarily due to dredging instead of capping of several DNAPL-impacted areas and removal of the QP-U DNAPL Area. The OM&M costs of this alternative ($5.2M) are lower than Alternative 3 because OM&M costs for dredging residual covers are less than for RCM or amended sand caps.

- Alternative 4a would have a lower capital cost ($33M) than Alternative 4 because the QP-S Area would be capped instead of dredged, and *in situ* solidification of the QP-U DNAPL Area would be cheaper than removal/off-site disposal. The OM&M costs ($5.6M) would be slightly higher than Alternative 4, primarily due to OM&M of the QP-S DNAPL Area cap. The total cost of this alternative ($39M) is more than Alternative 3 but less than Alternative 4.

- Alternative 5 would have a higher capital cost ($43M) than Alternative 4a due to the expanded treatment (via *in situ* solidification) of upland PTWs and removal of the QP-S DNAPL Area. The OM&M cost of this alternative ($4.5M) is less than Alternatives 4a because no DNAPL collection trenches are needed, due to the increased volume of PTW being treated. The total cost of this alternative ($48M) is slightly higher than Alternative 4.

- Alternative 6 would have a much higher capital cost ($58M) because it would remove the QP-U DNAPL Area and expand solidification treatment of upland PTWs and it would have the same OM&M cost ($4.5M) as Alternative 5. The total cost of this alternative is $62M.

- Alternative 7 would have a much higher capital cost ($79M) than Alternative 6, primarily due to treatment of all upland PTWs via *in situ* solidification. The OM&M cost of $2.9M, based on groundwater monitoring and inspection/maintenance of the upland cap, engineered sand cap, and ENR, would be lower than in Alternative 6. The total cost of this alternative is $82M.

- Alternative 8 would have much higher capital ($143M) and total ($146M) costs than Alternative 7 because all PTWs would be removed and thermally treated on-site, which has a much higher unit cost than *in situ* solidification of upland PTWs and removal/off-site disposal of PTWs in sediment. The OM&M cost ($2.9M) is the same as Alternative 7.

- Alternative 9 would have much higher capital ($277M) and total ($280M) costs compared to Alternatives 7 and 8 because of the much larger volume of soil and sediments addressed. The OM&M cost ($2.9M) is the same as Alternatives 7 and 8.

- Alternative 10 would have the highest capital ($397M) and total ($425M) costs of the alternatives. These costs are much higher than Alternative 9 because all contaminated soils would be removed and thermally treated onsite, which has a greater unit cost than *in situ* solidification. The OM&M cost ($28M) is also much higher because of long-term operation of a groundwater pump-and-treat system.

8.3 Comparative Analysis Summary

In this FS, 11 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. This evaluation is summarized in Table 7-3.

Alternative 1 does not meet the threshold requirements for overall protection and ARAR compliance and thus was not carried forward in the balancing criteria evaluation. Alternatives 2 through 10 satisfy the Overall Protection of Human Health and the Environment criterion, and would meet all ARARs if a TI waiver is granted for achieving MCLs in groundwater. Alternatives 2 through 10 were carried through to the comparative evaluation and analyzed based on the balancing criteria, as presented in Table 8-1 and summarized as follows:

- **Long-Term Effectiveness and Permanence.** Alternatives 2 and 3 are rated low, Alternatives 4 through 6 are rated moderate, and Alternatives 7 through 10 are rated high for this criterion.
- **Reduction of Toxicity, Mobility, or Volume through Treatment.** Alternatives 2 through 4a are rated low, Alternatives 5 and 6 are rated moderate, and Alternatives 7 through 10 are rated high for this criterion.
- **Short-Term Effectiveness.** Alternatives 2, 3, and 4a are rated high, Alternatives 4, 5, 6, and 7 are rated moderate, and Alternatives 8 through 10 are rated low for this criterion.
- **Implementability**. Alternatives 2, 3, and 4a are rated high, Alternatives 4, 5, 6, and 7 are rated moderate, and Alternatives 8 through 10 are rated low for this criterion.
- **Cost**. The estimated present worth costs of the alternatives cover a wide range, from $28M for Alternative 2 to $425M for Alternative 10. Capital costs range from $20 M (Alternative 2) to $397M (Alternative 10). OM&M costs range from $2.9M (Alternatives 7 through 9) to $28M (Alternative 10).

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 remedy may be one of the alternatives described in the FS or a combination of elements from different alternatives, as appropriate. State, tribal, and community acceptance of the preferred remedy will be evaluated in the ROD once comments on the FS and proposed plan are received.

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TABLES

Table 3-1 Chemicals of Concern by Medium

Quendall Terminals
Renton, Washington

	Medium													
	Soil		Groundwater	Indoor Air	Trench Vapor	Surface Water/ Porewater		Nearshore Sediment		Site-Wide Sediment		Fish/ Shellfish[b]	Food/Prey Item
Chemical of Concern[a]	**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 Key Chemical-Specific ARARs for Remedial Action at the Quendall Terminals Site

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.
To Be Considered (TBC) for groundwater that could potentially be a drinking water source (i.e., achieved as practicable).	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).	
ARARs for surface water if more stringent than promulgated state criteria.	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	
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.

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

Quendall Terminals
Renton, Washington

Act/Authority	Criteria/Issue	Citation	Brief Description	Applicability/Appropriateness
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.
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 and freshwater sediments.	Promulgated numeric cleanup levels are ARARs for freshwater sediments.

Table 4-2 Key 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

Table 4-2 Key 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
					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.
Soil Excavation and Upland Filling	Washington Hydraulics Code	Protection of Fish Life	Chapters 75.20 & 77.55 RCW; Chapter 220-110 WAC	Establishes requirements for performing work that would alter existing fish habitat.	ARAR, to the extent that it is more stringent than federal law, if remedial actions such as excavation or capping impact existing fish habitat. 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 fish habitat 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.
	Clean Water Act	Establishes requirements for discharges to wetlands within the identified shoreline jurisdiction. Wetland Mitigation Requirements Including Mitigation Ratios, Wetland	33 U.SC. § 1344; 33 CFR §§ 325.1(d), 332; 40 CFR § 230;	Establishes replacement requirements for wetlands affected by remedial actions to ensure no net loss of existing wetland acreage and functions; also establishes requirements for wetland buffers including replacement wetlands.	ARAR if remedial actions such as excavation or capping discharge to existing waters of the United States. Remedial actions must result in no net loss of aquatic habitat and function after sequential consideration of avoidance and mitigation.

Table 4-2 Key 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
		Buffer Requirements			
	Washington State Shoreline Management Act; Renton Shoreline Master Program	Establishes requirements for discharges to wetlands within the identified shoreline jurisdiction. Wetland Mitigation Requirements Including Mitigation Ratios, Wetland Buffer Requirements	Chapter 90.58 RCW; Renton Municipal Code subsections: 04-3-090.D.2.d.iv(c) and (d); 04-3-090.D.2.d.vi and d.vii; 04-3-090.D.2.d.x(d)	Establishes replacement requirements for wetlands affected by remedial actions to ensure no net loss of existing wetland acreage and functions; also establishes requirements for wetland buffers including replacement wetlands.	ARAR, to the extent that it is more stringent than federal law, if remedial actions such as excavation or capping discharge to existing jurisdictional wetlands. Remedial actions must result in no net loss of aquatic habitat and function after sequential consideration of avoidance and mitigation.
Soil Excavation and Upland Filling	Wetland Mitigation in Washington, Part 1 Version 1	Mitigation for filling wetlands	Ecology Publication 06-06-011a	Science and advisory recommendations for wetland mitigation regulations and plans, addressing wetland delineation and ranking, buffer sizes, mitigation ratios, etc.	TBC for specific mitigation parameters where no ARAR is on point
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.
	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

Table 4-2 Key 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 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.
Dredging, Capping, and/or Discharge to Lake Washington	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.
	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.
Well-Related Activities	Washington Water Well Construction	Monitoring Wells	"Water Well Construction Act	Establishes minimum standards for construction	ARAR for monitoring well design, construction, development, and

Table 4-2 Key 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
	Act		of 1971" (Chapter 18.104 RCW, as amended); "Minimum Standards for Construction and Maintenance of Wells" (Chapter 173-160 WAC)	and maintenance of wells.	abandonment. Also provides technical standards by which well cuttings and development water are handled.
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.
	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	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.

Table 4-2 Key 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
				artifacts, records, and material remains related to such a property.	
	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.
Other Remedial Activities	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 Key Location-Specific ARARs for Remedial Action at the Quendall Terminals Site

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.
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.

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

Quendall Terminals
Renton, Washington

Act/Authority	Criteria/Issue	Citation	Brief Description	Applicability/Appropriateness
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)						Notes
	Risk-Based Concentration (RBC)					Background Concentration (Ecology 1994)	
	Carcinogenic			Non-Carcinogenic	Ecological		
	EPA RSL ($1x10^{-4}$)	EPA RSL ($1x10^{-5}$)	EPA RSL ($1x10^{-6}$)	EPA RSL (HQ=1)			
2-Methylnaphthalene				240			
Arsenic	68	6.8	0.68	35		7.3	
Benzo(a)anthracene[2]	16	1.6	0.16	--	via HPAH		
Benzo(a)pyrene[2]	1.6	0.16	0.016	--	4.2		Robin highest HQ. Potential PRG back calculated from RI Report Table 7.2-9.
Benzo(b)fluoranthene[2]	16	1.6	0.16	--	via HPAH		
Benzo(k)fluoranthene[2]	160	16	1.6	--	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]	1600	160	16	--			
Dibenz(a,h)anthracene[2]	1.6	0.16	0.016	--	via HPAH		
Ethylbenzene	580	58	5.8	3,400			
Fluoranthene	--	--	--	2,400	via HPAH		
Indeno(1,2,3-cd)pyrene[2]	16	1.6	0.16	--	via HPAH		
Lead	--	--	--	400	37	17	Hawk highest HQ. Potential PRG back calculated from RI Report Table 7.2-11.
Naphthalene	380	38	3.8	130			
Pentachlorophenol	100	10	1	250	16		Rabbit highest HQ. Potential PRG back calculated from RI Report Table 7.2-13.
Pyrene	--	--	--	1,800	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 1×10^{-6} 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) EPA RSL ($1X10^{-4}$) = the EPA RBC at a excess cancer risk of $1X10^{-4}$.
4) EPA RSL (HQ=1) = the EPA 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.

RSL = Regional screening level, May 2016

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	EPA RSL ($1x10^{-4}$)	EPA RSL ($1x10^{-5}$)	EPA RSL ($1x10^{-6}$)	EPA RSL (HQ=1)
2-Methylnaphthalene	--				36
Acenaphthene	--				530
Arsenic	10	5.2	0.52	0.052	6
Benzene	5	46	4.6	0.46	33
Benzo(a)anthracene[2]	--	1.2	0.12	0.012	--
Benzo(a)pyrene[2]	0.2	0.34	0.034	0.0034	--
Benzo(b)fluoranthene[2]	--	3.4	0.34	0.034	--
Benzo(k)fluoranthene[2]	--	34	3.4	0.34	--
Chrysene[2]	--	340	34	3.4	--
Dibenz(a,h)anthracene[2]	--	0.34	0.034	0.0034	--
Dibenzofuran	--	--	--	--	7.9
Ethylbenzene	700	150	15	1.5	810
Fluoranthene	--	--	--	--	800
Fluorene	--	--	--	--	290
Indeno(1,2,3-cd)pyrene[2]	--	3.4	0.34	0.034	--
Naphthalene	--	17	1.7	0.17 [8]	6.1
Total Xylenes	10,000	--	--	--	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^{-6} 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) EPA RSL ($1X10^{-4}$) = the EPA RBC at a excess cancer risk of $1X10^{-4}$.
4) EPA RSL (HQ=1) = the EPA 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.
8) For the purpose of estimating the extent of the naphthalene plume resulting from contamination at Quendall, the RSL of 1.7 is used (see Section 4.3).

MCL = Maximum Contaminant Level
RSL = Regional screening level, May 2016

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	--	70	5.8	--
Anthracene	--	300	0.012	--
Benzene	--	2.1[3]	--	--
Benzo(a)anthracene	--	0.0012	0.018	--
Benzo(a)pyrene	--	0.00012	0.015	--
Fluoranthene	--	20	0.04	--
Fluorene	--	50	3	--
Naphthalene	--	--	1.1	--
PAH ESBQ TU	--	--	--	1 TU
Phenanthrene	--	--	0.4	--
Pyrene	--	20	0.025	--
Toluene	--	57	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 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) 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 x 10^{-6} 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) [1]														Notes
	ARARs		Risk-Based Concentration (RBC)											Background Concentration	
	Ecology SMS		Human Health									Ecological			
	Sediment Cleanup Objective	Cleanup Screening Level	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	--	
Benzo(a)pyrene[4]	--	--	5.5	0.55	0.055	120	12	1.2	19	1.9	0.19	260[6]	3.5[7]	0.15 mg/kg 6.2 mg/kg OC	The cPAH background threshold value (BTV) of 17.5 mg/kg OC is a 95/95 UTL considered to be a "do not exceed" value for looking at individual concentrations and comparing them to site background.
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	--	
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)	17	30	--	--	--	--	--	--	--	--	--	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 $1x10^{-6}$ 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) PRGs are not OC-normalized unless OC-normalized units are shown.
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) Fish/shellfish ingestion PRG back calculated from RI Report Table J-7-74, using sediment EPC of 602 mg/kg OC (RI Report Table 7.1-4).
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.
Site RA $1X10^{-4}$ = the Site-specific RBC at an excess cancer risk of $1X10^{-4}$.
RBC = Risk-Based Concentration
HQ = Hazard Quotient
U = 1/2 - undetected chemicals were included as one-half the detection limit.
Background values were calculated based on Benzo[a]pyrene equivalents.
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.
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

$$cPAH\left(\frac{\mu g}{kg\text{-OC}}\right) = \frac{cPAH\left(\frac{\mu g}{kg}\right)}{\frac{TOC\%}{100}\left(\frac{kg\text{-OC}}{kg}\right)}$$

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

	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]
Chemical of Concern[a]	**HHRA[c]**	**ERA[d]**	**HHRA**	**HHRA**	**HHRA**	**HHRA**	**ERA**	**HHRA**	**ERA**	**HHRA**	**ERA**	**HHRA**	**ERA**
2-Methylnaphthalene	240		36				4.7						
Acenaphthene			530			70	5.8						
Anthracene						300	0.012						
Arsenic	7.3 (b)		10 (MCL)										
Benzene			5 (MCL)	3.1 (c)	16 (c)	2.1 (c)							
Benzo(a)anthracene[e]	0.16 (c)	via HPAH	0.012 (c)			0.0012	0.018	0.55 (c)	via HPAH	12 (c)	via TPAH		
Benzo(a)pyrene[e]	0.016 (c)	4.2	0.2 (MCL)			0.00012	0.015	0.055 (c)	260	1.2 (c)	3.5	6.2 (c)	6.2 (c)
Benzo(b)fluoranthene[e]	0.16 (c)	via HPAH	0.034 (c)					0.55 (c)	via HPAH		via TPAH		
Benzo(k)fluoranthene[e]	1.6 (c)	via HPAH	0.34 (c)					0.55 (c)	via HPAH		via TPAH		
Chromium		51											
Chrysene[e]	16 (c)		3.4 (c)					5.5 (c)		120 (c)			
Dibenz(a,h)anthracene[e]	0.016 (c)	via HPAH	0.0034 (c)					0.55 (c)	via HPAH	12 (c)	via TPAH		
Dibenzofuran			7.9										
Ethylbenzene	5.8 (c)		700 (MCL)	9.7 (c)	49 (c)								
Fluoranthene		via HPAH	800			20	0.04		via HPAH		via TPAH		
Fluorene			290			50	3						
Indeno(1,2,3-cd)pyrene[e]	0.16 (c)	via HPAH	0.034 (c)					0.55 (c)	via HPAH	12 (c)	via TPAH		
Lead		37											
Naphthalene	3.8 (c)		0.17 (c)	0.72 (c)	3.6 (c)		1.1						
PAH ESBQ TU							1 TU		1 TU		1 TU		
Pentachlorophenol	1	16											
Phenanthrene							0.4						
Pyrene	1,800	via HPAH	87			20	0.025		via HPAH		via TPAH		
Toluene						57	2						
Total 10 of 16 HPAH (U = 1/2)		3.7							29				
Total 16 PAH (U = 1/2)									17 (SMS)		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^{-6} 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

SMS - Washington State Sediment Management Standards Sediment Cleanup Objective

TU - Toxic Unit

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	**ERA**
Residential Soil Regional Screening Level (RSL) May 2016	Robin highest HQ. PRG back calculated from RI Report Table 7.2-9
Residential Tapwater RSL May 2016	Hawk highest HQ. PRG back calculated from RI Report Table 7.2-11
Residental Air RSL May 2012	Rabbit highest HQ. PRG back calculated from RI Report Table 7.2-13
Industrial Air RSL May 2012	Raccoon highest HQ. PRG back calculated from RI Report Table 7.2-19
National Water Quality Criteria (Organism +Water)	EPA Region 3 Biological Technical Assistance Group (BTAG) Ecological Screening Level for Surface Water
Nearshore sediment human health PRG back calculated from RI Report Table J-7-65	Otter highest HQ. PRG back calculated from RI Report Table 7.2-38
Site-wide sediment human health PRG back calculated from RI Report Table J-7-68	Sandpiper highest HQ. PRG back calculated from RI Report Table 7.2-40

Table 4-9 - DNAPL, Thickness, and Estimated Volumes by Source Area[1]

Quendall Terminals
Renton, Washington

Source Area	Approximate Area in Acres	Cumulative Average/ Maximum DNAPL Thickness in Feet	Average/ Maximum Depth of DNAPL in Feet	Volume of DNAPL-Contaminated Soil and/or Sediment in Cubic Yards	Volume of Soil and/or Sediment to Bottom of DNAPL in Cubic Yards	DNAPL Volume in Gallons	Percentage of Soil and/or Sediment Containing DNAPL[3]	Percentage of DNAPL Logged as Oil-wetted[4]
Former May Creek Channel Area	1.5	2.5 / 8.8 (Max. MC-1)	17 / 34 (Max. BH-30C)	7,100	40,000	88,000	18%	40%
Still House Area	2.2	2.2 / 4 (Max. BH-8)	11 / 14 (Max. QP-7)	8,100	38,000	100,000	21%	27%
North Sump Area[2]	1.6	3.4 / 6 (Max. SP-5)	15 / 18 (Max. SP-7)	9,600	41,000	120,000	23%	3%
Quendall Pond Area Upland	1.6	1.9 / 5.2 (Max. RB-9)	18 / 27 (Max. BH-20C)	4,600	50,000	57,000	9%	58%
Quendall Pond Area Offshore	0.9	1.5 / 5 (Max. VS30)	10 / 16 (Max. VS2)	1,900	17,000	24,000	11%	84%
Rail Road Loading Area	0.2	4.9 / 11 (Max. Q2-D)	22 / 30 (Max. Q2-D)	1,700	7,800	21,000	22%	20%
T-Dock Area (sediment only)	1.7	1.0 / 3.8 (Max. VT-4)	1.5 / 3.8 (Max. VT-4)	2,900	4,400	36,000	66%	0%
Total	**9.7**	**--**	**--**	**36,000**	**200,000**	**445,000**	**--**	**--**

Notes:

[1]Expanded from Table 4.4-4 in the RI Report (Anchor QEA and Aspect, 2012).
[2]North Sump Area locations include: BH-23, HC-2, RB-19, RB-23, SP-5, SP-6, SP-7, SWB-4, and SWB-4a.
[3]Percentage of soil and/or sediment containing DNAPL is calculated as volume of soil/sediment containing DNAPL divided by the volume of soil/sediment to the bottom of DNAPL.
[4]Percentage of DNAPL logged as oil-wetted is calculated as the sum of oil-wetted interval thickness by area divided by the sum of total DNAPL thickness by area.

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

Quendall Terminals
Renton, Washington

Soil 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 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

Table 5-2 Initial Screening of Soil Technologies and Process Options

Quendall Terminals
Renton, Washington

Soil General Response Actions	Remedial Technology	Process Options	Description	Screening Comments
	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
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	Secondary Screening for Alternative Development: 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.	<u>Yes*</u>
	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.	<u>Yes*</u>
		Deed restrictions addressing soil disturbance and/or groundwater wells	Highly effective.	Implementable	Low/Low		<u>Yes*</u>
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.	<u>Yes*</u>
	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	Secondary Screening for Alternative Development: 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
In Situ Treatment	Mid-Temperature Thermal Treatment	Electrical Resistance Heating	Moderate to high for VOCs, moderate for SVOCs. Not effective for arsenic.	Implementable. 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
In Situ Treatment	Mid-Temperature Thermal Treatment	Thermal Conductive Heating	Moderate to high for VOCs, moderate for SVOCs. Not effective for arsenic.	Implementable. 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
In Situ Treatment	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
In Situ Treatment	High-Temperature Thermal Treatment	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
In Situ Treatment	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***
In Situ Treatment	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
In Situ Treatment	Chemical Treatment	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
In Situ Treatment	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**
In Situ Treatment	Bioremediation	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. Heterogeneous soils reduce capture effectiveness.	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

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	Technology 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	Secondary Screening for Alternative Development: 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 Technologies and Process Options into Remedial Alternatives

Quendall Terminals
Renton, Washington

Media	Technology General Response Actions	Remedial Technologies/ Process Options	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 4a	Alternative 5	Alternative 6	Alternative 7	Alternative 8	Alternative 9	Alternative 10
			No Action	Containment	Targeted PTW Solidification (RR and MC DNAPL Areas)	Targeted PTW Removal (TD, QP-S, and QP-U DNAPL Areas)	Targeted PTW Solidification (QP-U DNAPL Area) and Removal (TD DNAPL Area)	Targeted PTW Solidification (RR, MC, and QP-U DNAPL Areas and ≥ 4-Foot-Thickness) and Removal (TD and QP-S DNAPL Areas)	Targeted PTW Solidification (RR and MC DNAPL Areas and ≥ 2-Foot-Thickness) and Removal (TD, QP-S, and QP-U DNAPL Areas)	PTW Solidification (Upland) and Removal (Sediment)	PTW Removal (Upland and Sediment)	Solidification and Removal of Contaminated Soil and Removal of Contaminated Sediment	Removal of Contaminated Soil and Sediment
Upland DNAPL/Soil	Institutional Controls	Deed and Access Restrictions	--	X	X	X	X	X	X	X	X	X	X
	In Situ Containment	Cover or Cap	--	X	X	X	X	X	X	X	X	X	X
	In Situ Treatment	Solidification	--	--	Deep PTWs2	--	QP-U DNAPL Area and deep PTWs[2]	QP-U DNAPL Area plus shallow PTWs >4-foot cumulative thickness1 and deep PTWs2	ShallowPTWs >2-foot cumulative thickness1 and deep PTWs2	All PTWs	--	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	At former May Creek and Quendall Pond shoreline	--	--	--	--	--	--
		Excavation	--	--	--	QP-U DNAPL Area	--	--	QP-U DNAPL Area	--	All PTWs	All shallow contaminated soil (above approx. 15 feet bgs)	All contaminated soil
	Ex Situ Treatment	On-site Thermal Treatment	--	--	--	--	--	--	--	--			
	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	X
	Monitoring	Biological/Physical Recovery	--	X	X	X	X	X	X	X	X	X	X
	Enhanced Natural Recovery (ENR)	Thin-layer Placement	--	Offshore sediments outside PTW areas exceeding BTV	Offshore sediments outside PTW areas exceeding BTV	Offshore sediments outside PTW areas exceeding BTV	Offshore sediments outside PTW areas exceeding BTV	Offshore sediments outside PTW areas exceeding BTV	Offshore sediments outside PTW areas exceeding BTV	Offshore sediments outside PTW areas exceeding BTV	Offshore sediments outside PTW areas exceeding BTV	Offshore sediments outside PTW areas exceeding BTV	Offshore sediments outside PTW areas exceeding BTV
	In Situ Containment	Engineered Sand Cap	--	Nearshore sediments outside PTW areas	Nearshore sediments outside PTW areas	Nearshore sediments outside PTW areas	Nearshore sediments outside PTW areas	Nearshore sediments outside PTW areas	Nearshore sediments outside PTW areas	Nearshore sediments outside PTW areas	Nearshore sediments outside PTW areas	Nearshore sediments outside areas of PTWs or MCL exceedances	Nearshore sediments outside areas of PTWs or MCL exceedances
	In Situ Treatment	Amended Sand Cap	--	Aquatic DNAPL area DA-6	Aquatic DNAPL area DA-6	--	Aquatic DNAPL area DA-6	--	--	--	--	--	--
		RCM Cap	--	All aquatic DNAPL areas except DA-6	All aquatic DNAPL areas except DA-6	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	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 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 PTWs or MCL exceedances	Nearshore sediments in areas of PTWs 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)	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 Treatment	--	--	--	--	--	--	--	--	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	All removed sediment	--	--	--
Groundwater	Institutional Controls	Deed Restrictions	--	X	X	X	X	X	X	X	X	X	X
	Monitoring	Groundwater Monitoring	--	X	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	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 PTWs 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.

BTV = background threshold value
DNAPL = dense non-aqueous phase liquid
PTW = principal threat waste
QP-U= Quendall Pond-Upland
RCM = Reactive core mat
RR = Railroad

Table 6-2 Summary of Remedial Alternative Construction Quantities

Quendall Terminals
Renton, Washington

	Remedial Component	Alternative 2	Alternative 3	Alternative 4	Alternative 4a	Alternative 5	Alternative 6	Alternative 7	Alternative 8	Alternative 9	Alternative 10
		Containment	Targeted PTW Solidification (RR and MC DNAPL Areas)	Targeted PTW Removal (TD, QP-S, and QP-U DNAPL Areas)	Targeted PTW Solidification (QP-U DNAPL Area) and Removal (TD DNAPL Area)	Targeted PTW Solidification (RR, MC, and QP-U DNAPL Areas and ≥ 4-Foot-Thickness) and Removal (TD and QP-S DNAPL Areas)	Targeted PTW Solidification (RR and MC DNAPL Areas and ≥ 2-Foot-Thickness) and Removal (TD, QP-S, and QP-U DNAPL Areas)	PTW Solidification (Upland) and Removal (Sediment)	PTW Removal (Upland and Sediment)	Solidification and Removal of Contaminated Soil and Removal of Contaminated Sediment	Removal of Contaminated Soil and Sediment
Upland DNAPL/Soil	Soil Cap (acres)	22	22	22	22	22	22	22	22	22	22
	DNAPL Collection Trench (lf)	--	500	500	500	--	--	--	--	--	--
	In Situ Solidification (CY)										
	- DNAPL-impacted soil	--	3,600	--	5,900	17,000	25,100	30,500	--	8,400	--
	- Non-DNAPL-impacted soil	--	13,900	--	25,900	61,900	117,400	210,800	--	354,500	--
	Excavate and On-Site Thermal Treatment (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	500	400	2,700	--	--	--	--
	- Non-DNAPL-impacted soil	--	2,400	12,800	2,400	1,700	12,100	--	--	--	--
Aquatic DNAPL/ Sediment[2]	In Situ Remediation (acres)										
	-Enhanced natural recovery	17.6	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	6.2	6.4	6.4	5.5	5.5	3.9	3.9
	- Amended sand cap	0.7	0.7	--	0.7	--	--	--	--	--	--
	- RCM cap	4.9	4.9	2.0	2.0	2.0	2.0	--	--	--	--
	- Post dredge residuals management cover/backfilling	--	--	3.5	2.7	3.5	3.5	6.4	6.4	8.0	8.0
	Dredge and On-Site Thermal Treatment (CY)	--	--	--	--	--	--	--	58,300	173,100	173,100
	Dredge and Landfill Disposal (CY)	2,800	3,200	25,900	14,900	25,900	25,900	58,300	--	--	--
	Temporary Sheet Pile Enclosure (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	1,100	--	--	--	--
	Pump and Treat (gpm)	--	--	--	--	--	--	--	--	--	90

Notes:
-- not applicable
[1] Refer to Section 6 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
PTW = principal threat waste
RCM = reactive core mat

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) and Tribal Acceptance[1]	• State (Support Agency) and tribal 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 4a	Alternative 5	Alternative 6	Alternative 7	Alternative 8	Alternative 9	Alternative 10
	Containment	**Targeted PTW Solidification (RR and MC DNAPL Areas)**	**Targeted PTW Removal (TD, QP-S, and QP-U DNAPL Areas)**	**Targeted PTW Solidification (QP-U DNAPL Area) and Removal (TD DNAPL Area)**	**Targeted PTW Solidification (RR, MC, and QP-U DNAPL Areas and ≥ 4-Foot-Thickness) and Removal (TD and QP-S DNAPL Areas)**	**Targeted PTW Solidification (RR and MC DNAPL Areas and ≥ 2-Foot-Thickness) and Removal (TD, QP-S, and QP-U DNAPL Areas)**	**PTW Solidification (Upland) and Removal (Sediment)**	**PTW Removal (Upland and Sediment)**	**Solidification and Removal of Contaminated Soil and Removal of Contaminated Sediment**	**Removal of Contaminated Soil and Sediment**
Upland DNAPL in Gallons										
Removal via Collection Trench, with Off-site Incineration	--	1,300	1,300	1,300	--	--	--	--	--	--
Removal via Excavation, with Off-site Disposal	--	6,600	34,900	6,600	4,500	32,900	--	--	--	--
Removal via Excavation, with On-site Thermal Treatment	--	--	--	--	--	--	--	377,500	273,100	377,500
Total Upland DNAPL Removed	0	7,900	36,200	7,900	4,500	32,900	0	377,500	273,100	377,500
Total Upland DNAPLTreated (via *In Situ* Solidification)	0	44,700	0	28,300	210,800	311,000	377,500	0	104,400	0
Total Upland DNAPL Treated or Removed										
Gallons	**0**	**52,600**	**36,200**	**36,200**	**215,300**	**343,900**	**377,500**	**377,500**	**377,500**	**377,500**
Percent of Total Upland DNAPL	**0%**	**14%**	**10%**	**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 Treatment	--	--	--	--	--	--	--	32,200	32,200	32,200
Removal via Hydraulic Dredge[5], with Off-site Disposal	--	--	33,700	33,700	33,700	33,700	35,400	--	--	--
Removal via Hydraulic Dredge[5], with On-site Thermal Treatment	--	--	--	--	--	--	--	35,400	35,400	35,400
Total Sediment DNAPL Removed										
Gallons	**0**	**0**	**59,600**	**33,700**	**59,600**	**59,600**	**67,600**	**67,600**	**67,600**	**67,600**
Percent of Total Sediment DNAPL	**0%**	**0%**	**88%**	**50%**	**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**	**69,900**	**274,900**	**403,500**	**445,100**	**445,100**	**445,100**	**445,100**
Percent of Total	**0%**	**12%**	**22%**	**16%**	**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) PTW sediment in the nearshore area.

5) Hydraulic dredge element primarily targets relatively thin, shallow (<3 feet) PTW 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
PTW = principal threat wastes
QP-U = Quendall Pond-Upland
TD = T-Dock
MC = May Creek
QP-S = Quendall Pond-Sediment
RR = Railroad

Table 7-3 - Summary Evaluation of Alternatives

Quendall Terminals
Renton, Washington

	Remedial Alternative	Threshold Criteria: Protective of Human Health and the Environment?	Threshold Criteria: Complies with ARARs	NCP Balancing Criteria: Long-Term Effectiveness and Permanence	NCP Balancing Criteria: Reduction of Toxicity, Mobility, or Volume through Treatment	NCP Balancing Criteria: Short-Term Effectiveness	NCP Balancing Criteria: Implementability	NCP Balancing Criteria: Estimated Present Worth Cost[2] ($M)
1	No Action (Baseline for Comparison)	No	No	○	○	◑	●	$0
2	Containment	Yes	Yes with TI Waiver (Note 1)	○	○	●	◑	$28
3	Targeted PTW Solidification (RR and MC DNAPL Areas)	Yes	Yes with TI Waiver (Note 1)	○	○	●	◑	$35
4	Targeted PTW Removal (TD, QP-S, and QP-U DNAPL Areas)	Yes	Yes with TI Waiver (Note 1)	◑	○	◑	◑	$46
4a	Targeted PTW Solidification (QP-U DNAPL Area) and Removal (TD DNAPL Area)	Yes	Yes with TI Waiver (Note 1)	◑	○	●	●	$39
5	Targeted PTW Solidification (RR, MC, and QP-U DNAPL Areas and ≥ 4-Foot-Thickness) and Removal (TD and QP-S DNAPL Areas)	Yes	Yes with TI Waiver (Note 1)	◑	◑	◑	◑	$48
6	Targeted PTW Solidification (RR and MC DNAPL Areas and ≥ 2-Foot-Thickness) and Removal (TD, QP-S, and QP-U DNAPL Areas)	Yes	Yes with TI Waiver (Note 1)	◑	◑	◑	◑	$62
7	PTW Solidification (Upland) and Removal (Sediment)	Yes	Yes with TI Waiver (Note 1)	●	●	◑	◑	$82
8	PTW Removal (Upland and Sediment)	Yes	Yes with TI Waiver (Note 1)	●	●	○	○	$146
9	Solidification and Removal of Contaminated Soil and Removal of Contaminated Sediment	Yes	Yes with TI Waiver (Note 1)	●	●	○	○	$280
10	Removal of Contaminated Soil and Sediment	Yes	Yes with TI Waiver (Note 1)	●	●	○	○	$425

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 2015 dollars, and were calculated using a discount factor of 1.4 percent. The itemized estimates are provided in Appendix D.

[3] The short-term effectiveness of Alternative 7 is rated as "moderate" to differentiate it from Alternatives 8 through 10, which have substantially greater short-term impacts, particularly in the upland.

Legend:

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

Abbreviations:

DNAPL = dense non-aqueous phase liquid
MC = May Creek
PTW = principal threat wastes
QP-S = Quendall Pond-Sediment
QP-U = Quendall Pond-Upland
RR = Railroad
TD = T-Dock

Table 8-1 - Summary of 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 (Note 2)	No	--	--	--	--	Capital	OM&M	Total
2	Containment	Yes	Yes with TI Waiver (Note 3)	○	○	●	◑	20	8.2	$28
3	Targeted PTW Solidification (RR and MC DNAPL Areas)	Yes	Yes with TI Waiver (Note 3)	○	○	●	◑	25	10	$35
4	Targeted PTW Removal (TD, QP-S, and QP-U DNAPL Areas)	Yes	Yes with TI Waiver (Note 3)	◑	○	◑	◑	41	5.2	$46
4a	Targeted PTW Solidification (QP-U DNAPL Area) and Removal (TD DNAPL Area)	Yes	Yes with TI Waiver (Note 3)	◑	○	●	●	33	5.6	$39
5	Targeted PTW Solidification (RR, MC, and QP-U DNAPL Areas and ≥ 4-Foot-Thickness) and Removal (TD and QP-S DNAPL Areas)	Yes	Yes with TI Waiver (Note 3)	◑	◑	◑	◑	43	4.5	$48
6	Targeted PTW Solidification (RR and MC DNAPL Areas and ≥ 2-Foot-Thickness) and Removal (TD, QP-S, and QP-U DNAPL Areas)	Yes	Yes with TI Waiver (Note 3)	◑	◑	◑	◑	58	4.5	$62
7	PTW Solidification (Upland) and Removal (Sediment)	Yes	Yes with TI Waiver (Note 3)	●	●	◑	◑	79	2.9	$82
8	PTW Removal (Upland and Sediment)	Yes	Yes with TI Waiver (Note 3)	●	●	○	○	143	2.9	$146
9	Solidification and Removal of Contaminated Soil and Removal of Contaminated Sediment	Yes	Yes with TI Waiver (Note 3)	●	●	○	○	277	2.9	$280
10	Removal of Contaminated Soil and Sediment	Yes	Yes with TI Waiver (Note 3)	●	●	○	○	397	28	$425

Notes:

[1] Estimated mid-range present worth costs are in 2015 dollars, and were calculated using a discount factor of 1.4 percent. The itemized estimates are provided in Appendix D.

[2] Because this alternative does not satisfy the Threshold Criteria, it is not carried forward in the Balancing Criteria comparison.

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

[4] The short-term effectiveness of Alternative 7 is rated as "moderate" to differentiate it from Alternatives 8 through 10, which have substantially greater short-term impacts, particularly in the upland.

Abbreviations:

DNAPL = dense non-aqueous phase liquid
MC = May Creek
PTW = principal threat wastes
QP-S = Quendall Pond-Sediment
QP-U = Quendall Pond-Upland
RR = Railroad
TD = T-Dock

Legend:

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

FIGURES

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

Quendall Terminals Site Location and Vicinity Map

Quendall Terminals Feasibility Study Report
Renton, Washington

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

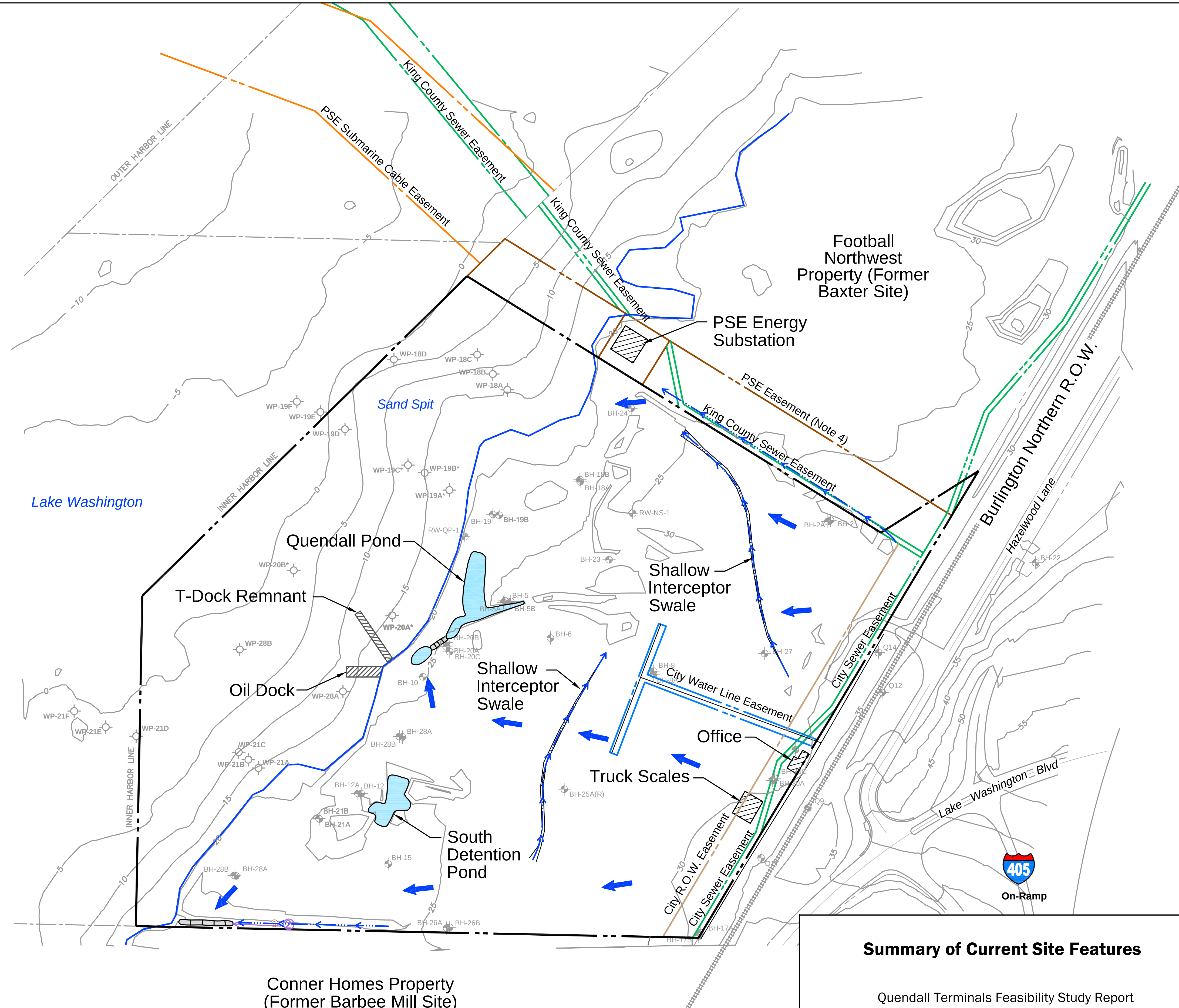
Notes:

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.



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

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

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- Stormwater Drainage Ditch with Silt Fence and/or Rock Check Dams (Approximate Location)
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Notes:

1) Vertical datum is North American Vertical Datum 1988 (NAVD 88).

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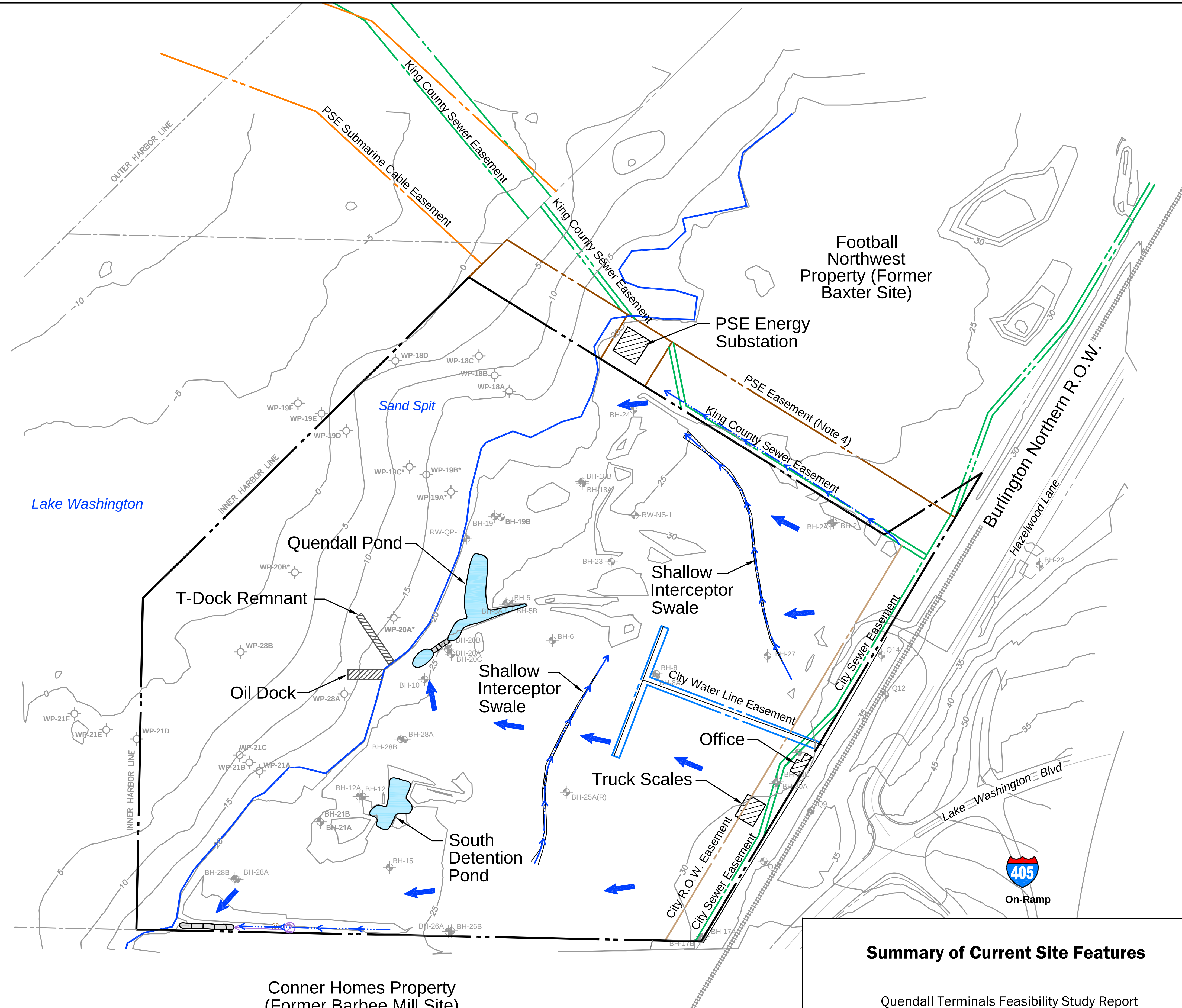
3) "City" refers to City of Renton in easement labels.

4) The southern boundary of the PSE Easement is the northern boundary of the Quendall Property.

N

0 200 400

Feet

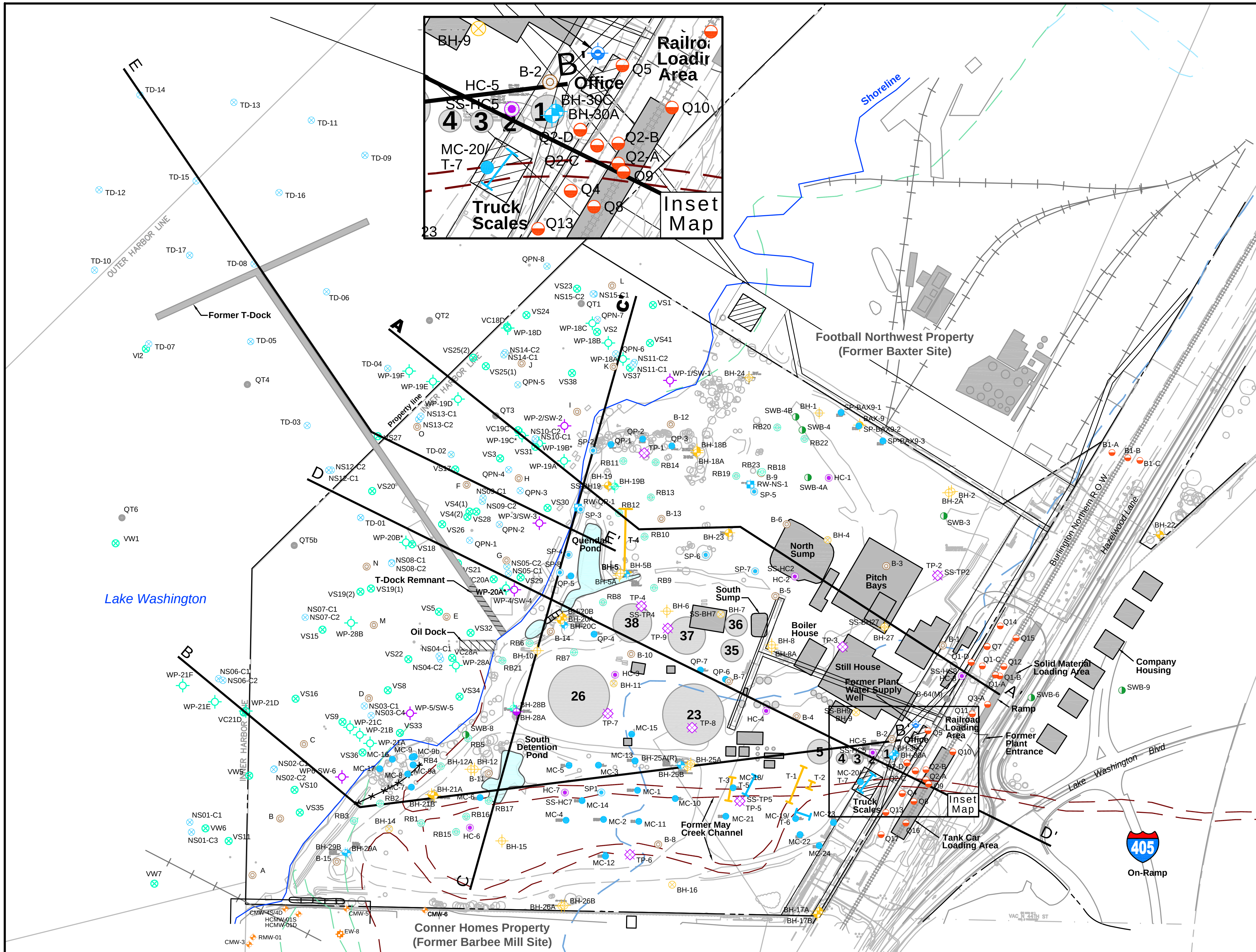


Summary of Current Site Features

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

N
0 200 400
Feet
Exploration Map

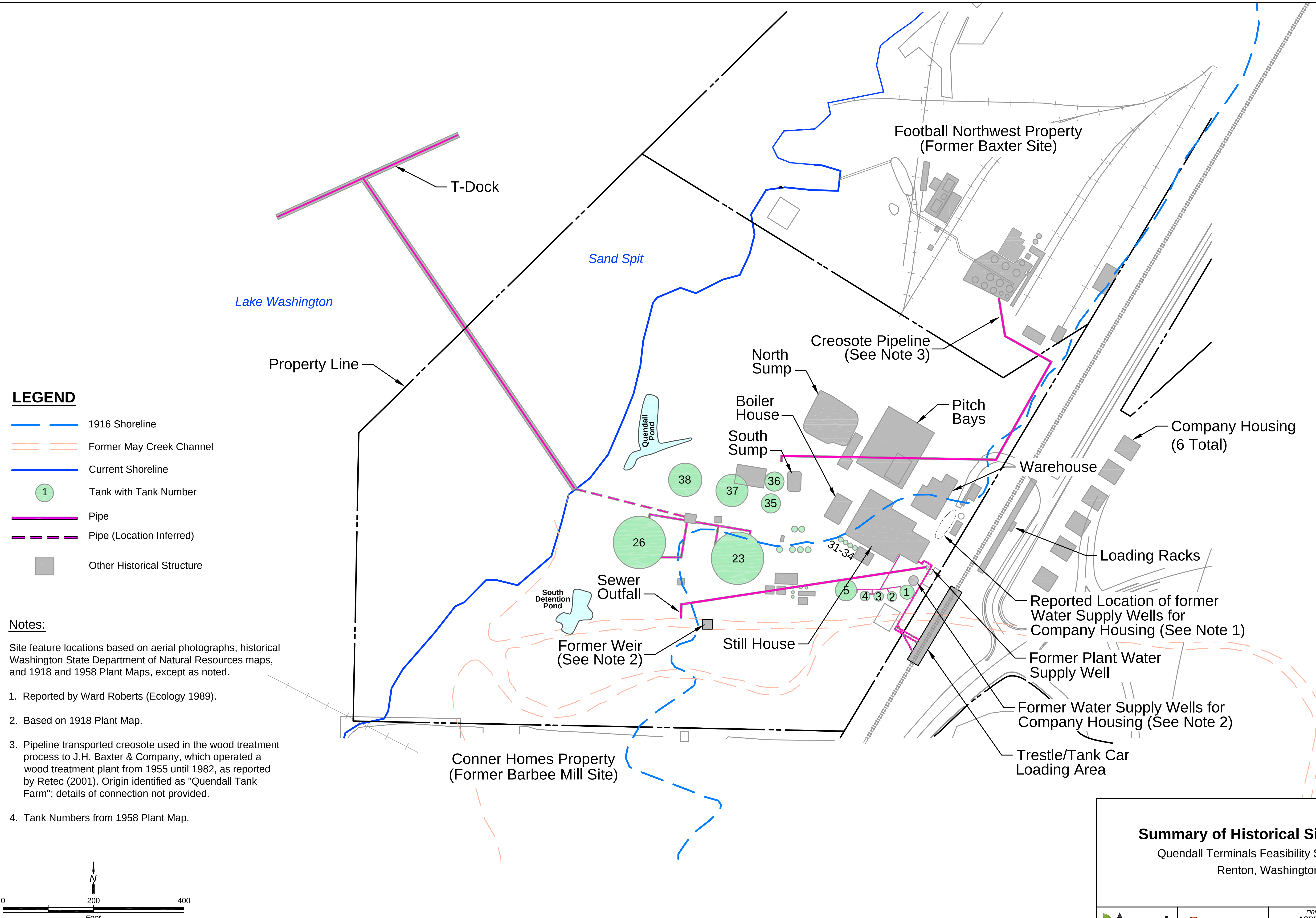
N
0 100 200
Feet
Inset Map

Exploration and Cross Section Location Map

Quendall Terminals Feasibility Study Report
Renton, Washington

Aspect CONSULTING | ARCADIS | FIRM: ASPECT | FIGURE NO.
DRAWN BY: JJP/DAH/SCC | 3-1

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



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.

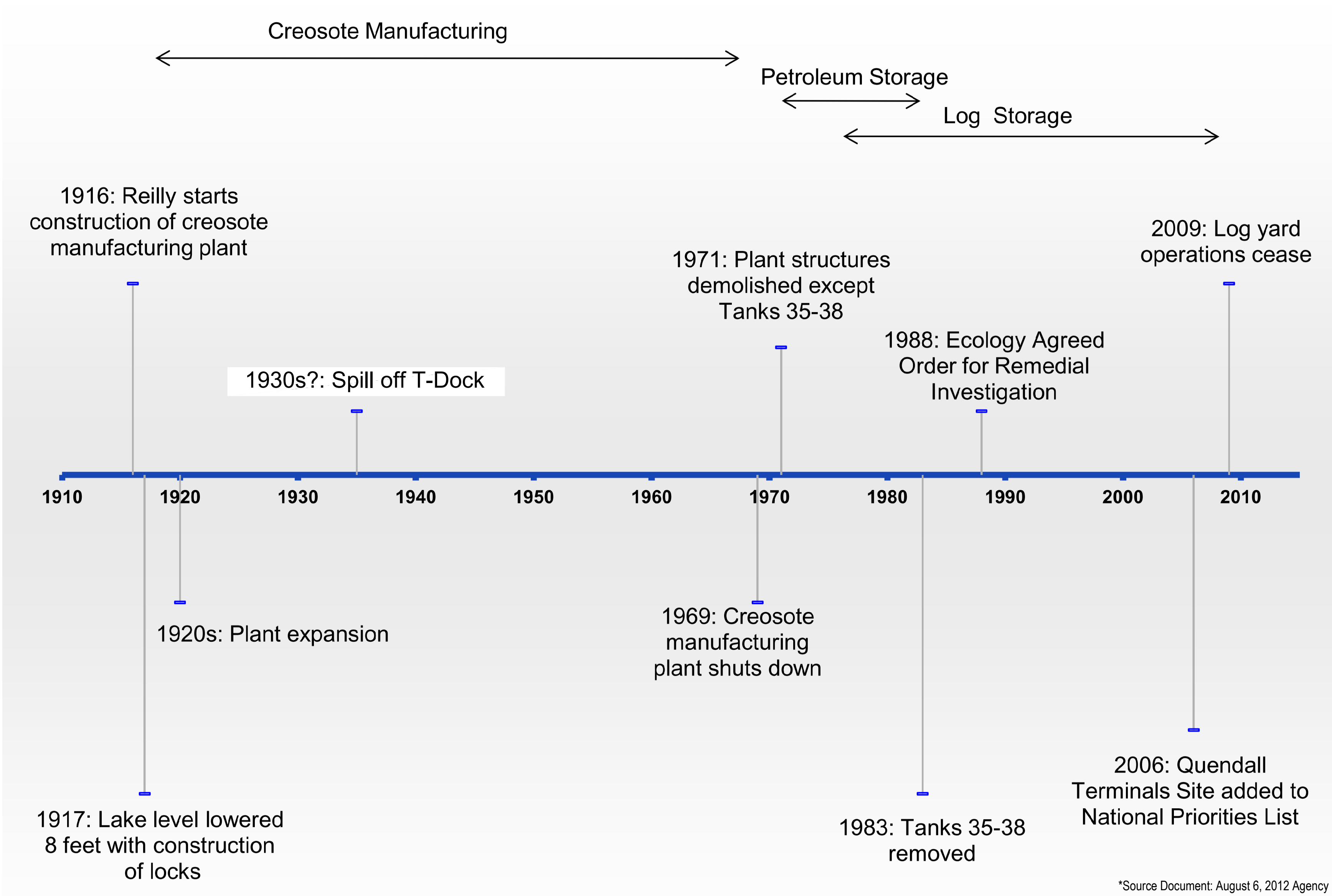
Summary of Historical Site Features

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\2015-09 Final\020027-32.dwg Figure 3-2 (11x17) || Coordinate System: NAD 1983 State Plane Washington North FIPS 4601 Feet || Date Saved: Sep 21, 2015 10:01am || User: scudd



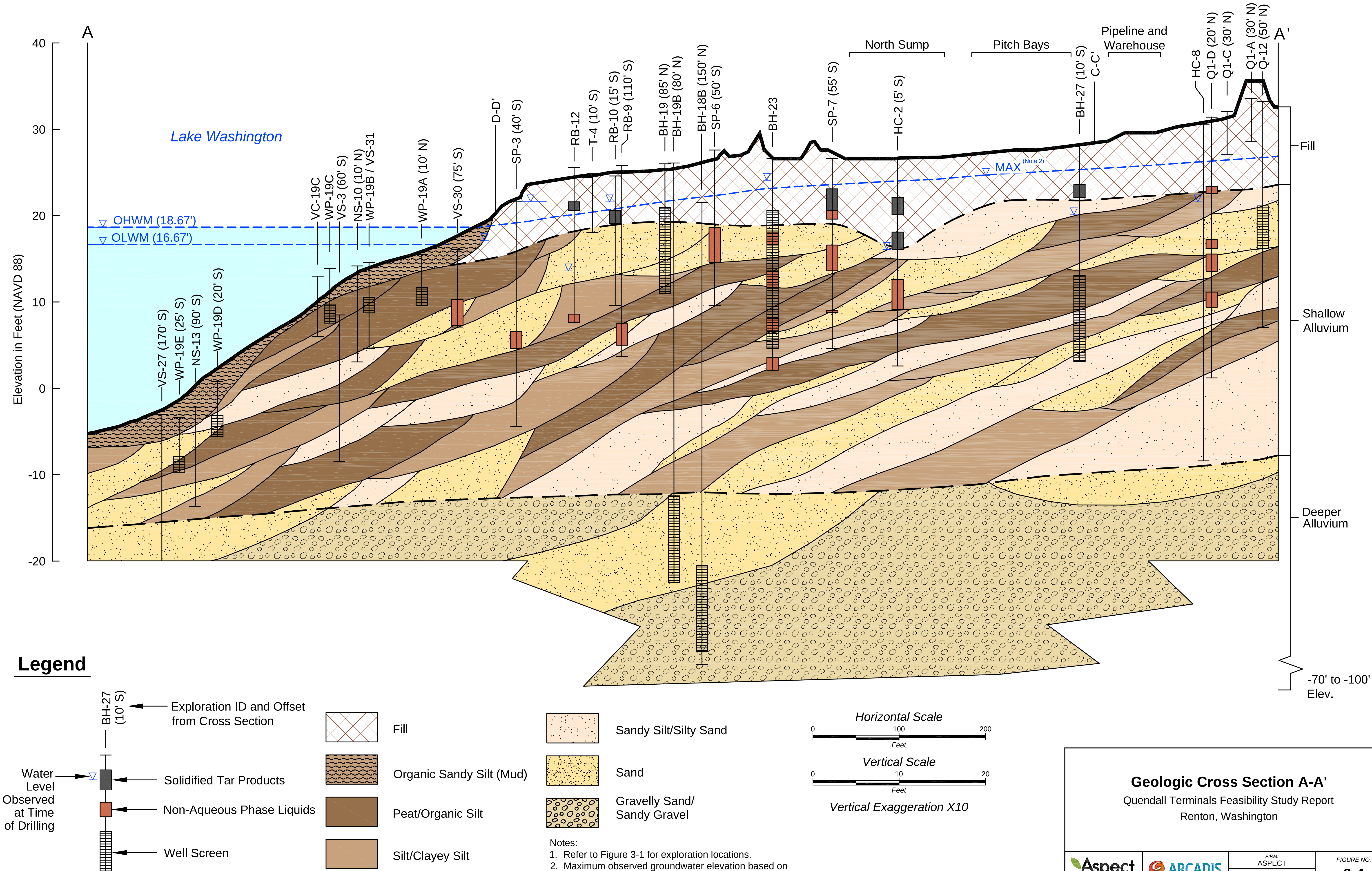
*Source Document: August 6, 2012 Agency Review Draft FS

Timeline of Site Operations

Quendall Terminals Feasibility Study Report
Renton, Washington

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



Notes:
1. Refer to Figure 3-1 for exploration locations.
2. Maximum observed groundwater elevation based on periodic monitoring of shallow aquifer monitoring wells.

Geologic Cross Section A-A'

Quendall Terminals Feasibility Study Report
Renton, Washington

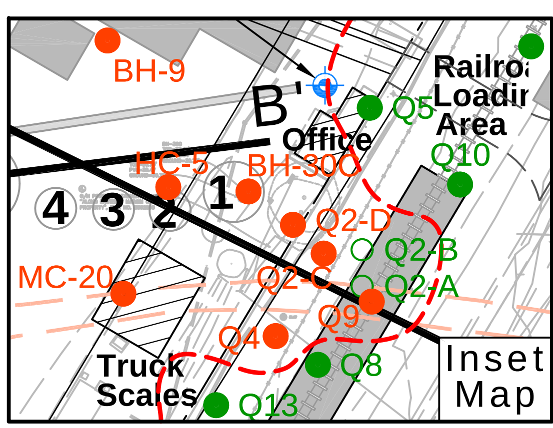
Aspect CONSULTING | ARCADIS | FIRM: ASPECT | DRAWN BY: JJP/PMB/SCC | FIGURE NO. 3-4

Legend

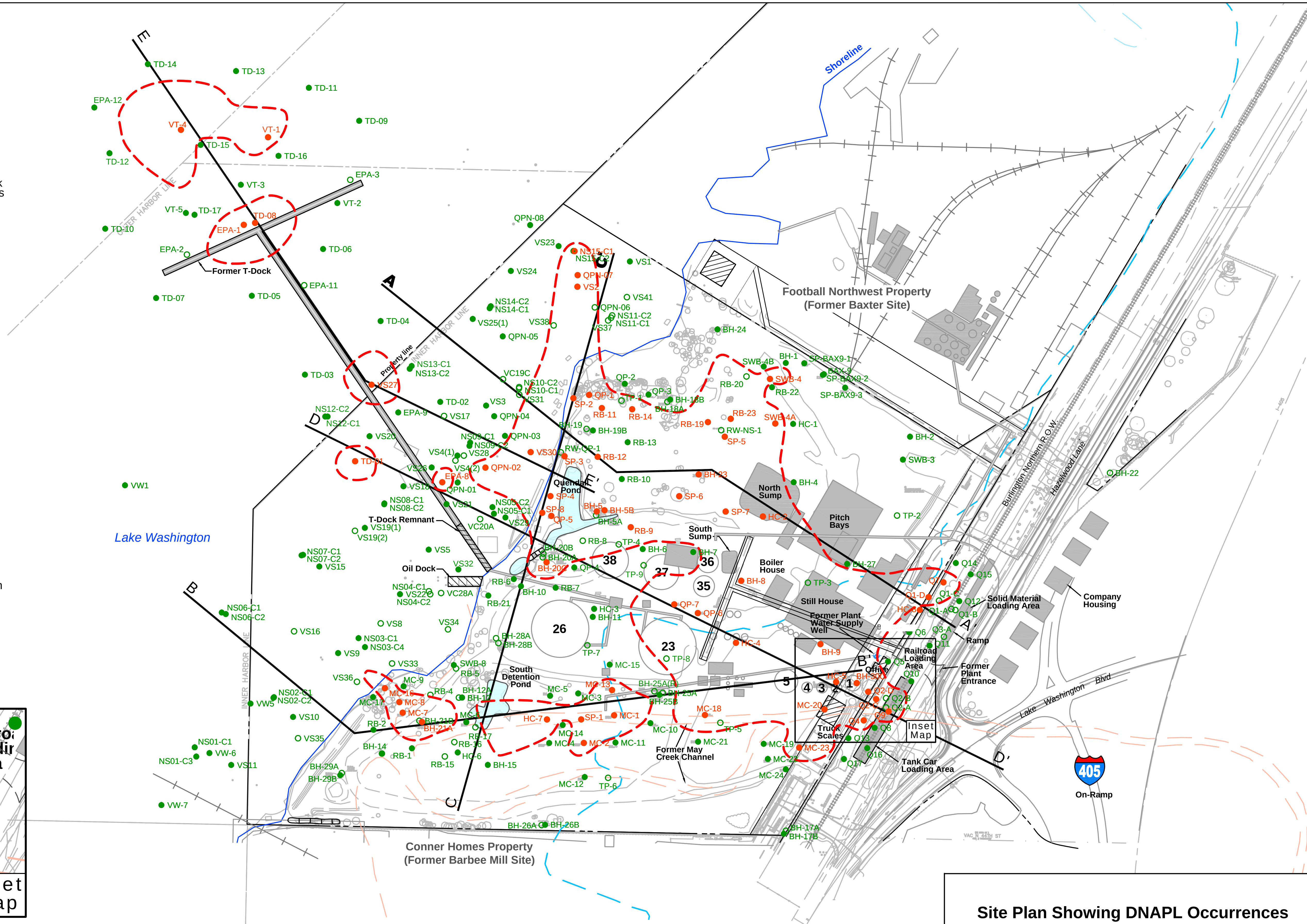
TD-08 ●	Boring with DNAPL
VT-3 ●	Boring with no DNAPL
EPA-2 ○	Boring with no DNAPL but base is above adjacent occurrences, or lack of adequate soil sample descriptions
(red dashed line)	Estimated Extent of DNAPL
	Detention Pond
	Existing Structure
23	Historical Tank with Tank Number
	Other Historical Feature
(blue line)	Current Shoreline
(dashed light blue line)	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).



0 100 200
Feet
Inset Map



0 200 400
Feet
Site Plan

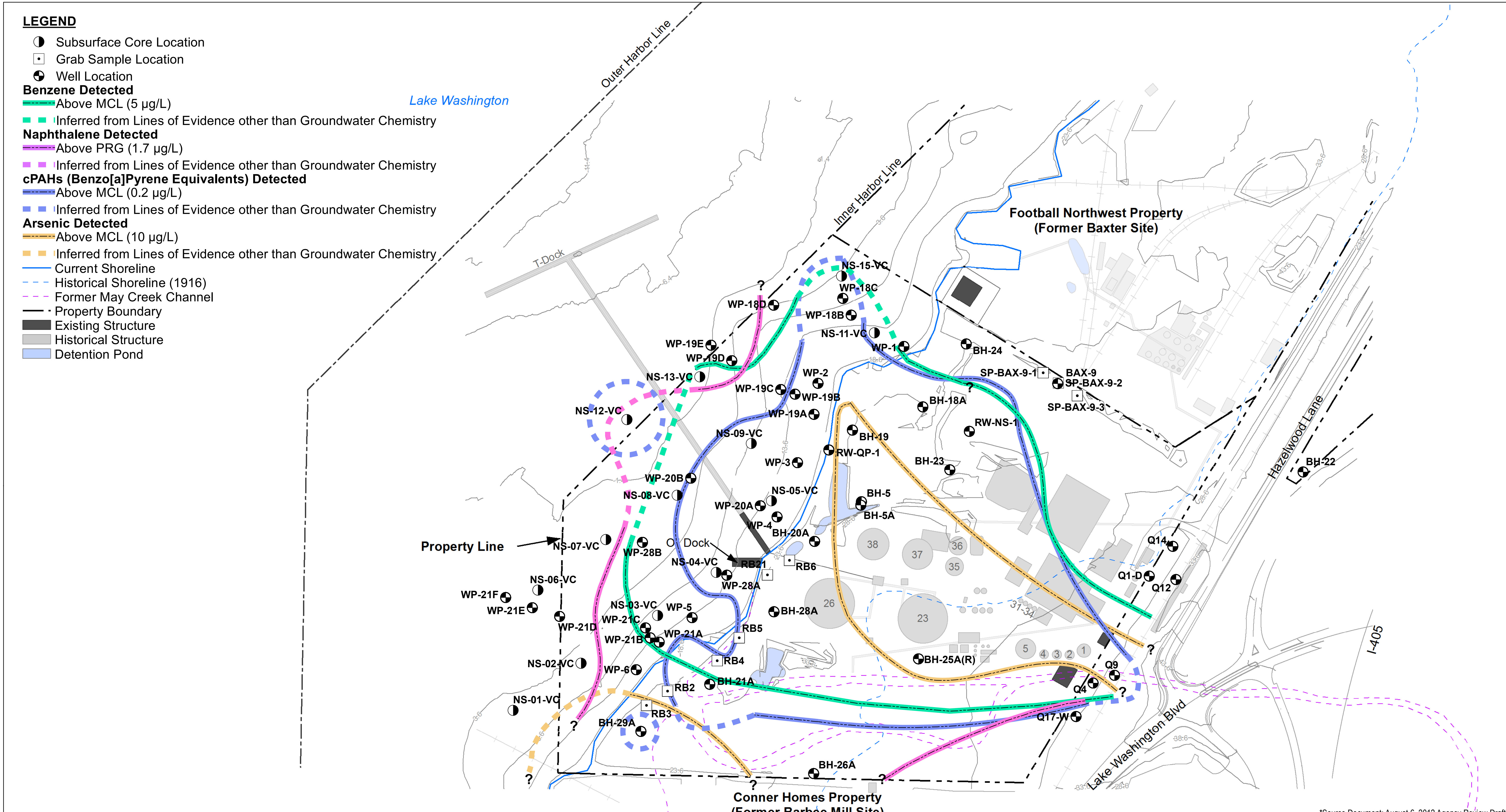
Site Plan Showing DNAPL Occurrences

Quendall Terminals Feasibility Study Report
Renton, Washington

Aspect CONSULTING | ARCADIS

FIRM: ASPECT
DRAWN BY: PMB/SCC
FIGURE NO. 3-5

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



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 (lower PRG based on cancer risk of 10^{-5}). Estimated extents do not consider dispersion.

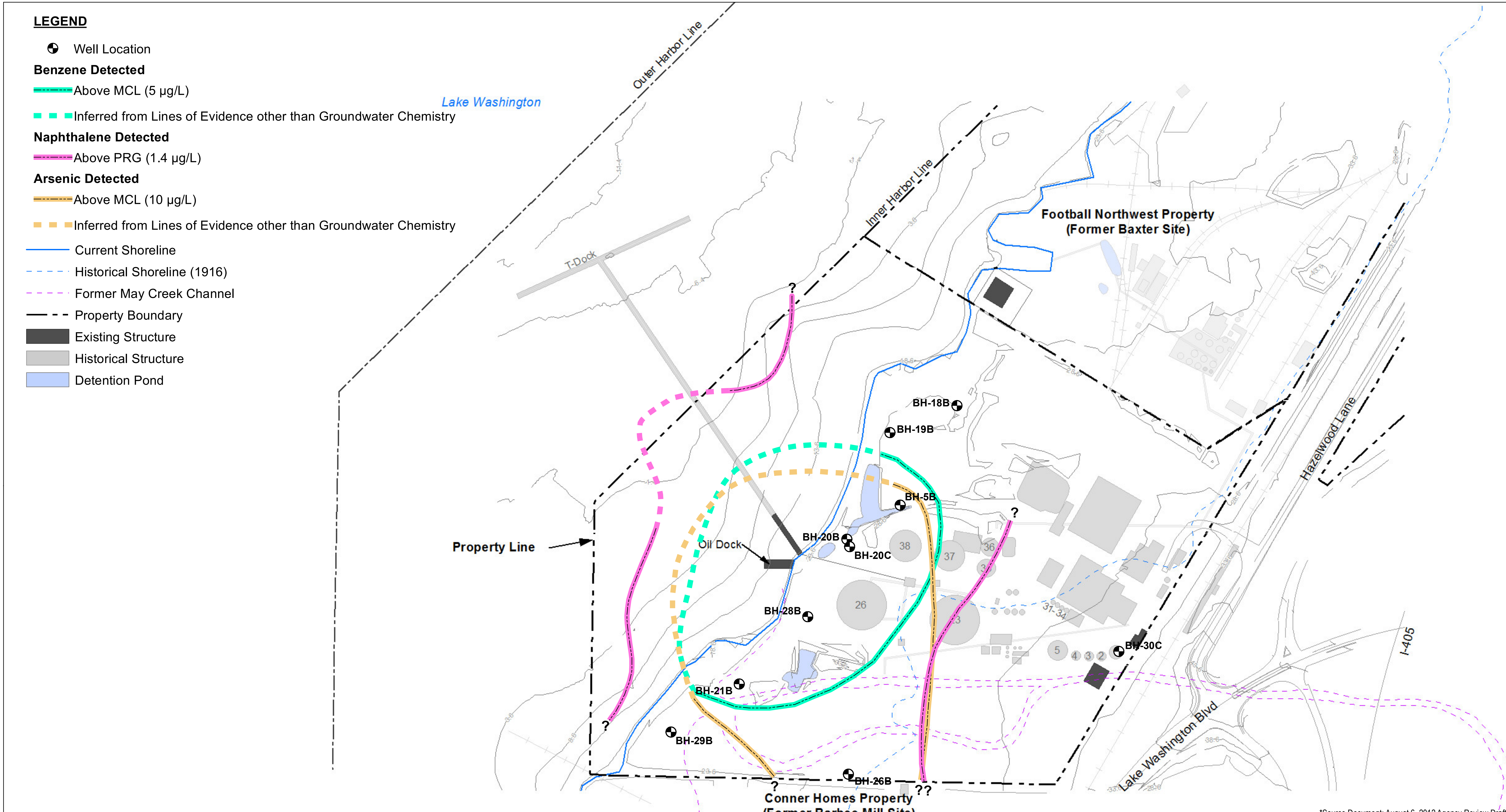
N

0 200 400
Feet

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



*Source Document: August 6, 2012 Agency Review Draft FS

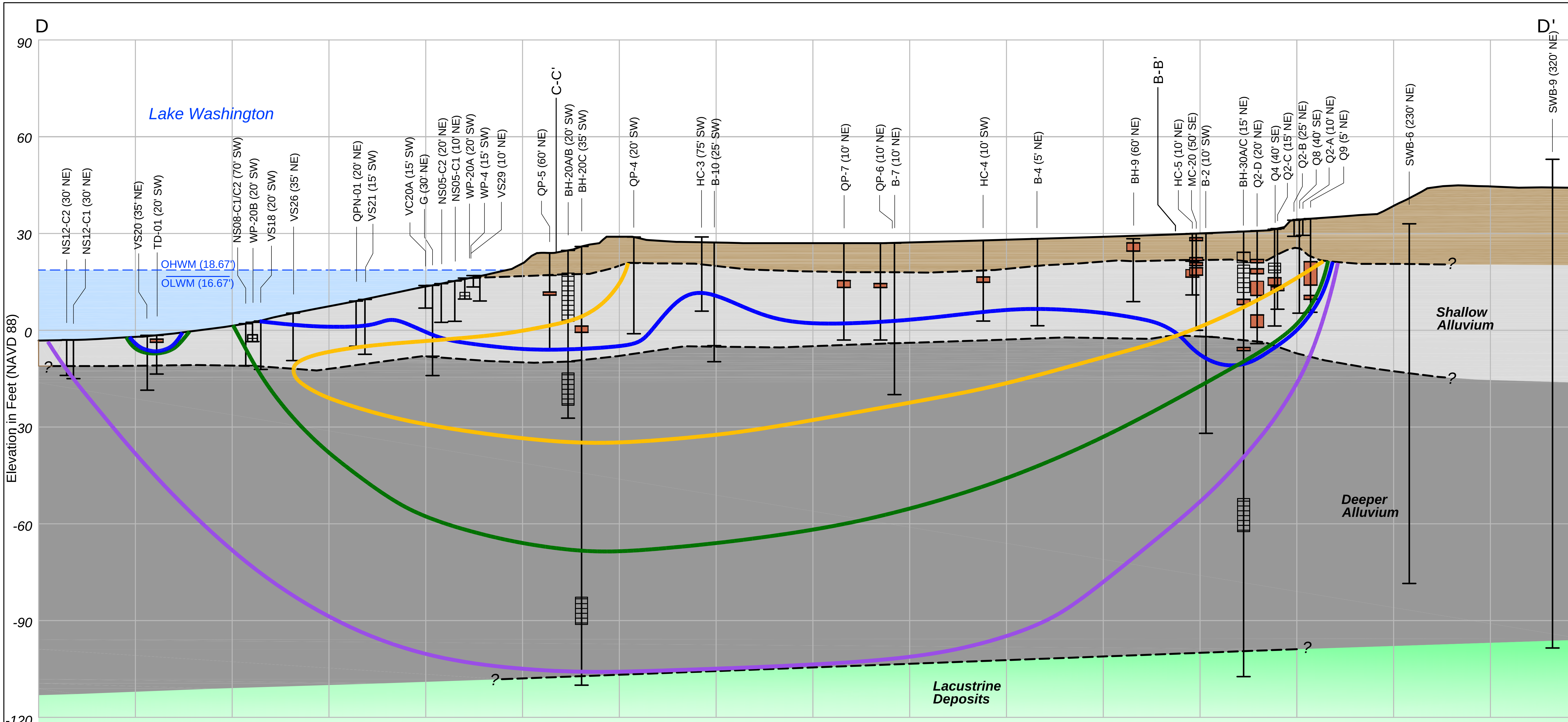
Notes:
1. Contour intervals are 5 ft, NAVD 88.
2. cPAHs (Benzo[a]pyrene Equivalent) have not been detected above the PRG in wells completed in the Deep Aquifer.
3. See Figures 5.2-2, 5.2-9, 5.2-15, and 5.2-17 of the RI Report for basis of approximate extents (Anchor QEA and Aspect 2012). Naphthalene 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

Approximate Extents of Benzene, Naphthalene, and Arsenic in the Deep Aquifer
Quendall Terminals Feasibility Study Report
Renton, Washington

FIRM: ANCHOR QEA
DRAWN BY: EBP
FIGURE NO. 3-7



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)

Horizontal Scale: 0, 100, 200 Feet

Vertical Scale: 0, 30, 60 Feet

Vertical Exaggeration X3.33

Notes:

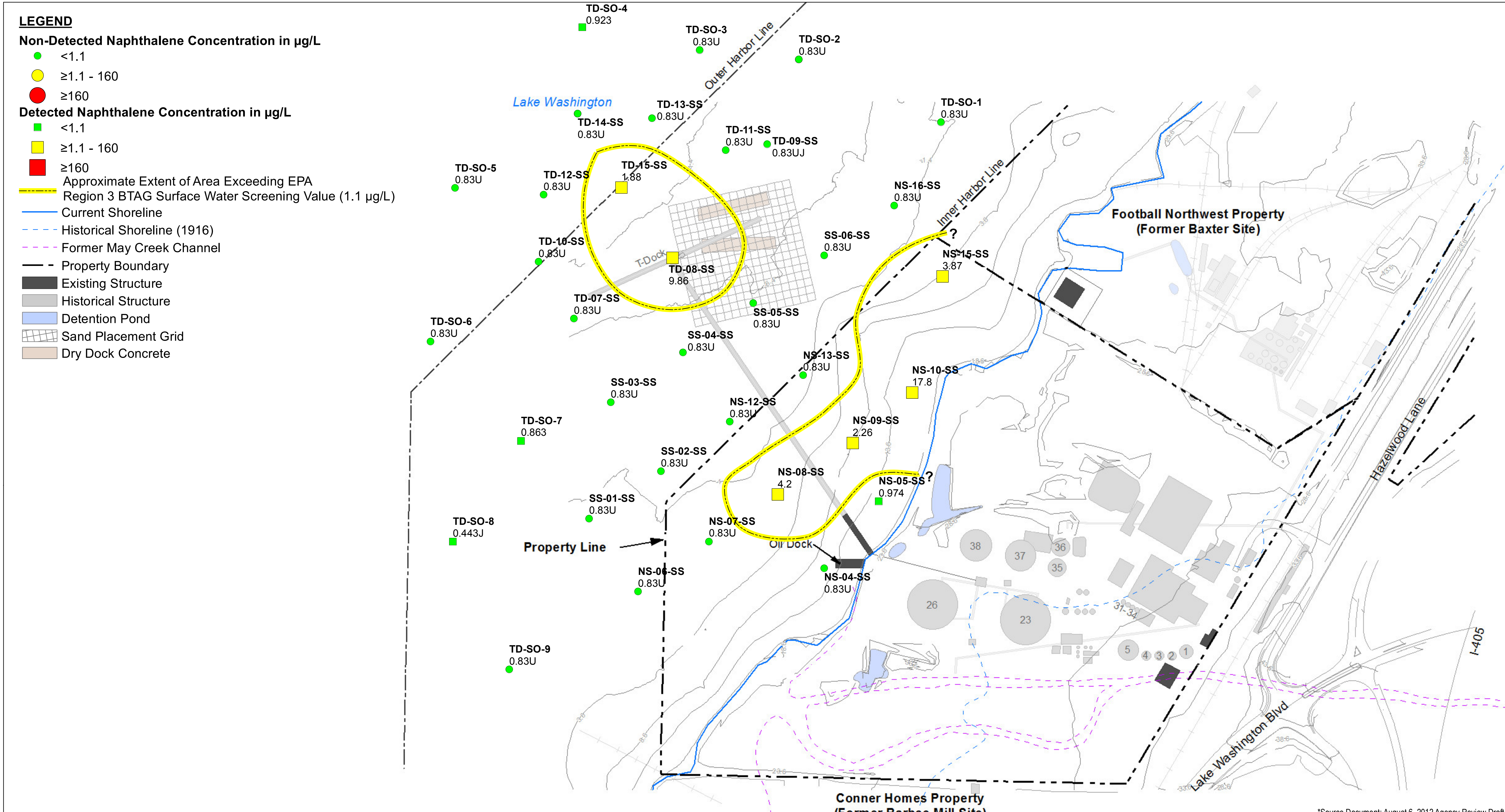
1. Refer to Figure 3-1 for exploration locations.
2. Vertical extents generally based on groundwater data from wells BH-20A, BH-20B, and BH-20C (Figures 5.2-1, 5.2-2, 5.2-8, 5.2-9, 5.2-14, 5.2-15, 5.2-16, and 5.2-17 of the RI Report (Anchor QEA and Aspect 2012)) and groundwater grab samples at BH-20C 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.

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

Quendall Terminals Feasibility Study Report

Renton, Washington

Aspect Consulting | ARCADIS | FIRM: ASPECT | DRAWN BY: JJP/DAH/SCC | FIGURE NO. 3-8



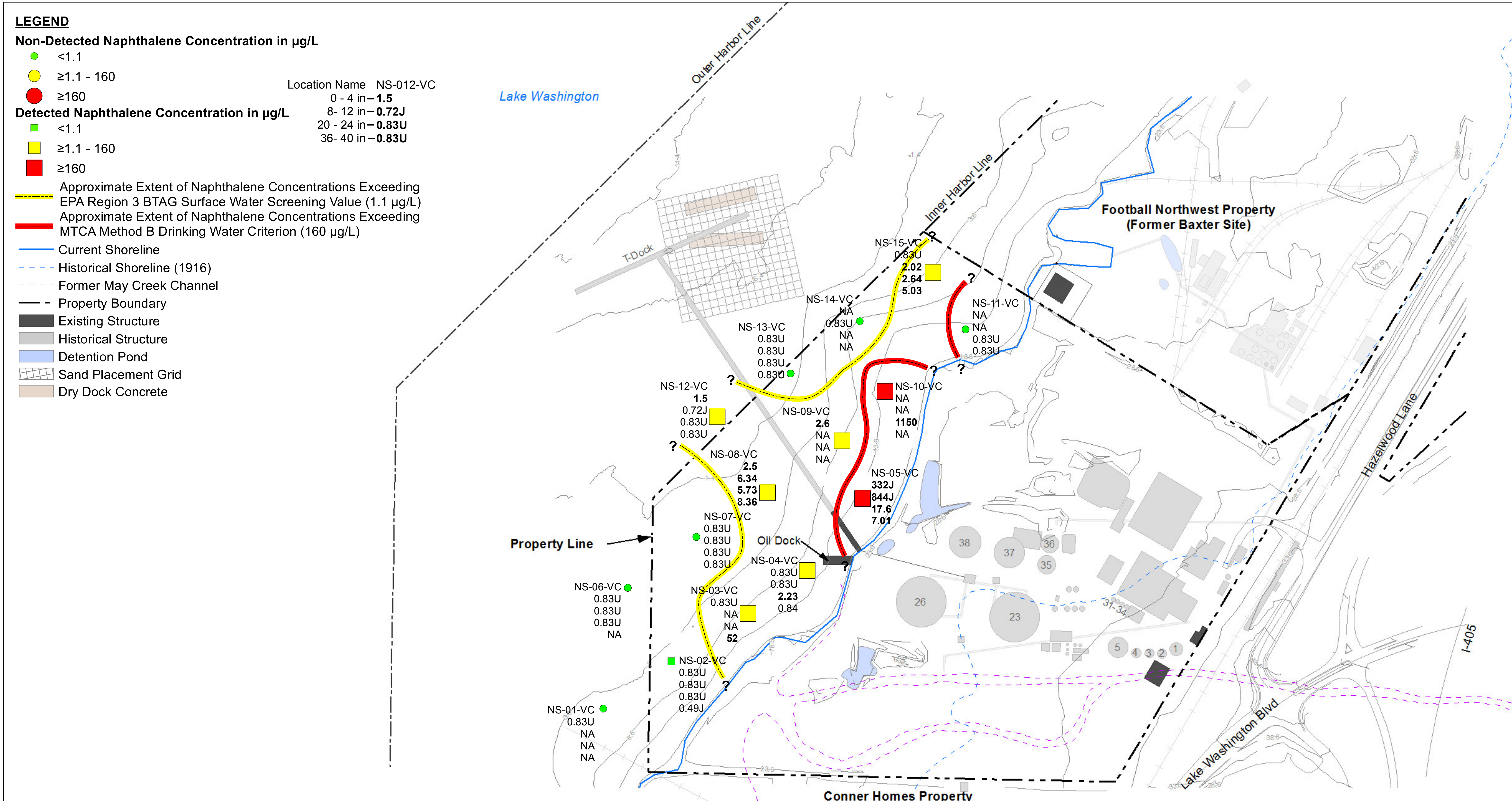
Notes:
1. Contour Intervals are 5 ft, NAVD 88.
2. U = Non-detect
3. J = Estimated value
4. The PRG screening level for naphthalene in sediment porewater is the EPA Region 3 Biological Technical Assistance Group (BTAG) Surface Water Screening Value of 1.1 micrograms per liter (µg/L). Exceedances of this screening level are shown on this figure.

N

0 200 400
Feet

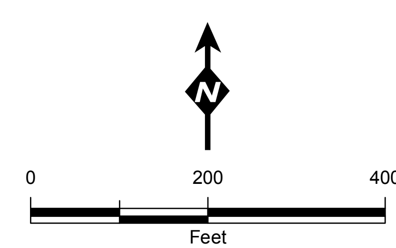
Surface Sediment Porewater Naphthalene Concentrations
Quendall Terminals Feasibility Study Report
Renton, Washington

Aspect CONSULTING | ANCHOR QEA | FIRM: ANCHOR QEA DRAWN BY: EBP | FIGURE NO. **3-9**



*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.



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

LEGEND

Detected Organic Carbon Normalized cPAH (B[a]P Equivalent) Concentration in mg/kg-OC

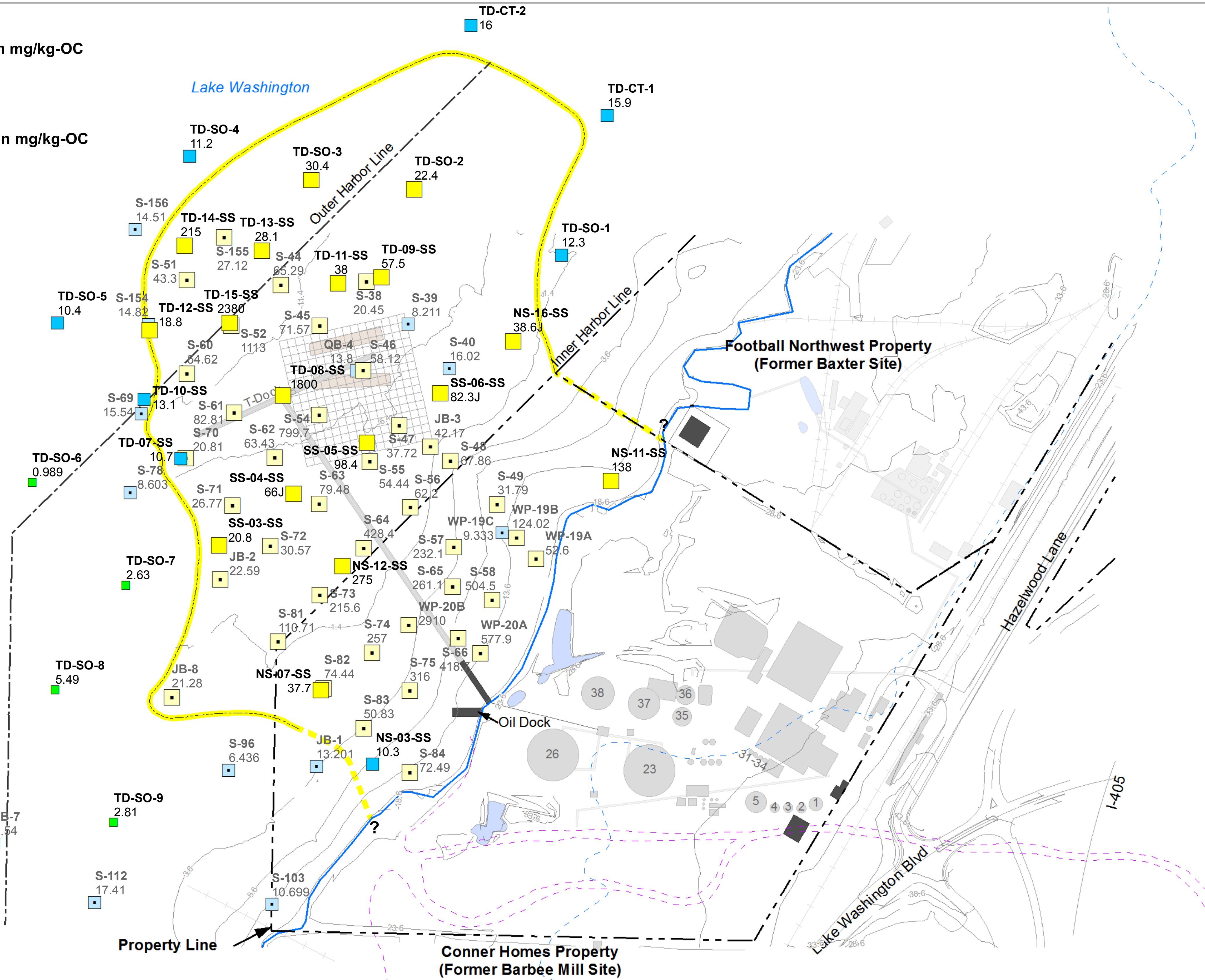
- <6.2
- ≥6.2 - 17.5
- ≥17.5

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)

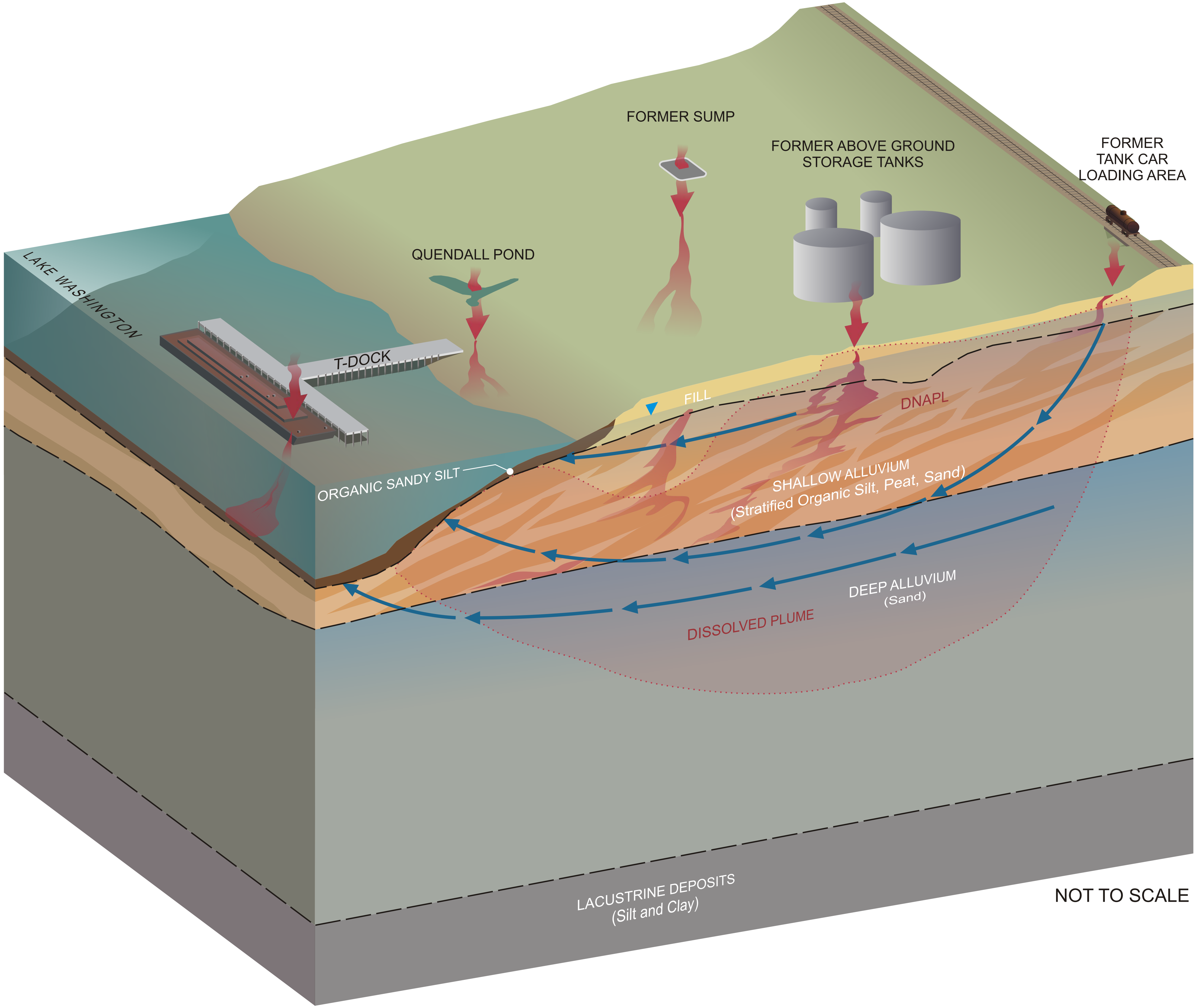


Notes:
1. Contour intervals are 5 ft, NAVD 88.
2. U = Non-Detect
3. J = Estimated Value
4. The organic carbon normalized PRG screening level for cPAHs in surface bulk sediment of 6.2 milligrams per kilogram (mg/kg)-OC is the 90 percent upper confidence limit on the mean of site-specific background samples 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).

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



NOT TO SCALE

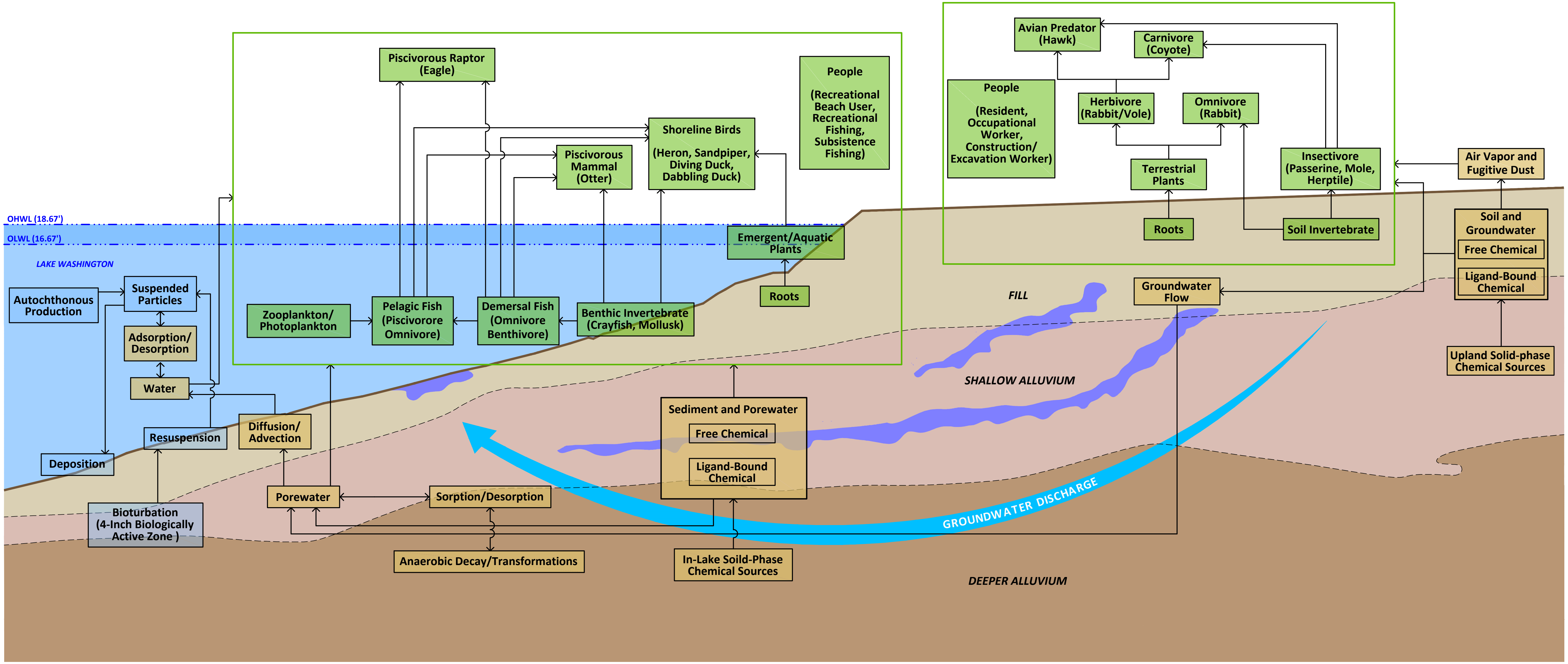
*Source Document: August 6, 2012 Agency Review Draft FS

Graphic Illustration of the DNAPL Conceptual Site Model

Quendall Terminals Feasibility Study Report
Renton, Washington

Aspect CONSULTING	ANCHOR QEA	FIRM: ANCHOR QEA DRAWN BY: EBP	FIGURE NO. 3-12

GIS Path: T:\projects_8\Quendall\Quendall Draft\3-12 Graphic Illustration of the DNAPL.mxd || Coordinate System: NAD 1983 StatePlane Washington North FIPS 4601 Feet || Date Saved: 9/22/2015 || User: ecrumbaker || Print Date: 9/22/2015



LEGEND:

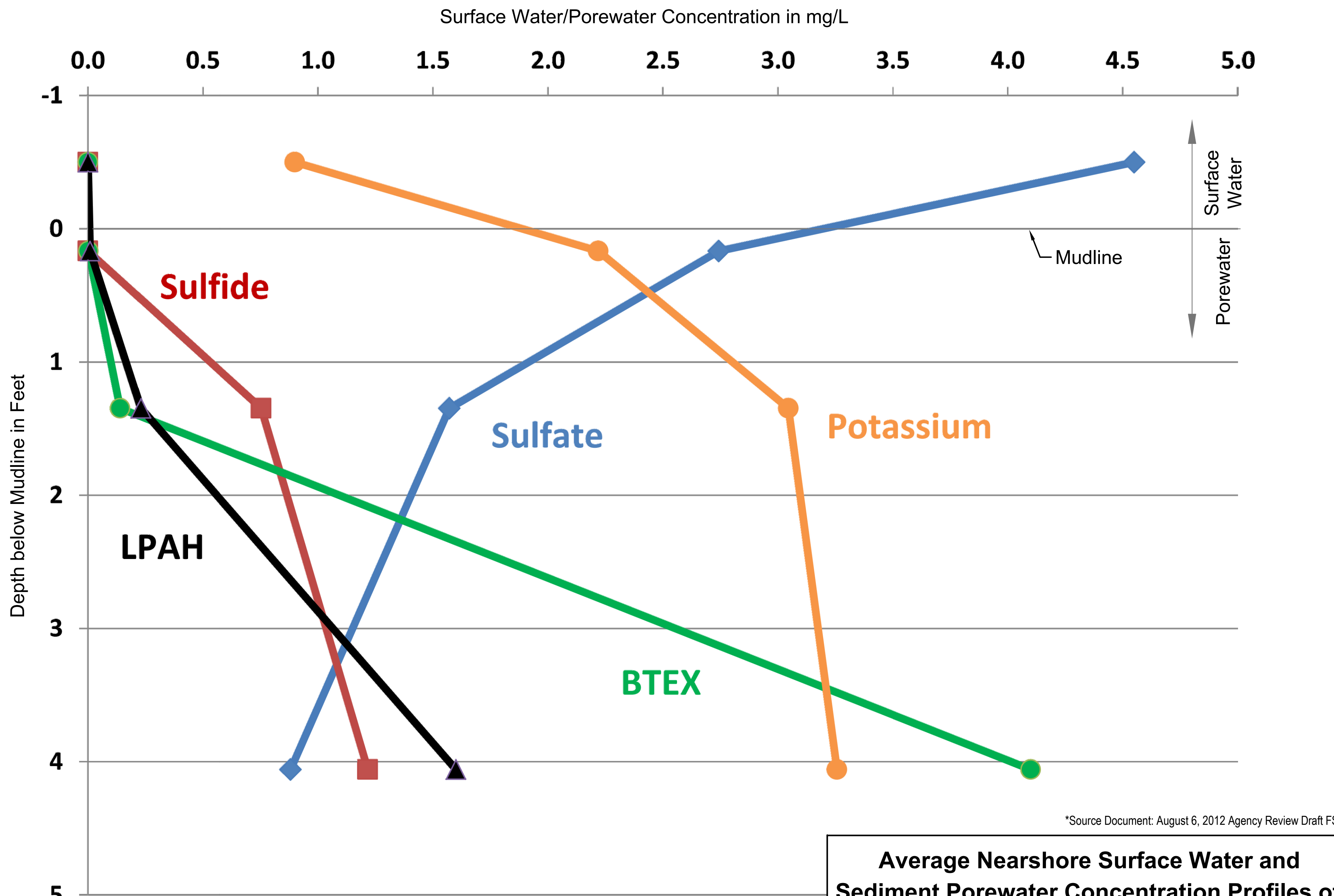
- Ground Surface
- Inferred Geologic Contact
- Shallow Alluvium
- Deeper Alluvium
- DNAPL
- Fill
- Hydrodynamics and Sediment Dynamics
- Biological Fate and Transport (Predation/Bioaccumulation/Biomagnification)
- Chemical Fate and Transport

*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

Aspect CONSULTING | ANCHOR QEA | FIRM: ANCHOR QEA | DRAWN BY: EBP | FIGURE NO. 3-13



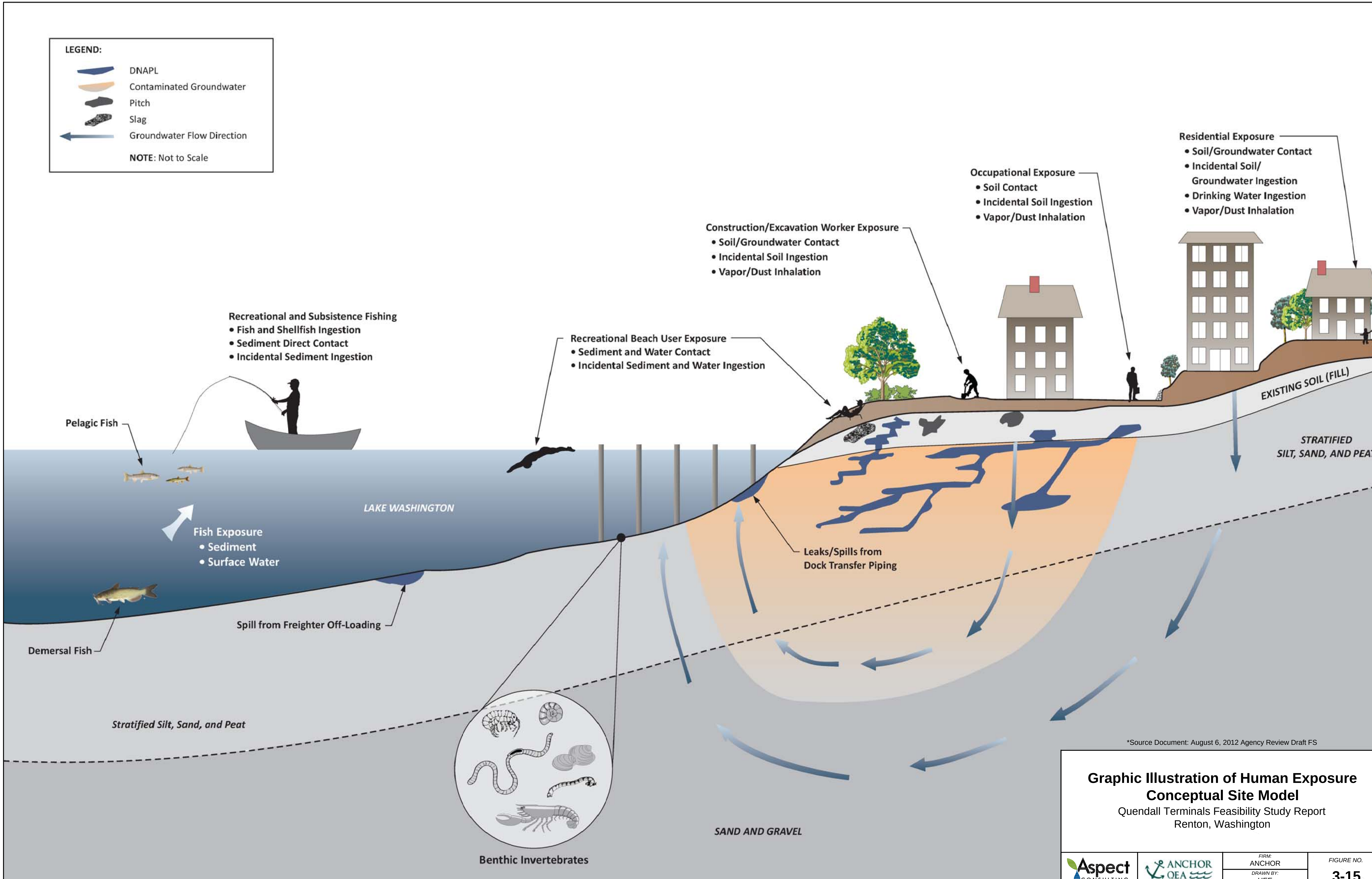
*Source Document: August 6, 2012 Agency Review Draft FS

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

Quendall Terminals Feasibility Study Report

Renton, Washington

Aspect CONSULTING	ANCHOR QEA	FIRM: ANCHOR QEA DRAWN BY: DJH	FIGURE NO. 3-14

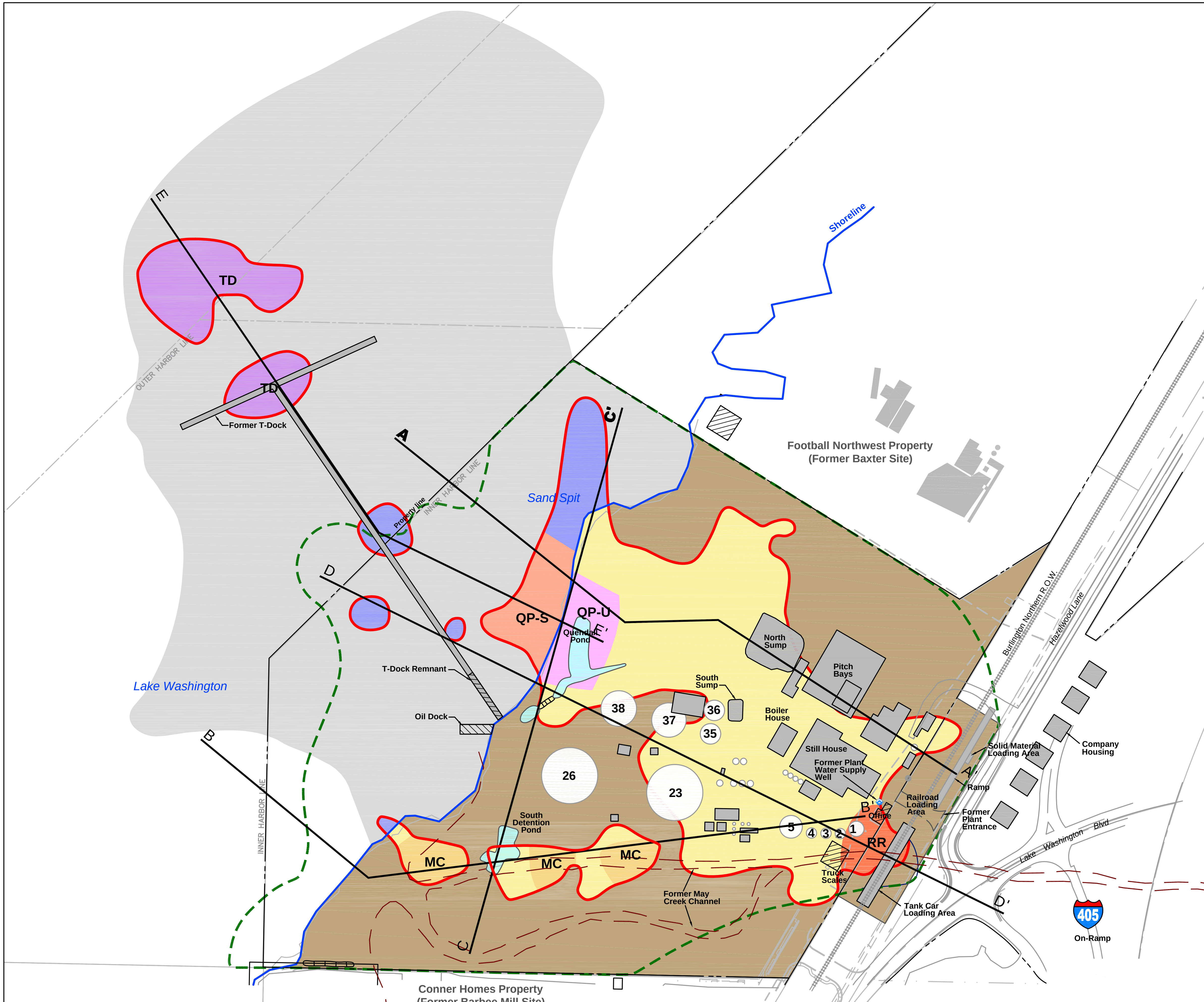


*Source Document: August 6, 2012 Agency Review Draft FS

Graphic Illustration of Human Exposure Conceptual Site Model
Quendall Terminals Feasibility Study Report
Renton, Washington

Aspect CONSULTING | ANCHOR QEA | FIRM: ANCHOR | DRAWN BY: HEE | FIGURE NO. 3-15

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

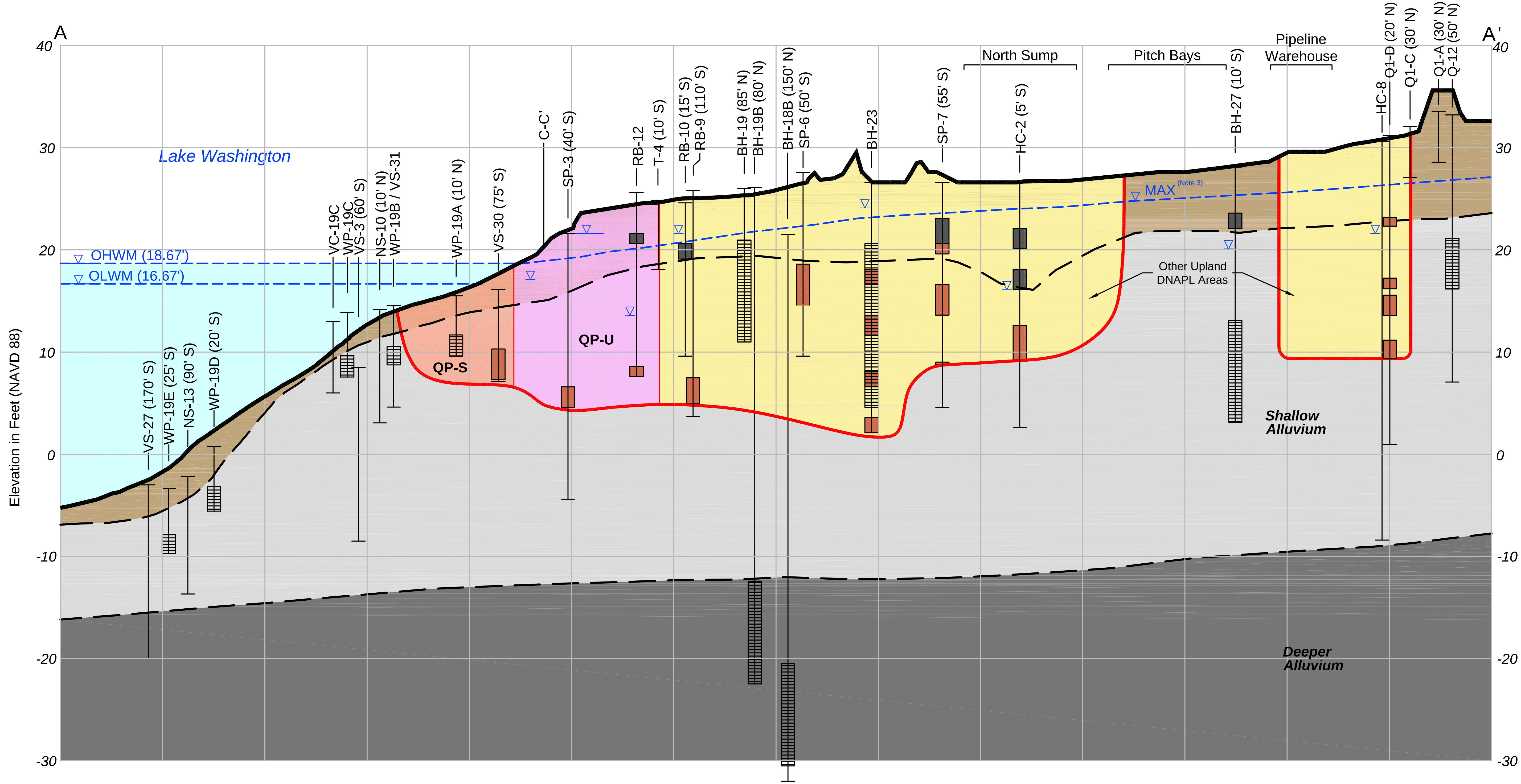
1. Refer to Section 4.4 for descriptions of the areas identified in the Legend.
2. Refer to Figure 3-5 for notes regarding delineation of DNAPL.

Areas Targeted for Remedial Action

Quendall Terminals Feasibility Study Report
Renton, Washington

Aspect CONSULTING | ARCADIS | FIRM: ASPECT | DRAWN BY: JJP/DAH/SCC | FIGURE NO. 4-1

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

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 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

Horizontal Scale

0 100 200

Feet

Vertical Scale

0 10 20

Feet

Vertical Exaggeration x10

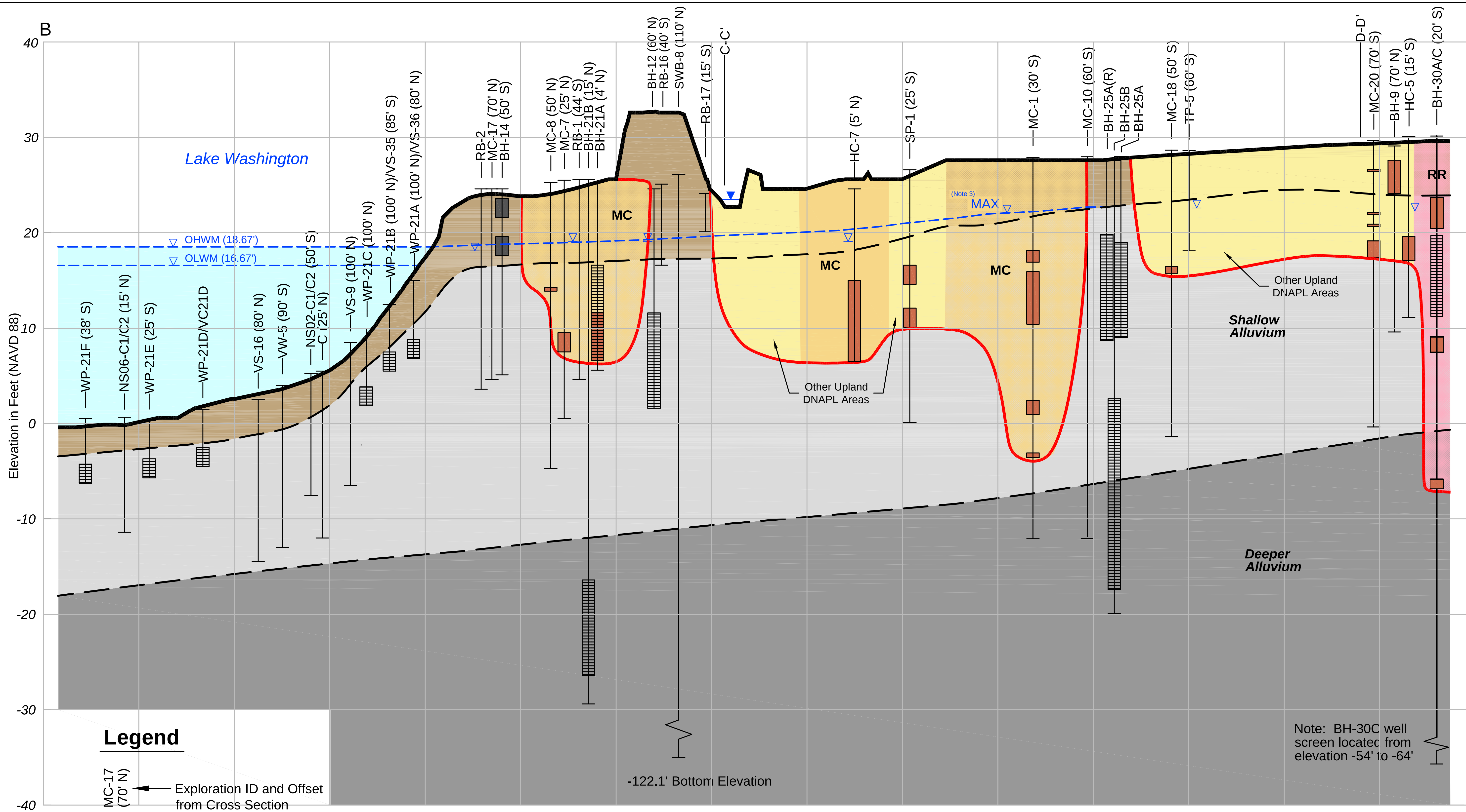
Notes:
1. Refer to Figure 3-1 for exploration locations.
2. Figure 4-1 Notes and Legend also apply to this figure.
3. Maximum observed groundwater elevation based on periodic monitoring of shallow aquifer monitoring wells.

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



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

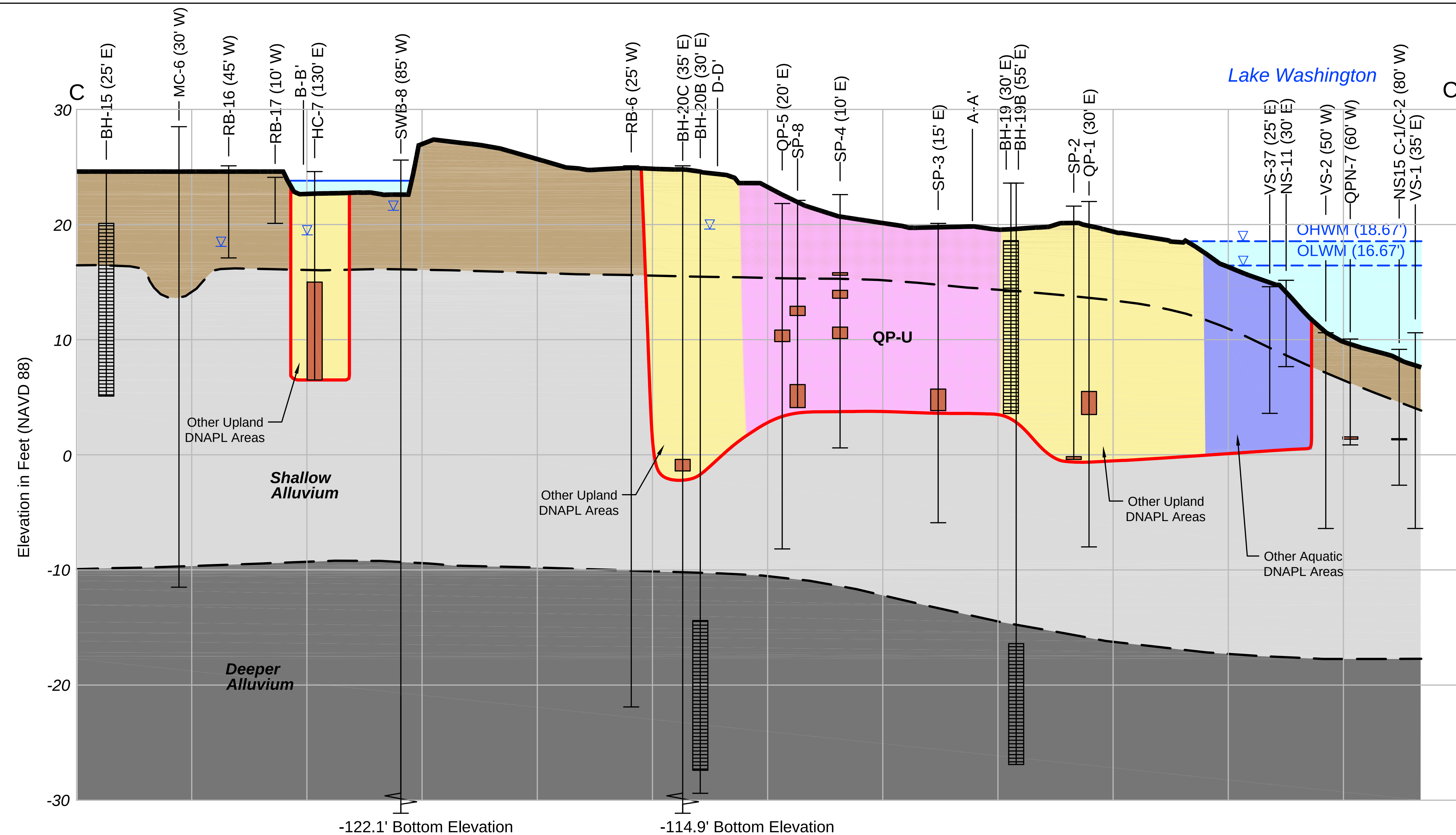
0 10 20
Feet

Vertical Exaggeration x10

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



Legend

BH-15 (25' E) — Exploration ID and Offset from Cross Section

Water Level Observed at Time of Drilling

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

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. Figure 4-1 Notes and Legend also apply to this figure.

Estimated Extent of DNAPL along Cross Section C-C'

Quendall Terminals Feasibility Study Report
Renton, Washington

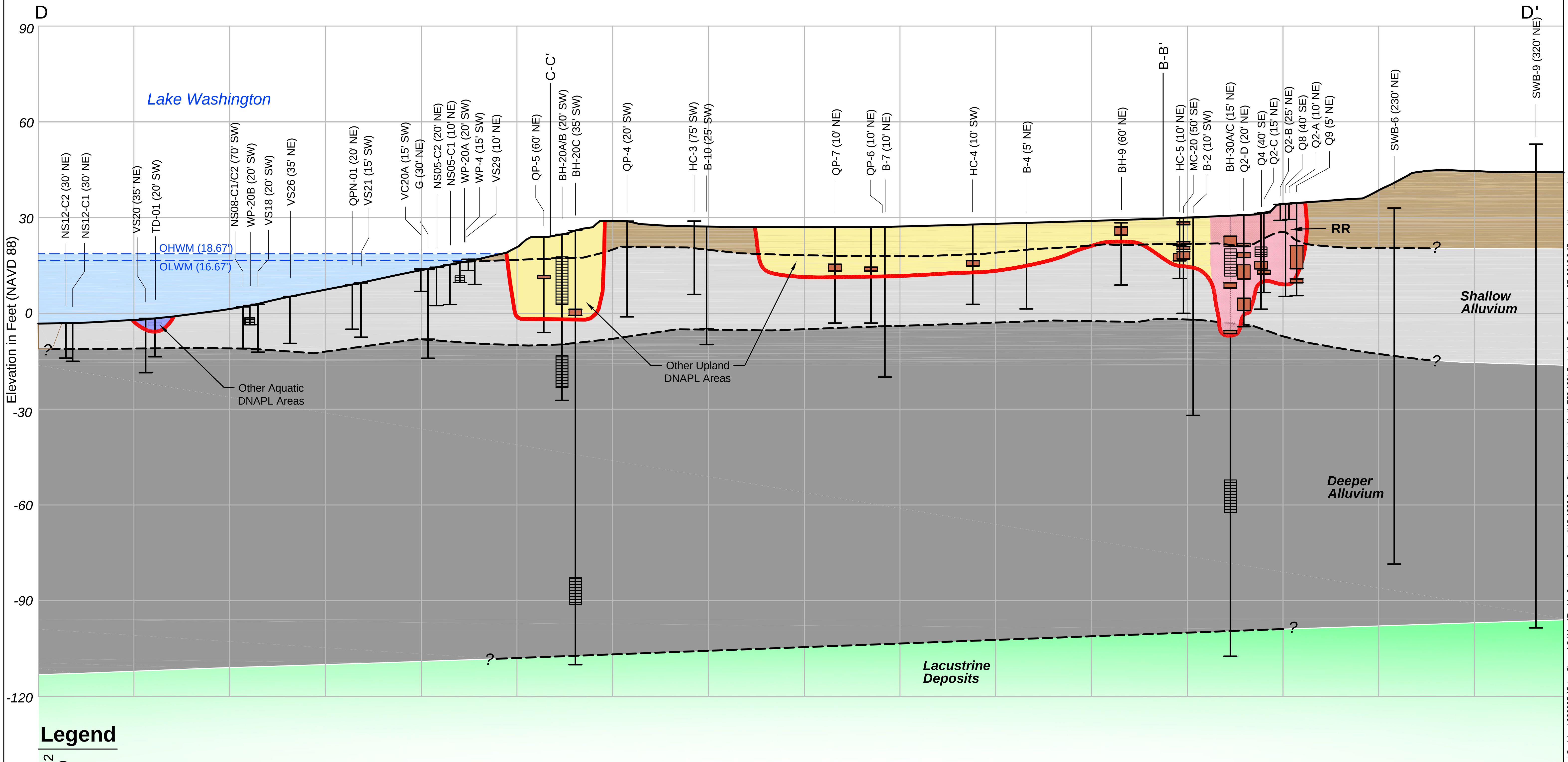
Aspect CONSULTING | ARCADIS

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.

Estimated Extent of DNAPL along Cross Section D-D'

Quendall Terminals Feasibility Study Report

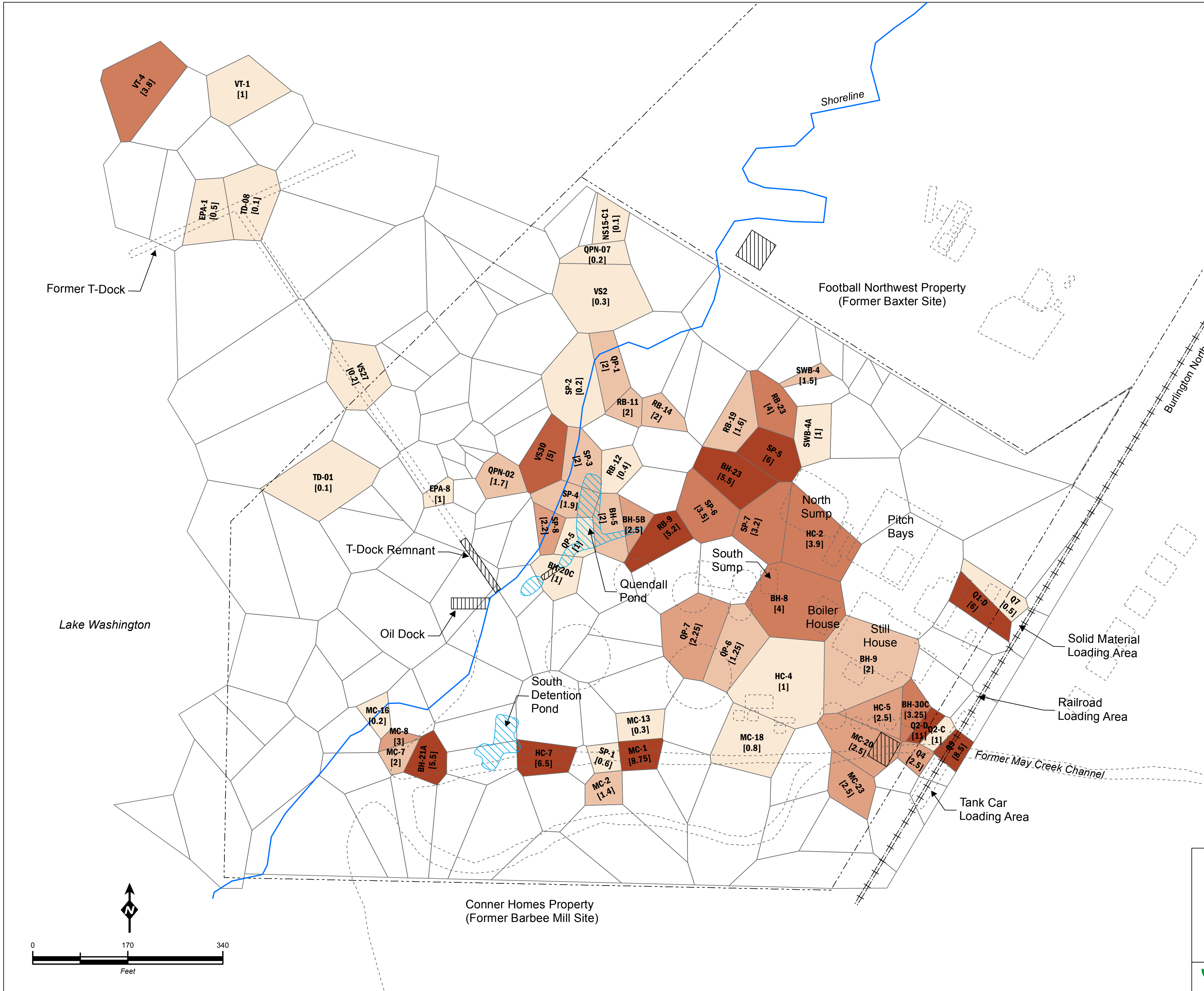
Renton, Washington

Aspect CONSULTING | ARCADIS

FIRM: ASPECT

DRAWN BY: JJP/DAH/SCC

FIGURE NO. 4-5



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.

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

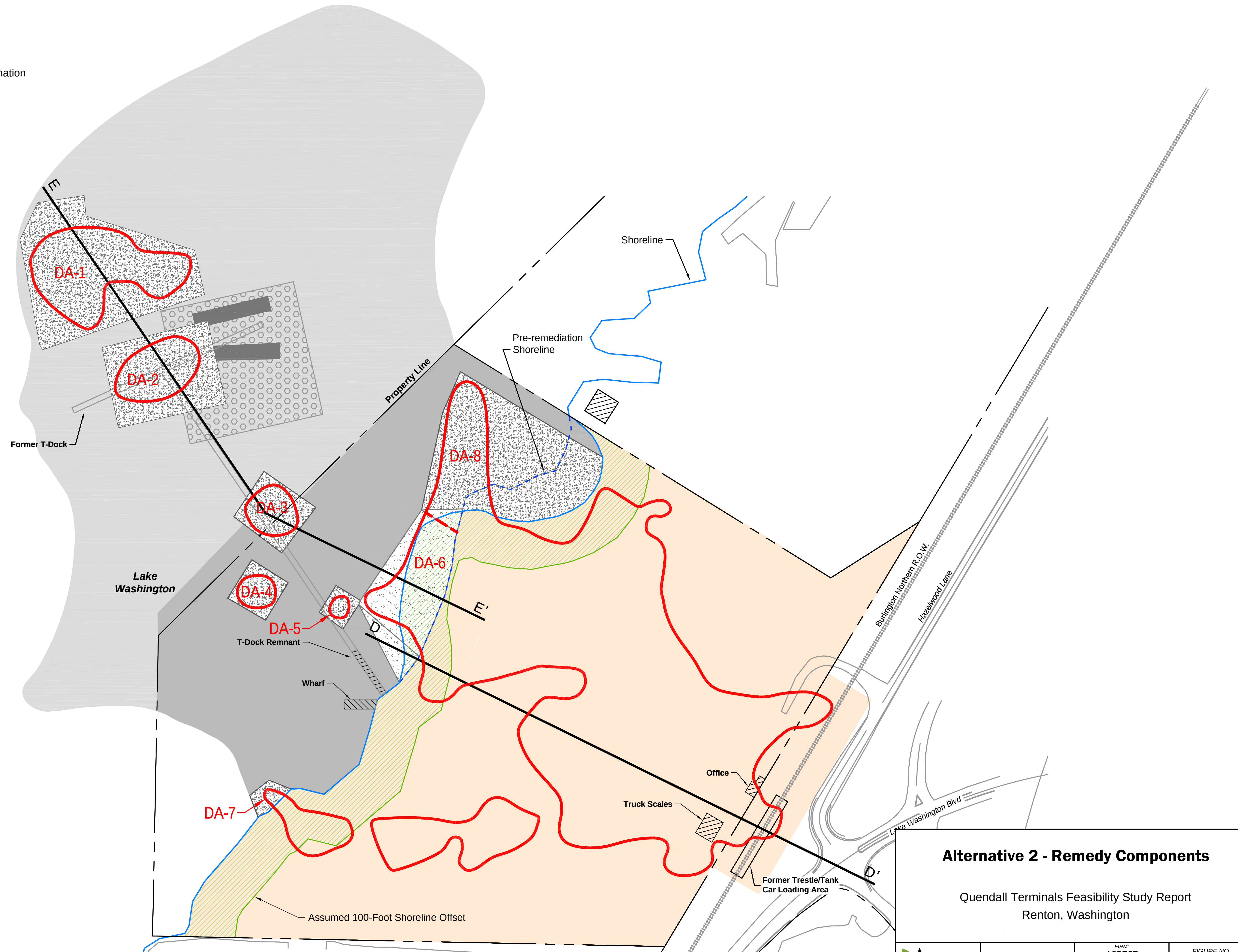
FIGURE 5-1
Environmental Dredge Bucket Used at Todd Shipyard, Harbor Island, Washington

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.

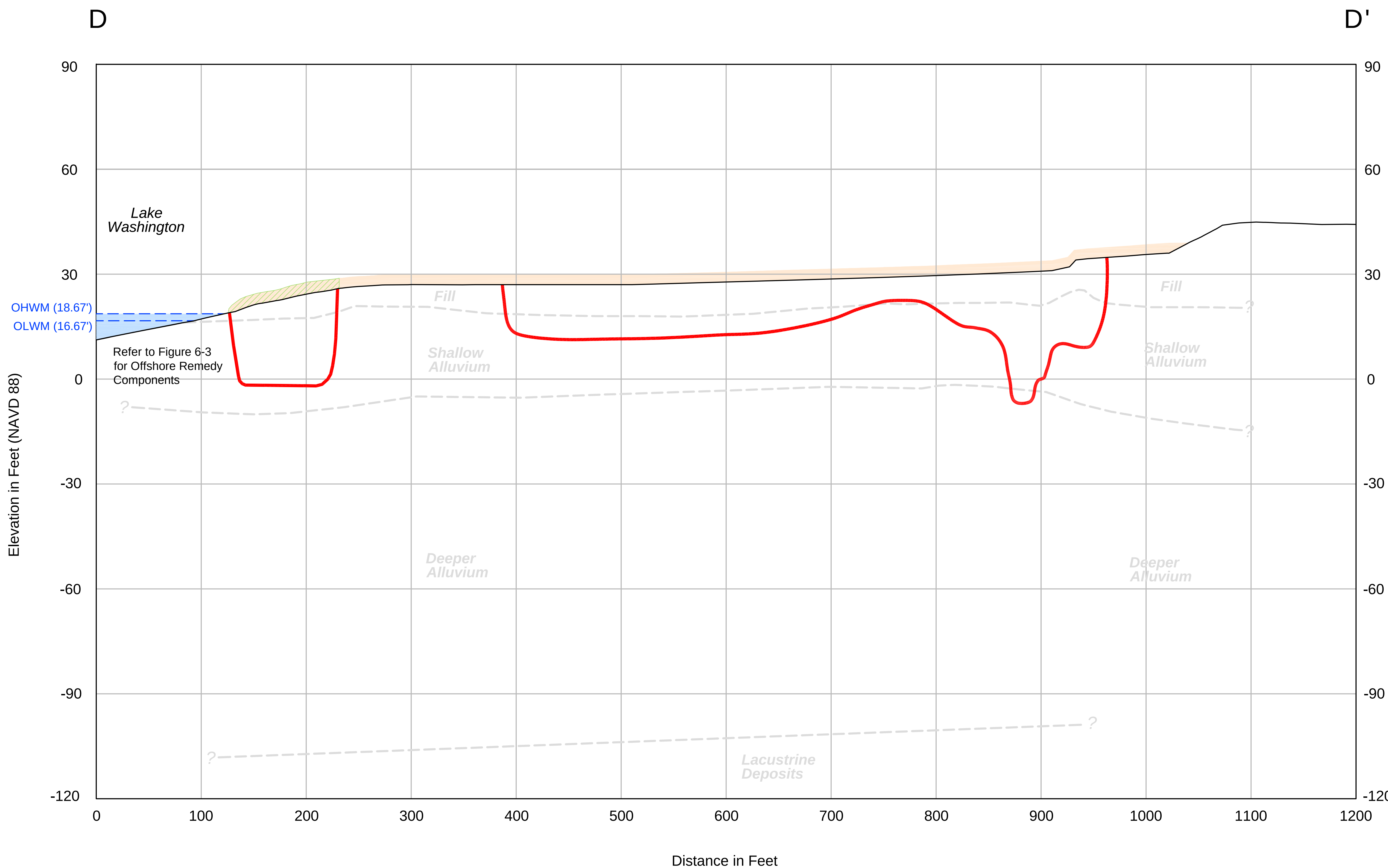


Alternative 2 - Remedy Components

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\2015-09 Interim Delivery\Section 6\020027_Plan-Alternative 2 (Shoreline Change).dwg ALT 2 NEW || Date Saved: Sep 29, 2015 3:41pm || User: scudd



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

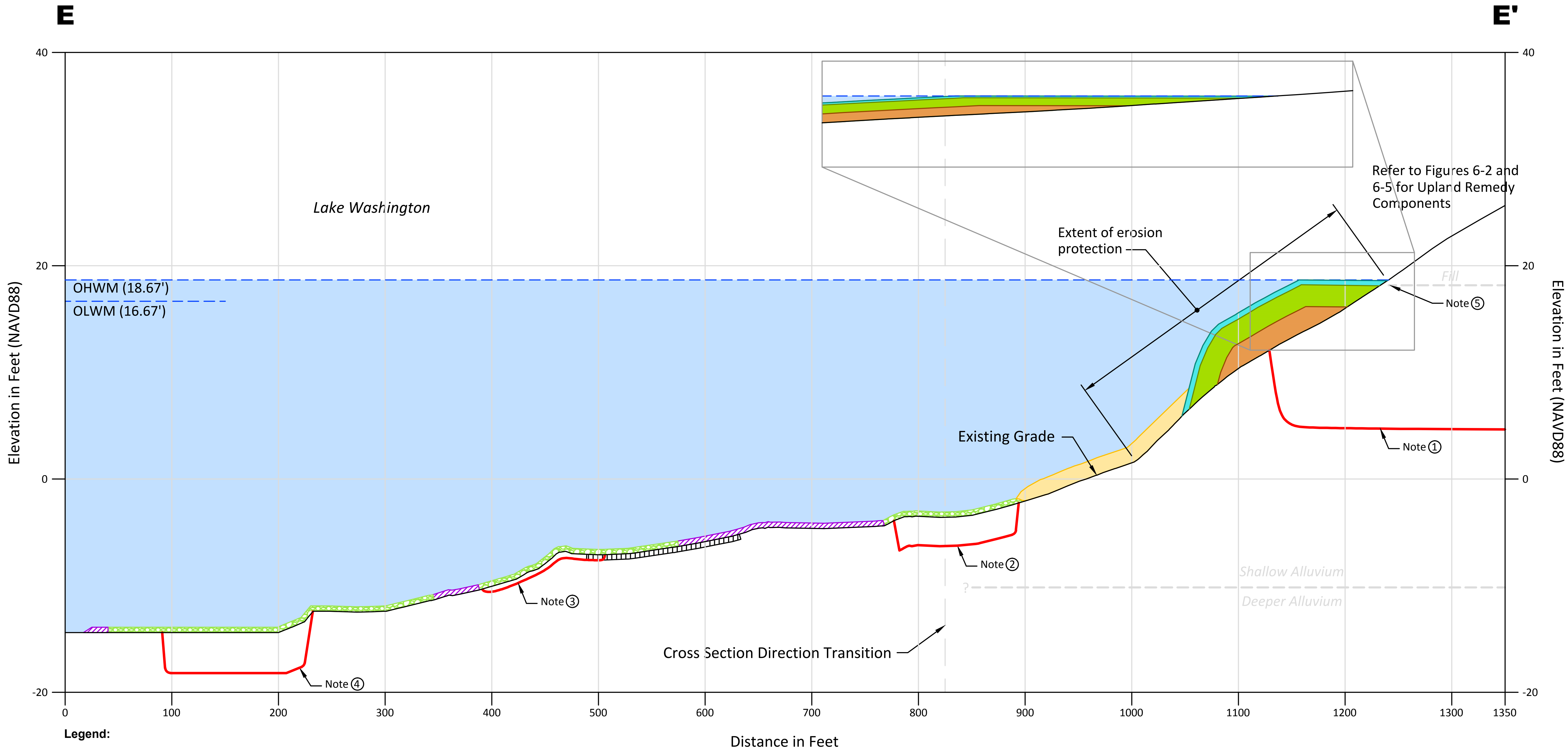
Alternative 2 - Upland Remedy Components along Cross Section D-D'

Quendall Terminals Feasibility Study Report
Renton, Washington

Aspect CONSULTING
ARCADIS

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

FIGURE NO. 6-2



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

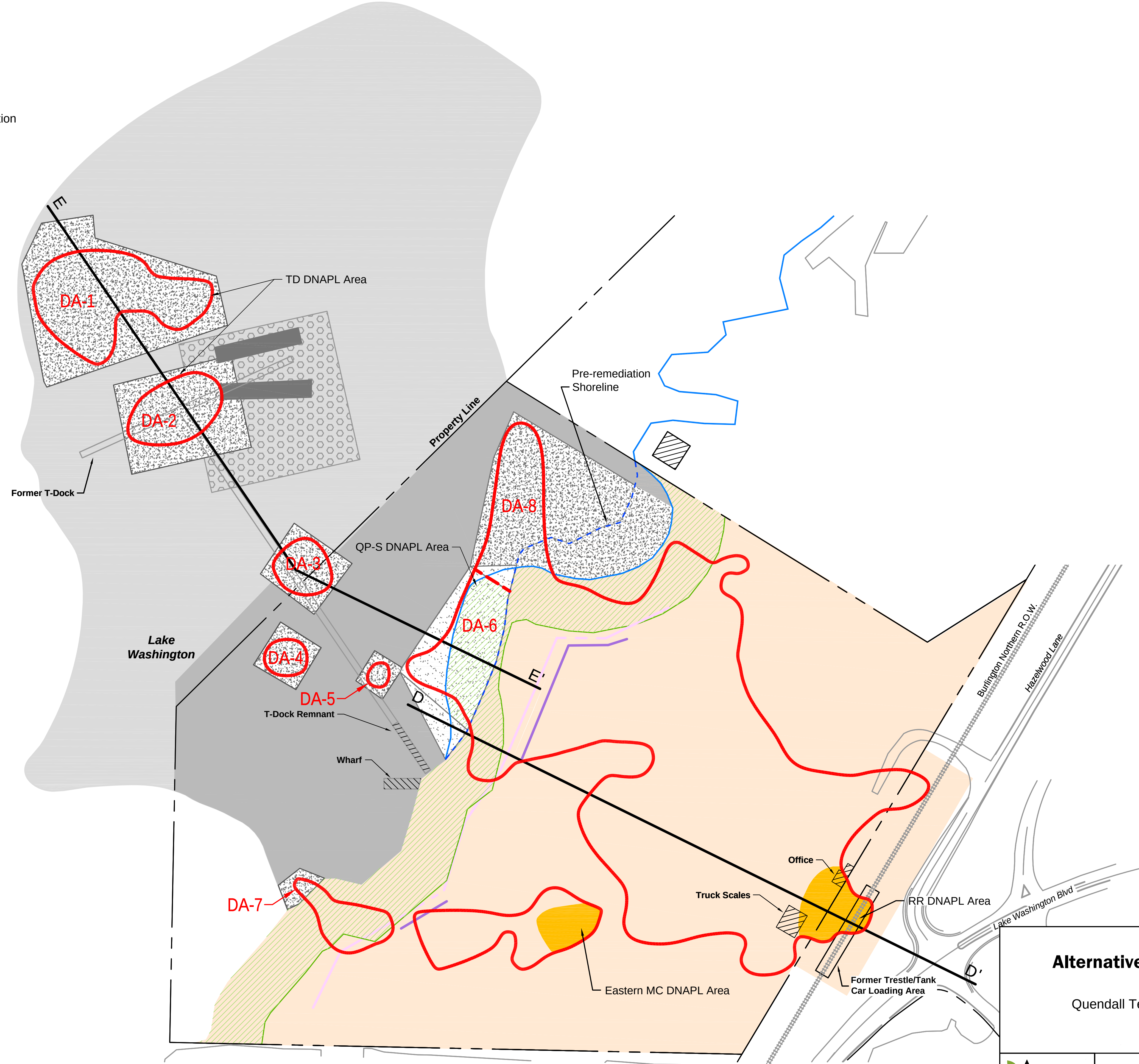
Alternatives 2 and 3 - Offshore Remedy Components along Cross Section E-E'

Quendall Terminals Feasibility Study Report

Renton, Washington

Aspect CONSULTING | ARCADIS | FIRM: ARCADIS | DRAWN BY: BKD | FIGURE NO. 6-3

CAD Path: G:\ENVCAD\SYRACUSE\ACT\WA000907\0000\00001\DWG\REPORT\000907G01.dwg 6-3 || Date Saved: Oct 05, 2015 3:28pm || 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)
- Amended Sand Reactive Cap
- DA-1 Aquatic DNAPL Area

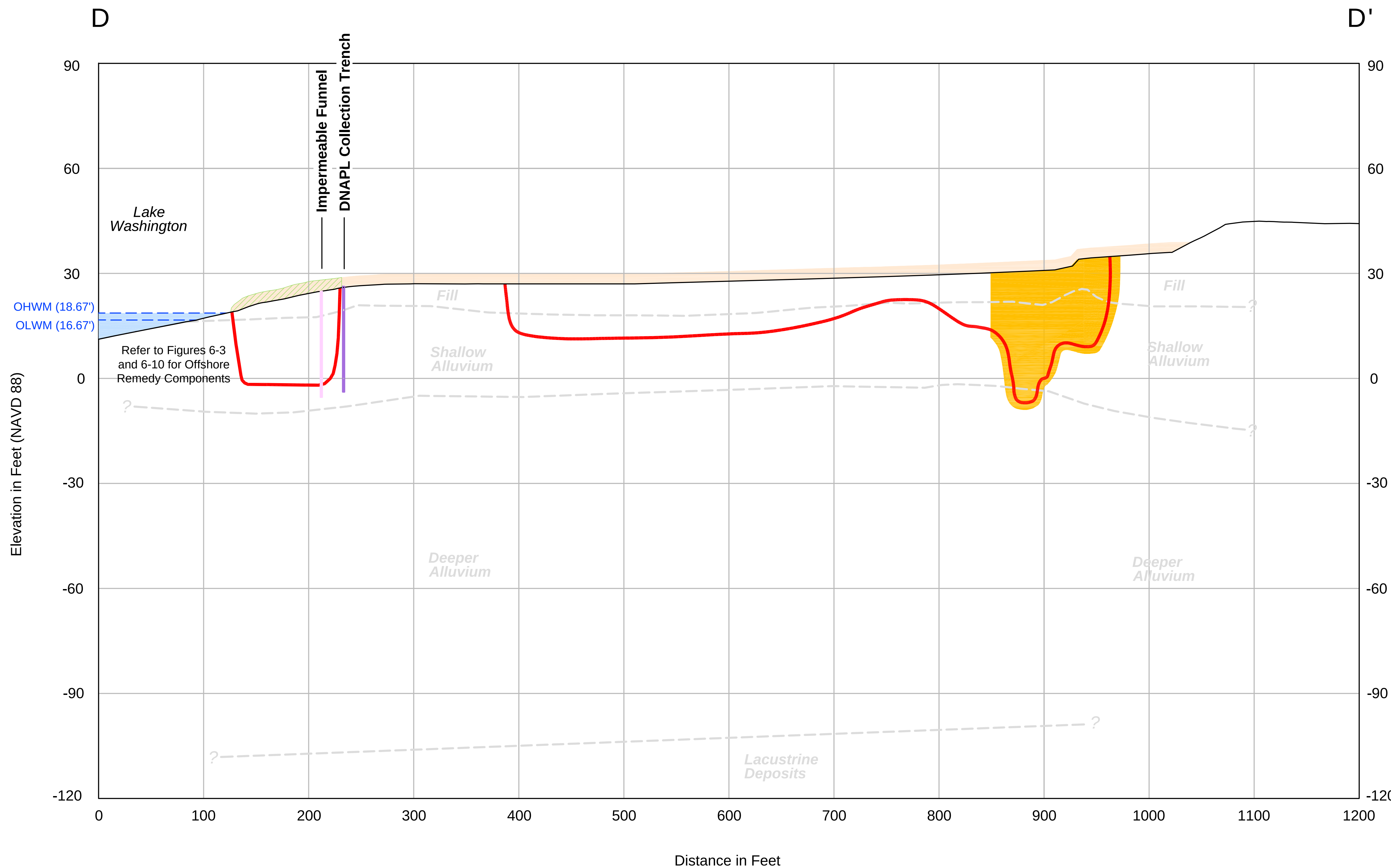
Notes:

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.

Alternative 3 - Remedy Components

Quendall Terminals Feasibility Study Report
Renton, Washington

Aspect CONSULTING | ARCADIS | FIRM: ASPECT | DRAWN BY: JJP/ELG/PMB/SCC | FIGURE NO. 6-4



Legend

Solidified Soil	Estimated Extent of DNAPL (Refer to Figure 4-5 for Basis.)
Permeable Cap	
Permeable Cap/Habitat Area	

Horizontal Scale

0 100 200

Feet

Vertical Scale

0 30 60

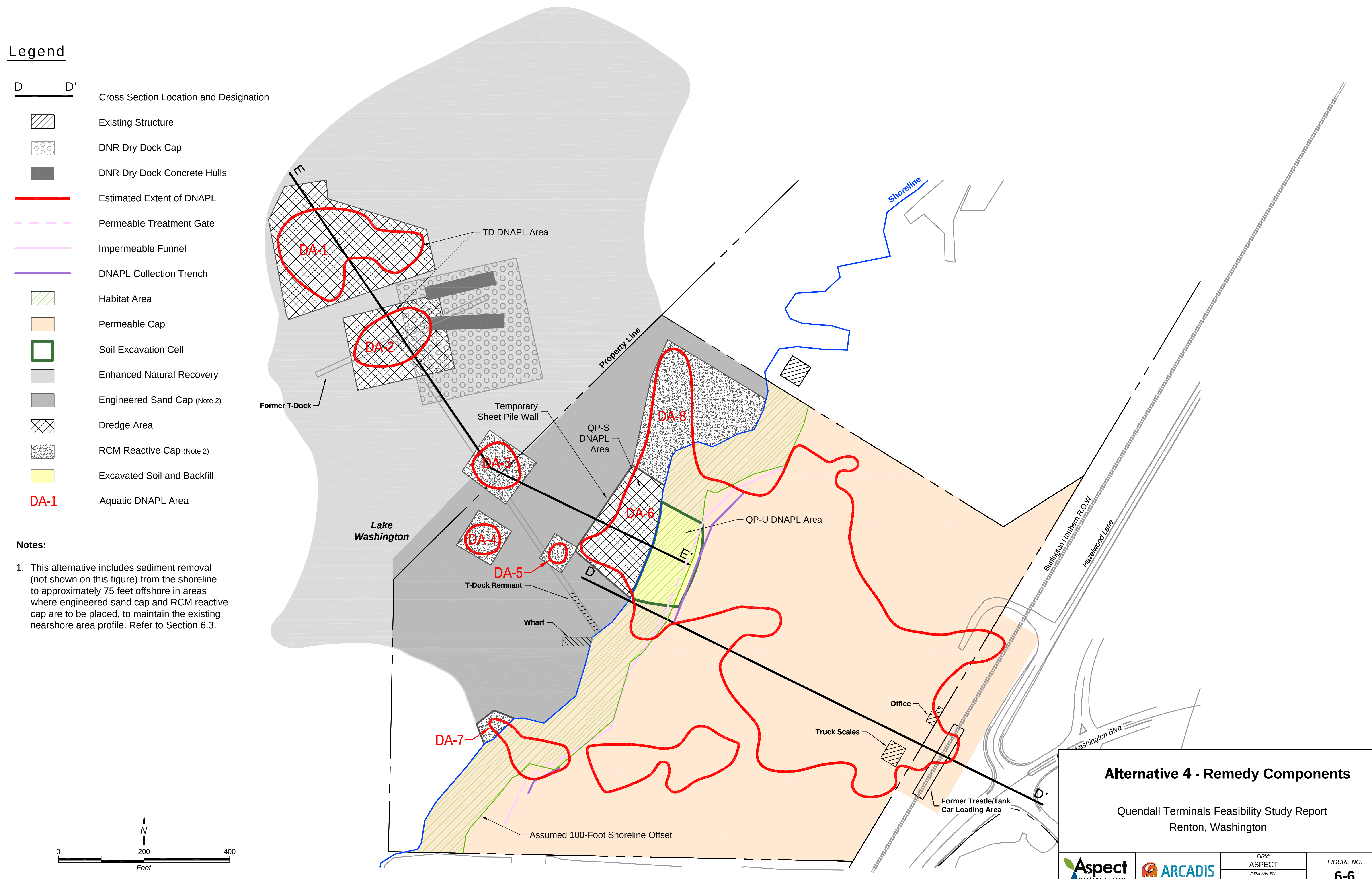
Feet

Vertical Exaggeration x 3.33

Alternatives 3 and 4a - 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

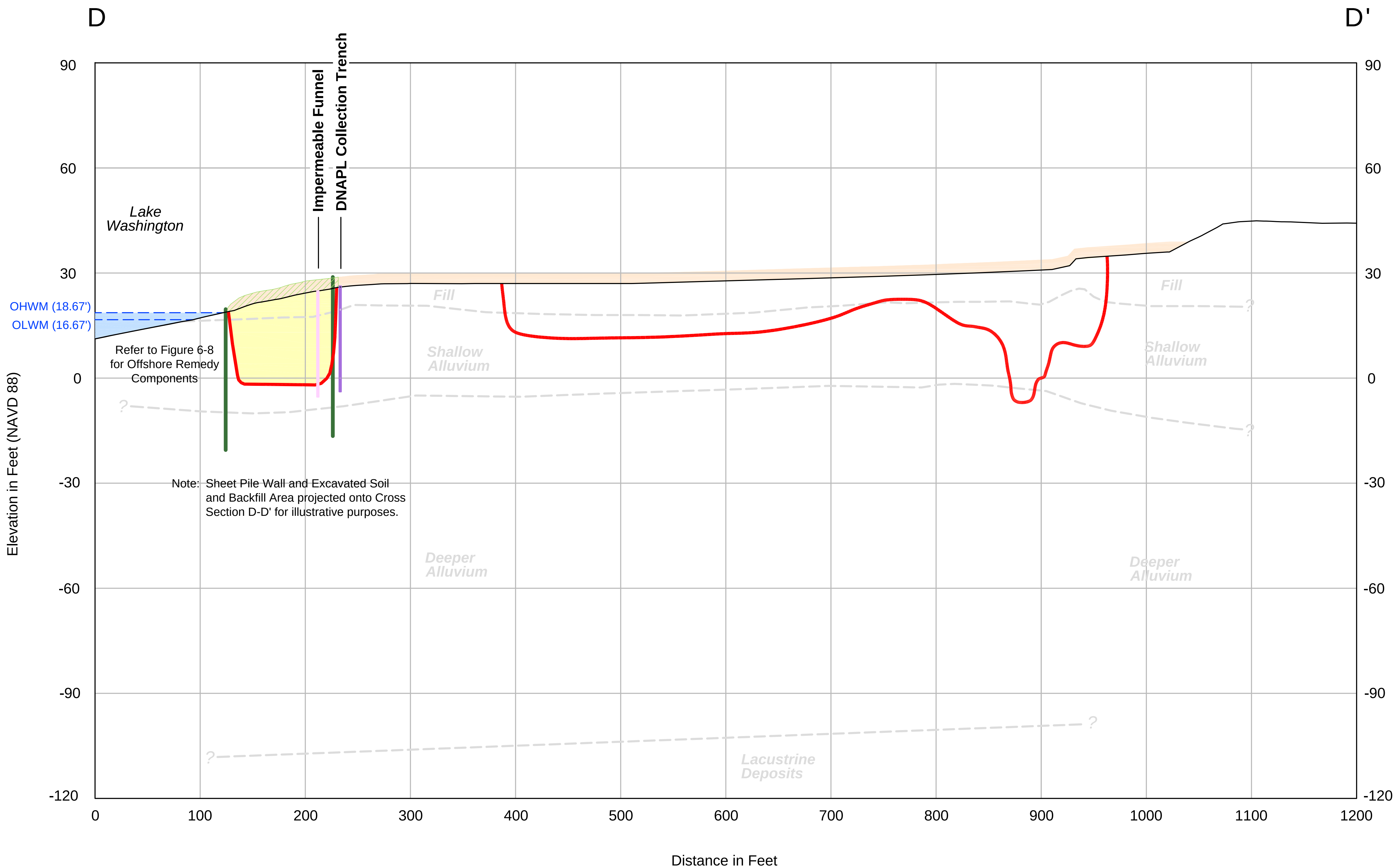


Alternative 4 - Remedy Components

Quendall Terminals Feasibility Study Report
Renton, Washington

Aspect CONSULTING | ARCADIS | FIRM: ASPECT | DRAWN BY: JJP/ELG/PMB/SCC | FIGURE NO. 6-6

CAD Path: Q:\Quendall\020027 Quendall Terminals\2015-09 Interim Delivery\Section 6\020027_Plan-Alternatives 2-8.dwg ALT 4 NEW || Date Saved: Oct 09, 2015 2:24pm || 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

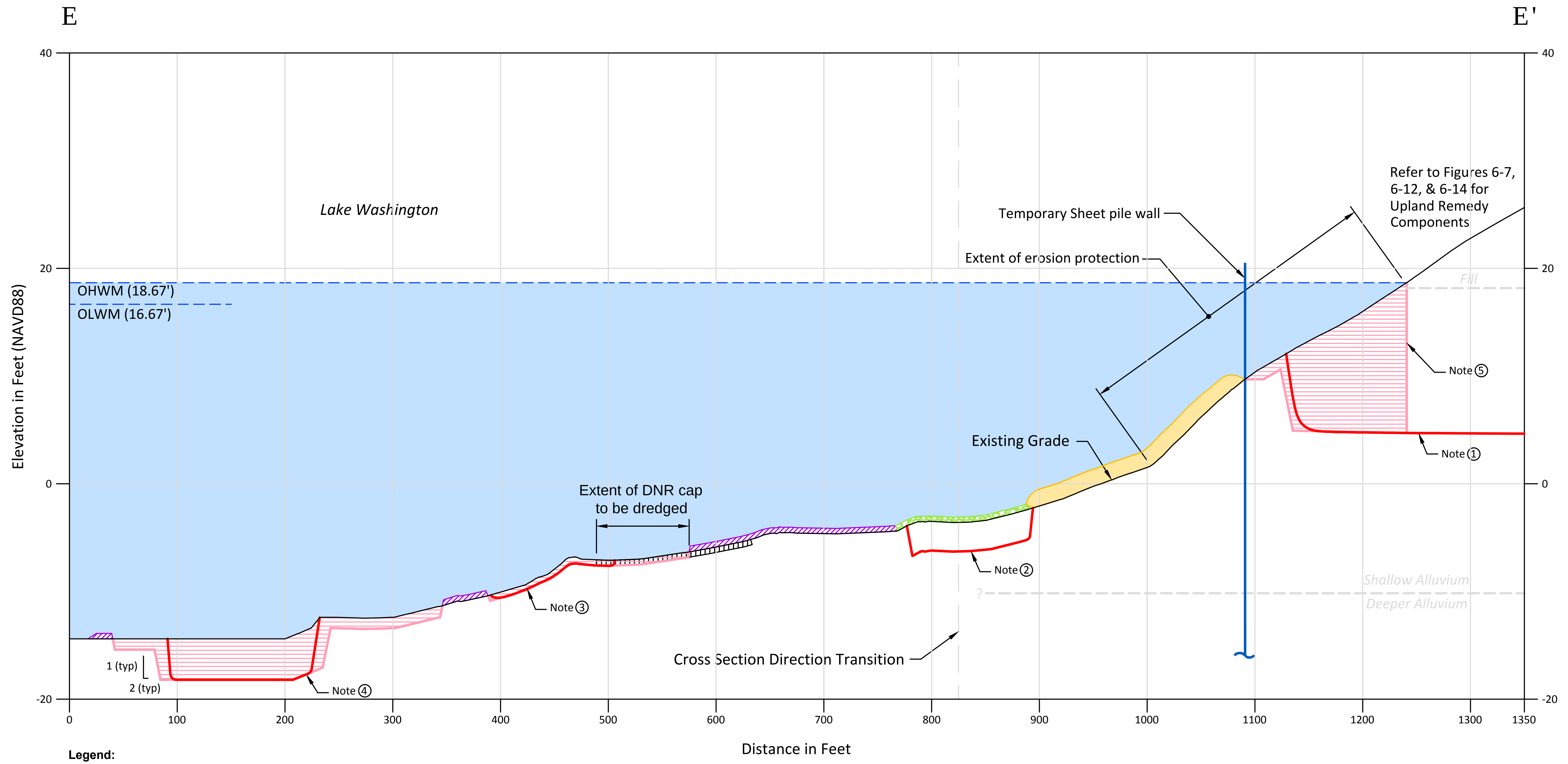
Alternative 4 - Upland Remedy Components along Cross Section D-D'

Quendall Terminals Feasibility Study Report
Renton, Washington

Aspect CONSULTING
ARCADIS

FIRM: ASPECT
DRAWN BY: JJP/PMB/ELG/SCC
FIGURE NO. **6-7**

CAD Path: Q:\Quendall\020027 Quendall Terminals\2015-09 Interim Delivery\Section 6\020027_SectionD-Alternatives 2-8.dwg ALT 4 NEW || Date Saved: Sep 24, 2015 4:40pm || 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)
- 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

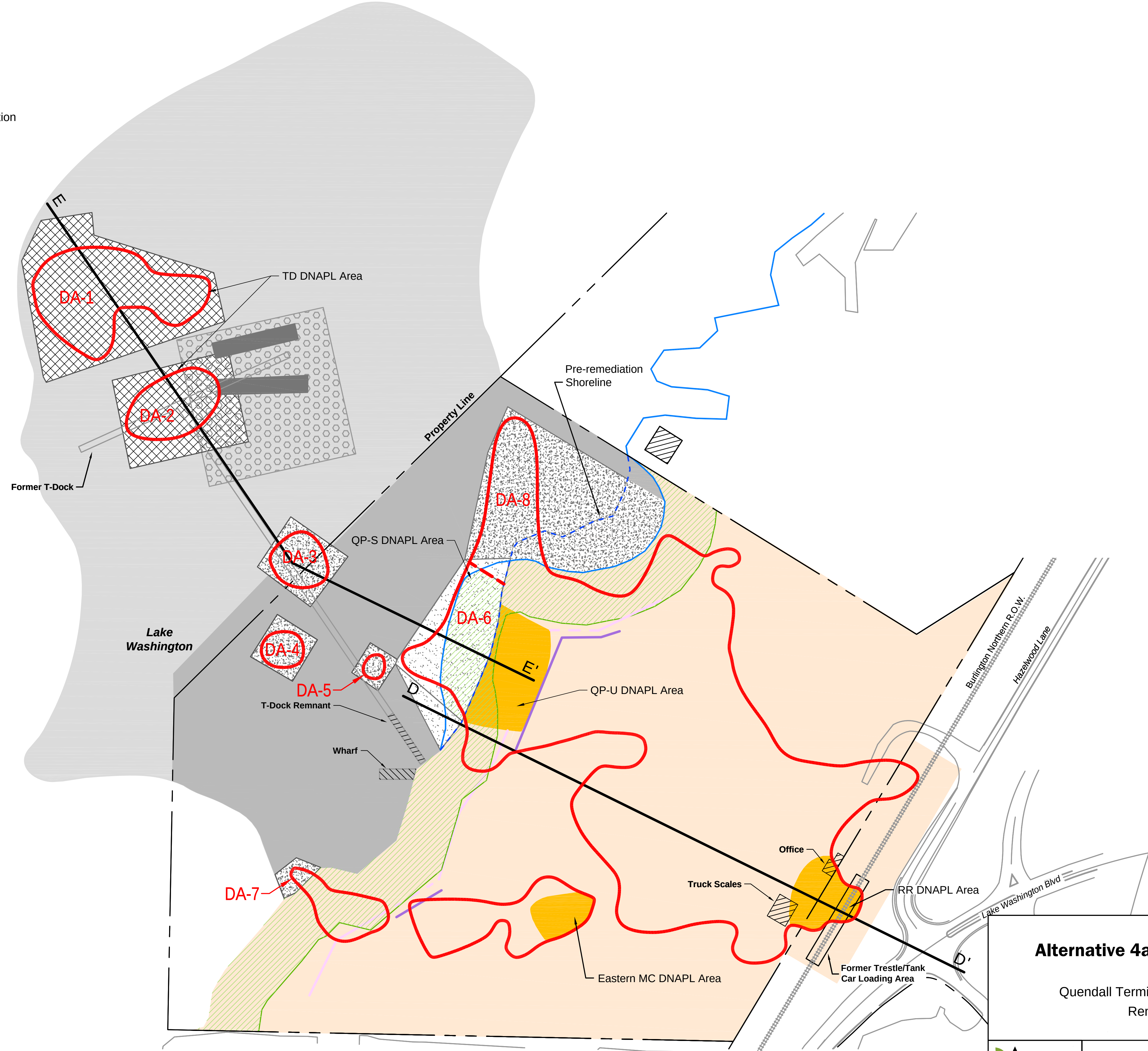
Alternatives 4, 5, & 6 - Offshore Remedy Components along Cross Section E-E'

Quendall Terminals Feasibility Study Report
Renton, Washington

Aspect CONSULTING | ARCADIS | FIRM: ARCADIS | DRAWN BY: BKD | FIGURE NO. 6-8

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)
	Dredge Area
	RCM Reactive Cap (Note 1)
	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

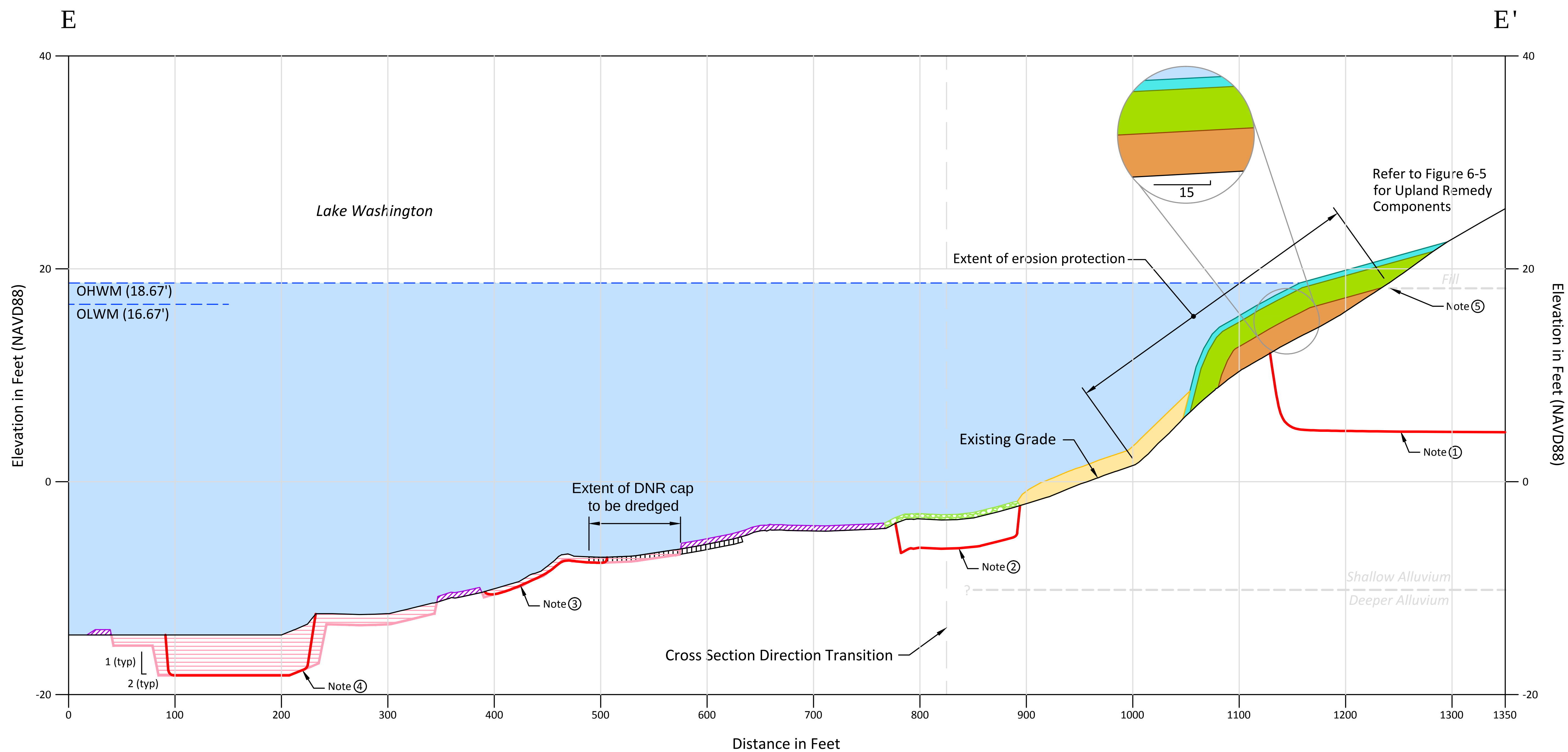
0 200 400
Feet

Alternative 4a - Remedy Components

Quendall Terminals Feasibility Study Report
Renton, Washington

Aspect CONSULTING | ARCADIS

FIRM: ASPECT
DRAWN BY: JJP/ELG/PMB/SCC
FIGURE NO. 6-9



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)
- 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

Alternative 4a - Offshore Remedy Components along Cross Section E-E'

Quendall Terminals Feasibility Study Report

Renton, Washington

Aspect CONSULTING | ARCADIS

FIRM: ARCADIS

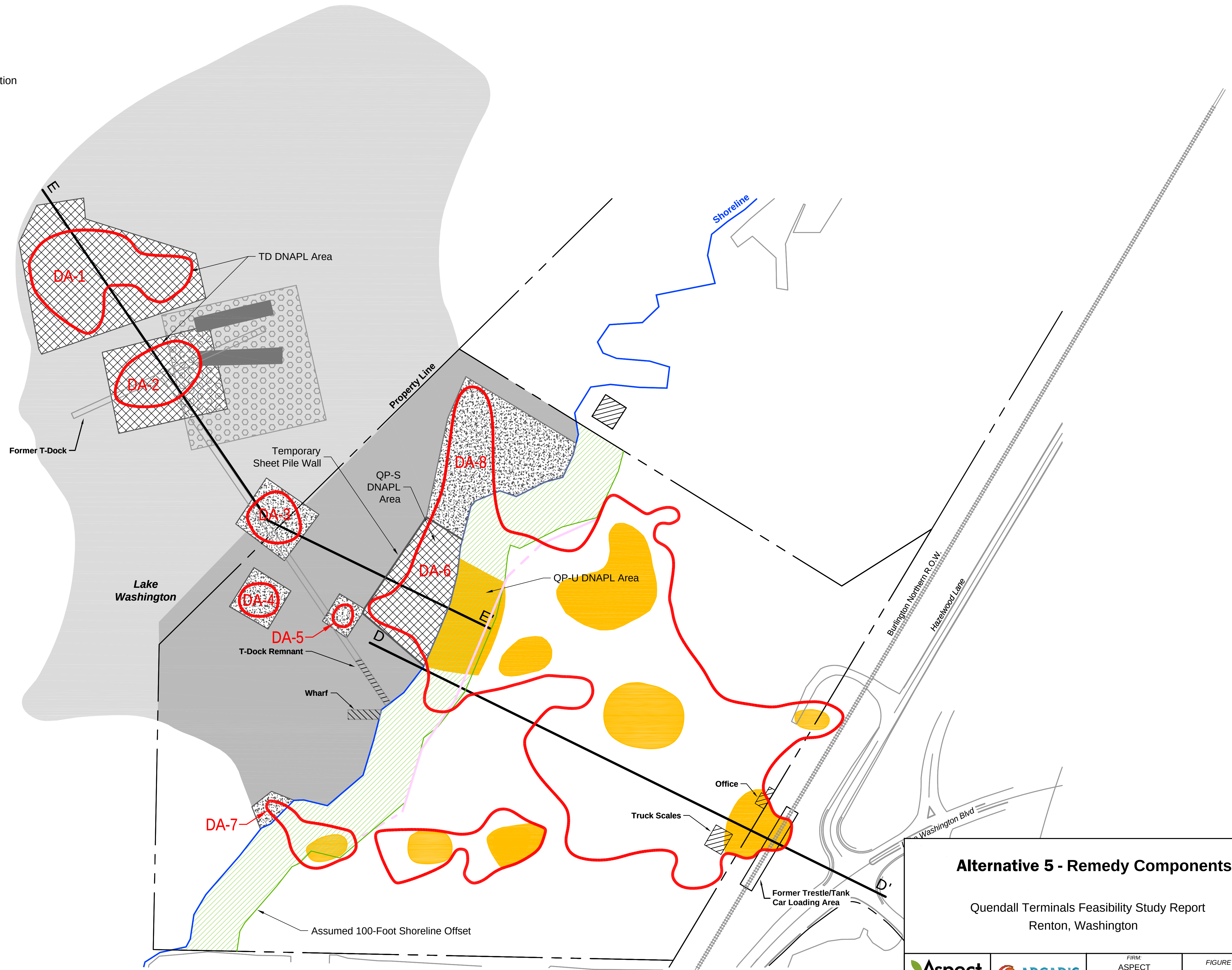
DRAWN BY: BKD

FIGURE NO. 6-10

CAD Path: G:\ENVCAD\SYRACUSE\ACT\WA000907\0000\00001\DWG\REPORT\0009O7G02.dwg 6-10 || Date Saved: Sep 29, 2015 11:36am || 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
	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:

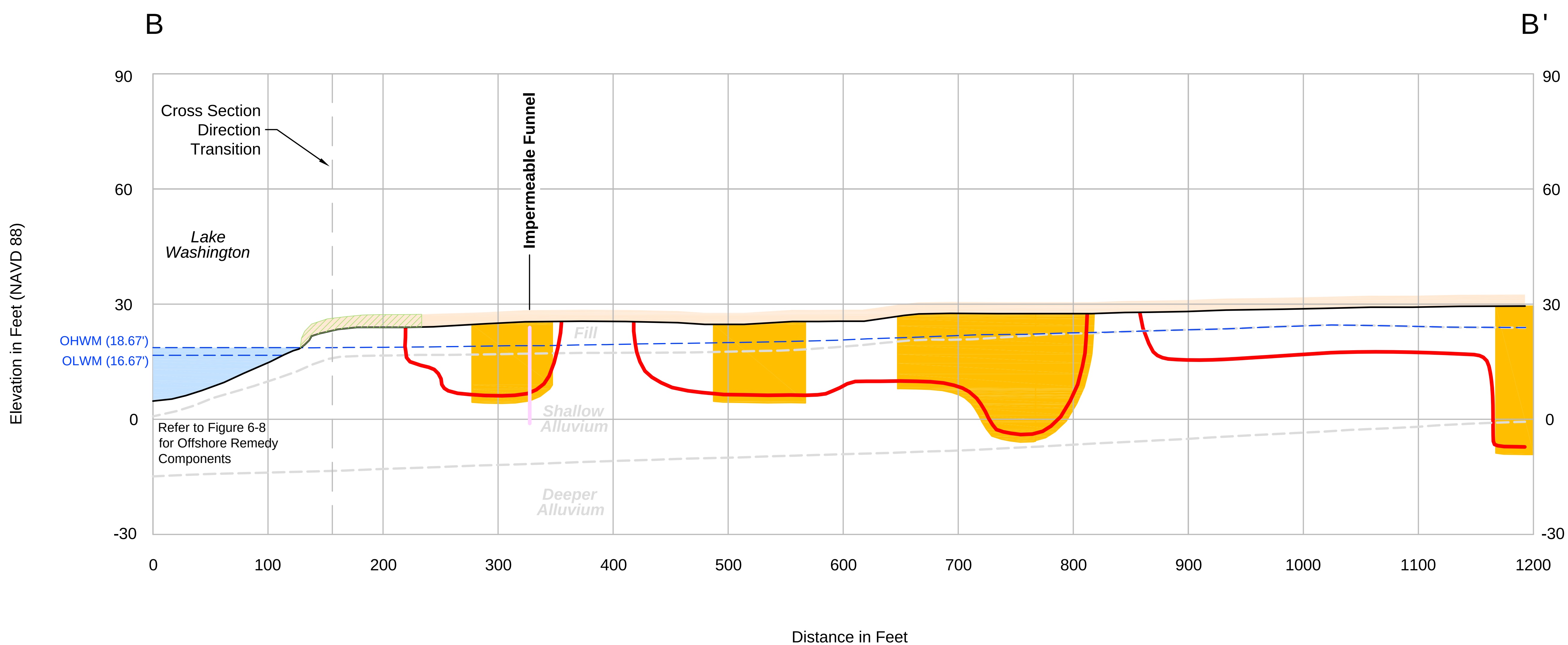
1. This alternative also includes permeable upland cap similar to Alternative 4. Refer to Figure 6-6 for cap extent.
2. This alternative includes sediment removal (not shown on this figure) from the shoreline to approximately 75 feet offshore in areas where engineered sand cap and RCM reactive cap are to be placed, to maintain the existing nearshore area profile. Refer to Section 6.3.

Alternative 5 - Remedy Components

Quendall Terminals Feasibility Study Report
Renton, Washington

Aspect CONSULTING | ARCADIS | FIRM: ASPECT; DRAWN BY: JJP/ELG/PMB/SCC | FIGURE NO. 6-11

CAD Path: Q:\Quendall\020027 Quendall Terminals\2015-09 Interim Delivery\Section 6\020027_Plan-Alternatives 2-8.dwg ALT 5 NEW || Date Saved: Oct 09, 2015 2:26pm || 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

Alternative 5 - Upland Remedy Components along Cross Section B-B'

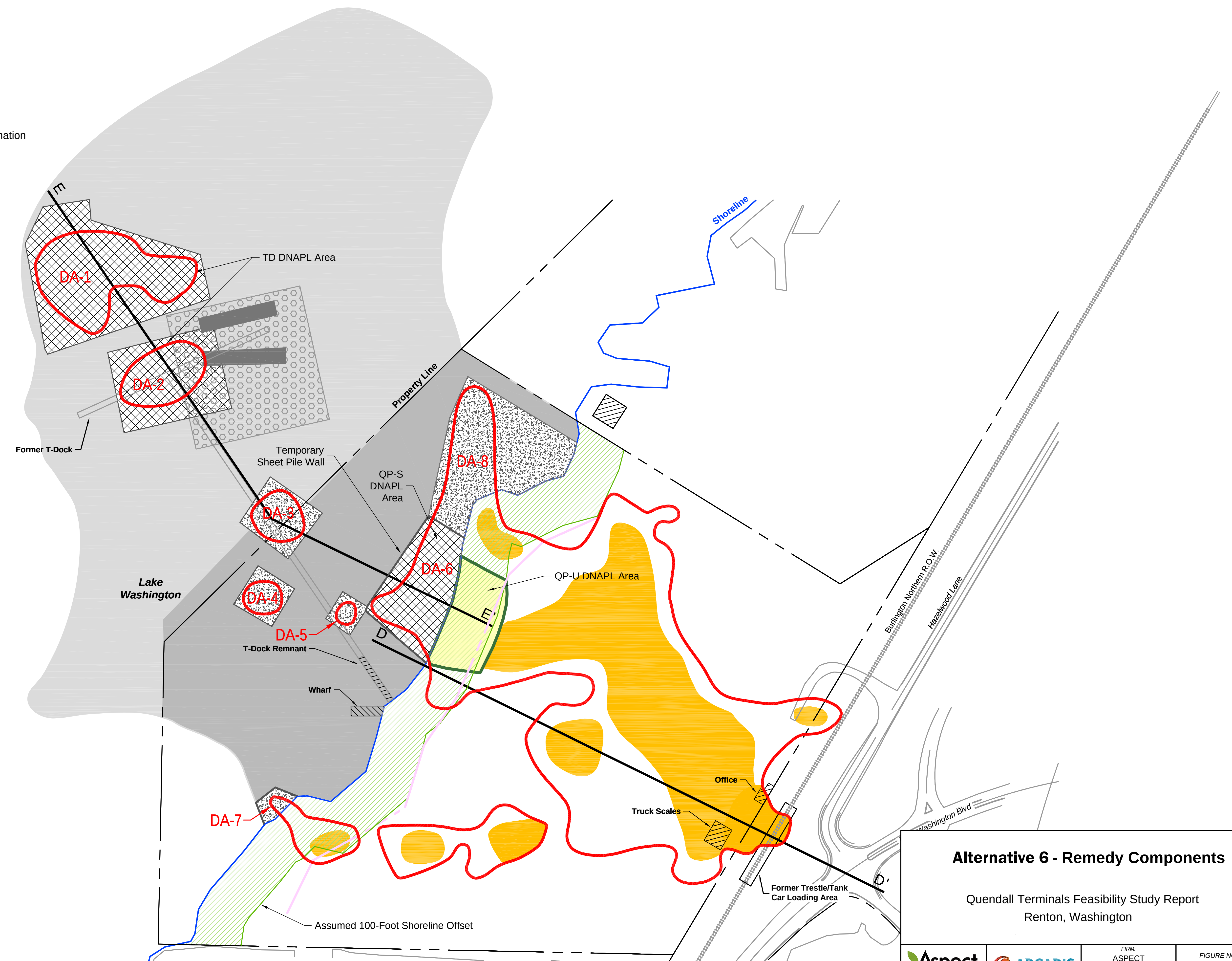
Quendall Terminals Feasibility Study Report

Renton, Washington

Aspect CONSULTING | ARCADIS | FIRM: ASPECT | DRAWN BY: JJP/PMB/ELG/SCC | FIGURE NO. 6-12

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



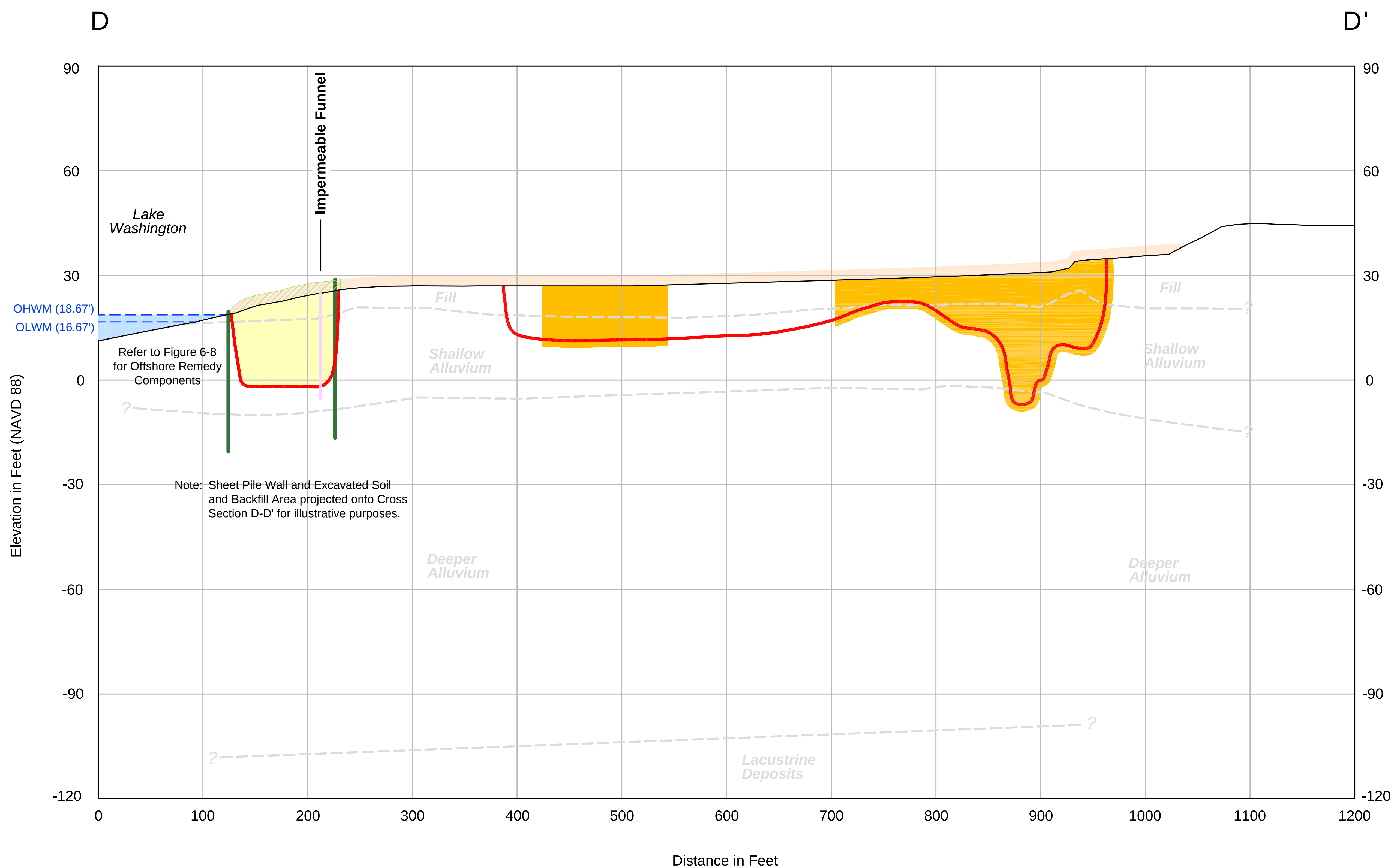
Notes:

1. This alternative also includes permeable upland cap similar to Alternative 4. Refer to Figure 6-6 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.

Alternative 6 - Remedy Components

Quendall Terminals Feasibility Study Report
Renton, Washington

Aspect CONSULTING | ARCADIS | FIRM: ASPECT / DRAWN BY: JJP/ELG/PMB/SCC | FIGURE NO. 6-13



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

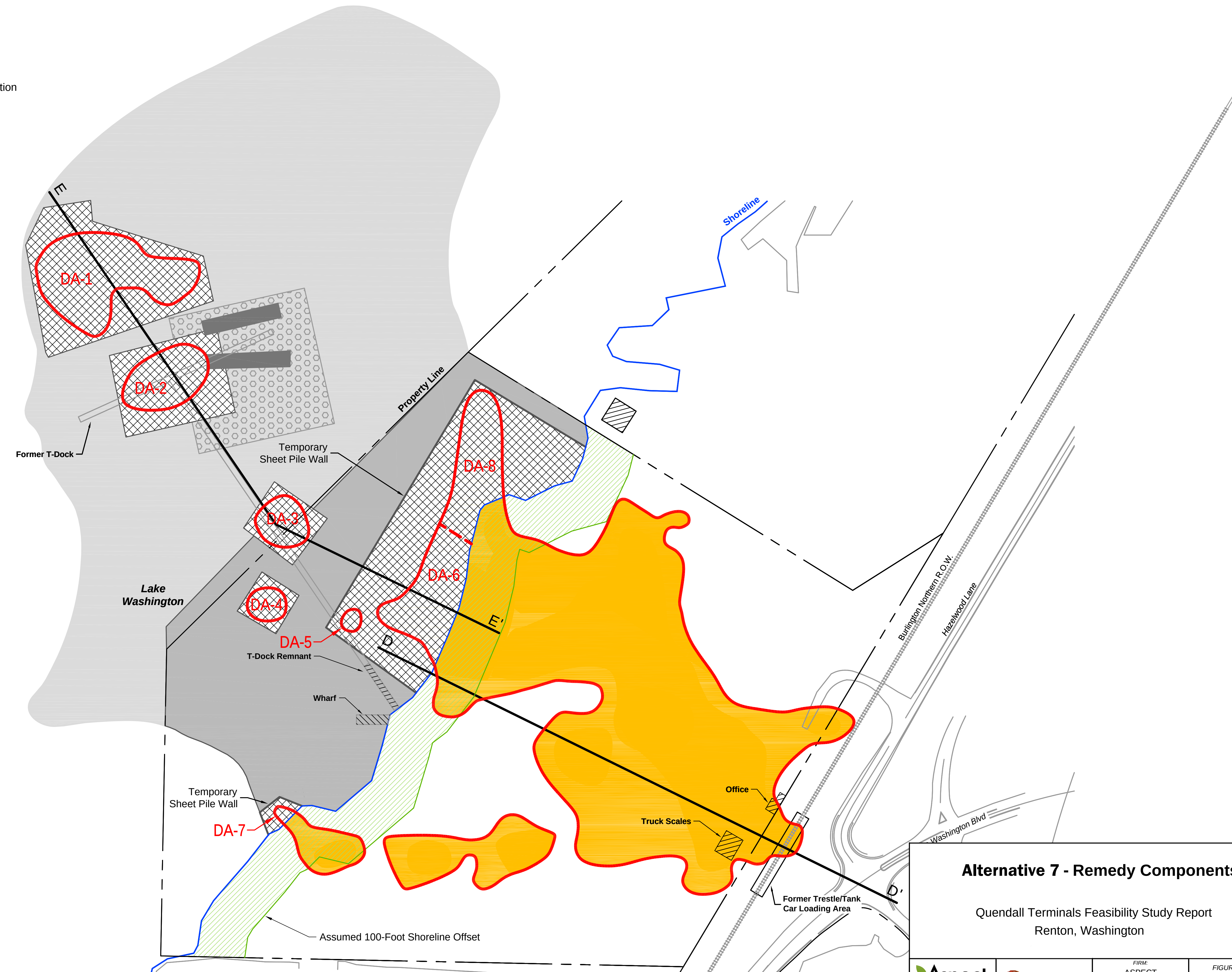
Alternative 6 - Upland Remedy Components along Cross Section D-D'

Quendall Terminals Feasibility Study Report
Renton, Washington

Aspect CONSULTING | ARCADIS | FIRM: ASPECT | DRAWN BY: JJP/PMB/ELG/SCC | FIGURE NO. 6-14

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:

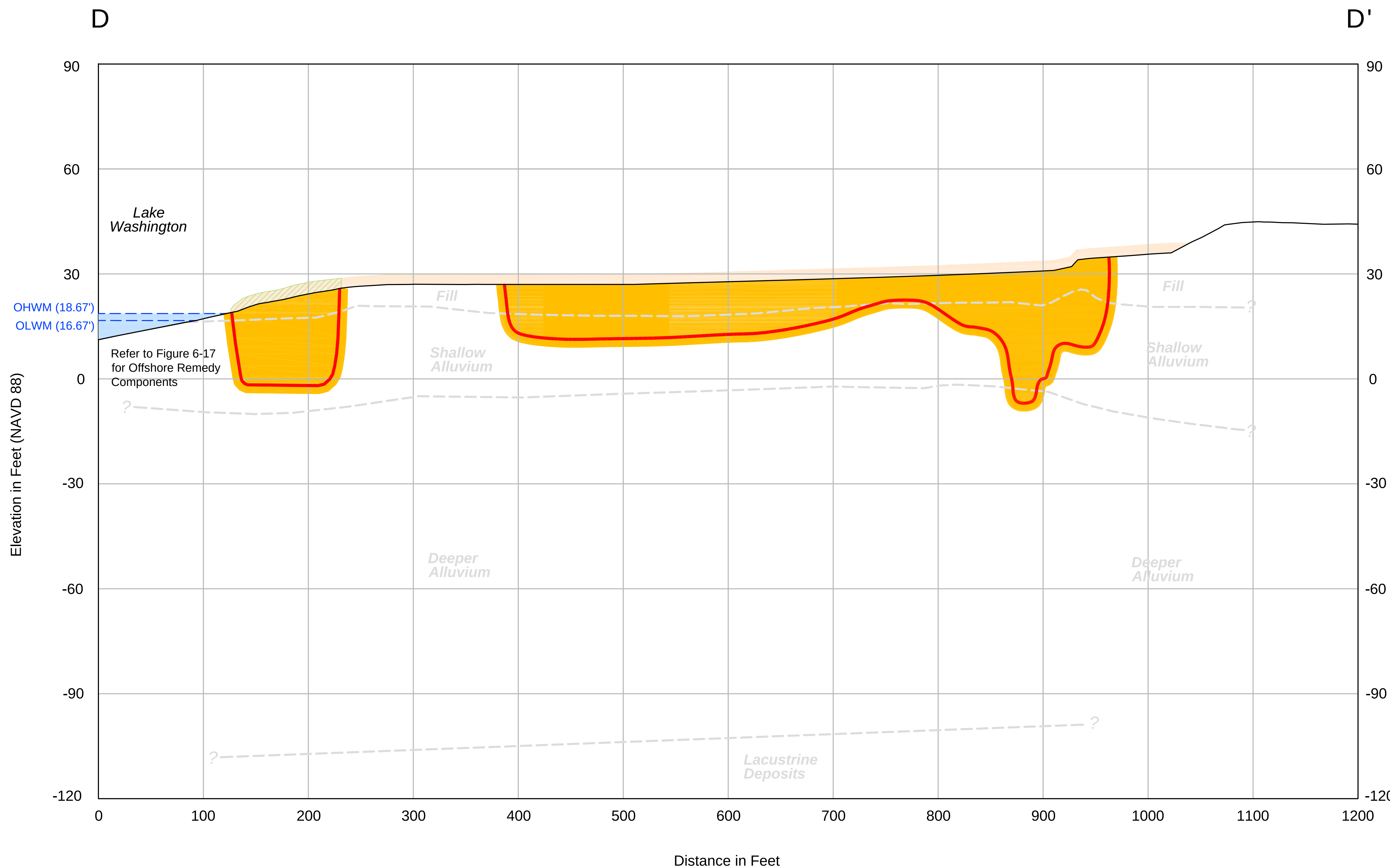
1. This alternative also includes permeable upland cap similar to Alternative 4. Refer to Figure 6-6 for cap extent.
2. This alternative includes sediment removal (not shown on this figure) from the shoreline to approximately 75 feet offshore in areas where engineered sand cap is to be placed, to maintain the existing nearshore area profile. Refer to Section 6.3.

Alternative 7 - Remedy Components

Quendall Terminals Feasibility Study Report
Renton, Washington

Aspect CONSULTING | ARCADIS | FIRM: ASPECT | DRAWN BY: JJP/ELG/PMB/SCC | FIGURE NO. 6-15

CAD Path: Q:\Quendall\020027 Quendall Terminals\2015-09 Interim Delivery\Section 6\020027_Plan-Alternatives 2-8.dwg ALT 7 NEW || Date Saved: Oct 09, 2015 2:28pm || 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

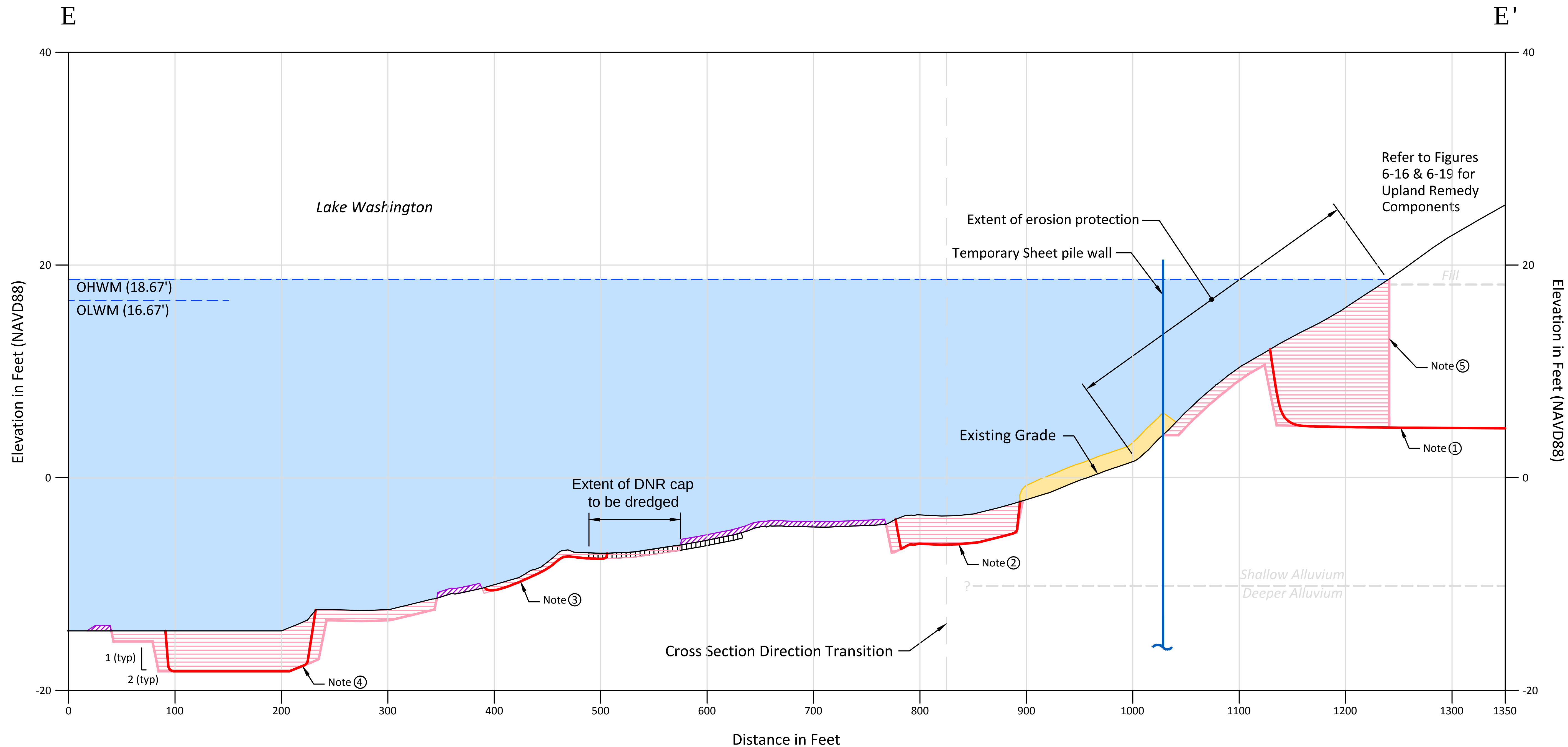
Vertical Exaggeration x 3.33

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. 6-16

CAD Path: Q:\Quendall\020027 Quendall Terminals\2015-09 Interim Delivery\Section 6\020027_SectionD-Alternatives 2-8.dwg ALT 7 NEW || Date Saved: Sep 24, 2015 4:53pm || 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

Alternatives 7 & 8 - Offshore Remedy Components along Cross Section E-E'

Quendall Terminals Feasibility Study Report

Renton, Washington

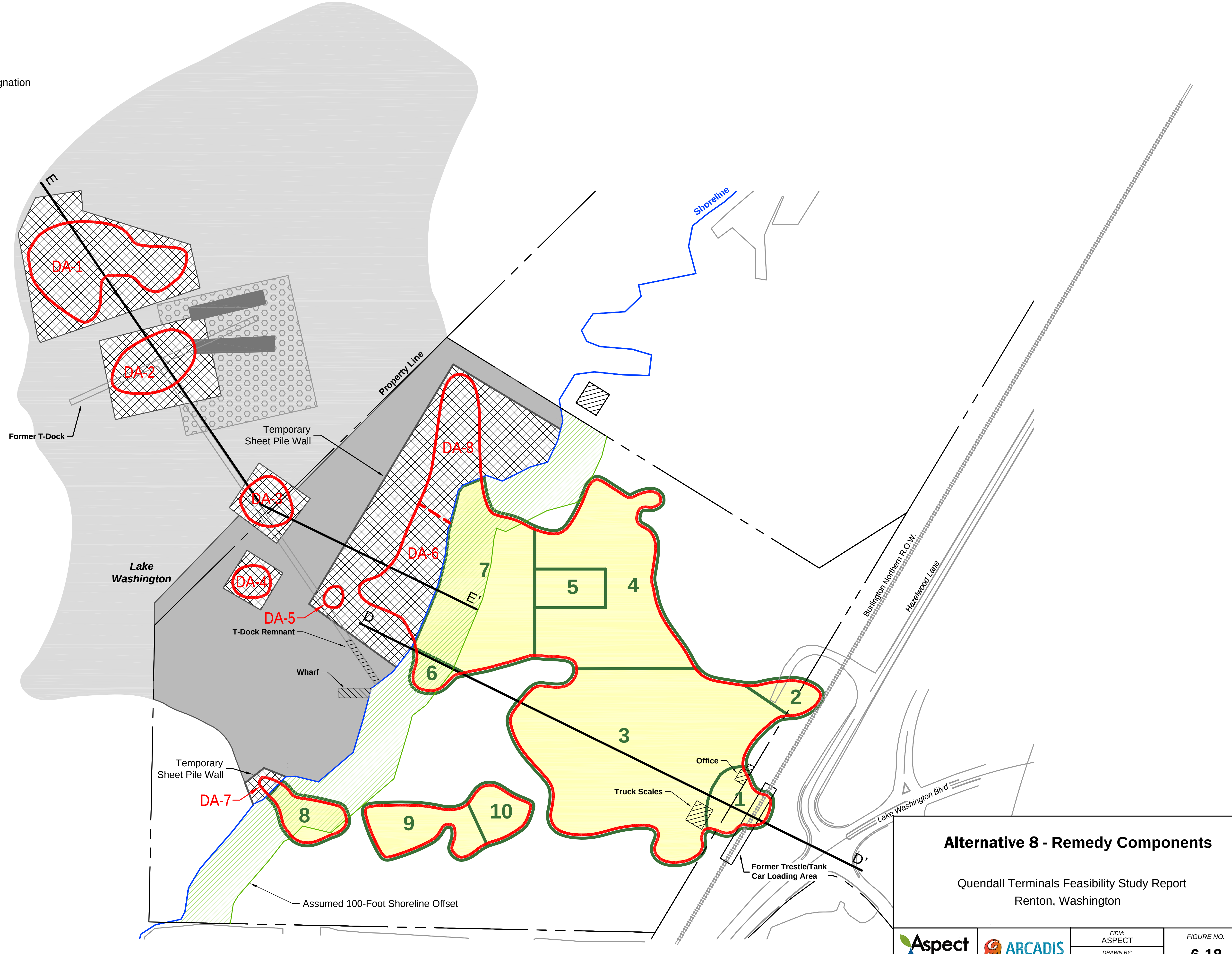
Aspect CONSULTING | ARCADIS | FIRM: ARCADIS | DRAWN BY: BKD | FIGURE NO. 6-17

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 4. Refer to Figure 6-6 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.



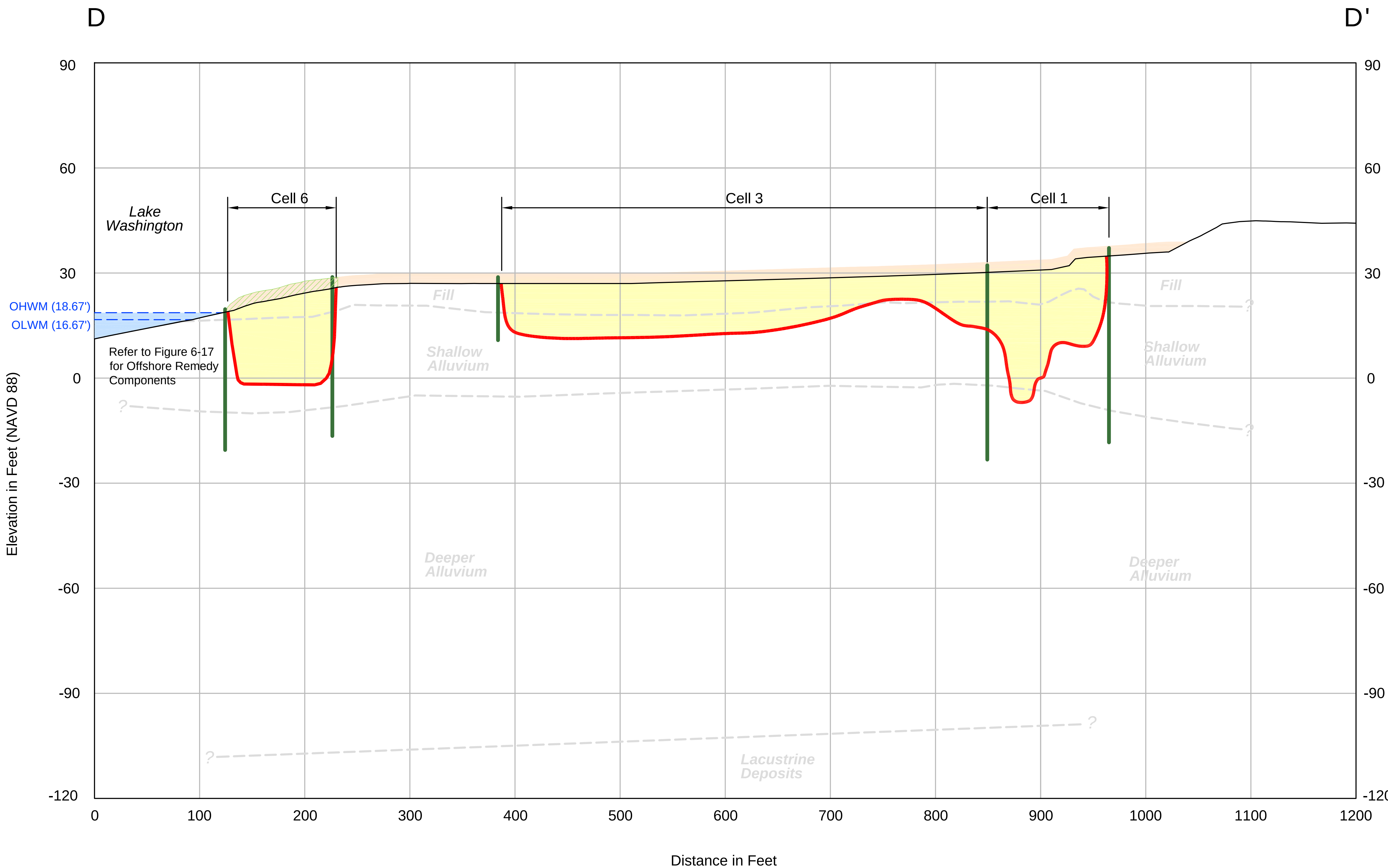
N

0 200 400
Feet

Alternative 8 - Remedy Components

Quendall Terminals Feasibility Study Report
Renton, Washington

Aspect CONSULTING | ARCADIS | FIRM: ASPECT | DRAWN BY: JJP/ELG/PMB/SCC | FIGURE NO. 6-18



Legend

Excavated Soil and Backfill	Estimated Extent of DNAPL (Refer to Figure 4-5 for Basis.)
Permeable Cap	Temporary Sheet Pile Wall
Permeable Cap/Habitat Area	

Horizontal Scale

0 100 200

Feet

Vertical Scale

0 30 60

Feet

Vertical Exaggeration x 3.33

Alternative 8 - Upland Remedy Components along Cross Section D-D'

Quendall Terminals Feasibility Study Report
Renton, Washington

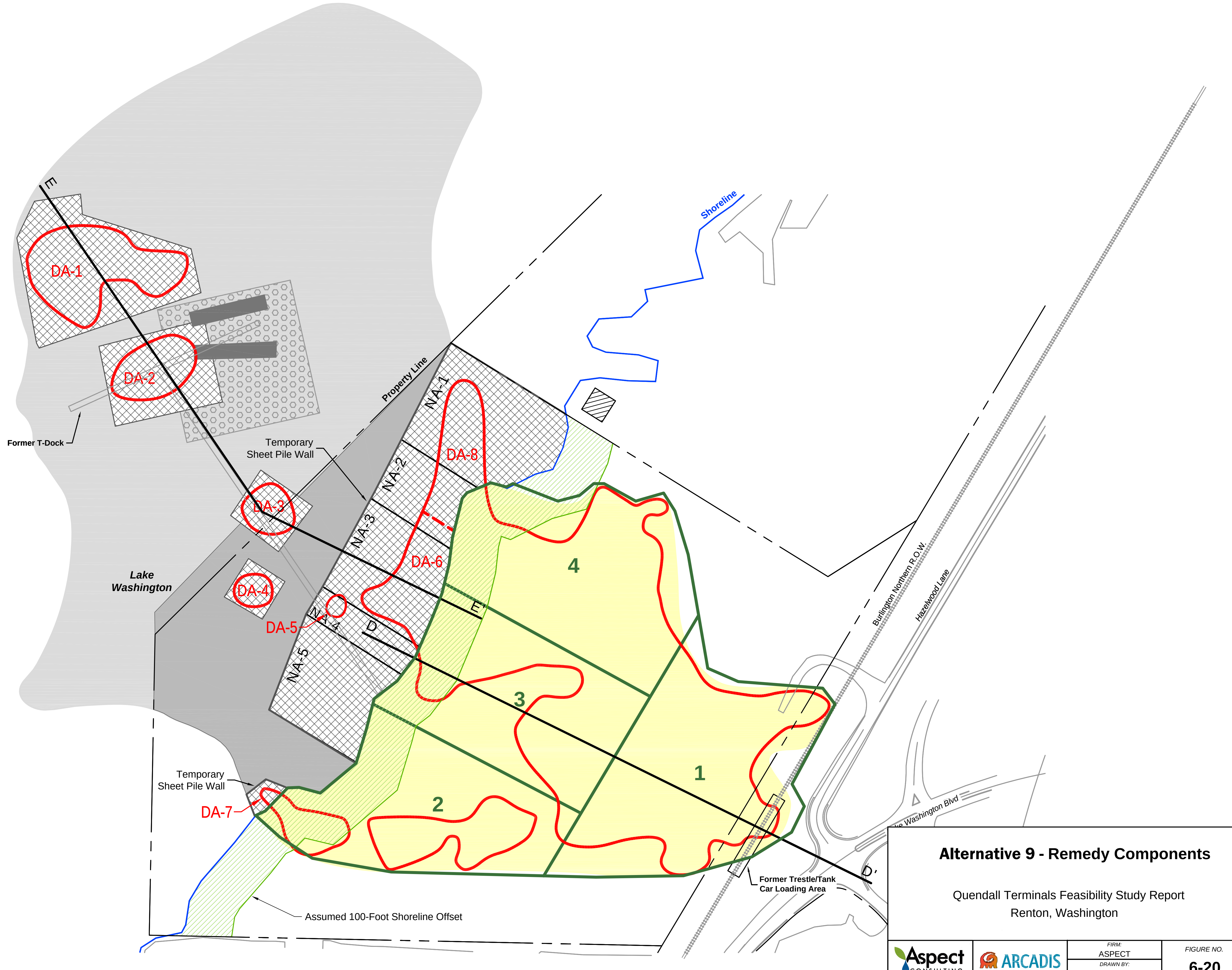
Aspect CONSULTING | ARCADIS | FIRM: ASPECT | DRAWN BY: JJP/PMB/ELG/SCC | FIGURE NO. 6-19

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 4. Refer to Figure 6-6 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.

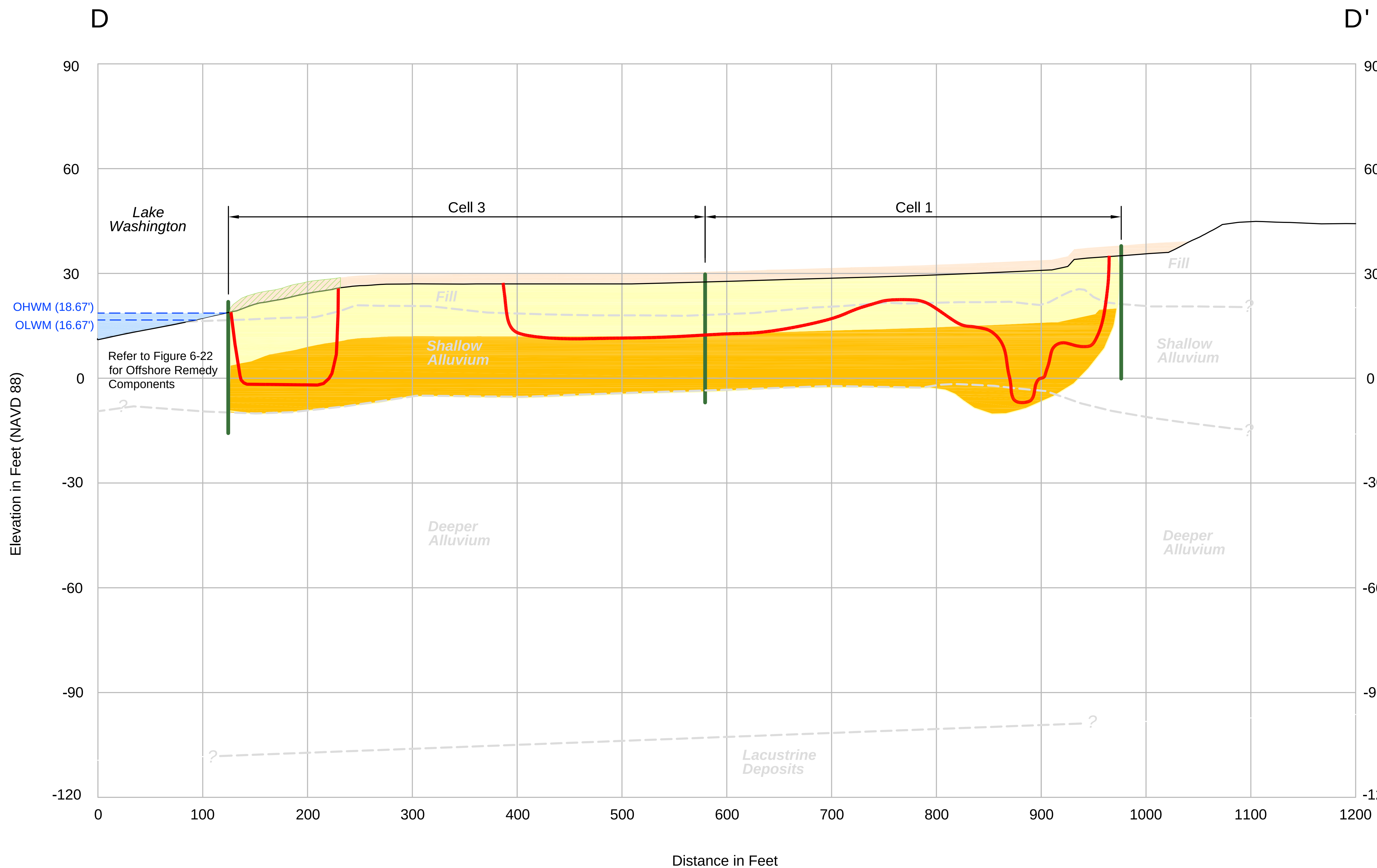


Alternative 9 - Remedy Components

Quendall Terminals Feasibility Study Report
Renton, Washington

Aspect CONSULTING | ARCADIS | FIRM: ASPECT | DRAWN BY: JJP/PMB/SCC | FIGURE NO. 6-20

CAD Path: Q:\Quendall\020027 Quendall Terminals\2015-09 Interim Delivery\Section 6\020027_Plan-Alternatives 9-10.dwg ALT 9 NEW || Coordinate System: NAD 1983 State Plane Washington North FIPS 4601 Feet || Date Saved: Oct 09, 2015 2:32pm || User: scudd



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

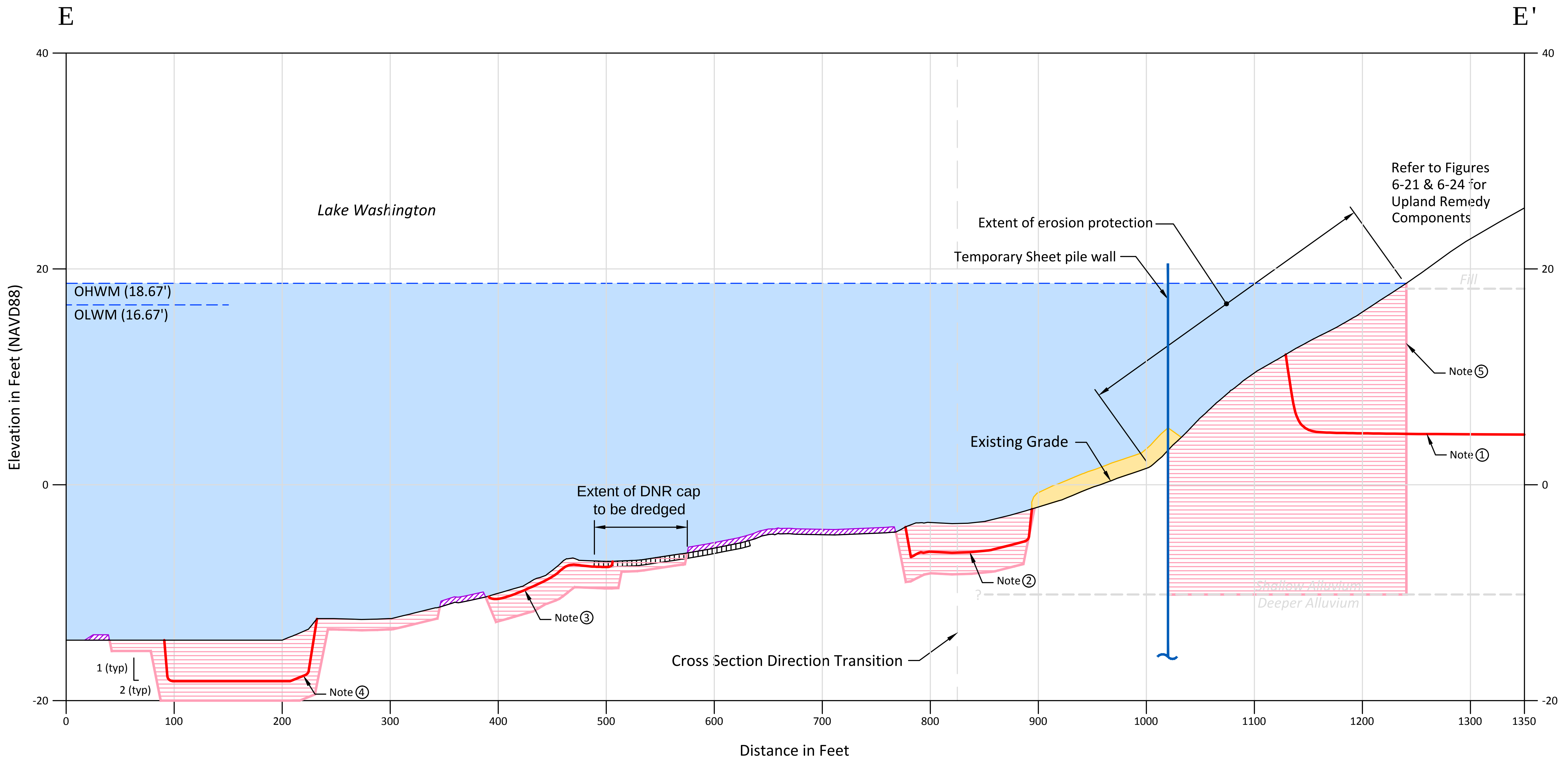
Feet

Vertical Exaggeration x 3.33

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. 6-21



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

Alternatives 9 & 10 - Offshore Remedy Components along Cross Section E-E'

Quendall Terminals Feasibility Study Report

Renton, Washington

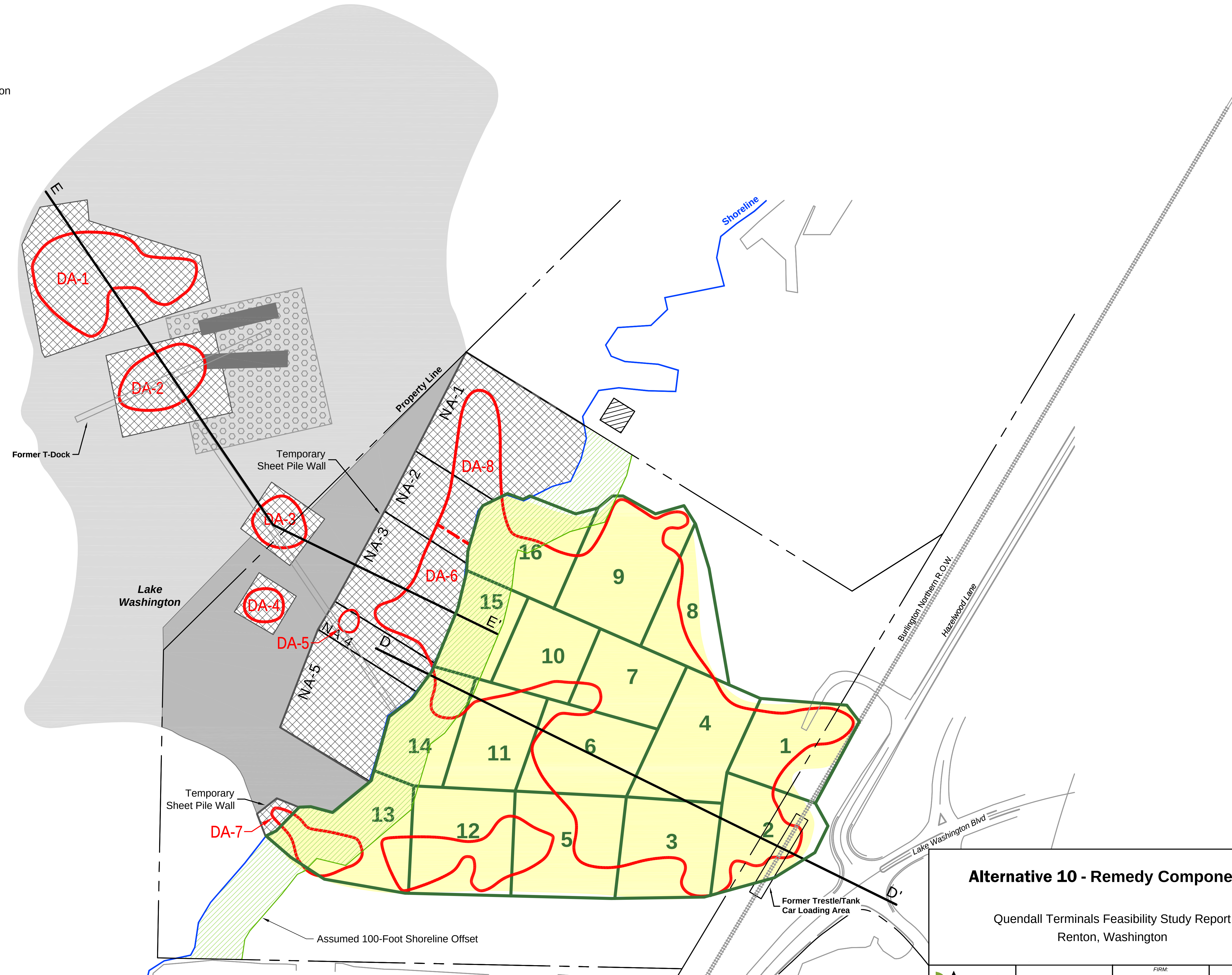
Aspect CONSULTING | ARCADIS | FIRM: ARCADIS | DRAWN BY: BKD | FIGURE NO. 6-22

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 4. Refer to Figure 6-6 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.

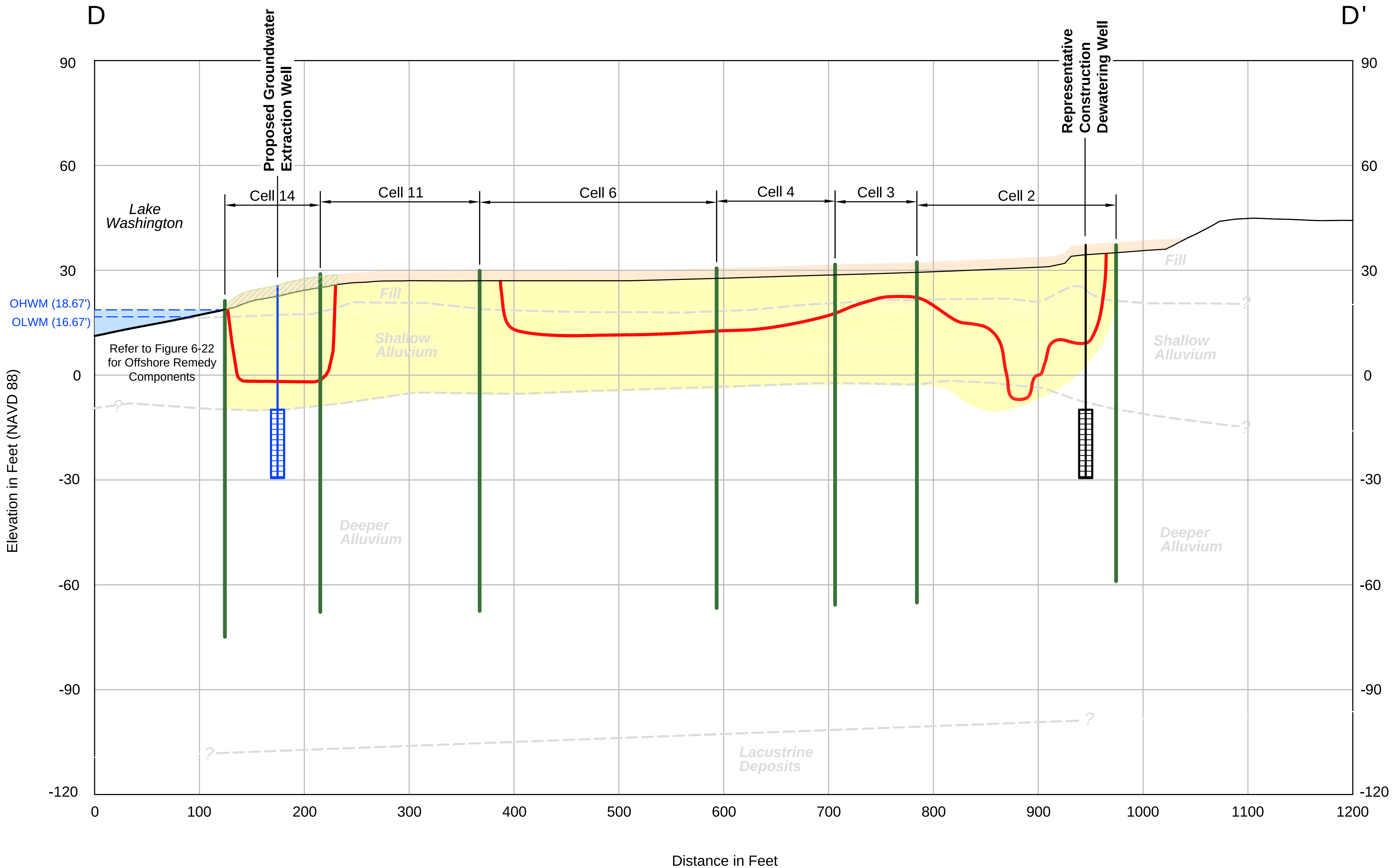


Alternative 10 - Remedy Components

Quendall Terminals Feasibility Study Report
Renton, Washington

Aspect CONSULTING | ARCADIS | FIRM: ASPECT | DRAWN BY: JJP/PMB/SCC | FIGURE NO. 6-23

CAD Path: Q:\Quendall\020027 Quendall Terminals\2015-09 Interim Delivery\Section 6\020027_Plan-Alternatives 9-10.dwg ALT 10 NEW || Coordinate System: NAD 1983 State Plane Washington North FIPS 4601 Feet || Date Saved: Oct 09, 2015 2:33pm || 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

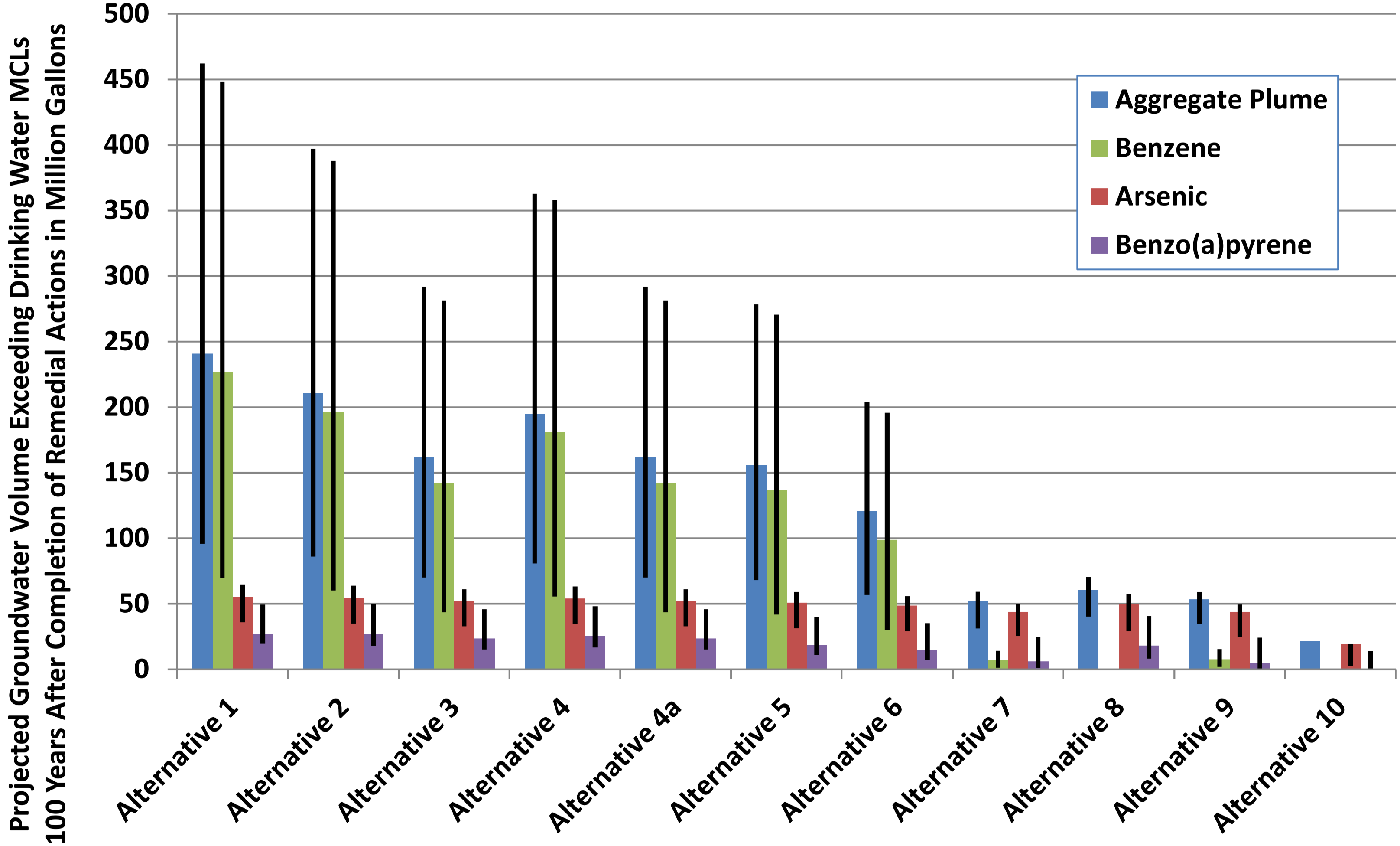
Alternative 10 - Upland Remedy Components along Cross Section D-D'

Quendall Terminals Feasibility Study Report
Renton, Washington

Aspect CONSULTING | ARCADIS

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

FIGURE NO. 6-24



Notes:

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

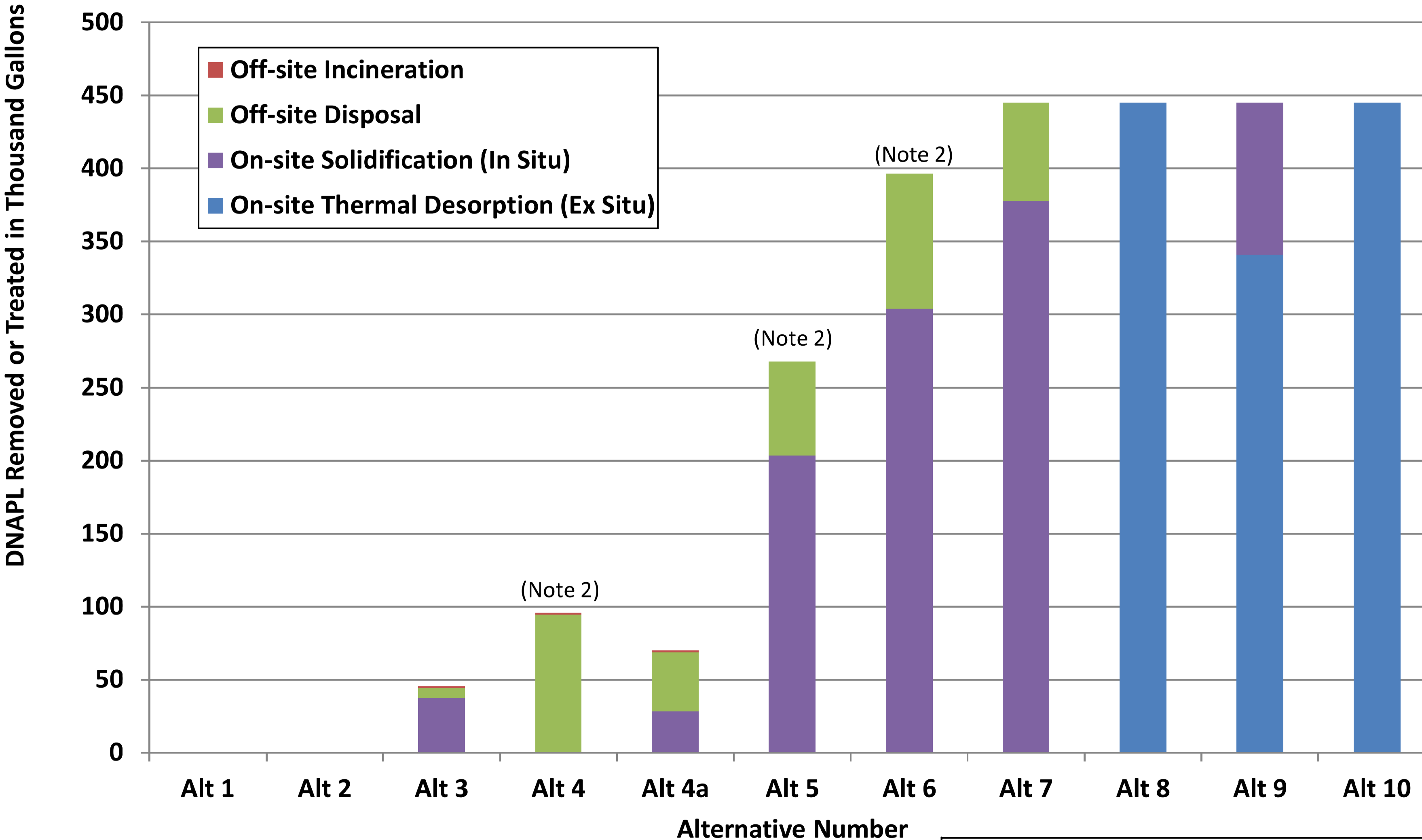
Restoration of groundwater for Alternative 4a is assumed to be similar to FS Alternative 3.

Projected Groundwater Restoration 100 Years After Implementation of Alternative Remedial Actions

Quendall Terminals Feasibility Study Report
Renton, Washington

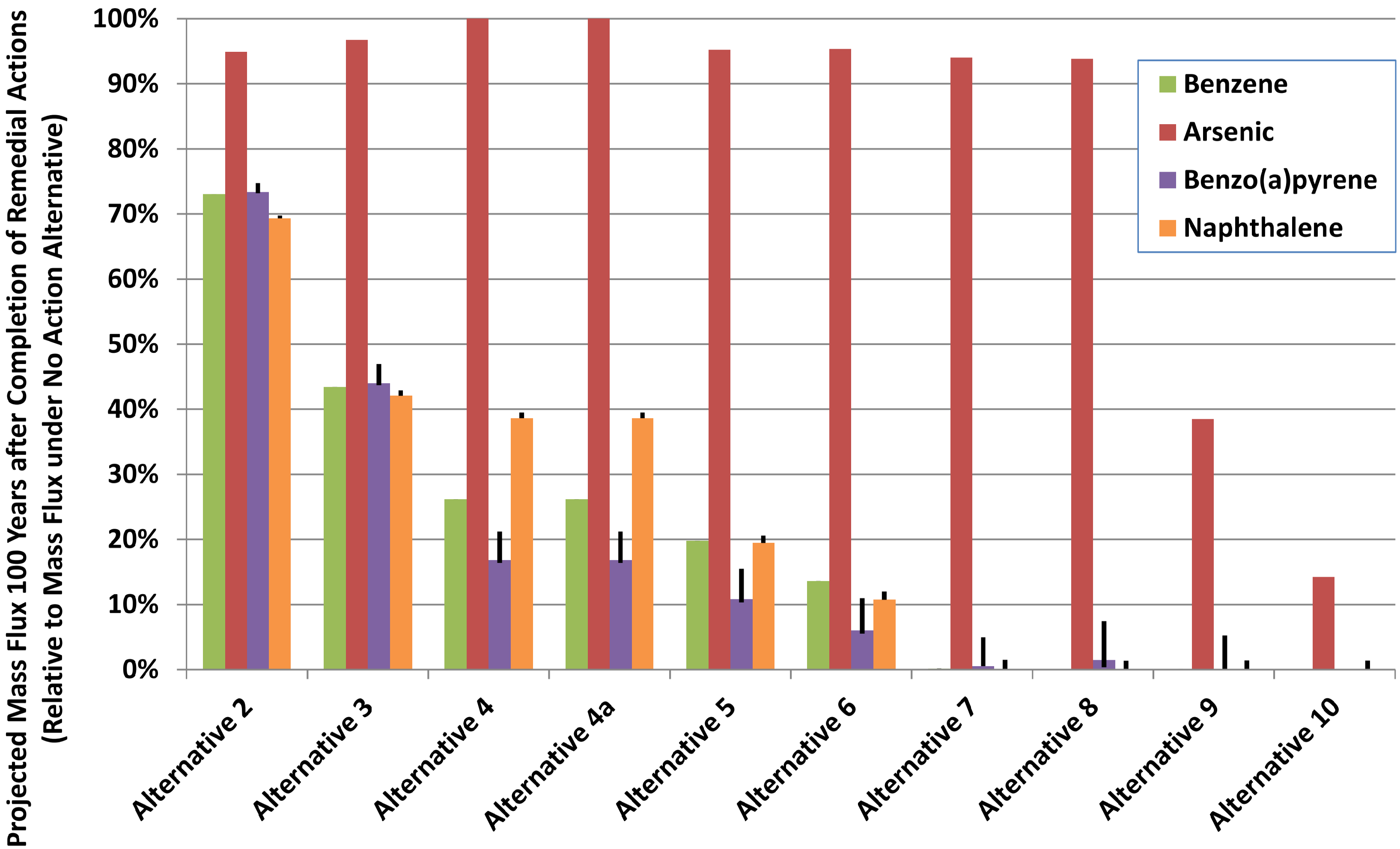
Aspect CONSULTING | ARCADIS | FIRM: ASPECT DRAWN BY: SCC | FIGURE NO. 7-1

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



Estimated DNAPL Volumes Removed or Treated Under Alternative Remedial Actions
Quendall Terminals Feasibility Study Report
Renton, Washington

Aspect CONSULTING | ARCADIS | FIRM: ASPECT, DRAWN BY: SCC | FIGURE NO. 7-2



Notes:

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 sensitivity analysis. Black bars for other alternatives are estimates derived from sensitivity analysis results.

See Appendix A for details.

Reduction in contaminant mass flux for Alternative 4a is assumed similar to FS Alternative 4.

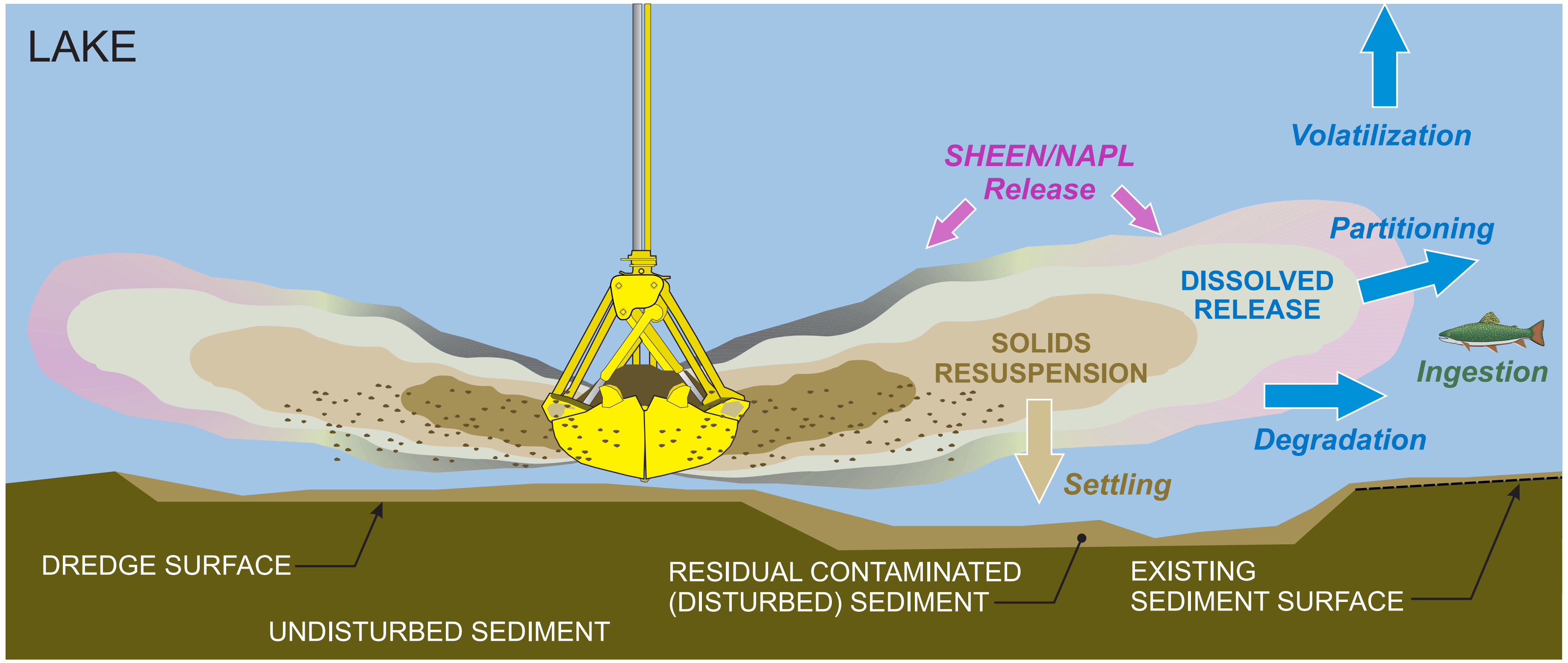
CAD Path: Q:\Quendall\020027 Quendall Terminals\2015-09 Interim Delivery\Section 7\020027-7-1.dwg Fig 7-3 | | Date Saved: Oct 05, 2015 3:52pm | | User: scudd

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

Quendall Terminals Feasibility Study Report

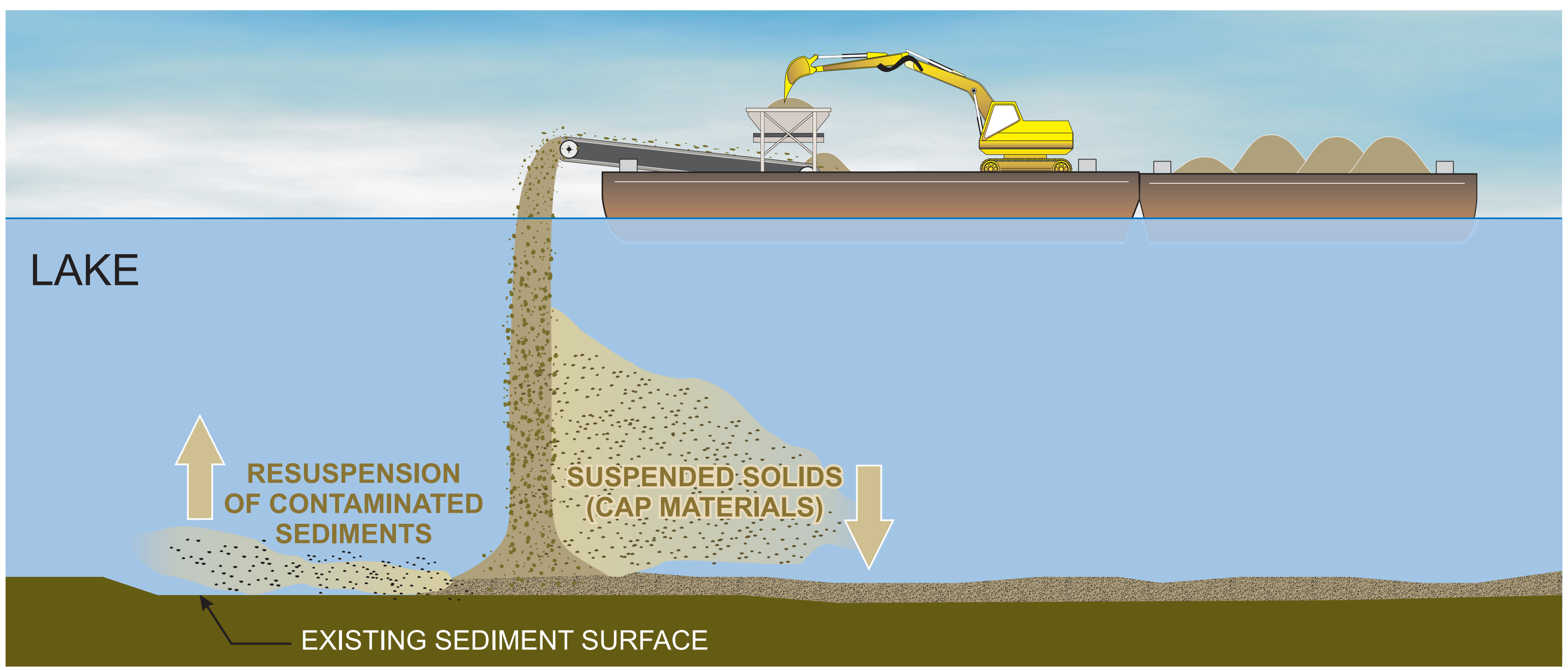
Renton, Washington

Aspect CONSULTING | ARCADIS | FIRM: ASPECT | DRAWN BY: SCC | FIGURE NO. 7-3



NOT TO SCALE

POTENTIAL IMPACTS OF DREDGING



NOT TO SCALE

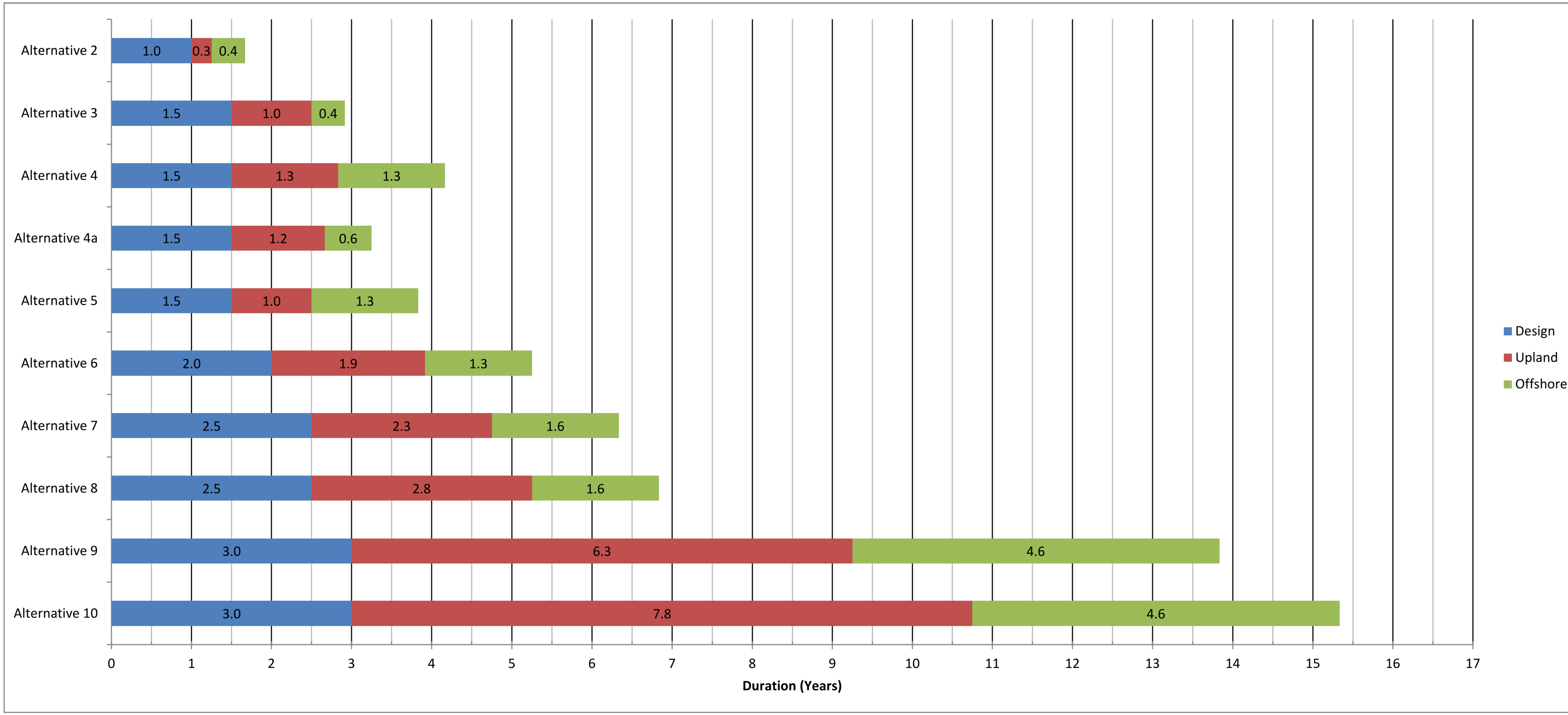
POTENTIAL IMPACTS OF CAPPING

Potential Short-Term Impacts of Sediment Capping and Dredging

Quendall Terminals Feasibility Study Report
Renton, Washington

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.

Summary of Estimated Remedy Design and Construction Durations

Quendall Terminals Feasibility Study Report
Renton, Washington

Aspect CONSULTING | ARCADIS | FIRM: ASPECT | DRAWN BY: SCC | FIGURE NO. 7-5