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Uplands Feasibility Study Report
BNSF Wishram Railyard
(Ecology Site Name BNSF Track Switching Facility)
Wishram, Washington

26 May 2022

Prepared for

BNSF Railway Company
605 Puyallup Avenue
Tacoma, Washington 98421

KJ Project No. 2096120.06

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(Ecology Site Name BNSF Track Switching Facility)
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Ecology Agreed Order No. DE 12897

Prepared by:

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This report was prepared by the staff of Kennedy/Jenks Consultants, Inc. under the supervision of the engineer whose seal and signature appear below.

The findings, recommendations, specifications, or professional opinions presented in this report were prepared in accordance with the generally accepted professional engineering practice and within the scope of the project. No other warranty, either expressed or implied, is provided.

5/26/2022

Ryan Hultgren, Project Engineer
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May 2022

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List of Acronyms

Acronym	Description
°C	degrees Celsius
AO	Agreed Order
API	American Petroleum Institute
ARAR	applicable, relevant, and appropriate requirement
AST	aboveground storage tank
bgs	below ground surface
BNSF	BNSF Railway Company
BTEX	benzene, toluene, ethylbenzene, and xylenes
CAP	Cleanup Action Plan
COC	constituent of concern
cPAH	carcinogenic polycyclic aromatic hydrocarbon
CPOC	conditional point of compliance
CRMP	cultural resources management plan
CSM	conceptual site model
CUL	cleanup level
CWA	Clean Water Act
cy	cubic yard
DAHP	Department of Archaeology and Historic Preservation
DCA	disproportionate cost analysis
DCAP	draft Cleanup Action Plan
DO	dissolved oxygen
DRO	diesel-range organics
EC	Environmental Covenant
EEBC	Environmental Effects-Based Concentration
Ecology	Washington State Department of Ecology
ERH	Electrical Resistive Heating
FS	feasibility study
GAC	granular activated carbon
GRO	gasoline-range organics
IC	Institutional Control
JARPA	Joint Aquatic Resources Permit Application
KJ	Kennedy/Jenks Consultants, Inc.
LDRM	LNAPL distribution and recovery model
LIF	laser-induced fluorescence

Acronym	Description
LNAPL	light non-aqueous phase liquid
LTTR	Low-Temperature Thermal Removal
µg/L	micrograms per liter
MCL	Maximum Contaminant Level
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
MNA	monitored natural attenuation
MTCA	Model Toxics Control Act
NSZD	natural source zone depletion
TPH-Dx	Total Petroleum Hydrocarbons as Diesel and Oil Extended
O&M	operations and maintenance
OHM	oil head monitoring
ORO	oil-range organics
ORP	oxidation-reduction potential
PAH	polycyclic aromatic hydrocarbon
PLC	programmable logic controller
POTW	Publicly Owned Treatment Works
PQL	practical quantitation limit
PVC	polyvinyl chloride
PVI	petroleum vapor intrusion
RAO	Remedial Action Objectives
RGW	reconnaissance groundwater
RI	remedial investigation
REL	Remediation Level
SP&S	Spokane, Portland, and Seattle Railway
TPH	total petroleum hydrocarbon
TPH-Dx	Total Petroleum Hydrocarbons as Diesel and Oil Extended
UST	underground storage tank
VOC	volatile organic compound
WAC	Washington Administrative Code

Section 1: Introduction

On behalf of the BNSF Railway Company (BNSF), Kennedy/Jenks Consultants, Inc. (KJ) prepared this Draft Feasibility Study (FS) Report for the BNSF Wishram Railyard (Ecology Site Name: BNSF Track Switching Facility) in Wishram, Washington (Figure 1).

The FS has been prepared in accordance with the Washington State Department of Ecology (Ecology) Model Toxics Control Act (MTCA) regulations published in Washington Administrative Code (WAC) 173-340 (Ecology 2007) and pursuant to an Agreed Order (AO, No. DE 12897) between Ecology and BNSF dated 7 October 2015.

1.1 Objectives

This FS evaluates cleanup options for the uplands portion of the site, with the goal of identifying the most feasible cleanup strategy that is protective of human health and the environment and meets the requirements of Ecology's MTCA regulations [WAC 173-340].

1.2 Site History

The Wishram Railyard was originally developed by the Spokane, Portland, and Seattle (SP&S) Railway between 1910 and 1912. Existing and historical site features are shown on Figures 2 through 5. The primary use of the railyard was, and remains, railcar switching. Historically, industrial activities (locomotive fueling and watering, fuel storage, as well as engine and car repairs) occurred in the westernmost portion (approximately 1,100 feet) of the railyard (i.e., the site), covering an area of approximately 6 to 10 acres, as shown on Figures 2 and 3. The eastern portion of the site generally refers to the area east of the former Signal Office and former Oil House and near a former septic drainage field, as shown on Figures 4 and 5. A detailed history of the Wishram Railyard was included in the *Uplands Remedial Investigation Report BNSF Wishram Railyard (Ecology Site Name BNSF Track Switching Facility) Wishram, Washington* (Uplands RI Report) (KJ 2020) and is summarized below.

Historical Fueling Operations

Steam locomotive fueling using oil was conducted at the site from approximately 1912 through 1956. Fueling facilities included a 30,000-barrel oil aboveground storage tank (AST) located north of the mainline tracks, an Elevated Oil Service 28,000-gallon AST located south of the mainline tracks, an oil unloading trough east of the Power House, a concrete sump, as well as associated appurtenances and piping (Figures 2 and 3). The oil ASTs and appurtenances were removed circa-1957 after the transition to diesel-fueled locomotives in the 1950s.

Diesel locomotives were fueled at the site from the early 1950s to the late 1970s. Diesel fueling was performed along a fueling spur and at a concrete fueling island (installed in 1949), located north and south, respectively, of the mainline tracks. The diesel fuel was initially stored in one 15,000-gallon and one 20,000-gallon underground storage tanks (USTs). In the late 1950s, diesel was stored in two 100,000-gallon ASTs (constructed in or after 1955) located northwest of the Maintenance Shop. Diesel fuel was transferred to and from the tanks by underground piping. The 100,000-gallon diesel ASTs were removed and fueling ceased at the site during the late 1970s. Based on available records in BNSF's internal UST database, the majority of the remaining tanks were removed in or prior to 1988.

Historical Maintenance Operations

Locomotives underwent maintenance and repairs in the former Engine House/Machine Shop. The former Engine House was constructed in 1911 as a rectangular run-through style building and underwent multiple additions until reaching its maximum footprint size in the 1940s (Figure 3). The former Engine House was demolished in the 1980s after it was no longer needed. Railcar repairs were performed in an area consisting of three tracks and the former (Car) Repair Shop, located to the southeast of the former Engine House/Machine Shop. The car repair shop building was removed in 1960.

Septic Drainage Field

A former septic drainage (leach) field and five septic tanks, located approximately 600 feet to the northeast of the former Engine House (Figure 5), was identified on a station layout map from 1959. Historical maps indicate that the septic system and drainage field treated and discharged wastewater generated on the railyard, as well as wastewater generated by the City of Wishram (single-family homes, a hotel, restaurant, etc.) starting sometime before 1962 and ceasing prior to 1996.

Lake Celilo

In 1957, the U.S. Army Corps of Engineers completed construction of The Dalles Dam, a hydroelectric dam just upstream of The Dalles, Oregon. The flood gates were closed in March 1957, and rising water created Lake Celilo, a 24-mile-long reservoir on the Columbia River. In the vicinity of the railyard, the surface water elevation increased by approximately 40 feet in just a few days, inundating formerly dry land south of the railyard (inundated lands), and significantly altering groundwater elevations and flow conditions beneath the railyard (see Figures 2 and 3). Operation of the hydroelectric dam results in daily fluctuations in the surface water elevation, impacting groundwater flow beneath the site. Adjacent to the railyard, daily surface water elevation changes have been recorded from a few inches up to approximately 4 feet.

1.3 Previous Investigations and Remedial Actions

A complete description of previous investigations and interim remedial actions is included in the Uplands RI Report (KJ 2020). Previous investigations and remedial actions are briefly summarized here. Areas where interim remedial actions were completed are shown on Figure 6.

Investigation activities were initiated onsite in 2002 to evaluate potential impacts to subsurface soils and groundwater from historical railyard activities. BNSF performed voluntary independent investigative and remedial actions through 2015. Site investigation and interim remedial activities included excavating and disposing soil containing petroleum hydrocarbons, removing and disposing former USTs, collecting soil and groundwater samples, conducting a laser-induced fluorescence (LIF) survey, and investigating light non-aqueous phase liquid (LNAPL) mobility in the vicinity of the former Power House. An air sparge/soil vapor extraction system was installed in early 2012, and was converted to a bioventing system in June 2012, to address residual hydrocarbon impacts in soil north and west of the Maintenance Shop. Operation of the bioventing system continued through July 2019.

BNSF and Ecology entered into an AO (No. 12897) in 2015 to complete the RI and FS. Field activities performed under the AO were substantially conducted between August 2016 and August 2020 and included collection of soil and groundwater samples, installation of groundwater monitoring wells, installation of four oil head monitoring (OHM) wells, collection of LNAPL samples for mobility testing, monthly inspections of the nearshore Columbia River surface from the bank, collection of oil sheen/oil droplet samples from the surface of the Columbia River, and investigation of the presence and extent of LNAPL impacts in the nearshore inundated lands bordering the site. Additional field activities to aid in the feasibility evaluation of remediation alternatives were conducted between July and September 2019 and are summarized in Appendix A. Evaluations of groundwater flow conditions beneath and in the vicinity of the site, as well as the potential migration of dissolved hydrocarbons from the site to the Columbia River were also conducted as part of the RI activities and are summarized in the Uplands RI Report (KJ 2020).

The site is situated within the Columbia Hills Archaeological District as designated by the Washington State Department of Archaeology and Historic Preservation (DAHP), in a culturally significant area due to its proximity to Celilo Falls. The Geoarchaeological Monitoring of Additional Remedial Investigations report (Jacobs 2018) provides a detailed description of the historical background of the site and its potential cultural resources. A cultural resources management plan (CRMP) (AECOM 2016) was developed to establish protocols for managing cultural resources. The CRMP was submitted to the DAHP and the Confederated Tribes and Bands of the Yakama Nation. Subsurface investigative activities conducted in 2016 and 2018 were completed in accordance with the CRMP. Intrusive activities were performed under permit from DAHP.

1.4 Summary of Site Conditions

A complete description of current site conditions is included in the Uplands RI Report (KJ 2020). Site conditions are briefly summarized below.

Petroleum hydrocarbons are present in soil and groundwater in the vicinity of former USTs, former ASTs, and former infrastructure used to store and transfer fuel oils. LNAPL beneath the site is composed of both diesel and Bunker-C oil fuels; and is primarily located beneath the former underground oil pipelines and the former Power House (Figures 7 and 8). MTCA Method A and Method B Cancer and Noncancer Cleanup Levels (CULs) were used as screening values for chemicals reported in soil and groundwater samples during the RI.

A summary of conditions reported in the Uplands RI Report through 2019 and subsequent groundwater monitoring in 2020 follows:

- Petroleum hydrocarbons [reported as diesel-range organics (DRO) and oil-range organics (ORO)] are present in soil and groundwater at concentrations above MTCA

Method A CULs in areas associated with loading, unloading, and storage of fuel oil and diesel fuel.

- o Figures 9 and 10 show DRO/ORO results in unsaturated and saturated soil, respectively, in the main area of the site. DRO/ORO was not reported above MTCA Method A CULs in the eastern area of the site.

- o Petroleum hydrocarbon results in groundwater for DRO/ORO and total petroleum hydrocarbons – diesel range fraction (sum of DRO and ORO results) expressed as TPH-Dx are shown on Figures 11, 12, and 13 for the main area and Figures 14, 15, and 16 for the eastern area. DRO/ORO and TPH-Dx were reported in samples from monitoring wells and reconnaissance groundwater (RGW) sampling locations above groundwater MTCA Method A CULs, primarily in the historical fueling operations areas of the main area. TPH-Dx results were slightly above the CULs in samples from three RGW locations (no wells have been installed) near the former septic drainage field (eastern area, Figure 15).

- Suspected legacy sources of petroleum hydrocarbons have been decommissioned and removed from the site and impacted soil has been removed as part of interim remedial measure (IRM) activities. Where implemented, IRMs successfully removed petroleum hydrocarbons down to the water table or bedrock such that soil samples collected from all but 11 of 145 soil borings/excavation confirmation sampling locations in site areas in the unsaturated zone do not contain residual petroleum hydrocarbons above MTCA Method A CULs. A limited area of residual hydrocarbons is present near the berm (based on one sample) but does not significantly contribute to the overall presence of dissolved phase hydrocarbons in other areas of the site. Horizontal migration of vadose zone soil impacts is not expected because lateral gradients or geologic features that would result in horizontal movement are not present.

- The vertical and lateral extent of LNAPL beneath the site was delineated by conventional methods (advancing borings and installing monitoring wells) and the LIF survey. The LIF data were qualitatively evaluated with respect to field observations of the presence of LNAPL in soil borings, occurrence of measurable LNAPL thicknesses in monitoring wells, and interpretation of the LIF logs for fuel types(s) (e.g., diesel-like and Bunker C/oil-like). The data were quantitatively evaluated with respect to soil laboratory analytical results for petroleum hydrocarbons and estimates of residual LNAPL concentrations. These data were reviewed to assess the potential presence of LNAPL in the subsurface and to estimate LNAPL mobility. LNAPL mobility relates to the potential for LNAPL to flow from one location to another under an existing gradient. "Residual LNAPL" is present at or below LNAPL residual saturation and will not accumulate in a well or migrate across an area. "Mobile LNAPL" is present above the residual saturation and will accumulate in a well, but not migrate across an area. "Migrating LNAPL" is present above the residual saturation level and will migrate across an area under the appropriate hydraulic forces.

  LNAPL with properties consistent with both diesel and Bunker-C oil is present south of the mainline tracks near the former underground oil pipelines and the former Power House (Figures 7 and 8). Diesel LNAPL is present at the groundwater surface and in the periodically saturated vadose zone. Diesel and Bunker-C LNAPL is submerged at depths between the groundwater surface and up to 60 feet below the top of groundwater as a result of the formation of Lake Celilo. With the impoundment of Lake Celilo, the groundwater table rose rapidly, trapping LNAPL in the subsurface at depths similar to the pre-impoundment depth of groundwater. Submerged LNAPL is estimated to be greater than 60 years old based on known facility operations and the formation of Lake Celilo. LNAPL observed south of the mainline is classified as potentially recoverable, as evidenced by observations of measurable LNAPL in three of the four OHM wells and by laboratory measurements of LNAPL physical properties. LNAPL was not observed in the southernmost row of LIF borings bordering the berm separating the site from the Columbia River, nor in the monitoring wells installed along the berm during the RI (berm monitoring wells), and no evidence has been observed that the LNAPL body is migrating.

LNAPL with properties consistent with a weathered diesel fuel was historically present north of the mainline track in the vicinity of the Maintenance Shop. LNAPL in this area was located at the elevation of the pre-impoundment groundwater surface and in the periodically saturated vadose zone. Prior to January 2016, LNAPL was frequently observed in wells WMW-7 and WMW-8, located near the Maintenance Shop. Bioventing was implemented in this area as an IRM between 2012 and 2019. Except for a single event in November 2016 (0.10 foot measured in WMW-8), LNAPL has not been measured in either well since January 2016. A hydrocarbon sheen is inconsistently observed at the groundwater interface in wells WMW-7 and WMW-8. Soil gas measurements from 2019 feasibility field activities show oxygen at near-atmospheric concentrations and little to no carbon dioxide in this area (Appendix A), indicating that air exchange rates in the vadose zone are sufficient to sustain aerobic degradation of the petroleum hydrocarbons.

- Hydrocarbons in the gasoline range (GRO) were present above the MTCA Method A CUL in 12 of the 53 samples analyzed for GRO between 2004 and 2018. Elevated GRO concentrations in soil were located below the groundwater table in the vicinity of two former gasoline USTs (southwest of the Maintenance Shop) and the former Power House (Figure 17). GRO has not been reported at concentrations above its MTCA Method A CUL in groundwater samples since 2004, including those wells in close proximity to soil borings with GRO concentrations above the MTCA Method A CUL (Figure 18). Given their limited extent and concentrations, GRO does not pose risk to human health or the environment. No evidence of LNAPL associated with gasoline has been observed at the site.

- Volatile organic compounds (VOCs) typically associated with gasoline [benzene, toluene, ethylbenzene, and xylenes (BTEX compounds)], which typically pose the greatest potential risk to receptors, are present above MTCA Method A CULs in only two of 177 soil samples (benzene only); and do not exceed MTCA Method A CULs in groundwater samples collected since 2004. Fuel additives 1,2-dibromoethane [ethylene dibromide (EDB)] and 1,2-dichloroethane (EDC) were not reported above laboratory reporting limits in 128 soil samples collected and analyzed for these constituents. Chlorinated solvents and other VOCs were not reported at concentrations above MTCA Method A CULs in the 177 soil samples, nor in groundwater samples. The relative absence of VOCs and the lack of buildings in or near impacted areas indicates vapor intrusion is an incomplete exposure pathway under current site conditions.

- Polycyclic aromatic hydrocarbons (PAHs), including carcinogenic PAHs (cPAHs) which were used to calculate Total cPAHs, were reported above applicable MTCA Method A or B CULs in less than 10 percent of soil and groundwater samples. PAHs above MTCA Method A CULs are associated with samples that contained DRO and ORO above MTCA Method A CULs.

- Metals reported in soil were below applicable MTCA Method A or B CULs in 126 of 127 samples. Metals reported in monitoring well groundwater samples above applicable MTCA Method A or B CULs were limited to dissolved and total arsenic, total barium (one sample only), dissolved iron, and dissolved manganese. Iron, manganese, and arsenic are present in groundwater in locations where petroleum hydrocarbons and residual organics affect groundwater geochemistry and liberate naturally occurring metals in soil into groundwater.

Section 2: Conceptual Site Model

A Conceptual Site Model (CSM) is included in the Uplands RI Report (KJ 2020). The CSM is briefly summarized below. Representative cross sections and a plan view CSM are presented on Figures 19 through 22.

2.1 Site-Related Constituents and Locations

Based on historical railroad operations and previous investigations, constituents of concern (COCs) identified for the site include Total Petroleum Hydrocarbons expressed as DRO, ORO, and to a limited extent, GRO. Dissolved and total arsenic, dissolved iron, and dissolved manganese are also present in site groundwater as a result of reducing conditions caused by the natural degradation of DRO and ORO in groundwater.

General areas within the present upland remediation investigation areas (i.e., not including inundated lands to the south of the railyard, beneath the Columbia River) where petroleum hydrocarbon-related constituents have been identified include the following (see Figure 22):

- Around the Mainline tracks (mainline track area) – vicinity of the former Boiler House and its former UST, former Pump House (associated with former Diesel ASTs), and the current Maintenance Shop.
- South of Mainline tracks (eastern and western LNAPL areas and dissolved phase) – vicinity of former diesel and oil fueling areas and underground piping, former Oil Unloading Track, former Oil Trough, and former Power House.
- Former Engine House/Machine Shop and vicinity.
- Berm Area south of the former Engine House/Machine Shop.
- Former Oil House east of the former Signal Office/former Store House.

Potential operational sources of petroleum hydrocarbon-related constituents in these areas (historical oil and diesel fueling operations and steam power production, storage of oil and diesel fuel in multiple ASTs and USTs onsite, transport of oil in associated underground piping systems) are no longer present. Current site conditions are the result of historical impacts.

2.2 Fate and Transport

Transport of COCs includes leaching from impacted saturated soils and submerged LNAPL bodies, downward migration from historically impacted unsaturated soils to the saturated zone during precipitation events, and migration in shallow-zone groundwater through advection and dispersion. Low concentrations of carbon dioxide and high concentrations of oxygen in soil gas (Appendix A, Figure A3) indicate that petroleum hydrocarbons adsorbed to unsaturated soils are naturally degrading through aerobic biodegradation. COCs adsorbed to saturated soils will migrate through dissolution and advective/dispersive forces.

As presented in the Uplands RI Report (KJ 2020), the Columbia River is a losing stream more than 80 percent (10 months) of the year. Appendix A includes graphs of the daily average hydraulic gradient (in feet per foot) calculated between select monitoring wells and the river during between December 2016 and April 2018 and between March 2019 and August 2021. A negative hydraulic gradient value results when the river elevation is greater than the groundwater elevation and implies water flowing away from the river (losing stream condition), while a positive value implies water flowing to the river (gaining stream condition). Over the two monitoring periods, losing stream conditions were observed more than 80 percent of the time in shallow berm wells (WMW-14, WMW-16, and WMW-18). Site groundwater discharges to surface water in the Columbia River during a very limited portion of the year. Therefore, transport of COCs offsite is limited.

2.3 Potential Exposure Pathways

Potentially complete exposure pathways for human and ecological receptors at the site include direct contact and/or incidental ingestion by construction workers and railyard workers of affected media (soil and groundwater). The vapor intrusion pathway has previously been identified as an incomplete exposure pathway due to lack of VOCs reported in soil and groundwater and the limited number of buildings (e.g., Maintenance Shop) onsite. A petroleum vapor intrusion (PVI) initial assessment presented in the Uplands RI Report (KJ 2020) concluded that PVI is not a risk in the Maintenance Shop. Although shallow groundwater at the site is not a current source of drinking water nor is it identified as a future drinking water source since potable water is supplied to the site by the City of Wishram, in accordance with WAC 173-340-720, groundwater at the site is considered potable for current and future uses. Therefore, human consumption of shallow site groundwater is a potential exposure pathway. The former water supply wells (Well #2 and Well #3) were decommissioned between 22 March and 19 April 2022 in accordance with WAC 173-160-381.

The following exposure pathways are considered to be potentially complete for human receptors based on the existing site conditions and uses (Figure 23):

- Surface and subsurface soil direct contact and/or incidental ingestion by site, construction, and utility workers.

- Groundwater direct contact and/or incidental ingestion by site, construction, and utility workers [saturated conditions exist within approximately 10 to 15 feet below ground surface (bgs)].

- Consumption of groundwater by site, construction, and utility workers.

- Surface water direct contact and/or incidental ingestion by site, construction, and utility workers, and recreational users.

- Consumption of aquatic organisms by recreational users.

Direct contact and/or incidental ingestion exposure pathways for soil and groundwater can be controlled by institutional controls (ICs) and soil management/construction plans. The ICs would be put in place to protect onsite receptors.

Ecological exposures to site-related constituents in upland areas of the site are negligible, as gravel and asphalt cover render ecological exposure routes incomplete across much of the site. Ecological receptors may occupy the sparsely vegetated areas along the berm separating the site from the Columbia River. Potential exposure risks along the berm are negligible given the existing analytical data characterizing berm surface soil (i.e., no known impacts) and delineated depth of subsurface impacts beyond anticipated receptor exposure depth. Further, the primary COCs present in soil underlying the berm (i.e., petroleum hydrocarbon-related compounds) are not expected to bioaccumulate in the food chain.

Ecological exposures in the adjacent reach of the Columbia River are possible, specifically the potential for consumption of organisms by recreational users and other aquatic organisms. Investigation of environmental conditions in the area of the inundated lands in the adjacent reach of the Columbia River is ongoing.

Section 3: Proposed Cleanup Standards

The process of setting cleanup standards includes establishing Remedial Action Objectives (RAOs), identifying the CULs and Remediation Levels (RELs) that will be used to identify areas of the site requiring remediation based on current and future use and designated beneficial use, and identifying the point of compliance locations where remediation progress will be evaluated.

RAOs are narrative statements describing the goals of the remedial action. They identify the conditions targeted by the remedy in each environmental media to protect human health and the environment. RAOs are based on consideration of current and future land use, and groundwater and surface water beneficial use designations.

BNSF Wishram Railyard Property

The Klickitat County, Washington zoning map [https://www.klickitatcounty.org/284/Zoning-Map; (Klickitat County Zoning Map)], indicates the railyard is zoned as an “Industrial Park.” The site is currently used as a railyard and meets the definition of an industrial property in WAC 173-340-200 and the applicability criteria of soil cleanup standards for industrial properties under WAC 173-340-745(1)(a) parts (i)(A) through (F). The railyard and areas north of the mainline track area (e.g., the maintenance shop and bullpen) have controlled access, including fencing between the existing depot and maintenance shop, a fenced-in bullpen north of the maintenance shop, and are patrolled by railroad police. The primary potential exposures to potentially impacted surface and subsurface soil, groundwater and adjacent surface water are to adult railroad, construction, and utility workers.

The site is fully developed as an industrial railyard where buildings, pavement, rail lines, and surfaces (comprising approximately 94 percent of the land area) are designed and managed per federal regulations to remove and control vegetation, limit the potential for vegetation with deep root zones and use by wildlife. The railyard surface areas, covered by gravel, asphalt, or other impervious structures (e.g., buildings) minimize potential exposure to the soil. Along the Columbia River, engineered embankments (forming the berm area) composed of large riprap protect the banks from erosion and restrict potential deeper soil contact by occupants and wildlife. Foreseeable future use of the site is anticipated to remain the same, with railyard operations including railcar switching on tracks located just south of the Depot (Figure 2).

Off-Railyard Properties

The area to the north of the railyard property boundary (off-railyard properties) (see Figure 2), is zoned as “Rural Center”. Potential petroleum hydrocarbon impacts related to the railyard are limited to the vicinity of the former boiler house and former heating oil UST within this area. The UST and approximately 750 tons of petroleum hydrocarbon-impacted soil were removed in April 2002 (see Figure 6 for approximate lateral extent of the excavation area). Petroleum hydrocarbon-impacted soils were excavated to the top of the bedrock surface (to the extent practicable) at a depth of approximately 16 feet below ground surface (bgs); groundwater was not encountered in the excavation. Confirmation soil samples from the north, east, and south sidewalls of the excavation indicated diesel- and oil-range petroleum hydrocarbon impacts remained in-place from approximately 14.5 to 15.5 feet bgs (see Figures 9 and 10).

Fire District #11 Wishram is listed as the property owner of the two property parcels located in this area (Figure 2). Current features include two warehouse storage-type buildings used by the fire department in the eastern parcel and a U.S. Post Office in the western parcel. Surface areas covered by gravel or impervious structures (buildings) comprise approximately 65 percent of the land area between the two parcels and minimize potential exposure to the subsurface soil. The primary potential exposures to potentially impacted subsurface soil and groundwater are to adult construction and utility workers.

In accordance with WAC 173-340-720, designated groundwater uses include potential drinking water source, although shallow groundwater at the site is not a current source of drinking water nor is it identified as a future drinking water source since potable water is supplied to the site by the City of Wishram. Beneficial use designations for the Columbia River near the site include water supply, spawning and rearing aquatic life, wildlife, and miscellaneous such as recreation, aesthetics, hydroelectric power generation, and commercial navigation and transportation.

3.1 Remedial Action Objectives

The RAOs for the Upland Area FS are based on the CSM, which identified the potential receptors and exposure pathways present at the site. The RAOs include the following:

- Protect site, construction, and utility workers from direct contact with and incidental ingestion of soil containing COCs at concentrations above CULs during typical operations and soil excavations.
- Protect site, construction, and utility workers from direct contact with and ingestion of groundwater containing COCs at concentrations above CULs.
- Due to the depth of groundwater greater than 6 feet bgs, terrestrial ecological receptors are not expected to encounter groundwater in the upland area of the site.
- Protect aquatic and recreational receptors immediately adjacent to the site from direct contact with and incidental ingestion of surface water containing COCs at concentrations above applicable surface water criteria discharging to the Columbia River.
- Protect recreational users and aquatic biota from ingestion of aquatic organisms containing COCs at concentrations above applicable standards.

3.2 Points of Compliance

Points of compliance are locations where site conditions are compared to numeric criteria to evaluate whether CULs have been met and are used during remediation to evaluate the performance of the remedy and confirm protection of identified exposure pathways and receptors. Generally, the standard point of compliance under MTCA is sitewide. As provided for in WAC 173-340-720(8)(c), where it can be demonstrated under WAC 173-340-350 through 173-340-390 that it is not practicable to meet the cleanup level throughout the site within a reasonable restoration time frame, Ecology may approve a conditional point of compliance that shall be as close as practicable to the source of hazardous substances, and except as provided under WAC 173-340-720(8)(d), not to exceed the property boundary. MTCA defines CPOCs, including soil depths, for several potential receptor exposure pathways. Proposed points of compliance for soil and groundwater are discussed below.

3.2.1 Unsaturated Subsurface Soil

The standard point of compliance for soil based on human exposure via direct contact is sitewide to a depth of 15 feet bgs as the typical maximum depth of soil disturbing activities [WAC 173-340-740(6)(d)]. The unsaturated vadose zone within much of the railyard extends from the ground surface to 10 feet bgs and along the berm from the ground surface to approximately 15 feet bgs. A conditional point of compliance for soil, with adoption of ICs, is the water table depth of 10 feet bgs in the railyard.

BNSF Wishram Railyard Property. The site is fully developed as an industrial railyard where buildings, pavement, rail lines, and surfaces are designed and managed per federal regulations to remove and control vegetation, limit the potential for vegetation with deep root zones, and limit use by wildlife. Railroad operations control subsurface disturbance and can be formally established by ICs. Along the Columbia River, engineered embankments composed of large riprap protect the banks from erosion and restrict potential deeper soil contact by occupants and wildlife. As a result, soil between the ground surface and the groundwater table will be evaluated using applicable industrial MTCA Methods A and C cleanup levels, and soil concentrations protective of groundwater and protective of groundwater to surface water pathways.

Off-Railyard Property. The current use of the properties north of the maintenance shop area includes small business and commercial services uses (e.g., the U.S. Post Office and fire department storage buildings), although the zoning designation as “Rural Center” allows for other non-commercial uses including homes and eating/drinking establishments. Therefore, unsaturated zone soil in these areas will be evaluated using applicable MTCA Methods A and B unrestricted cleanup levels, along with consideration of soil concentrations protective of groundwater. As this area is not adjacent to surface water, soil concentrations protective of groundwater discharging to surface water will not be considered.

3.2.2 Saturated Subsurface Soil

The standard point of compliance for soil based on human exposure via direct contact is sitewide to a depth of 15 feet bgs as the typical maximum depth of soil disturbing activities [WAC 173-340-740(6)(d)]. The depth to groundwater in much of the railyard is 10 feet bgs. Groundwater was not encountered in the 2002 excavation adjacent to the former boiler house. However, based on 2016 and 2018 soil borings near the former 30,000-barrel Oil AST and the Maintenance Shop area, the depth to groundwater in the off-railyard properties to the north of the railyard was estimated as 14 feet bgs in the Uplands RI Report (KJ 2020).

BNSF Wishram Railyard Property. Soil between the groundwater table (approximately 10 feet bgs) and 15 feet bgs will be evaluated using applicable industrial MTCA Method A and C cleanup levels and, for those constituents likely to leach to groundwater, soil concentrations for the saturated zone that are protective of groundwater and protective of groundwater to surface water pathways. Impact to groundwater from subsurface soil in the saturated zone will be evaluated based on direct measurement of groundwater conditions and remediation of soil in the saturated zone will be evaluated based on groundwater cleanup performance data.

Off-Railyard Property. Soil between the groundwater table (approximately 14 feet bgs) and 15 feet bgs will be evaluated as saturated zone soil using applicable unrestricted Method A and B cleanup levels for soil off-railyard property to the north of the maintenance shop (rural center zoned) and, for those constituents likely to leach to groundwater, soil concentrations for the saturated zone that are protective of groundwater. Potential impacts to groundwater from subsurface soil in the saturated zone will be evaluated based on direct measurement of groundwater conditions and remediation of soil in the saturated zone will be evaluated based on groundwater cleanup performance data.

3.2.3 Groundwater and Surface Water

Groundwater. The standard point of compliance for groundwater is sitewide. In accordance with WAC 173-340-720, designated groundwater uses include potential drinking water source, although shallow groundwater at the site is not a current source of drinking water nor is it identified as a future drinking water source since potable water is supplied to the site by the City of Wishram. It is unlikely that human or ecological receptors would contact groundwater during normal site use. Contact with groundwater will be managed through ICs, and RELs will be selected to protect human and ecological receptors.

Groundwater/Surface Water Interface. The proposed CPOC for monitoring groundwater at the interface with surface water is the line of existing shallow and deep monitoring wells installed on the berm bordering the Columbia River. The potential exposure pathway by which human or ecological receptors could encounter site groundwater is by flux of site groundwater into the Columbia River. Protection of surface water will be assessed at the berm, even though analysis performed during the RI demonstrated that flux of site groundwater toward the Columbia River occurs during only approximately 2 months of the year. The CPOC will be further defined in the draft Cleanup Action Plan (DCAP).

3.3 Proposed CULs and RELs

A summary of the development of proposed CULs and identification of COCs for soil, groundwater, and surface water is provided in Appendix B. Identification of COCs is based on a comparison of soil and groundwater sampling results presented in the Uplands RI Report and 2020 groundwater sampling results to the proposed CULs.

MTCA requires sites to be cleaned up to protect human health and the environment. WAC 173-340-704(1) through (3), provides summaries as to the applicability of MTCA Methods A, B, and C cleanup levels. Where site conditions meet MTCA Method A CULs for a site-related constituent, risks to human health and the environment are considered acceptable. MTCA Methods B and C provide alternative approaches to establishing CULs based on site-specific evaluation of potential risk to human and ecological receptors. CULs developed using MTCA Methods B and C must not be set at levels below the practical quantitation limit (PQL) or background.

Risk evaluations take into account site conditions that limit exposure or migration of residual site constituents. CULs may be based on the absence of exposure pathways. Once practical methods of treatment have been employed, residual constituents may remain. Proposed remedies for this site include a combination of active and passive measures, and ICs applied in series or independently. In areas where it may become infeasible to meet CULs through active remediation, passive methods and ICs will be applied once practicable remedial limits are met. RELs may be defined according to MTCA by quantitative or qualitative means.

The following provides a summary of the proposed CULs for the site based on MTCA (for applicable media), other applicable, relevant, and appropriate requirements (ARARs) for groundwater and surface water, and other relevant information pertinent to establishing site-specific remedial goals. Available and applicable MTCA Methods A, B, and C cleanup levels and screening levels were obtained from Ecology's CLARC master data table (updated in July 2021) (Ecology 2021a). RELs are established to indicate what site conditions will be addressed with different cleanup methods and may be narrative or qualitative in nature. Table 1 summarizes the proposed COCs and CULs based on these ARARs. Development of the proposed CULs and constituents evaluated by media is presented in Appendix B. CULs and RELs will be established in the DCAP.

3.3.1 Soil CULs and RELs

Appendix B presents proposed CULs [in milligrams per kilogram (mg/kg)] for constituents reported in one or more soil samples collected from the vadose zone (Table B-3A) and the shallow (between 10 and 15 feet bgs) saturated zone (Table B-3B). Impact to groundwater from the deep (below 15 feet bgs) saturated zone soil will be evaluated based on direct measurement of groundwater conditions, and remediation of soil in the saturated zone will be evaluated based on groundwater cleanup performance data.

Proposed CULs were established by comparing applicable industrial MTCA Method A and C CULs for railyard property and MTCA Method A and B CULs for off-railyard property, background concentrations, PQLs, and for those constituents proven likely to leach to groundwater, soil concentrations (calculated using the fixed parameter 3-phase partitioning model described in WAC 173-340-747(4) and MTCA Equation 747-1) for the vadose or saturated (as applicable) zone that are protective of groundwater and the groundwater to surface water pathway. Development of proposed soil CULs is summarized in Section B3-4 of Appendix B. Identified COCs based on reported results above the proposed CULs are listed below and summarized in Table 1. The proposed CULs for the identified COCs are based on MTCA Method A CULs, which are the same concentrations for unrestricted and restricted (industrial) CULs for the COCs.

- GRO – 30 mg/kg (Method A), based on the presence of benzene, although at low concentrations, in saturated soil samples collected from the site.
- DRO – 2,000 mg/kg (Method A).
- ORO – 2,000 mg/kg (Method A).
- Total petroleum hydrocarbon (TPH-Dx) – 2,000 mg/kg (Method A).

The proposed soil RELs for petroleum hydrocarbon related constituents are equivalent to the above CULs. The soil CULs and RELs will be established in the DCAP.

3.3.2 Groundwater CULs and RELs

Beneficial use designations for the groundwater beneath the site include use as a potential drinking water source. Proposed groundwater CULs protective of drinking water were established from consideration of MTCA Method B cancer and noncancer CULs, ARARs including state and federal Maximum Contaminant Levels (MCLs), MTCA Method A CULs for select constituents (DRO, ORO, and TPH-Dx), background concentrations for arsenic, and PQLs. Development of proposed groundwater CULs is summarized in Section B3-1 and Table B-1 of Appendix B.

Remedies to address potential human exposure to DRO and ORO within the railyard area, including ICs and environmental covenants (ECs), are evaluated where groundwater contains DRO or ORO above the MTCA Method A CULs. Where potential exposure to groundwater is restricted, CULs will be selected based on the surface water pathway; proposed CULs for surface water are presented in Section 3.3.4.

Based on the CSM and the capacity for ICs to control direct contact and incidental ingestion pathways for groundwater within the rail yard, contact within the Columbia River is the only potentially complete unrestricted exposure pathway for site groundwater; therefore, the surface water screening levels will be applied to site groundwater with the potential to enter the Columbia River.

Results from groundwater monitoring conducted between November 2016 and August 2020 were selected as representative data for current dissolved phase groundwater conditions. Constituents reported in one or more groundwater monitoring well samples collected since November 2016 above the proposed CUL for groundwater are identified as COCs in Table 1. Identified COCs and proposed groundwater CULs [in micrograms per liter (µg/L)] are as follows:

- DRO – 500 µg/L as an unrestricted use goal (Method A).
- ORO – 500 µg/L as an unrestricted use goal (Method A).
- Total petroleum hydrocarbon (TPH-Dx) – 500 µg/L as an unrestricted use goal (Method A).
- 1-methylnaphthalene – 1.5 µg/L (Method B Cancer).
- Total arsenic – 5 µg/L (Background[1]).
- Total barium – 2,000 µg/L (State and Federal MCL). Total barium has been reported above the proposed groundwater CUL in one groundwater sample.

[1] Background concentration for arsenic from MTCA Table 720-1 Method A CULs, subject to change based on potential policy updates resulting from Ecology's draft *Natural Background Groundwater Arsenic Concentrations in Washington State* (July 2021), Publication 14-09-044.

- Dissolved Iron – 11,000 µg/L (Method B Noncancer).
- Dissolved manganese – 750 ug/L (Method B Noncancer).

Groundwater RELs are established to indicate the nature and concentrations of COCs addressed with different cleanup methods. The proposed groundwater RELs for petroleum hydrocarbon-related constituents identify criteria for transitioning from active removal or destruction to monitored natural attenuation (MNA), and include the following:

- Statistically significant stable or decreasing trends in groundwater concentrations will be established using Mann-Kendall, Mann-Whitney, or similar analysis for a period of 3 years (or 12 sampling events). Statistical methods to evaluate groundwater concentration trends will be provided in the groundwater compliance monitoring plan in the DCAP.
- Groundwater geochemistry indicates conditions suitable for natural attenuation.

The groundwater CULs and groundwater RELs for transitioning from active to passive remedial action will be established in the DCAP.

3.3.3 Surface Water CULs

Surface water will be protected by remediating groundwater in the vicinity of the berm to applicable CULs. Surface water COCs are based on constituents identified in site groundwater, since groundwater is in direct communication with the river. The proposed CPOC for demonstrating that site groundwater meets surface water beneficial uses is the line of groundwater monitoring wells along the berm.

Beneficial use designations for the Columbia River near the site include use as potential drinking water supply, along with spawning and rearing aquatic life, wildlife, and miscellaneous use such as recreation, aesthetics, hydroelectric power generation, and commercial navigation and transportation. Proposed surface water CULs protective of drinking water and aquatic life were established based on surface water Method B cancer and noncancer cleanup levels, ARARs including fresh surface water concentrations that are protective of human health and protective of aquatic life under acute and chronic exposure conditions as established under state (WAC 173-201A-240) and federal laws [Section 304 of the Clean Water Act (CWA)], Environmental Effects-Based Concentrations (EEBCs) from Implementation Memo No. 23 (Ecology 2021b) for petroleum hydrocarbons (e.g., weathered diesel), Risk Assessment Information System (RAIS) concentrations, Method A for select constituents for beneficial use as potable water, background concentrations, and PQLs.

Development of proposed surface water CULs is summarized in Section B3-3 of Appendix B. Constituents reported above the proposed CUL for surface water in one or more groundwater samples collected since November 2016 from monitoring wells located along the berm are identified as COCs in Table 1. The berm wells include 10 shallow monitoring wells (WMW-14 through WMW-23) and six deep monitoring wells (RMD-1 through RMD-6).

The proposed surface water COCs and respective CULs (and their sources) for monitoring wells located along the berm are as follows:

- DRO – 500 µg/L as an unrestricted use goal (Method A CUL) for human health exposure considerations and 3,000 µg/L (EEBC weathered DRO) for ecological receptor exposure considerations.
- ORO – 500 µg/L as an unrestricted use goal (Method A CUL) for human health exposure considerations and 3,000 µg/L (EEBC weathered DRO) for ecological receptor exposure considerations.
- Total petroleum hydrocarbon (TPH-Dx) – 500 µg/L as an unrestricted use goal (Method A CUL) for human health exposure considerations and 3,000 µg/L (EEBC weathered DRO) for ecological receptor exposure considerations.
- 1-methylnaphthalene – 2.1 µg/L (RAIS).
- Total arsenic – 5 µg/L (Method A, Background).
- Total lead – 2.5 µg/L (Surface Water Aquatic Life Fresh/Chronic WAC 173-201A and CWA §304). Total lead has been reported above the proposed surface water CUL in three groundwater samples.
- Dissolved iron – 1,000 µg/L (Surface Water Aquatic Life Fresh/Chronic CWA §304).
- Dissolved manganese – 50 µg/L (Surface Water Human Health Fresh Water CWA §304).

The surface water CULs will be established in the DCAP.

3.3.4 LNAPL RELs

The proposed petroleum hydrocarbon LNAPL RELs, to indicate when to transition from active removal or destruction to natural source zone depletion (NSZD), is based on the mobility of the LNAPL and potential for the LNAPL to migrate. LNAPL will be removed until:

- Ambient-temperature transmissivity is below 0.8 feet squared per day (ITRC 2018), or
- Removal rates approach asymptotic conditions.

The LNAPL RELs for transitioning from active to passive remedial action will be established in the DCAP.

Section 4: Estimates of Impacted Media Above Proposed Cleanup Levels

This section provides estimates of the extents of impacted site media (summarized in Table 2) based on the findings of the RI.

4.1 Shallow Soil

The estimated volume of shallow (above the groundwater table) petroleum hydrocarbon-impacted soil outside of the LNAPL body area, based on the proposed soil cleanup standards presented in Section 3, is approximately 170 cubic yards. Soil with DRO and ORO at concentrations above the proposed CULs occurs between 6 and 9 feet bgs on the northern side of the berm in the vicinity of boring B-16-01, as shown on Figure 9. The estimated spatial extent of impacts is also based on low-level LIF responses within the same depth interval in LIF borings CR4, CR4.5, and CR5 (Figure 7). Soil above 6 feet bgs in this area is not impacted.

Impact to groundwater from subsurface soil in the saturated zone will be evaluated based on direct measurement of groundwater conditions and remediation of soil in the saturated zone will be evaluated based on groundwater cleanup performance data.

4.2 LNAPL

LNAPL has been identified south of the mainline tracks near the former underground oil pipelines and the former Power House. As shown in cross section depictions of the LNAPL and residual TPH impacted areas (Figures 19, 20, and 21), the estimated vertical and horizontal LNAPL extents vary by depth and apparent thickness in the formation at each location. As described below and shown on Figure 22, eastern and western LNAPL areas have been defined based on the variations of depth and apparent LNAPL thickness, as well as depths to bedrock.

Area and volume estimates of LNAPL in the subsurface are presented in Table 2. LNAPL volume calculations assume a uniform soil porosity of 40 percent (upper bound measurement), LNAPL saturation values of 33 percent in the eastern LNAPL area and 17 percent in the western LNAPL area, and uniform distribution throughout the impacted area, including the outer limits where residual saturation concentrations are lowest. Based on these assumptions, LNAPL volumes represent a conservative estimate.

In the eastern LNAPL area, spatial and vertical LNAPL extents are relatively continuous. The eastern LNAPL mass, based on LIF data and soil borings, is approximately 17,000 square feet in area, with apparent LNAPL impacts ranging from approximately 5 feet in thickness (in soil boring B-12-8) to approximately 60 feet in thickness (in soil boring for OHM-1) and averaging 14 feet. Apparent LNAPL thicknesses of approximately 12 feet or more have been measured in wells OHM-1, OHM-2, and OHM-3, located within the eastern LNAPL area (KJ 2020). Depths to LNAPL impacts range from approximately 10 feet bgs to approximately 85 feet bgs (LIF location D06). The estimated total volume of LNAPL is approximately 203,000 gallons and the estimated recoverable volume of LNAPL is approximately 56,900 gallons (approximately 28 percent of the pore volume).

In the smaller, western LNAPL area, LNAPL occurs in thin lenses approximately 0.5 to 4 feet in thickness at shallow (between approximately 11 and 13 feet bgs) and deep (between approximately 20 and 25 feet bgs) depth intervals. The western LNAPL mass is approximately 5,200 square feet in total area (2,600 square feet in each of shallow and deep zones). The estimated total volume of LNAPL in the shallow and deep intervals is approximately 4,100 gallons. The estimated recoverable volume of LNAPL for the two depth intervals is approximately 30 gallons (approximately 0.6 percent of the pore volume). LNAPL has not been measured in well OHM-4, located in the western LNAPL area (KJ 2020).

4.3 Dissolved-Phase Impacts in Groundwater

Dissolved phase DRO and ORO concentrations above the proposed CUL of 500 µg/L were identified in wells north and south of the mainline tracks (mainline track area), and at wells near the former Engine House area (Figures 11 to 16). The approximate spatial extent of dissolved-phase impacts in the mainline track area is 88,000 square feet, and the approximate spatial extent of dissolved-phase impacts near the former Engine House area is 24,000 square feet.

Section 5: Technology Screening and Alternative Development

This section presents the rationale for identifying remedial alternatives to address soil and groundwater containing COCs at concentrations exceeding site-specific CULs. Section 5.2 presents the initial screening of remedial technologies to identify potentially applicable process options. Remedial methods passing the initial screening process are combined to create potentially feasible remedial alternatives, which are described in Section 5.3.

5.1 Identification and Evaluation of Potential Remedial Methods

General response actions are broad categories of remedial methods that can address the cleanup of a specific matrix (e.g., soil, groundwater). Remedial technologies are various techniques within the general response actions. Process options are specific processes within each remedial technology category. General response actions, remedial technologies, and process options that may be appropriate for addressing site conditions and petroleum hydrocarbon site-related constituents in soil and groundwater are presented in Table 3.

Process options were initially screened using three criteria: effectiveness, implementability, and relative cost, as summarized below:

- Effectiveness involves consideration of a process option's ability to address the anticipated volume of soil and groundwater, meet cleanup standards, and protect human health and the environmental during construction and implementation.

- Implementability includes technical and administrative considerations. This criterion focuses on the ability to technically address COCs in a selected matrix at concentrations reported during the RI process. It also evaluates the permits necessary for onsite and offsite activities and discharges, and the availability of offsite facilities, services, and materials.

- Cost is based on engineering judgments rather than detailed estimates. Process options that are judged to be similar in effectiveness and ability to be implemented yet estimated to cost several times more than other process options in the same technology category, were eliminated from further consideration.

Process options that are not appropriate for site conditions, planned future site uses, or constituents and concentrations contained in soil and groundwater were eliminated from further consideration. In addition, process options that are innovative but unproven were also eliminated. If more than one process option in a remedial technology group was identified as potentially appropriate for the site, further screening was performed, and one process option was selected to represent that technology group.

5.2 Remedial Technologies Screening

General response actions that may be applicable for remediating impacted soil are summarized below and further evaluated in Table 4:

- Natural Source Zone Depletion (NSZD): Depletion of petroleum hydrocarbon related compounds through natural biological and abiotic processes. Data obtained from carbon trap samples indicate NSZD is occurring at rates between 350 and 6,000 gallons per acre per year near the submerged LNAPL body. These results demonstrate that NSZD is an active and effective process for consideration in each alternative (see Appendix A).

- Containment: Installation of a physical barrier that will encapsulate and isolate the impacted soils. The impacted soils will be left in place and the petroleum hydrocarbons will naturally degrade over time.

- Removal: Petroleum hydrocarbons between the ground surface and the top of the water table will be removed through physical processes and disposed offsite at a licensed facility. Removal processes could include:

    - Excavation – Using an excavator or large diameter auger to physically remove the soils from the subsurface. The excavated area will be backfilled with clean fill.

    - Thermal Extraction – Using heat to increase subsurface temperatures to 50 to 70 degrees Celsius (°C) to reduce the viscosity of the petroleum hydrocarbons combined with extraction technologies (e.g., physical removal or soil vapor extraction) to remove them from the subsurface. Residual petroleum hydrocarbons remaining in the subsurface will naturally degrade over time.

- *In Situ* Treatment: The use of physical or chemical processes to stabilize or destroy COCs in the subsurface. *In Situ* technologies include:

    - Solidification/Stabilization – Mixing chemicals (e.g., cement, fly ash, bentonite) with the soil at depth that bind with the petroleum hydrocarbons and soil to solidify the impacted area and control mobility/leachability of the COCs.

    - Chemical Destruction – Injecting or mixing oxidants (e.g., peroxide, ozone) into the subsurface soil at depth resulting in degradation or destruction of the petroleum hydrocarbons adsorbed to the soil.

    - Thermal Destruction – Applying conductive/resistive heating technologies to heat the subsurface above 100 °C to physically destroy in place the petroleum hydrocarbons or vaporize them for removal. Soil gasses produced in the process are extracted, treated if necessary, and vented to the atmosphere.

General response actions that may be applicable for remediating the LNAPL are summarized below and further evaluated in Table 4:

- NSZD: Depletion of LNAPL through natural biological and abiotic processes. Data obtained from carbon trap samples indicate NSZD is occurring at rates between 350 and

6,000 gallons/acre/year near the submerged LNAPL body. These results demonstrate that NSZD is an active and effective process for consideration in each alternative (see Appendix A).

- Containment: Installation of a physical or hydraulic barrier that will encapsulate and isolate the LNAPL. The LNAPL will be left in place and the petroleum hydrocarbons will naturally degrade over time.

- Removal: LNAPL at and below the water table (submerged LNAPL) will be removed through physical processes and disposed offsite at a licensed facility. Removal processes could include:

  - Excavation - Using an excavator or large diameter auger to physically remove the soils from the subsurface. The excavated area will be backfilled with clean fill.

  - Extraction – Applying physical processes such as skimming, vacuum enhanced skimming, vacuum extraction, and multi-phase extraction to remove the LNAPL from the subsurface. Residual petroleum hydrocarbons remaining in the subsurface will naturally degrade over time.

  - Thermal Extraction – Using electrical resistive heating to heat the subsurface to between 50°C to 70°C to reduce the viscosity of the petroleum hydrocarbons then remove them from the subsurface using extraction technologies. Residual petroleum hydrocarbons remaining in the subsurface will naturally degrade over time.

- *In Situ* Treatment: The use of physical or chemical processes to stabilize or destroy the LNAPL in the subsurface. *In Situ* technologies include:

  - Chemical Destruction – Injecting oxidants (e.g., peroxide, ozone) into with the subsurface that react with the LNAPL resulting in degradation or destruction of the petroleum hydrocarbons.

  - Geochemical Stabilization – Injection of chemicals to create a geochemical reaction between oxidant and soils resulting in mineralization around LNAPL globules to treat and encapsulate in place

  - Thermal Destruction – Applying sufficient energy (heat) and oxygen to the LNAPL body to initiate combustion resulting in the physical destruction of the petroleum hydrocarbons. Soil gasses produced in the process are extracted, treated if necessary, and vented to the atmosphere.

  - Biological Destruction – Biological destruction of LNAPL in the subsurface occurs through increasing oxygen concentrations and/or temperature in the impacted zone to increase biological activity. Biological degradation takes place at the interface between the LNAPL body and areas where sufficient oxygen supply is present and progresses inward into the interior of the LNAPL body.

- *Ex Situ* Treatment: LNAPL, water, and soil vapors removed from the subsurface could be treated using the following treatment options:

    - Soil Vapor Treatment – using granular activated carbon (GAC) or thermal/catalytic oxidizers to remove COCs from effluent to below permitted discharge limits. Vapors can also be condensed and combined with the liquid waste streams for treatment and disposal.

    - Oil/Water Separation – LNAPL and groundwater would be removed from the subsurface simultaneously. LNAPL and water would be separated and the LNAPL containerized, then shipped off-site for disposal or recycling. Water would be treated on-site using GAC then discharged to the local publicly owned treatment works (POTW) under an industrial wastewater permit.

General response actions that may be applicable for remediating dissolved phase petroleum hydrocarbons beneath the site are summarized below and further evaluated in Table 4:

- MNA: Natural attenuation occurs through dispersion, dilution, sorption, volatilization, and biological transformation or destruction of the petroleum hydrocarbons. Petroleum hydrocarbon biodegradation is more energetically favorable and complete under aerobic (oxidizing) than anaerobic (reducing) conditions. When groundwater is monitored for available electron acceptors and other parameters indicative of the natural attenuation process, it is referred to as monitored natural attenuation or MNA.

- Containment: Installation of a physical or hydraulic barrier that will contain and control the dissolved petroleum hydrocarbons. Removal of the dissolved phase constituents may or may not be combined with containment as part of the process.

- Removal: Dissolved phase petroleum hydrocarbons can be removed from the subsurface through groundwater extraction. Under certain conditions, extraction can be enhanced using surfactants.

- *In Situ* Treatment: The use of physical or chemical processes to stabilize or destroy the dissolved phase petroleum hydrocarbons. *In Situ* technologies include:

    - Physical/Chemical Destruction – Injecting oxidants into the subsurface that react with the petroleum hydrocarbons resulting in degradation or destruction of the petroleum hydrocarbons.

    - Biological Destruction –. Injecting oxygen into groundwater to promote aerobic biological degradation processes is a proven effective means of degrading heavy end, long chain petroleum hydrocarbons in place.

- *Ex Situ* Treatment: Fluids extracted from wells are treated using GAC, ozone or other technology applicable to petroleum hydrocarbons. Treated effluent would be discharged to the local wastewater treatment plant under an industrial wastewater permit

Performance and/or confirmation monitoring are required components of all response actions. Performance monitoring includes sampling during removal or treatment to assess progress and/or achievement of CULs. Groundwater confirmation monitoring is required to assess long-term effectiveness and compliance with CULs.

MTCA requires that the process options used minimize the amount of untreated COCs remaining at the site to the extent practicable, and that preference be given to a permanent solution and hierarchy of preferred remedial methods. In general, technologies that reuse, recycle, destroy, or detoxify hazardous substances will result in permanent solutions.

5.3 Development of Alternatives

This section identifies alternatives appropriate for addressing the COCs in soil and groundwater. These alternatives are identified using the requirements and expectations described in MTCA (WAC 173-340-360), which include:

- Meeting threshold requirements for remedial alternatives (refer to Section 7.1).
- Using permanent solutions to the maximum extent practicable.
- Providing for a reasonable restoration timeframe.

Ecology has the following expectations for cleanup action alternatives (WAC 173-340-370):

- Use treatment technologies whenever practicable.
- Minimize the need for long-term management of impacted materials by destroying, detoxifying, or removing hazardous substances that are above CULs.
- Recognize the need to use engineering controls, such as containment for sites with large volumes of relatively low levels of hazardous substances.
- Implement measures to control precipitation and runoff from contacting affected soils and waste materials.
- Consolidate hazardous substances to the maximum extent practicable if the hazardous substances remain onsite.
- Control/minimize releases to surface water via runoff and groundwater discharges exceeding CULs.
- Consider the use of natural attenuation of hazardous substances, which may be appropriate under some circumstances.
- Do not undertake cleanup actions that will result in a greater overall threat to human health and the environment than will other alternatives.

MTCA requires treatment, wherever practicable, for sites containing liquid wastes, areas containing high concentrations of hazardous substances, highly mobile materials, or discrete areas of hazardous substances that lend themselves to treatment. MTCA also recognizes that engineering controls (such as covenants, containment, caps, and covers) are appropriate for sites or portions of sites that contain large volumes of materials with relatively low levels of hazardous substances where treatment is impracticable [WAC 173-340-370(3)].

Based on the regulatory considerations, site-specific conditions, and the assessment of the remedial technologies summarized in Section 5.2 and in Table 4, the following five remedial alternatives were developed for further evaluation (and summarized in Table 5). For Alternatives 1, 3, 4, and 5, the timeframe to achieve RELs is estimated. Based on the available data, the timeframe to achieve restoration is estimated to be greater than 30 years for each alternative. Alternative 1 is presented as the permanent solution (baseline alternative) against which the other alternatives are evaluated for the purpose of determining whether the cleanup action selected is permanent to the maximum extent practicable (173-340-350(8)(c)(ii)(A)). The baseline alternative is the most practicable, technically possible solution for the site. Remedial actions that are not technically possible to implement (e.g., excavation of deep soils) are identified in Tables 3 and 4.

Alternatives 1 through 5 include ICs and ECs as part of the remedy. Accordingly, Ecology will perform a periodic review once every 5 years after initiation of the cleanup action as required under WAC 173-340-440 and as described in WAC 173-340-420.

Alternative 1: Physical LNAPL Removal, Focused Biosparge, and MNA

- LNAPL will be removed periodically using a mobile vacuum unit in the eastern LNAPL area. Relatively thinner areas of LNAPL in the western LNAPL area will be treated through biosparging. After RELs have been achieved, LNAPL thickness, soil gas, and groundwater concentrations will be monitored to confirm and quantify NSZD.

- Dissolved phase petroleum in the southern end of the eastern LNAPL area, in the mainline track area and beneath the Engine House will be assessed for natural attenuation and followed by implementation of compliance groundwater monitoring. After RELs have been achieved, petroleum hydrocarbons will be monitored to confirm concentrations and extents are decreasing.

- Dissolved phase metals in groundwater will be addressed by remediating petroleum hydrocarbons and the corresponding return of measured geochemical parameters to their ambient conditions.

- Impacted soils in the vadose zone beneath the berm will be excavated and disposed of offsite.

- A Groundwater Covenant will be enacted to restrict future use of site groundwater.

Periodic LNAPL removal is expected to be implemented for approximately 10 years. Focused biosparging is expected to be implemented for less than 5 years. Once biosparging and physical LNAPL removal ceases, MNA and NSZD assessments will be conducted for a 3-year period, followed by compliance monitoring until CULs are achieved.

Alternative 2: Institutional Controls and Environmental Covenants with Compliance Groundwater Monitoring

- No active remediation is performed. Constituent concentrations will continue to decrease through NSZD and natural attenuation. ICs and ECs will be managed in perpetuity or until CULs are met.

- ICs are implemented to control site uses that could potentially expose receptors to impacted media including soil and groundwater.

Compliance groundwater monitoring will be implemented.

Alternative 3: LNAPL Containment, Biosparge, MNA, and Targeted Excavation

- The eastern and western LNAPL areas will be contained using a sheet pile wall on three sides, LNAPL thickness and soil gas concentrations will be monitored within the contained LNAPL areas to confirm and quantify NSZD.

- Dissolved phase petroleum hydrocarbons around the mainline tracks and beneath the Engine House will be assessed for natural attenuation. and treated through biosparging as a contingency. Biosparging will be implemented as a contingency to MNA to enhance aerobic biodegradation in areas where groundwater is not naturally aerobic. After RELs have been achieved, petroleum hydrocarbons will be monitored to confirm concentrations and extent are decreasing.

- Dissolved phase metals in groundwater will be addressed by remediating petroleum hydrocarbons and the corresponding return of measured geochemical parameters to their ambient conditions.

- Impacted soils in the vadose zone beneath the berm will be excavated and disposed offsite.

- A Groundwater Covenant will be enacted to restrict future use of site groundwater.

The timeframe for active remediation (biosparging) if implemented, is estimated to be less than 5 years.

Alternative 4: Physical LNAPL Removal, Biosparge, MNA, and Targeted Excavation

- LNAPL will be removed periodically using a mobile vacuum unit in the eastern LNAPL area. After physical removal has achieved practicable limits, biosparging may be implemented as necessary to enhance biological degradation and address dissolved phase DRO and ORO if present from residual LNAPL. Relatively thinner areas of LNAPL in the western LNAPL area and dissolved phase in the southern end of the eastern LNAPL area will be treated through biosparging. After RELs have been achieved, LNAPL thickness and soil gas will be monitored to confirm and quantify NSZD.

- Dissolved phase petroleum in the mainline track area and beneath the Engine House will be assessed for natural attenuation and treated through biosparging as a contingency. Biosparging will be implemented as a contingency to MNA to enhance aerobic biodegradation in areas where groundwater is not naturally aerobic. After RELs have been achieved, petroleum hydrocarbons will be monitored to confirm concentrations and extent are decreasing.

- Dissolved phase metals in groundwater will be addressed by remediating petroleum hydrocarbons and the corresponding return of measured geochemical parameters to their ambient conditions.

- Impacted soils in the vadose zone beneath the berm will be excavated and disposed of offsite.

- A Groundwater Covenant will be enacted to restrict future use of site groundwater.

Periodic LNAPL removal is expected to be implemented for approximately 10 years. If applied, biosparging to enhance residual LNAPL biodegradation is expected to be implemented for less than 5 years. Biosparging in dissolved phase impacted areas is expected to be implemented for less than 5 years. Once biosparging and physical LNAPL removal ceases, MNA and NSZD assessments will be conducted for a 3-year period, followed by compliance monitoring until CULs are achieved.

Alternative 5: Low-Temperature Thermal LNAPL Removal (LTTR), Biosparge, MNA, and Targeted Excavation

- The eastern LNAPL area will be heated to approximately 50°C to 70°C to reduce LNAPL viscosity and improve mobility. Removal and heating approaches will be adapted to target specific areas based on observations of improved LNAPL recovery, changes in thickness, and the effect of temperature. After physical removal has achieved practicable limits, remediation wells can be converted to implement biosparging as needed to enhance biological degradation in the areas where elevated temperatures are present and oxygen becomes limited due to increased biological activity. Relatively thinner areas of LNAPL in the western LNAPL area will be treated using biosparging. After active LNAPL removal and sparging have achieved RELs, LNAPL thickness and soil gas concentrations will be monitored within LNAPL areas to confirm and quantify NSZD.

- Dissolved phase petroleum hydrocarbons in the mainline track area and beneath the Engine House will be assessed for natural attenuation and treated using biosparging as a contingency. Biosparging will be implemented as a contingency to MNA to enhance aerobic biodegradation in areas where groundwater is not naturally aerobic. After RELs have been achieved, petroleum hydrocarbons will be monitored to confirm concentrations and extent are decreasing.

- Dissolved phase metals in groundwater will be addressed by remediating petroleum hydrocarbons and the corresponding return of measured geochemical parameters to their ambient conditions.

- Impacted soils in the vadose zone beneath the berm will be excavated and disposed of offsite.

- A Groundwater Covenant will be enacted to restrict future use of site groundwater.

The timeframe for active remediation (subsurface heating, LNAPL removal and biosparging) is expected to be less than 5 years. Once biosparging and physical LNAPL removal ceases, MNA and NSZD assessments will be conducted for a 3-year period, followed by compliance monitoring until CULs are achieved.

5.3.1 Alternative 1 – Physical LNAPL Removal, Focused Biosparge, MNA, and Targeted Excavation

Alternative 1 involves physical removal of LNAPL in the eastern LNAPL area, focused biosparging in the western LNAPL area, excavation of shallow impacted soils, and MNA for dissolved phase petroleum impacts. Monitored NSZD in the LNAPL areas and MNA for dissolved impacts will be implemented once RELs for active remediation have been met. During and following physical removal of LNAPL to achieve RELs, natural attenuation is expected to eliminate the transport of dissolved phase petroleum hydrocarbons to the river during high groundwater conditions (approximately 2 months out of the year). This alternative uses removal and destruction technologies, along with ICs and ECs, to control exposures to potential receptors (onsite workers, visitors, nearby residents, trespassers, and surface water).

The key components of Alternative 1 are depicted on Figure 24. This alternative consists of the following general actions:

- Design and Permitting: LNAPL removal tests will be conducted, and removal will be modeled using the American Petroleum Institute (API) LNAPL Distribution and Recovery Model (LDRM; API 2007a and 2007b) to evaluate extraction well spacing and removal timeframe. An LDRM estimate of LNAPL recoverability is provided in Appendix D and summarized in Section 5.3.6. A biosparging pilot study will be conducted to evaluate the radius of influence and sparge rate, identify the design parameters and design a full-scale system for the western LNAPL area. A Cleanup Action Plan (CAP) and a Joint Aquatic Resources Permit Application (JARPA) will be prepared for construction and excavation near the Columbia River. Permits will be obtained, including well permits for the LNAPL removal wells, biosparge wells, and associated monitoring wells; and building permits for the biosparge system(s). Subsurface intrusive activities will include cultural resources monitoring completed in accordance with the CRMP under permit from DAHP. Because the biosparge system will not result in discharges to the atmosphere, an air permit is not needed. Samples of the LNAPL and groundwater in the extraction wells will be collected and analyzed for waste profiling and to identify appropriate disposal methods. Discharge of effluent water to the local POTW will require completion (and approval by the Klickitat County PUD) of a feasibility study to establish acceptable discharge volume, concentration limits, and monitoring requirements.

- Site preparation. Activities will include grading for equipment access, delineation of work zones and laydown areas, and identification of underground utilities within the footprint of the drilling and excavation areas. Utilities impacted by the remedial activities will be protected in-place, relocated, removed, or abandoned in-place as appropriate.

- Installation. In the eastern LNAPL area, existing OHM wells and new recovery wells installed within the LNAPL extent will be used for LNAPL removal. Current estimates assume up to 15 new LNAPL recovery wells will be installed within the LNAPL body, on approximately 40-foot centers. New recovery wells will be constructed of 4- to 6-inch-diameter, stainless steel wire-wrapped screen connected to stainless steel or polyvinyl chloride (PVC) risers.

  In the western LNAPL area, five shallow biosparge wells will be installed to depths of approximately 25 feet bgs and three paired shallow (25 feet bgs) and deep (60 feet bgs) wells will be installed to address dissolved-phase and LNAPL impacts at varying depths throughout the area. Biosparge system installation includes constructing treatment pads/sheds, and furnishing air compressors, programmable logic controllers (PLCs), distribution manifolds and piping, and biosparge wells.

- Operation and Monitoring. LNAPL will be removed from wells by periodic high-vacuum extraction or other methods depending on the results of the LDRM and field implementation testing. Adequate time will be allowed for LNAPL to recharge prior to subsequent extraction events. Between extraction events, the presence and apparent thickness of the LNAPL will be monitored. Physical removal will allow for adaptive management strategies to increase or decrease the frequency of removal and to expand the extraction well network based on observed site conditions. Once LNAPL removal and biosparging operations have met their design objectives (i.e., RELs), active remediation will be discontinued and monitored NSZD will be implemented in the LNAPL areas (eastern and western). NSZD in the LNAPL areas is expected to eliminate the transport of petroleum hydrocarbons to the river during high groundwater conditions.

  Concurrent with the implementation of the active remedy in the LNAPL areas, MNA will be implemented in the berm area south of the former Power House, the mainline track area, and beneath the former Engine House. MNA will be assessed in general accordance with Ecology's *Guidance on Remediation of Petroleum-Contaminated Ground Water by Natural Attenuation* (NA Guidance) (Ecology 2005) and will include collecting groundwater samples for DRO, ORO, and natural attenuation parameters semi-annually for 3 years. Compliance groundwater monitoring will be implemented following completion of the MNA assessment and will include annual to biennial monitoring for geochemical parameters and analysis of DRO and ORO.

- Groundwater Covenant. A restrictive covenant will be enacted to prohibit the installation of wells for the purpose of water supply within the site boundary, restrict the extraction of groundwater for purposes other than construction and hydraulic control dewatering, monitoring/investigation, or remediation, and require groundwater extracted within the site boundary be evaluated via data review and testing and the discharge managed in accordance with state and federal regulations.

Excavation of impacted soils along the berm, south of the Power House, and MNA of groundwater are common components of Alternatives 1, 3, 4, and 5. As such, these components are described in Sections 5.3.7 and 5.3.8, respectively.

Timeframe. The time to achieve RELs is estimated to be 10 years, and the time to reach CULs is estimated to be more than 30 years (depending on NSZD rates) following cessation of active remediation. LNAPL recovery is typically most productive during early phases of removal and becomes asymptotic as the rebound of LNAPL thickness decreases with time. Active LNAPL removal is estimated to be implemented over a 10-year timeframe. Biosparge operations are expected to be implemented over a 2- to 5-year period (concurrent with physical removal of the LNAPL) in the western LNAPL area. NSZD monitoring in the eastern LNAPL area will be conducted once physical removal actions cease and in the western LNAPL area once biosparging ceases. An MNA assessment will be implemented for approximately 3 years in the berm area south of the former Power House, the mainline track area, and beneath the former Engine House, concurrent with the implementation of the active remedies. Compliance groundwater monitoring will continue until CULs are met. ECs and ICs established for the site are expected to remain in place until a no further action determination is provided by Ecology.

Cost: The estimated cost for this alternative is summarized in Appendix D, Table D1.

5.3.2 Alternative 2 – Institutional Controls (ICs) and Environmental Covenants (ECs) with Compliance Groundwater Monitoring

This alternative involves developing ICs and ECs to limit exposures to potential receptors (onsite workers, visitors, nearby residents, and trespassers). Note that while the following describes what will be implemented as part of Alternative 2, the nature of the ICs and ECs describe herein is part of each of the five alternatives. Compliance groundwater monitoring will be implemented in select wells to monitor constituent concentrations. This alternative does not include active remediation; however, constituent concentrations will continue to decrease by natural processes (NSZD and natural attenuation). ICs will be implemented to restrict exposure to impacted soil and groundwater. To limit exposures during construction activities, ICs will be implemented and maintained using an EC developed in accordance with Ecology procedures. Specifically, the EC will:

- Control activities that may result in the release of residual COCs, create a new exposure to residual COCs, or disturb the subsurface environment through plans and procedures approved by Ecology.

- Provide notification that residual COCs may be present and include deed restrictions that limit future development and use of the site.

- Prohibit the installation of wells for the purpose of water supply within the site boundary.

- Restrict the extraction of groundwater for purposes other than construction and hydraulic control dewatering, monitoring/investigation, or remediation.

- Require that groundwater extracted within the site boundary be evaluated via data review and testing and the discharge managed in accordance with state and federal regulations.

- Require that utilities or other subsurface infrastructure within the site boundary where the depth is greater than the highest measured groundwater be designed and constructed based on groundwater conditions.

Timeframe: The timeframe to implement this alternative is less than 1 year. However, ICs and ECs will remain in place in perpetuity or until CULs are met.

Cost: The estimated cost for this alternative is summarized in Appendix D, Table D2.

5.3.3 Alternative 3 – LNAPL Containment, Biosparge, MNA, and Targeted Excavation

Alternative 3 includes installing a sheet pile wall to the east, south, and west of the LNAPL body to control downgradient transport of dissolved phase petroleum hydrocarbons during high groundwater conditions and allow the LNAPL body to naturally degrade (monitored NSZD). Biosparging will be implemented to remediate dissolved phase petroleum hydrocarbons in the mainline track area and beneath the former Engine House (contingent on an MNA assessment - see Section 5.3.8). Excavation of shallow impacted soils will occur in a portion of the berm area. MNA will be implemented for dissolved phase petroleum hydrocarbons once RELs for active remediation have been met. This alternative uses physical containment, ICs, and ECs to control exposures to potential receptors (onsite workers, visitors, nearby residents, trespassers, and surface water).

The key components of Alternative 3 are depicted on Figure 25. This alternative consists of the following general actions:

- Design and Permitting. Borings will be advanced along the alignment of the sheet pile wall to collect geotechnical data and design the sheet pile wall. A biosparging pilot study will be conducted to evaluate the radius of influence and sparge rate, identify the design parameters, and design a full-scale system. A CAP and a JARPA will be prepared for construction near the Columbia River, as well as excavation activities. Permits will be obtained, including well permits for the geotechnical borings, biosparge wells, and associated monitoring wells; and building permits for the sheet pile wall and the biosparge system. Subsurface intrusive activities will include cultural resources monitoring completed in accordance with the CRMP under permit from DAHP. Because the biosparge system will not result in discharges to the atmosphere, an air permit is not needed.

- Site preparation. Activities will include grading for equipment access, delineation of work zones and laydown areas, and identification of underground utilities within the footprint of the wall and the excavation. Utilities impacted by the remedial activities will be protected in-place, relocated, removed, or abandoned in-place as appropriate.

- Installation. Sheet pile wall installation includes driving individual interlocked steel sheets to the desired depth along three sides of the LNAPL body and grading the surface for drainage to minimize infiltration of stormwater into the subsurface. Biosparge system installation includes constructing treatment pads/sheds, and furnishing air compressors, PLCs, distribution manifolds and piping, and biosparge wells. Forty-five biosparge wells will be installed to depths of approximately 25 feet bgs to address dissolved-phase impacts at varying depths throughout the remediation area (Figure 25). The number, location, and depth of biosparge wells in each area will be evaluated based on the MNA assessment.

- Operation and Monitoring. The sheet pile wall requires no operational activities. Groundwater pumping from within the sheet pile wall will not be performed as the groundwater gradient across the site is relatively flat throughout most of the year, and groundwater typically (approximately 10 months per year) flows away from the Columbia River. Groundwater inside the wall will be monitored, using existing or new monitoring wells (as needed) to evaluate NSZD, as well as document groundwater elevations inside the wall area. Groundwater outside the wall will be monitored to confirm groundwater elevations and that CULs are achieved.

  The biosparging system will deliver ambient air to groundwater under either intermittent or continuous operation based on system monitoring results. Regular operations and maintenance (O&M) will be performed to assess the performance of the biosparging system. O&M activities will include measurement of system parameters (flow rate, pressure response, etc.), flow rate/time adjustments, and measurements of dissolved oxygen concentrations in groundwater. Monitoring wells will also be installed, as needed, to evaluate operations of the biosparging system. Once biosparging operations have met the design objectives, active remediation will be discontinued, and MNA followed by compliance groundwater monitoring will be implemented.

- Groundwater Covenant. A restrictive covenant will be enacted to prohibit the installation of wells for the purpose of water supply within the site boundary; restrict the extraction of groundwater for purposes other than construction and hydraulic control dewatering, monitoring/investigation, or remediation; and require groundwater extracted within the site boundary be evaluated via data review and testing and the discharge managed in accordance with state and federal regulations.

Excavation of impacted soils along the berm, and MNA of groundwater are further described in Sections 5.3.7 and 5.3.8, respectively.

Timeframe: As this alternative does not include active removal or destruction of the LNAPL, the time to achieve RELs is estimated to be greater than 30 years, and the time to achieve CULs is more than 50 years. Installation of the containment barrier will take less than 1 year. Biosparge operations are expected to be implemented over a 2- to 5-year period. MNA for groundwater outside the containment wall will be assessed for approximately 3 years following cessation of the biosparging. NSZD monitoring inside the containment wall and compliance groundwater monitoring of selected wells outside the containment wall are expected to continue in perpetuity or until CULs are met. ECs and ICs established for the site are expected to remain in place in perpetuity.

Cost: The estimated cost for this alternative is summarized in Appendix D, Table D3.

5.3.4 Alternative 4 – Physical LNAPL Removal, Biosparge, MNA, and Targeted Excavation

Alternative 4 involves physical removal of LNAPL in the eastern LNAPL area, biosparging in the western LNAPL area and southern end of the eastern LNAPL area, biosparging contingent on an MNA assessment in the mainline track area and beneath the former Engine House, and excavation of shallow impacted soils in a portion of the berm area. Monitored NSZD in the LNAPL areas and MNA for dissolved impacts in the biosparge areas will be implemented once RELs for active remediation have been met. Based on soil gas monitoring for NSZD parameters in the eastern LNAPL area, LNAPL removal wells may be converted to biosparge wells after RELs for physical LNAPL recovery have been achieved. Biosparging is expected to enhance the attenuation of and to eliminate the transport of dissolved phase petroleum hydrocarbons to the river during high groundwater conditions. This alternative uses removal and destruction technologies, along with ICs and ECs, to control exposures to potential receptors (onsite workers, visitors, nearby residents, trespassers, and surface water).

The key components of Alternative 4 are depicted on Figure 26. This alternative consists of the following general actions:

- Design and Permitting: LNAPL removal tests will be conducted, and removal will be modelled using the API LDRM to evaluate extraction well spacing and removal timeframe. An LDRM estimate of LNAPL recoverability is provided in Appendix D and summarized in Section 5.3.6. A biosparging pilot study will be conducted to evaluate the radius of influence and sparge rate, identify the design parameters and design a full-scale system. A CAP and a JARPA will be prepared for construction and excavation near the Columbia River. Permits will be obtained, including well permits for the LNAPL removal wells, biosparge wells, and associated monitoring wells; and building permits for the biosparge systems. Subsurface intrusive activities will include cultural resources monitoring completed in accordance with the CRMP under permit from DAHP. Because the biosparge systems will not result in discharges to the atmosphere, an air permit is not needed. Samples of the LNAPL and groundwater in the extraction wells will be collected and analyzed for waste profiling and to identify appropriate disposal methods. Discharge of effluent water to the local POTW will require completion (and approval by the Klickitat County PUD) of a feasibility study to establish acceptable discharge volume, concentration limits, and monitoring requirements.

- Site preparation. Activities will include grading for equipment access, delineation of work zones and laydown areas, and identification of underground utilities within the footprint of the drilling and excavation areas. Utilities impacted by the remedial activities will be relocated, removed, or abandoned in-place as appropriate.

- Installation. In the eastern LNAPL area, existing OHM wells and new recovery wells installed within the LNAPL extent will be used for LNAPL removal. Current estimates assume up to 15 new LNAPL recovery wells will be installed within the LNAPL body, on approximately 40-foot centers. New recovery wells will be constructed of 4- to 6-inch-diameter, stainless steel wire-wrapped screen connected to stainless steel or PVC risers.

- As with Alternatives 1 and 3, biosparge system installation includes constructing treatment pads/sheds, and furnishing air compressors, PLCs, distribution manifolds and piping, and biosparge wells. In the western LNAPL area, mainline track area, and beneath the former Engine House, 50 biosparge wells will be installed to depths between approximately 20 to 40 feet bgs to address dissolved-phase and LNAPL impacts at varying depths; and three paired shallow (25 feet bgs) and deep (60 feet bgs) wells will be installed. At the southern end of the LNAPL removal area, 10 paired (20 total) biosparge wells will be installed to depths of approximately 25 feet bgs (shallow) and 60 feet bgs (deep) to address dissolved-phase impacts (Figure 26). The number, location, and depth of biosparge wells in each area will be evaluated based on the MNA assessment.

  Operation and Monitoring. LNAPL will be removed from wells by periodic high-vacuum extraction or other methods depending on the results of the LDRM and field implementation testing. Adequate time will be allowed for LNAPL to recharge prior to subsequent extraction events. Between extraction events, the presence and apparent thickness of the LNAPL will be monitored. Physical removal will allow for adaptive management strategies to increase or decrease the frequency of removal and to expand the extraction well network based on observed site conditions. Once LNAPL removal (eastern area) and biosparging (western area) operations have met their design objectives (i.e., RELs), active remediation will be discontinued and monitored NSZD will be assessed. Based on soil gas monitoring for NSZD parameters in the eastern LNAPL area, LNAPL removal wells may be converted to biosparge wells to further enhance biodegradation. MNA for dissolved impacts in the biosparge areas will be assessed once RELs for active remediation have been met. MNA will be assessed in general accordance with Ecology's NA Guidance (Ecology 2005) and will include collecting groundwater samples for DRO, ORO, and natural attenuation parameters semi-annually for 3 years. Compliance groundwater monitoring will be implemented following completion of the MNA assessment and will include annual to biennial monitoring for geochemical parameters and laboratory analysis for DRO and ORO.

- Groundwater Covenant. A restrictive covenant will be enacted to prohibit the installation of wells for the purpose of water supply within the site boundary, restrict the extraction of groundwater for purposes other than construction and hydraulic control dewatering, monitoring/investigation, or remediation, and require groundwater extracted within the site boundary be evaluated via data review and testing and the discharge managed in accordance with state and federal regulations.

Excavation of impacted soils along the berm, and MNA of groundwater are further described in Sections 5.3.7 and 5.3.8, respectively.

Timeframe. The time to achieve RELs is estimated to be 10 years, and the time to reach CULs is estimated to be more than 30 years (depending on NSZD rates) following cessation of active remediation. LNAPL recovery is typically most productive during early phases of removal and becomes asymptotic as the rebound of LNAPL thickness decreases with time. Active LNAPL removal is estimated to be implemented over a 10-year timeframe. Biosparge operations are expected to be implemented over a 2- to 5-year period (concurrent with physical removal of the LNAPL) in the western LNAPL, the mainline track area, and beneath the former Engine House. NSZD monitoring in the eastern LNAPL area will be conducted while LNAPL is being removed. If implemented in the eastern area after physical LNAPL removal, biosparge operations are expected to be implemented over a 3- to 5-year period. MNA will be assessed for approximately 3 years following cessation of biosparge operations in the western LNAPL, mainline track, and Engine House areas, and for 3 years following cessation of physical LNAPL removal activities in the eastern LNAPL area (or following cessation of biosparging, if implemented). Compliance groundwater monitoring will continue until CULs are met. ECs and ICs established for the site are expected to remain in place until a no further action determination is provided by Ecology.

Cost: The estimated cost for this alternative is summarized in Appendix D, Table D4.

5.3.5 Alternative 5 – Low-Temperature Thermal Removal (LTTR), Biosparge, MNA, and Targeted Excavation

Alternative 5 involves heating the subsurface to enhance physical removal of the LNAPL in the eastern LNAPL area, biosparging in the western LNAPL area and southern end of the eastern LNAPL area, biosparging contingent on MNA assessment in the mainline track area and beneath the former Engine House, and excavation of shallow impacted soils in a portion of the berm area. The saturated subsurface in the eastern LNAPL area will be heated to an average temperature between 50 and 70°C to reduce the LNAPL viscosity and interfacial tension and facilitate its removal through multi-phase extraction wells. The effluent will be treated onsite, with the groundwater being discharged to the local POTW and LNAPL being disposed offsite at a permitted facility. Temperatures will be limited to less than 90°C at the heating points to avoid steam production/vaporization of groundwater. Active extraction during heating will result in an inward hydraulic gradient controlling LNAPL migration within the remediation area and biosparging along the southern end of the eastern LNAPL area is expected to eliminate the transport of dissolved phase petroleum hydrocarbons to the river, therefore physical containment is not needed. Alternative 5 assumes electrical resistive heating (ERH) will be used. ERH is the best way to control temperatures between wells and more uniformly distribute heat throughout the subsurface to alter LNAPL properties for efficient recovery. Monitored NSZD in the LNAPL areas and MNA for dissolved impacts in the biosparge areas will be implemented once RELs for active remediation have been met. Based on soil gas monitoring for NSZD parameters in the eastern LNAPL area, multi-phase extraction wells may be converted to biosparge wells after RELs for physical LNAPL recovery have been achieved. Increased temperatures will stimulate greater biological activity, which may benefit from additional oxygen delivery to the subsurface. This alternative uses removal and destruction technologies, along with ICs and ECs, to control exposures to potential receptors (onsite workers, visitors, nearby residents, trespassers, and surface water).

The key components of Alternative 5 are depicted on Figure 27. This alternative consists of the following general actions:

- Design and Permitting: A pilot test will be conducted to evaluate and confirm the low temperature heating mechanism and model the removal using the LDRM to evaluate extraction well spacing and removal timeframe. An LDRM estimate of LNAPL recoverability, including effects of increasing temperature, is provided in Appendix D and summarized in Section 5.3.6. A biosparging pilot study will be conducted to evaluate the radius of influence and sparge rate, identify the design parameters and design a full-scale system. A CAP and a JARPA will be prepared for construction and excavation near the Columbia River. Permits will be obtained including well permits for the LNAPL removal wells, biosparge wells, and associated monitoring wells; building permits for the heating and biosparge systems, and discharge permits (industrial wastewater, National Pollutant Discharge Elimination System, and/or air permit). Subsurface intrusive activities will include cultural resources monitoring completed in accordance with the CRMP under permit from DAHP. Because the LNAPL removal system is not expected to produce significant off-gas, and the biosparge system will not result in discharges to the atmosphere, an air permit is not needed. Samples of the LNAPL and groundwater in the extraction wells will be collected and analyzed for waste profiling and identification of appropriate disposal methods. Discharge of effluent water to the local POTW will require completion (and approval by the Klickitat County PUD) of a feasibility study to establish acceptable discharge volume, concentration limits, and monitoring requirements.

- Site preparation. Activities will include grading for equipment access, delineation of work zones and laydown areas, and identification of underground utilities within the footprint of the drilling and excavation areas. Utilities impacted by the remedial activities will be protected in-place, relocated, removed, or abandoned in-place as appropriate.

- Installation. Existing wells OHM-1, OHM-2, OHM-3, and WMW-1 are constructed of PVC and, therefore, will be decommissioned. New heating and recovery wells will be installed within the eastern LNAPL body. Preliminary evaluation of the LNAPL data indicates up to 54 electrode locations and 18 fluid recovery wells will be installed within the LNAPL body. Recovery wells will be constructed of 4-inch-diameter, stainless steel wire-wrapped screens and risers. The type and spacing of the thermal elements will be based on subcontractor recommendations. Thermally enhanced recovery is an adaptable approach following initial phases of operation. Both the temperature and heating areas can be adjusted through changes in the application of energy to the system. Depending on observed influence of the extraction wells, additional removal points can be installed if needed, and the frequency of LNAPL extraction can be selected adaptively to align extraction with the observed effects of heating. Following LNAPL recovery, extraction wells can be converted for use as biosparge points to add oxygen to the subsurface. Temperatures in the range of 50°C are optimal for biodegradation of petroleum hydrocarbons and will result in an oxygen-limited system following completion of the low-temperature LNAPL removal. The addition of oxygen while the subsurface temperature is elevated and during cool down will help maintain the active aerobic biodegradation of the residual hydrocarbons.

- As with Alternatives 1, 3, 4, and 5, biosparge system installation includes constructing treatment pads/sheds, and furnishing air compressors, PLCs, distribution manifold and piping, and biosparge wells. In the western LNAPL area, the mainline track area, and beneath the former Engine House, 50 biosparge wells will be installed to depths between approximately 20 to 40 feet bgs, and three pairs of shallow (25 feet bgs) and deep (60 feet bgs) sparge wells, to address dissolved-phase and LNAPL impacts at varying depths. At the southern end of the LNAPL removal area, 10 paired (20 total) biosparge wells will be installed to depths of approximately 25 feet bgs (shallow) and 60 feet bgs (deep) to address dissolved-phase impacts (Figure 27). The number, location, and depth of biosparge wells in each area will be evaluated based on the MNA assessment.

- Operation and Monitoring: Fluids (LNAPL) will be removed until RELs are achieved. Biosparging operations will continue until groundwater results indicate it has met its design objectives. Following cessation of active remediation, monitored NSZD and MNA will be implemented for 3 years in the eastern and western LNAPL areas, in the mainline track area, beneath the former Engine House, and in the berm area south of the former Power House. MNA will be assessed in general accordance with Ecology's NA Guidance (Ecology 2005) and will include collecting groundwater samples for DRO, ORO, and natural attenuation parameters semi-annually for 3 years. Compliance groundwater monitoring will be implemented following completion of the MNA assessment and will include annual to biennial monitoring for DRO and ORO.

- Groundwater Covenant. A restrictive covenant will be enacted to prohibit the installation of wells for the purpose of water supply within the site boundary; restrict the extraction of groundwater for purposes other than construction and hydraulic control dewatering, monitoring/investigation, or remediation; and require groundwater extracted within the site boundary be evaluated via data review and testing and the discharge managed in accordance with state and federal regulations.

Excavation of impacted soils along the berm, and MNA of groundwater are described in Sections 5.3.6 and 5.3.7, respectively.

Timeframe. The time to achieve RELs is expected to be 2 to 5 years, and the time to reach CULs is estimated to be more than 30 years (depending on NSZD rates) following cessation of active remediation. Active thermally enhanced LNAPL removal is estimated to be implemented over a 1- to 2-year period. Biosparge operations are expected to be implemented over a 2- to 5-year period (concurrent with LNAPL removal) in the western LNAPL, the mainline track area, and beneath the former Engine House. Monitored NSZD and MNA will be assessed for approximately 3 years following cessation of active remediation. Compliance groundwater monitoring of selected wells will continue until CULs are met. ECs and ICs established for the site are expected to remain in place until a no further action determination is provided by Ecology.

Cost: The estimated cost for this alternative is summarized in Appendix D, Table D5.

5.3.6 LNAPL Recovery Estimate

The API LDRM was used to estimate the percentages of (a) recoverable LNAPL and (b) total LNAPL that could potentially be removed from the subsurface in the eastern LNAPL area under Alternatives 1, 4, and 5. The LDRM was populated with laboratory-measured physical properties of LNAPL and water samples collected from wells OHM-1, OHM-2, and OHM-3; as well as soil properties for soil cores collected from the three OHM well borings. LNAPL removal rates for a representative well for three different temperature scenarios [roughly representing the physical (21 °C) and two (38 and 55 °C) low temperature thermal removal options] were estimated by varying the LNAPL viscosity (based on laboratory data) and elapsed time. The individual well results were then applied to a representative number of wells (18 wells, six of each well type representing the three OHM wells in the eastern LNAPL area) to estimate LNAPL removal from the submerged LNAPL body.

Relative to Alternative 1 and Alternative 4, which include physical LNAPL removal, LNAPL viscosity and density data collected at 21 °C was run for 10 years of LNAPL recovery well operation. This scenario was used to represent LNAPL recovery without subsurface heating. Relative to Alternative 5, which includes heating the subsurface to temperatures between 50 and 70 °C to enhance physical removal of the LNAPL, a LNAPL viscosity and density data collected at 55 °C was run for 1 year of LNAPL recovery well operation. A second temperature heating scenario, using LNAPL viscosity and density data collected at 38 °C, was also modeled for 1 year to assess the impact from heating the subsurface to a very low temperature.

The model estimates the initial total LNAPL and total recoverable LNAPL based on input LNAPL and soil properties, and the LNAPL recovered based on well characteristics and elapsed time. By individual well, the estimated percentage of recoverable LNAPL was higher for a well with a lithology of gravel with silt and sand (OHM-1) than wells with fine sand (OHM-2 and OHM-3).

Model results showed that the estimated percentages of recoverable submerged LNAPL removed were similar for the physical removal (21 °C) scenario after 10 years (20 percent removed) and the low temperature (55 °C) scenario after 1 year (21 percent). The percent recovery for the very low temperature scenario (38 °C) was roughly half (10 percent) of the higher temperature scenario after 1 year. Results indicate that the percent of LNAPL recovered under the physical removal (21 °C) scenario over a 10-year period will be roughly the same as the percent recovered over a 1-year period when the low-temperature thermal option is applied to the subsurface. However, the time difference between the two options is negligible when compared to the estimated time to achieve the overall cleanup objectives. The LDRM evaluation is further described in Appendix C.

5.3.7 Shallow Berm Excavation

This remedial process involves removing and disposing of impacted soils offsite at a permitted facility. Based on existing data, a small area with shallow petroleum-hydrocarbon impacted soil is present on the northern side of the berm south of the former Power House, in the vicinity of soil boring B-16-01 and LIF borings TG-CR4, TG-CR4.5, and TF-CR5 (Figures 19 through 22). Petroleum hydrocarbon-impacted soil is anticipated to be encountered at depths between approximately 6 and 9 feet bgs. The estimated volume of in-place petroleum hydrocarbon-impacted soil is 170 cubic yards (cy). The vertical and lateral extents of soils exceeding the CULs will be confirmed in advance of conducting the physical removal. This remedial process is a component of Alternatives 1, 3, 4, and 5 described above.

The excavation process will include removing and stockpiling soil from the upper 6 feet for testing for potential reuse as backfill material. The impacted soils estimated to be between

6 and 9 feet bgs will then be excavated, stockpiled separately, and characterized for disposal at an offsite licensed Subtitle D landfill facility as non-hazardous waste. Subsurface intrusive activities will include cultural resources monitoring, which will be completed in accordance with the CRMP under permit from DAHP.

Excavation sidewalls will be sloped appropriately for safety; however, workers will not be allowed to enter the excavation. *In situ* confirmation samples will be collected in advance of performing the removal activities, to minimize the time the excavation near the riverbank remains open. The excavation will be backfilled with the overburden material, as well as clean fill material (imported from a local quarry) and compacted to existing grade.

Utilities within the excavation area will be temporarily rerouted, as necessary. Dewatering is not expected to be needed based on the known depth of the impacted soils (9 feet bgs) and the average depth to groundwater (10 to 15 feet bgs beneath the berm).

Timeframe: the time required to complete this activity is expected to be less than 3 months.

Cost: The estimated cost is included in the cost estimate spreadsheets in Appendix B.

5.3.8 Groundwater Monitoring

MNA of impacted groundwater is a component of Alternatives 1, 3, 4, and 5 described above, with a contingency of biosparging to enhance biodegradation in Alternatives 3, 4, and 5. Since shallow source material in the unsaturated zone has been removed during previous interim remedial actions (Section 1.3), MNA is an appropriate remedial option for dissolved phase groundwater impacts. Natural attenuation will be evaluated prior to implementing biosparging as a contingency, and performed once RELs are achieved, in the mainline tracks area, the former Engine House area, and in the LNAPL areas and south of the former Power House.

MNA primarily relies on biological transformation or destruction of the petroleum hydrocarbons. Groundwater monitoring will be performed at selected locations to demonstrate conditions needed for biological degradation are present, natural attenuation is occurring, and the groundwater impacts are stable or decreasing. MNA includes collecting groundwater samples for field water quality parameters [e.g., dissolved oxygen (DO) and oxidation-reduction potential (ORP)] and conducting specific laboratory analyses to confirm the natural processes are occurring. Compliance monitoring will be implemented once sufficient MNA data is collected to substantiate MNA is occurring and evaluate the timeframe for concentrations to reach their CULs.

Natural attenuation of residual and dissolved petroleum hydrocarbons through aerobic biodegradation mechanisms relies on sufficient dissolved oxygen [typically greater than 2 milligrams per liter (mg/L)] in groundwater. Therefore, in areas where groundwater is naturally aerobic, biosparging will not be implemented. If dissolved oxygen is depressed (less than 2 mg/L, i.e., anaerobic conditions) and dissolved phase petroleum hydrocarbon concentrations are not stable or decreasing, then biosparging may be implemented to increase the dissolved oxygen concentrations in the aquifer. Following cessation of active remediation (i.e., LNAPL removal and biosparging), groundwater will be monitored to demonstrate remediation goals can be achieved through MNA and NSZD.

MNA primarily relies on biological transformation or destruction of the petroleum hydrocarbons. Groundwater monitoring will be performed at selected locations to demonstrate conditions needed for biological degradation are present, natural attenuation is occurring, and the groundwater impacts are stable or decreasing. MNA includes collecting groundwater samples for field water quality parameters (e.g., DO and ORP) and conducting specific laboratory analyses to confirm the natural processes are occurring. Compliance monitoring will be implemented once sufficient MNA data is collected to substantiate MNA is occurring and evaluate the timeframe for concentrations to reach their CULs.

Timeframe: An MNA assessment will be conducted for a 3-year period. The duration may differ in different areas of the site, depending on the results. Compliance monitoring will be implemented following completion of the MNA assessment and will continue until CULs are achieved.

Cost: Groundwater monitoring costs are included in the cost estimate spreadsheets in Appendix B. The cost estimate spreadsheet for Alternative 2 includes 30 years of compliance monitoring (without an MNA evaluation). The cost estimate spreadsheets for Alternatives 1, 3, 4, and 5 include groundwater monitoring during active remediation (e.g., biosparging, ambient temperature physical LNAPL removal, and/or thermally enhanced LNAPL removal activities) followed by 3 years of MNA and 27 years of compliance monitoring on an annual to biennial basis.

Section 6: Evaluation of Remedial Alternatives

This section presents a preliminary analysis of the remedial alternatives against the MTCA threshold criteria (Section 6.1), followed by detailed analyses (Section 6.2).

6.1 MTCA Threshold Criteria

A remedial action must meet certain threshold criteria to be considered under the MTCA [WAC 173-340-360 (2)(a)]. An alternative cannot be selected if it cannot meet the following threshold requirements:

- Protect human health and the environment
- Comply with cleanup standards
- Comply with applicable state and federal laws
- Provide for compliance monitoring.

A cleanup is presumed to be protective of human health and the environment if it achieves the CULs and/or mitigates exposure through controls. Compliance with cleanup standards involves achieving CULs at an appropriate point of compliance, implementing ICs in those area where remediation to CULs is not appropriate or feasible but RELs have been met. An alternative can comply with applicable federal and state laws by protecting human health and the environment through a combination of active and passive remedial measures and/or the implementation of ICs.

Compliance monitoring assesses the protection of human health and the environment during construction and the O&M period of a cleanup action. Compliance monitoring assesses whether a remedial action has met RELs and/or CULs and verifies its long-term effectiveness. Compliance with the threshold requirements does not imply untreated hazardous substances cannot remain onsite. MTCA recognizes non-treatment alternatives can comply with cleanup standards, provided compliance monitoring is included to confirm protection of human health and the environment.

Table 6 summarizes the evaluation of the alternatives in relation to MTCA's threshold criteria. Based on this evaluation, five proposed alternatives meet the threshold criteria - they can achieve CULs; have an acceptable point of compliance; and provide for compliance monitoring. No Action is included as required for comparison. While No Action will achieve CULs over a long timeframe, it is unlikely to be accepted as compliant with state and federal laws and does not provide for compliance monitoring.

6.2 Alternatives Analysis

MTCA specifies that when selecting a remedial action, preference shall be given to actions that are "permanent to the maximum extent practicable." To determine whether a remedial action uses permanent solutions to the maximum extent possible, a disproportionate cost analysis

(DCA) shall be used [WAC 173-340-360(3)(b)]. Costs are disproportionate to benefits if the incremental cost of the alternative over that of a lower cost alternative exceed the incremental degree of benefits achieved by the alternative over that of the lower cost alternative.

The most practical permanent alternative evaluated in the feasibility study shall be the baseline cleanup alternative against which other alternatives are compared. The permanency of alternatives is largely qualitative and is based on best professional judgment.

This section evaluates each remedial alternative against seven criteria set in WAC 173-340-360(3)(f) in order to establish whether a cleanup is permanent to the maximum extent practical. The seven criteria are:

1. Protectiveness
2. Permanence
3. Cost
4. Effectiveness over the long-term
5. Management of short-term risks
6. Technical and administrative implementability
7. Consideration of public concerns.

These criteria, as well as a restoration timeframe and compliance with federal and state ARARs, are evaluated below. An evaluation of the five alternatives relative to these seven criteria is provided in Table 6. The following summarizes the analysis of the alternatives under each criterion ranked on a scale of 1 to 10. A score of 10 indicates the alternative meets the criterion significantly well and 1 indicates the alterative does not meet the criterion well or at all. Remediation elements common to Alternatives 1, 2, 3, 4, and 5 do not contribute to differential rankings as these common elements carry the same benefits and risks when applied similarly or identically. The most significant differences are observed in evaluating the LNAPL remedy for each alternative; therefore, the following evaluation is focused on the various proposed remedial alternatives for LNAPL.

6.2.1 Protectiveness

Protectiveness is the degree existing risks are reduced, the time required to reduce risk and attain cleanup standards, onsite and offsite risks resulting from implementing the alternative, and improvement of overall environmental quality.

Protectiveness

Alternative 1 – Physical Removal, Focused Biosparge, MNA, and Targeted Excavation	5
Alternative 2 - Institutional Controls and Environmental Covenants with Compliance Groundwater Monitoring	2

Protectiveness

Alternative 3 - LNAPL Containment, Biosparge, MNA, and Targeted Excavation	4
Alternative 4 - Physical Removal, Biosparge, MNA, and Targeted Excavation	6
Alternative 5 – LTTR, Biosparge, MNA, and Targeted Excavation	7

Alternatives 2 and 3 are protective, but do not actively remove LNAPL, leaving higher potential for future exposure. Alternatives 1 and 4 will remove a fraction of the LNAPL mass, leaving residual mass for NSZD. Alternative 5 will remove LNAPL faster than Alternatives 1 and 4 but will still leave residual mass for NSZD. Active remediation via biosparging is included in Alternatives 1, 4, and 5 for the western LNAPL area and in Alternatives 3, 4, and 5 for dissolved phase impacts. Tradeoffs between timeframe and likelihood of effectiveness result in the differential scores among these alternatives. Alternatives 1, 4, and 5 are similar in intent to actively address LNAPL source and differ in timeframe and approach and are the most protective.

6.2.2 Permanence

A permanent cleanup achieves cleanup standards without requiring further action such as long-term monitoring or ICs. The remedial action alternatives were compared based on their adequacy in destroying hazardous substances, reducing or eliminating hazardous substance releases and sources, the irreversibility of waste treatment process, and the characteristics and quantity of treatment residuals generated.

Permanence

Alternative 1 – Physical LNAPL Removal, Focused Biosparge, MNA, and Targeted Excavation	7
Alternative 2 - Institutional Controls and Environmental Covenants with Compliance Groundwater Monitoring	2
Alternative 3 - LNAPL Containment, Biosparge, MNA, Targeted Excavation	3
Alternative 4 - Physical LNAPL Removal, Biosparge, MNA, and Targeted Excavation	7
Alternative 5 – LTTR, Biosparge, MNA, and Targeted Excavation	7

Alternatives 2 and 3 do not provide permanent measures to address site conditions without long-term monitoring or ICs, though Alternatives 2 and 3 provide long-term protection with ongoing maintenance. Alternatives 1, 4, and 5 include LNAPL removal to the extent practicable using different methods. Each option includes long-term monitoring.

6.2.3 Cost

The costs to implement the alternatives, including the construction, operation, and the long-term monitoring, were estimated to assess practicability (see Section 7.2). Long-term costs include O&M costs, monitoring costs (including 30 years of compliance monitoring after cessation of active remediation), equipment replacement costs, and the costs of maintaining ICs.

Cost	
Alternative 1 - Physical LNAPL Removal, Focused Biosparge, MNA, and Targeted Excavation	6
Alternative 2 - Institutional Controls and Environmental Covenants with Compliance Groundwater Monitoring	9
Alternative 3 - LNAPL Containment, Biosparge, MNA, and Targeted Excavation	5
Alternative 4 - Physical LNAPL Removal, Biosparge, MNA, and Targeted Excavation	5
Alternative 5 – LTTR, Biosparge, MNA, and Targeted Excavation	1

Alternative 2 is the lowest cost alternative that includes measures to protect human health and the environment, which consist primarily of long-term monitoring and reporting once controls are in place. Alternatives 1, 3, 4, and 5 have similar or identical costs for some project elements, including planning, biosparging, shallow excavation, groundwater monitoring, and reporting elements that scale based on the number of locations included or the duration of activities. Alternatives 3 and 4 were ranked the same as their respective costs were within 5 percent. Costs for Alternatives 4 and 5 include biosparge treatment in five areas [western LNAPL area, eastern LNAPL area (after LNAPL removal), and dissolved phase in the southern end of eastern LNAPL area, mainline tracks area, and former Engine House] compared to one area for Alternative 1 (western LNAPL area) and two areas for Alternative 3 (mainline tracks area and former Engine House). The most significant differences in conceptual scope and cost among these alternatives are for the LNAPL remedy. The cost to implement physical removal (Alternatives 1 and 4) is significantly less than the cost to implement LTTR (Alternative 5). Estimated costs for each alternative are described in Section 7.

6.2.4 Long-Term Effectiveness

Long-term effectiveness is the degree of certainty that the alternative will be successful, the reliability of the alternative during the period of time hazardous substances are expected to remain onsite at concentrations that exceed CULs, the magnitude of residual risk with the alternative in place, and the effectiveness of controls required to manage treatment residues or remaining wastes.

Long-Term Effectiveness	
Alternative 1 - Physical LNAPL Removal, Focused Biosparge, MNA, and Targeted Excavation	7
Alternative 2 - Institutional Controls and Environmental Covenants with Compliance Groundwater Monitoring	3
Alternative 3 - LNAPL Containment, Biosparge, MNA, and Targeted Excavation	4
Alternative 4 - Physical LNAPL Removal, Biosparge, MNA, and Targeted Excavation	9
Alternative 5 – LTTR, Biosparge, MNA, and Targeted Excavation	9

Alternatives 2 and 3 provide effective long-term control but rely on controls to protect human health and the environment for a long period of time while hazardous substances remain on site, increasing uncertainty of future protection. Alternatives 1, 4, and 5 each remove LNAPL, significantly reducing the likelihood of exposure in the future. Alternatives 1 and 4 remove LNAPL at ambient temperatures using simple and measurable methods; changes in LNAPL thickness and transmissivity can be measured over time and risks from unidentified isolated residuals or migration are limited. Alternative 4 uses biosparging as a more active remedy to address dissolved phase impacts. Alternative 5 uses heat to modify the physical properties of the LNAPL to shorten the extraction time; but is not expected to significantly increase the amount of LNAPL removed over the project lifecycle compared to Alternatives 1 and 4.

6.2.5 Short-Term Risks

Short-term risk is the risk to human health and the environment associated with each alternative during construction and implementation, and the effectiveness of measures that will need to be taken to manage such risks.

Short-Term Risks

Alternative 1 - Physical LNAPL Removal, Focused Biosparge, MNA, and Targeted Excavation	8
Alternative 2 - Institutional Controls and Environmental Covenants with Compliance Groundwater Monitoring	9
Alternative 3 - LNAPL Containment, Biosparge, MNA, and Targeted Excavation	3
Alternative 4 - Physical LNAPL Removal, Biosparge, MNA, and Targeted Excavation	8
Alternative 5 – LTTR, Biosparge, MNA, and Targeted Excavation	4

Alternative 2 has little to no risk associated with implementation related to ICs and other planned activities are relatively limited in scale. Alternative 3 includes the most invasive and significant construction elements. Installation of sealed interlocking sheet piles to the proposed depths is challenging work that involves the management of significant health and safety risks to workers and the most significant potential environmental impact of the activities in each of the alternatives. Alternatives 1 and 4 include conventional drilling and LNAPL recovery methods that have relatively lower short-term risk ranking among the active remedial approaches. Alternative 5 includes construction risks similar to Alternative 4 with the addition of construction of treatment systems and high voltage electrical connections, and the addition of heat to the subsurface system. Operational risks for Alternative 5 include heating of the subsurface to moderate temperatures that pose limited thermal risks. Controlling the temperature to remain between 50 and 70°C limits LNAPL migration and vaporization risks. The use of ERH introduces electrical risk from current passing through the subsurface to produce heat.

6.2.6 Ability to Implement

The ability to implement includes technical feasibility; availability of necessary offsite facilities, services, and materials; administrative and regulatory requirements; scheduling; access constraints; and integration with existing facility operations and other current or potential remedial actions.

Ability to Implement

Alternative 1 - Physical LNAPL Removal, Focused Biosparge, MNA, and Targeted Excavation	8
Alternative 2 - Institutional Controls and Environmental Covenants with Compliance Groundwater Monitoring	9
Alternative 3 - LNAPL Containment, Biosparge, MNA, Targeted Excavation	5
Alternative 4 - Physical LNAPL Removal, Biosparge, MNA, and Targeted Excavation	8
Alternative 5 – LTTR, Biosparge, MNA, and Targeted Excavation	6

Alternative 2 is easily implemented. Alternative 3 includes significant construction elements and is therefore, challenging to implement. Installation of sealed interlocking sheet piles to the proposed depths is challenging work. Alternatives 1 and 4 include conventional drilling and LNAPL recovery methods that are relatively easy to implement. Alternative 5 involves construction implementation methods similar to Alternatives 1 and 4 with the addition of treatment system construction and high voltage electrical connections. For Alternative 5, controlling the temperature to remain between 50 and 70°C is implementable using thermocouples throughout the wellfield.

6.2.7 Consideration of Public Concerns

Ecology may assist with considering public concerns during selection of the remedial action. A Public Notice and Participation period is required (WAC 173-340-600) before implementation of the action.

6.2.8 Restoration Timeframe

MTCA requires that remedial alternatives provide a reasonable restoration timeframe, which means:

- Assessing the remedial alternatives relative to:
  - The practicability of achieving a shorter restoration timeframe
  - The ability to achieve cleanup levels at the point of compliance with a greater degree of long-term effectiveness.
- Considering the impacts to current and future use of the site, surrounding areas, and associated resources that are, or may be, affected by releases from the site.
- Considering the availability of alternative water supplies.
- Evaluating the likely effectiveness and reliability of institutional controls.

The time required to attain RELs for each remedial alternative was estimated and is summarized below. Based on the available data, the timeframe to achieve restoration is estimated to be more than 30 years for each alternative.

Restoration Timeframe

Alternative 1 - Physical LNAPL Removal, Focused Biosparge, MNA, and Targeted Excavation	6
Alternative 2 - Institutional Controls and Environmental Covenants with Compliance Groundwater Monitoring	1
Alternative 3 - LNAPL Containment, Biosparge, MNA, and Targeted Excavation	1
Alternative 4 - Physical LNAPL Removal, Biosparge, MNA, and Targeted Excavation	6
Alternative 5 – LTTR, Biosparge, MNA, and Targeted Excavation	8

The excavation element common to Alternatives 1, 3, 4, and 5 can occur quickly after a period of design and permitting and will be accomplished in less than 1 year, and concurrent with construction of other remedial systems. Biosparging elements common to these alternatives could likewise be designed and constructed in a short timeframe (less than 1 year) and will likely operate on the order of 2 to 5 years, if needed. Alternatives 2 and 3 do not actively remove LNAPL, leaving higher potential for future exposure. Alternatives 1 and 4 will remove a fraction of the LNAPL mass, leaving residual mass for NSZD. Physical removal will recover the mobile LNAPL within a period of less than 10 years with curtailed recovery events following the initial more intensive period. Alternative 5 will remove mobile LNAPL faster (within 1 to 2 years following implementation) than Alternatives 1 and 4 but will still leave residual mass for NSZD.

Assessment of monitored NSZD and MNA in applicable alternatives, will extend 3 years beyond cessation of the active remedy. Compliance monitoring will be implemented following completion of active remediation and the MNA assessment. For cost estimating purposes, compliance monitoring is estimated to extend for 27 years beyond completion of the 3-year monitored NSZD and MNA assessment period.

6.2.9 Summary of Alternative Ranking

The alternative rankings described above, including the calculated total score, are summarized in Table 6. Alternative 4 has the highest total score while Alternative 3 has the lowest. Because of tradeoffs between criteria, total scores for Alternatives 1, 4, and 5 are within a similar range of values.

6.2.10 Compliance with ARARs

Action-specific ARARs regulate technologies or activities associated with the implementation of the remedial action. Action-specific ARARs are typically technology- or activity-based requirements or limitations. Potential ARARs for the site include the soil and groundwater CULs provided by MTCA, as well as the non-numerical requirement LNAPL be removed to the extent necessary to mitigate the potential for migration. Alternative 2 does not satisfy these ARARs as they will not include removal or containment of site-related constituents. Alternative 3 will satisfy ARARs by improving groundwater conditions at the selected point of compliance to meet groundwater CULs; however, Alternative 3 does not include removal of LNAPL as it is based on physical containment of the LNAPL body. Alternatives 1, 4, and 5 satisfy ARARs as these alternatives are intended to remediate site soil and groundwater in accordance with MTCA and include removal and biological degradation of the LNAPL mass.

Section 7: Comparative Analysis of Alternatives

7.1 Comparative Analysis

Based on the analysis of alternatives above, the following comparative analysis and disproportionate cost analysis (Section 7.2) contribute to the identification of the recommended alternative. The five alternatives are compared as most favorable to least favorable as:

- Alternative 4 - Physical LNAPL Removal, Biosparge, MNA, and Targeted Excavation
- Alternative 5 – LTTR, Biosparge, MNA, and Targeted Excavation
- Alternative 1 - Physical LNAPL Removal, Focused Biosparge, MNA, and Targeted Excavation
- Alternative 3 - LNAPL Containment, Biosparge, MNA, and Targeted Excavation
- Alternative 2 - Institutional Controls and Environmental Covenants with Compliance Groundwater Monitoring

Alternative 4 – Physical LNAPL Removal is a proven and mature approach that is readily implementable with commonly available equipment. It also requires little specialized labor besides the installation of LNAPL removal wells, and its impact on site operations will be minimal. The frequency of LNAPL removal and other operational parameters will be adjusted to maintain efficiency over the duration of the remediation process (e.g., performing more frequent LNAPL removal in the summer months, adjusting removal frequency as LNAPL mass decreases). Using seasonal temperature change to maximize LNAPL recovery adds a sustainability element to the project as compared to electrical heating. While the treatment timeframe is longer than Alternative 5, Alternative 4 avoids the operational and implementability challenges and significant energy consumption and resulting carbon emissions that come with ERH.

Alternative 5 – LTTR using ERH is a technically advanced, proven, and mature approach that requires specialized equipment and the application of significant electrical power. Operation of ERH systems is challenging, but routinely achieves target temperatures and cleanup goals in conditions similar to those at the site. Operation is adaptable to target LNAPL removal in specific areas or enhance operation for variable timeframes based on performance. The equipment installation and operation are expensive and therefore, are only efficient when applied continuously without extended shutdowns that result in cooling. System efficiency declines as the timeframe needed for cleanup increases as high energy inputs continue while mass removal efficiencies decrease. High energy use is associated with higher carbon emissions and relatively lower sustainability.

Alternative 1 – Physical LNAPL Removal is a proven and mature approach that is readily implementable with commonly available equipment. It also requires little specialized labor besides the installation of LNAPL removal wells, and its impact on site operations will be minimal. The frequency of LNAPL removal and other operational parameters will be adjusted to maintain efficiency over the duration of the remediation process (e.g., performing more frequent LNAPL removal in the summer months, adjusting removal frequency as LNAPL mass decreases). Using seasonal temperature change to maximize LNAPL recovery adds a sustainability element to the project as compared to electrical heating. The treatment timeframe is longer than Alternative 4 due to relying on MNA and NSZD processes to remediate dissolved phase impacts in several areas rather than additional biosparging systems. The treatment timeframe is also longer than Alternative 5; however, Alternative 1 avoids the operational and implementability challenges and significant energy consumption and resulting carbon emissions that come with ERH.

Alternative 3 – Three-Sided Sheet Pile Wall provides adequate protection of both human health and the environment and contains the dissolved phase petroleum hydrocarbons eliminating the migration pathway to the river but does not accelerate the timeframe for cleanup over natural processes and leaves LNAPL in place behind the sheet pile wall. It is also the most challenging from a construction and implementability perspective due to the methods involved and the quality control needed to achieve certainty of remedy performance. Equipment used to install sheet pile walls have relatively higher environmental impact and safety concerns. Therefore, while protective, it is not preferred over other alternatives.

Alternative 2 – Institutional Controls and Environmental Covenants with Compliance Groundwater Monitoring could feasibly protect human health over the timeframe needed for natural processes to address site-related compounds, but do not actively protect applicable potential environmental receptors via applicable potential pathways over the long-term. Alternative 2 is the most sustainable protective alternative with the lowest emissions and overall impact to the environment.

7.2 Disproportionate Cost Analyses

Costs for the five alternatives are summarized below and presented in detail in Appendix D, Tables D1 through D5 with a summary in Table D6. Several components of the cost estimates, including planning, permitting, administration and reporting; biosparging; shallow berm excavation; and monitoring have similar cost estimates and expected timeframes. The LNAPL remedies have the most significant differences in cost to achieve similar outcomes.

Alternative	Total
Alternative 1 – Physical LNAPL Removal, Biosparge, MNA, and Targeted Excavation	$ 5,067,000
Alternative 2 - Institutional Controls and Environmental Covenants with Compliance Groundwater Monitoring	$1,420,000
Alternative 3 - LNAPL Containment, Biosparge, MNA, and Targeted Excavation	$6,682,000
Alternative 4 – Physical LNAPL Removal, Biosparge, MNA, and Targeted Excavation	$6,983,000
Alternative 5 - LTTR, Biosparge, MNA, and Targeted Excavation	$9,410,000

Alternatives 2 and 3 rely, in part, on the mitigation of the direct contact exposure pathway through institutional controls and reliance on groundwater monitoring to assess the natural processes that may affect some of the contaminant concentrations. Alternatives 1, 4, and 5 involve a variety of cleanup actions with LNAPL removal and biosparging or MNA as their central component. The primary difference between these three alternatives is how LNAPL will be remove from the subsurface. The three alternatives each propose to remove LNAPL to the maximum extent practicable, consistent with the requirements under MTCA. Alternatives 1 and 4 propose to remove LNAPL to the extent practicable under ambient conditions while Alternative 5 involves applying heat to reduce LNAPL viscosity, thereby enhancing recovery at the extraction points. Under Alternative 5, RELs are expected to be achieved in less than 5 years, whereas under Alternatives 1 and 4, RELs are expected to be achieved over a 10-year to 15-year (Alternative 4 if eastern LNAPL biosparging is implemented) period. At the end of the active remedy phase, work will transition to passive remediation through MNA and NSZD. Restoration timeframes under each of these three alternatives is estimated to be more than 30 years once active remediation has ceased.

Regarding the DCA, as stated in WAC 173-340-360(3)(e)(ii)(B), the most practicable permanent solution evaluated in the feasibility study shall be the baseline cleanup action alternative against which cleanup action alternatives will be compared. Alternative 1 fits this criterion. The permanency of alternatives is largely qualitative and is based on best professional judgment. To document the qualitative analysis, weighting factors are assigned for each of the six non-cost benefits criteria listed in WAC 173-340-360(3)(f) to represent the importance of each benefit criterion and are expressed as a percent. Weighting factors, as provided by Ecology in its 16 November 2021 memorandum to BNSF, for each non-cost criteria are summarized below.

- **Protectiveness.** A weighting factor of 30% is assigned based on its overarching importance relative to the ultimate goal of environmental cleanup and protection of human health and the environment.
- **Permanence.** A weighting factor of 20% is assigned in association with the need or lack thereof for further action in the future.
- **Long Term Effectiveness.** A weighting factor of 20% is assigned in association with a measure of certainty related to the robustness of the action, as well as confidence in the technology used for the protection of human health and the environment.
- **Short Term Risk.** A weighting factor of 10% is assigned because the majority of short-term risks can be managed through the use of best practices during process design and construction.
- **Ability to Implement.** A weighting factor of 10% is assigned because, although an important consideration, implementability is less associated with environmental concerns than with the above criteria.
- **Consideration of Public Concerns.** A weighting factor of 10% is assigned because the majority of public concern issues are incorporated in the protectiveness, permanence, and long-term effectiveness criteria.

The overall ranking (i.e., the benefit) of each alternative was compared to its cost to provide a benefit/cost ratio. Based on the benefit/cost ratio evaluation, presented in Table 7, Alternative 2 is the best alternative for the site. However, as Alternative 2 relies on the mitigation of the direct contact exposure pathway through institutional controls and does not actively remove the LNAPL to the maximum extent practicable, this alternative is eliminated from consideration. Alternatives 1 and 4 have similar benefit/cost ratios. As Alternative 4 ranks higher in its total weighted benefit, Alternative 4 is a better alternative for the site.

Section 8: Summary of Recommended Alternative

Alternative 4, which involves periodic physical LNAPL removal within the LNAPL body and targeted remediation for other site areas, is the recommended alternative. Below is a summary of the recommended remedial alternative and its key advantages.

Alternative 4 includes the following components:

- Eastern LNAPL area: Install approximately 15 LNAPL recovery wells within the LNAPL body. LNAPL will be removed periodically from these 15 wells plus three existing OHM wells by high-vacuum extraction or other methods depending on the results of the LDRM and field implementation testing. Adequate time will be allowed for LNAPL to recharge prior to subsequent extraction events. Once LNAPL removal has met the RELs, monitored NSZD will be assessed for a 3-year period to confirm residual hydrocarbons will continue to degrade. Biosparging may be implemented as necessary to enhance biological degradation and address dissolved phase DRO and ORO if present from residual LNAPL.

- Western LNAPL area: Install 11 biosparge wells in the western LNAPL area to increase *in situ* degradation rates. Implement biosparging until objectives for active remediation have been met. Biosparge wells will be installed to depths ranging from approximately 20 to 40 feet bgs (shallow) and 60 feet bgs (deep) to address dissolved-phase and LNAPL impacts at varying depths. Once LNAPL RELs have been achieved in the western LNAPL area, monitored NSZD will be implemented for a 3-year period to confirm residual hydrocarbons will continue to degrade.

- Groundwater impacts (multiple areas): Implement biosparging if needed until objectives for active remediation (sustained aerobic groundwater conditions) have been met. Install 65 biosparge wells, as needed, around the mainline tracks area, beneath the former Engine House, and at the southern end of the eastern LNAPL removal area, to depths ranging from approximately 20 to 65 feet bgs to address dissolved-phase impacts at varying depths; in some areas, paired shallow and deep wells will be installed. Once biosparging operations have met their RELs, active remediation will be discontinued. MNA will then be implemented for a 3-year period to confirm remaining dissolved phase hydrocarbon concentrations will continue to decrease. Groundwater samples will be analyzed for DRO, ORO, and natural attenuation parameters.

- Compliance groundwater monitoring: Select wells will be monitored for DRO, ORO, and other water quality parameters following completion of the MNA and monitored NSZD programs. Compliance groundwater monitoring will continue until site-related constituents in groundwater are at or below their respective CULs, or until otherwise directed by Ecology.

- Shallow soil impacts under berm area: A small area with shallow petroleum hydrocarbon-impacted soil is present below the northern side of the berm south of the former Power House. Petroleum hydrocarbon-impacted soil from this area will be excavated and disposed of offsite. The excavation process will include removing and stockpiling soil from the upper 6 feet for testing for potential reuse as backfill material. The impacted soils between 6 and 9 feet bgs will then be excavated, stockpiled separately, and characterized for disposal at an offsite licensed Subtitle D landfill facility as a non-hazardous waste.

The selected alternative is protective of potential receptors and considers overall environmental impact and sustainability, while avoiding implementation challenges, performance uncertainty, and short-term impacts posed by Alternative 5. While LNAPL removal at ambient temperature results in a longer remediation timeframe, the estimated restoration timeframe is similar to Alternative 5 and recovers neither more nor less of the recoverable LNAPL. Because the LNAPL is not migrating towards the river, the additional time anticipated for physical removal does not represent an increased risk to the environment. As the site's use as an active railyard is not expected to change for the foreseeable future, the remedy will not result in impacts to current or future use of the site, and ICs and ECs will be easily maintained.

References

AECOM. 2016. Cultural Resources Management Plan.

American Petroleum Institute (API). 2007a. LNAPL Distribution and Recovery Model (LDRM). Volume 1: Distribution and Recovery of Petroleum Hydrocarbon Liquids in Porous Media. API Publication 4760, January 2007.

American Petroleum Institute (API). 2007b. LNAPL Distribution and Recovery Model (LDRM) Volume 2: User and Parameter Selection Guide. API Publication 4760. January 2007.

Interstate Technology Regulatory Council (ITRC). 2018. LNAPL-3: LNAPL Site Management: LLCSM Evolution, Decision Process, and Remediation Technologies, March 2018.

Jacobs Engineering. 2018. Geoarchaeological Monitoring of Additional Remedial Investigations.

Kennedy/Jenks Consultants. 2020. Uplands Remedial Investigation Report BNSF Wishram Railyard (Ecology Site Name BNSF Track Switching Facility) Wishram, Washington. Prepared by Kennedy/Jenks Consultants for BNSF Railway Company. 20 October 2020.

The Risk Assessment Information System. Ecological Benchmark Tool for Chemicals. https://rais.ornl.gov/tools/eco_search.php?select=chem. Accessed November 2021.

Washington State Department of Ecology. 2005. Guidance on Remediation of Petroleum-Contaminated Ground Water by Natural Attenuation. Washington State Department of Ecology Toxics Cleanup Program. Publication No. 05-09-091 (Version 1.0). July 2005.

Washington State Department of Ecology. 2007. Model Toxics Control Act Statute and Regulation. Washington State Department of Ecology. Publication No. 94-06. Revised November 2007.

Washington State Department of Ecology. 2021a. Cleanup Levels and Risk Calculation (CLARC) Tables. July 2021. https://fortress.wa.gov/ecy/ezshare/tcp/CLARC/CLARC_Master.xlsx

Washington State Department of Ecology. 2021b. Implementation Memorandum No. 23: Concentrations of Gasoline and Diesel Range Organics Predicted to be Protective of Aquatic Receptors in Surface Waters. Publication No. 19-09-043. 25 August 2021.

Washington State Department of Ecology. 2022. Natural Background Groundwater Arsenic Concentrations in Washington State Study Results. Publication 14-09-044. January 2022.

Tables

SUMMARY OF CONSTITUENTS OF CONCERN (COCs) AND PROPOSED CLEANUP LEVELS (CULs)
BNSF Wishram Railyard, Wishram, Washington

Media / COCs	Units	Proposed CUL	Proposed CUL Source
Groundwater			
Diesel-Range Organics	µg/L	500	Method A
Oil-Range Organics	µg/L	500	Method A
Total TPH-Dx	µg/L	500	Method A
Arsenic, total	µg/L	5	Method A, Background
Barium, total	µg/L	2,000	Maximum Contaminant Level (WA State and Federal)
Iron, dissolved	µg/L	11,000	Method B Noncancer
Manganese, dissolved	µg/L	750	Method B Noncancer
Surface Water			
Diesel-Range Organics	µg/L	500 / 3,000	Method A / Environmental effects-based concentration
Oil-Range Organics	µg/L	500 / 3,000	Method A / Environmental effects-based concentration
Total TPH-Dx	µg/L	500 / 3,000	Method A / Environmental effects-based concentration
Arsenic, total	µg/L	5	Method A, Background
Lead, total	µg/L	2.5	Aquatic Life Water Quality Criteria (173-201A / CWA §304)
Iron, dissolved	µg/L	1,000	Aquatic Life Water Quality Criteria (CWA §304)
Manganese, dissolved	µg/L	50	Human Health Water Quality Criteria (CWA §304)
Soil - Vadose Zone			
Diesel-Range Organics	mg/kg	2,000	Method A
Oil-Range Organics	mg/kg	2,000	Method A
Total TPH-Dx	mg/kg	2,000	Method A
Soil - Saturated Zone			
Gasoline-Range Organics	mg/kg	30	Method A
Diesel-Range Organics	mg/kg	2,000	Method A
Oil-Range Organics	mg/kg	2,000	Method A
Total TPH-Dx	mg/kg	2,000	Method A

Notes:

COC = Constituents of concern

CUL = Cleanup level. Refer to Appendix B to the Draft Feasibility Study Report for more information.

µg/L = micrograms per liter

mg/kg = milligrams per liter

Total TPH-Dx = Total TPH-Dx concentrations calculated by summing diesel-range organics (DRO) and oil-range organics (ORO) concentrations.

Cleanup Levels:

Groundwater: Cleanup level values based on Model Toxics Control Act (MTCA) Method B values (B Cancer or B Non Cancer) and MTCA Method A values for groundwater (Table 720-1) based on Washington State Administrative Code (WAC) 173-340-720 from Cleanup Levels and Risk Calculation (CLARC) tables (Accessed February 2021), and Washington State (246-290 WAC) and Federal (40 CFR 141) Maximum Contaminant Levels (MCLs).

Surface Water: Cleanup level values based on Ecology MTCA Method B values (B Cancer or B Non Cancer), MTCA Method A values and other applicable, relevant, and appropriate requirements (ARARs) under applicable state (173-201A-240 WAC) and federal laws [Section 304 of the Clean Water Act (CWA); 40 CFR Subpart D 131.45] for surface water based on WAC 173-340-730 from CLARC tables (Accessed February 2021).

Environmental Effects-Based Concentrations, from Concentrations of Gasoline and Diesel Range Organics Predicted to be Protective of Aquatic Receptors in Surface Waters, Implementation Memorandum No. 23 (Ecology, 25 August 2021).

Soil: Cleanup level values based on Ecology MTCA Method C values (Cancer and Noncancer) and MTCA Method A (Table 745-1) values for soil based on WAC 173-340-745 and 3-Phase Model Soil Protective of Groundwater Vadose (Eq. 747-1) and 3-Phase Model Soil Protective of Groundwater to Surface Water Vadose Fresh Water (Eq. 747-1). from CLARC tables (Accessed February 2021).

TABLE 2

SUMMARY OF REMEDIAL AREAS AND VOLUMES
BNSF Wishram Railyard

Action	Media Type	Impacted Area (sf)	Depth Interval of Petroleum Impacts (feet bgs)	Overexcavate to 10 feet bgs (cy)	Disposal Volume (cy)
Shallow Berm Soil Excavation	Soil	1,500	6 to 9	560	170

Site Area	Media Type	Impacted Area (sf)
Engine House	Dissolved-Phase Groundwater	24,000
North and South of Mainline Tracks	Dissolved-Phase Groundwater	90,000

Area	Media Type	Impacted Area (sf)	Estimated Soil Volume (cf)	Total Pore Volume (gal)	LNAPL in Pore Volume (gal)	Recoverable LNAPL by Physical Removal (gal)
LNAPL Area (East)	LNAPL	17,000	205,700	615,500	203,200	56,900
LNAPL Area (West) Shallow	LNAPL	2,600	2,600	7,800	1,400	10
LNAPL Area (West) Submerged	LNAPL	2,600	5,200	15,600	2,700	20

Notes:

sf = square feet
bgs - below ground surface
cf = cubic feet
cy = cubic yards
gal = gallons
LNAPL = light non-aqueous phase liquid

Volume of total fluids based on total porosity estimate of 40%.

Volume of LNAPL based on estimate of initial LNAPL saturation in soil cores of approximately 33% in eastern LNAPL area (geomean of 4 results) and 17% in western LNAPL areas (OHM-4 core).

Volume of Recoverable LNAPL by physical means from geomean of residual core plug saturations for the eastern LNAPL area (28% of pore volume) and the OHM-4 core result (0.6% of pore volume) in the western LNAPL area.

GENERAL RESPONSE ACTIONS AND REMEDIAL TECHNOLOGIES CONSIDERED
BNSF Wishram Railyard

Soil					
Shallow Soil Impacts Occurring as Residual Diesel Fuel and Oil (Ground Surface to Water Table)					
Summary of Shallow Soil Conditions:	Suspected legacy sources of petroleum hydrocarbons have been decommissioned and removed from the site and impacted soil has been removed as part of interim remedial measure (IRM) activities. Where implemented, IRMs successfully removed petroleum hydrocarbons down to the water table or bedrock such that soil samples collected from all but 11 of 145 soil borings/excavation confirmation sampling locations in site areas in the unsaturated zone do not contain residual petroleum hydrocarbons above MTCA Method A cleanup levels (CULs). A limited area of residual hydrocarbons is present near the berm (based on one sample), but does not significantly contribute to the overall presence of dissolved phase hydrocarbons in other areas of the site. Horizontal migration of vadose zone soil impacts is not expected because lateral gradients or geologic features that would result in horizontal movement are not present.				
General Response Action	**Remedial Technology**	**Process Option**	**Description**	**Retained for Further Screening (Yes / No)**	**Comments**
No Action	No Action	No Action	No remedial action.	No	Retained for comparison.
Natural Source Zone Depletion (NSZD)	Natural Source Zone Depletion (NSZD)	Natural Source Zone Depletion (NSZD)	Petroleum hydrocarbon constituents and/or LNAPL are naturally depleted over time by volatilization and degradation.	**Yes**	Applicable for treatment of petroleum-impacted soil through natural biological and abiotic processes.
Containment	Barrier	Encapsulation	Installation of a physical subsurface barrier around the source area to control or impede petroleum hydrocarbon and/or LNAPL migration and installing a low permeable cover.	**Yes**	Potentially applicable to encapsulate and isolate impacted soils, but horizontal migration of vadose zone impacts is not expected.
Removal	Excavation	Excavation, Transportation, and Disposal	Residual petroleum hydrocarbons and/or LNAPL physically removed and treated or disposed.	**Yes**	Applicable for removal of impacted soil, would address source area but may not fully address impacts to groundwater.
	Thermal Extraction	Low Temperature Thermal Heating - Electrical Resistance Heating (ERH)	Electrical energy is used to heat soil using electrical resistance between electrode rods. Heating reduces the viscosity and interfacial tension of LNAPL for enhanced hydraulic recovery. No locations are heated above 100 °C to avoid vaporization of water and target compounds.	**Yes**	Potentially applicable but if implemented in vadose zone only, minimal vadose zone thickness will result in significant heat loss to the surface.
		High Temperature Thermal Heating - Thermal Conductive Heating (TCH)	Electrical energy is used to heat soil using heater elements and conductive heating to vaporize water and volatile petroleum hydrocarbon and/or LNAPL constituents and reduce the viscosity and interfacial tension of LNAPL for enhanced hydraulic recovery. At temperatures much greater than 100 °C larger molecule hydrocarbons are vaporized and mobilized. Vapor phase is recovered through vapor extraction.	**Yes**	Potentially applicable but if implemented in vadose zone only, minimal vadose zone thickness will result in significant heat loss to the surface.
		Radio-Frequency Heating (RFH)	Electromagnetic energy is used to heat soil to reduce the viscosity and interfacial tension of LNAPL for enhanced hydraulic recovery. Vapors also recovered via vapor extraction.	**Yes**	Potentially applicable but if implemented in vadose zone only, minimal vadose zone thickness will result in significant heat loss to the surface. May interfere with communications equipment necessary for railroad operations.
In-Situ Treatment	Physical/Chemical	In-Situ Soil Mixing (Solidification/Chemical Destruction)	Chemical reagents are mixed with the soil/LNAPL using an excavator or large-diameter auger. Residual petroleum hydrocarbons and/or LNAPL is physically bound within the stabilized mass or chemically treated/destroyed.	**Yes**	Applicable for stabilization or treatment of vadose zone soil.
	Thermal Destruction	In-Situ Smoldering Technology: Self-Sustaining Treatment for Active Remediation (STAR)	Controlled combustion reaction, destroys LNAPL embedded in soil while simultaneously generating enough energy to propagate through the subsurface. Vapor is recovered via vapor extraction.	**Yes**	Potentially applicable but if implemented in vadose zone only, minimal vadose zone thickness will result in significant heat loss to the surface. LNAPL is not present in the vadose zone making ignition of residual hydrocarbons impractical.
	Biological	Bioventing	Injecting air or oxygen to existing soil microorganisms in the vadose zone to stimulate natural in situ biodegradation of contaminants.	No	Pilot test results indicate vadose zone is aerobic.
		Phytoremediation	Using plants and tress (e.g., Poplar) to remove and or chemically destroy/alter LNAPL and residual petroleum hydrocarbons in the subsurface.	No	LNAPL body is in the middle of an active railyard.

GENERAL RESPONSE ACTIONS AND REMEDIAL TECHNOLOGIES CONSIDERED
BNSF Wishram Railyard

Groundwater

Groundwater Impacts Occurring as LNAPL, Submerged LNAPL, and dissolved-phase diesel fuel and oil

LNAPL/Submerged LNAPL Remedial Alternatives

Summary of LNAPL/Submerged LNAPL Conditions:	LNAPL has been observed primarily near the southern end of the site near the former underground oil pipelines and the former Power House. Mobility and migration evaluation in soil cores indicates LNAPL is classified as mobile as defined by ITRC. The formation of Lake Celilo caused a rapid and permanent increase in groundwater elevation, submerging the majority of LNAPL in the subsurface and increasing the pore entry pressure of the submerged LNAPL, thereby minimizing or eliminating the potential for the submerged viscous LNAPL to migrate horizontally. The specific gravity of the LNAPL (0.96) and observation of LNAPL floating on top of the water table indicate that the submerged LNAPL does not exhibit the potential to migrate vertically downward into the bedrock. LNAPL properties and investigation data collected over time (including the absence of LNAPL in river berm monitoring wells) indicate LNAPL is not migrating laterally beneath the site.

General Response Action	Remedial Technology	Process Option	Description	Retained for Further Screening (Yes / No)	Comments
No Action	No Action	No Action	No remedial action.	No	Retained for comparison.
Natural Source Zone Depletion (NSZD)	Natural Source Zone Depletion (NSZD)	Natural Source Zone Depletion (NSZD)	LNAPL constituents are naturally depleted from the LNAPL body over time by volatilization, dissolution, and degradation.	**Yes**	Applicable for treatment of LNAPL through natural biological and abiotic processes.
Containment	Barriers	Physical Containment	Installation of a physical subsurface barrier around the source area to prevent or impede LNAPL migration.	**Yes**	Applicable to encapsulate and isolate the LNAPL body.
		Hydraulic Containment	A local groundwater flow gradient is created (such as by pumping) to prevent or impede LNAPL migration.	**Yes**	Applicable to encapsulate and isolate the LNAPL body.
Removal	Excavation	Backhoe, Excavators, Loaders, Dozers, Large Diameter Auger	LNAPL body physically removed using excavator or large diameter augers and treated or disposed.	**Yes**	NAPL body can be removed using large-diameter augers.
	Extraction	High Vacuum Extraction	A vacuum is applied to physically remove LNAPL.	**Yes**	Applicable for mass removal from saturated zone.
		Conventional/Passive Skimming	LNAPL hydraulically removed from top of groundwater column within a well using belt skimmers.	**Yes**	Applicable for mass removal from saturated zone.
		Vapor Enhanced Skimming	LNAPL hydraulically removed from top of groundwater column within a well using belt skimmers. Movement of LNAPL towards skimming wells induced by applying a vacuum to the wellhead to create a pressure gradient.	**Yes**	Applicable for mass removal from saturated zone.
		Multi-Phase Extraction (MPE)/Total Fluids Extraction (TFE)	High vacuum extraction applied to surface of fluid column, or pumps within the liquid column, to remove LNAPL and water, and induce LNAPL movement towards extraction well by creating a pressure gradient.	**Yes**	Applicable for mass removal from saturated zone.
	Thermal Extraction	Low Temperature Thermal Heating - Electrical Resistance Heating (ERH)	Electrical energy is used to heat the saturated subsurface using electrical resistance between electrode rods. Heating reduces the viscosity and interfacial tension of LNAPL for enhanced hydraulic recovery. No locations are heated above 100 °C to avoid vaporization of water and target compounds.	**Yes**	Applicable to reduce LNAPL viscosity and aid in removal.
		High Temperature Thermal Heating - Thermal Conductive Heating (TCH)	Electrical energy is used to heat the subsurface using heater elements and conductive heating to vaporize water and volatile LNAPL constituents and reduce the viscosity and interfacial tension of LNAPL for enhanced hydraulic recovery. At temperatures much greater than 100 °C larger molecule hydrocarbons are vaporized and mobilized. Vapor phase is recovered through vapor extraction.	**Yes**	Applicable for mass removal from saturated zone via liquid and vapor phase.
		Hot Water Flooding	Injection of hot water into the LNAPL body to reduce interfacial tension and viscosity of the LNAPL, enhancing LNAPL mobility. LNAPL is removed through fluid extraction.	**Yes**	Applicable to reduce LNAPL viscosity and aid in removal.
		Steam Enhanced Extraction	Injection of steam into the subsurface to heat soil/LNAPL to reduce the viscosity and interfacial tension of LNAPL. LNAPL, condensed fluids, and groundwater removed using total fluids extraction. Steam is recovered through vapor extraction and re-heated/re-used.	**Yes**	Applicable to reduce LNAPL viscosity and aid in removal.
		Radio-Frequency Heating (RFH)	Electromagnetic energy is used to heat soil to reduce the viscosity and interfacial tension of LNAPL for enhanced hydraulic recovery. Vapors also recovered via vapor extraction.	**Yes**	Potentially applicable to reduce LNAPL viscosity and aid in removal. RF heating is less easily controlled than other options. Localized temperatures above 100° C can cause vaporization of water and hydrocarbons. May interfere with communications equipment necessary for railroad operations.
In-Situ Treatment	Physical/Chemical	Air Sparging	Air or oxygen is injected into the saturated zone to induce mobilization of the LNAPL. Mobile LNAPL removed through fluids extraction. Addition of air/oxygen also increases biological activity of the indigenous microorganisms, increasing LNAPL degradation rate.	No	Not expected to sufficiently mobilize high viscosity LNAPL.
		Surfactant / Cosolvent Flushing	Injection of a solvent or surfactant to increase LNAPL solubility and LNAPL mobility. The LNAPL and dissolved-phase petroleum hydrocarbons are removed through fluid extraction.	No	Studies indicate option does not effectively remove high viscosity LNAPL.
		In-Situ Chemical Oxidation (ISCO)	LNAPL is depleted/destroyed through the addition of a chemical oxidant into the LNAPL zone.	**Yes**	Potentially applicable but volume of oxidant required to deplete LNAPL body is prohibitive.
		In-situ Geochemical Stabilization	LNAPL is depleted/destroyed through the addition of a chemical oxidant into the LNAPL zone. Geochemical reaction between oxidant and soils results in mineralization around LNAPL globules to treat and encapsulate in place.	**Yes**	Potentially applicable but volume of oxidant required to deplete LNAPL body and create mineralization is prohibitive.
		In-Situ Soil Mixing (Solidification/Chemical Destruction)	Chemical reagents are mixed with the soil/LNAPL using an excavator or large-diameter auger. LNAPL is physically bound within the stabilized mass or chemically treated/destroyed.	No	Depth of LNAPL body is prohibitive for in-situ mixing.
	Thermal Destruction	In-Situ Smoldering Technology: Self-Sustaining Treatment for Active Remediation (STAR)	Controlled combustion reaction, destroys NAPL embedded in soil while simultaneously generating enough energy to propagate through the subsurface.	**Yes**	Applicable for destroying LNAPL but success depends on effective delivery of heat and air to ignite and maintain combustion and LNAPL connectivity in the subsurface to pass combustion through the target area.
	Biological	Biosparging	Air or oxygen is injected into the saturated zone to increase the biological activity of the indigenous microorganisms, increasing LNAPL degradation rate.	**Yes**	Applicable for biological treatment of petroleum-impacted groundwater and LNAPL.
		Enhanced Bioremediation	Nutrients are injected into subsurface to stimulate biological activity and increase rate of dissolution, thereby increasing degradation rate of dissolved constituents.	**Yes**	Can be combined with biosparging for aerobic degradation, or nutrient injection to enhance anaerobic degradation.
Ex-Situ Treatment	Aboveground Treatment	Aboveground Vapor Treatment	Required to control off-gas of volatile components of TPH. Design will be specific to the remedial alternative selected.	**Yes**	Applicable for site conditions.
		Oil/Water Separation	LNAPL and groundwater are physically separated. Water can be treated and reused and discharged. Oil can be reused, recycled or disposed.	**Yes**	Applicable for site conditions.

GENERAL RESPONSE ACTIONS AND REMEDIAL TECHNOLOGIES CONSIDERED
BNSF Wishram Railyard

Groundwater					
Groundwater Impacts Occurring as LNAPL, Submerged LNAPL, and dissolved-phase diesel fuel and oil					
Dissolved Phase Petroleum Hydrocarbon Remedial Alternatives					
Summary of Dissolved Phase Groundwater Conditions:	Dissolved phase DRO and ORO concentrations reported above their CULs typically occur in the southern and central portions of the site in the wells near the former oil pipelines, western portion of the berm, and the former Engine House, and in wells west of the Maintenance Shop.				
General Response Action	**Remedial Technology**	**Process Option**	**Description**	**Retained for Further Screening (Yes / No)**	**Comments**
No Action	No Action	No Action	No remedial action.	No	Retained for comparison.
Monitored Natural Attenuation (MNA)	Monitored Natural Attenuation (MNA)	Monitored Natural Attenuation (MNA)	Petroleum hydrocarbon constituents are naturally depleted from the saturated zone over time by volatilization, dissolution, and degradation.	**Yes**	Applicable for treatment of petroleum-impacted groundwater through natural biological and abiotic processes.
Containment	Barrier	Physical Containment	Subsurface barrier is constructed to prevent or impede groundwater migration.	**Yes**	Applicable to encapsulate and isolate dissolved phase petroleum hydrocarbons.
Removal	Extraction	Groundwater Extraction/Hydraulic Containment	Groundwater and dissolved-phase petroleum hydrocarbons are extracted from subsurface for aboveground treatment.	**Yes**	Applicable for site conditions.
		Surfactant Pump & Treat	Batch extractions/injections (recirculation) of surfactant for LNAPL/dissolved phase recovery, treatment with granular activated carbon (GAC) and discharged to sanitary sewer.	No	Injection of chemicals into subsurface near Columbia River is a significant concern for regulatory agency and third-party stakeholders.
In-Situ Treatment	Physical/Chemical	In-Situ Chemical Oxidation (ISCO)	Adsorbed and dissolved-phase petroleum hydrocarbons are depleted by injecting chemical oxidant (e.g., peroxide, ozone) into groundwater.	**Yes**	Applicable for destruction or degradation of petroleum hydrocarbons
		Nanoscale Technology Injection	Targeted emplacement of material (i.e., zero-valent iron) in the subsurface that binds and destroys dissolved-phase petroleum hydrocarbons.	No	Physical contact with petroleum required. Injection across remediation zone difficult to manage; Material costs prohibitive. Variable groundwater flux between site and river may render this option ineffective.
		Permeable Reactive Barrier (PRB)	Subsurface emplacement of reactive materials (e.g., activated carbon) through which groundwater will move through and exit as treated water.	No	Technically impracticable due to variable groundwater flux between site and river.
		Air Sparging/Soil Vapor Extraction	Air injected into groundwater to remove residual and dissolved-phase petroleum hydrocarbons from the saturated interval, and removed through vapor extraction. AS/SVE will also enhance microbial degradation of the adsorbed and dissolved phase petroleum hydrocarbons. Vapors treated aboveground then discharged to air.	**Yes**	Applicable to volatilize dissolved phase petroleum hydrocarbons.
	Biological	Biosparging	Air or oxygen is injected into the saturated zone to enhance microbial degradation of the adsorbed and dissolved phase petroleum hydrocarbons.	**Yes**	Applicable for biological treatment of petroleum-impacted groundwater.
		Enhanced Bioremediation	Nutrients are injected into subsurface to stimulate biological activity and increase petroleum hydrocarbon degradation rate.	No	Natural system is in oxygenated state.
		Phytoremediation	Using plants and trees (e.g., Poplar) to remove and or chemically destroy/alter LNAPL and residual petroleum hydrocarbons in the subsurface.	No	Treatment area is in the middle of an active railyard.
Ex-Situ Treatment	Physical/Chemical	Aboveground Fluids Treatment	Fluids extracted from wells are treated using GAC, Ozone or other technology applicable to petroleum hydrocarbons, then discharge to the local wastewater treatment plant or to the river under NPDES permit.	**Yes**	Applicable for site conditions.

TABLE 4

DETAILED SCREENING OF REMEDIAL TECHNOLOGIES
BNSF Wishram Railyard

Soil					
Shallow Soil Impacts Occurring as Residual Diesel Fuel and Oil (Ground Surface to Water Table)					
Summary of Shallow Soil Conditions:	Suspected legacy sources of petroleum hydrocarbons have been decommissioned and removed from the site and impacted soil has been removed as part of interim remedial measure (IRM) activities. Where implemented, IRMs successfully removed petroleum hydrocarbons down to the water table or bedrock such that 134 of the 145 soil samples collected from borings/excavation confirmation locations in the unsaturated zone do not contain residual petroleum hydrocarbons above MTCA Method A cleanup levels (CULs). A limited area of residual hydrocarbons is present near the berm (based on one sample), but does not significantly contribute to the overall presence of dissolved phase hydrocarbons in other areas of the site. Horizontal migration of vadose zone soil impacts is not expected because constituents are adsorbed to soil and above the shallow groundwater table.				
General Response Action	**Remedial Technology**	**Process Option**	**Effectiveness**	**Implementability**	**Retained (Yes / No)**
Natural Source Zone Depletion (NSZD)	NSZD	NSZD	Petroleum hydrocarbon constituents and/or LNAPL are readily degraded through natural processes, particularly when sufficient oxygen is present. The quantity and extent of petroleum hydrocarbon sources affects the timeline of degradation and the overall effectiveness of NSZD within a defined timeframe. Soil gas measurements show oxygen at near-atmospheric concentrations with little to no carbon dioxide, indicating conditions are sufficient to sustain aerobic degradation.	Limited change in existing monitoring infrastructure required. Respirometry testing to track progress is easily performed.	**Yes**
Containment	Barrier	Encapsulation	Based on the limited nature and extent of hydrocarbons in soil between ground surface and the water table, encapsulation will not have a measurable beneficial effect on soil and groundwater conditions or the potential for exposure.	Soil containing residual hydrocarbons in the unsaturated zone is not widespread. Encapsulation of the limited area of residual hydrocarbons identified near the berm is possible but is in an area of the site where the costs and effort of long term operation, monitoring, and maintenance of an encapsulation remedy are not favorable compared to removal.	No
Removal	Excavation	Excavation, Transportation, and Disposal	Following confirmation of the extent of hydrocarbons near the berm, physical removal by excavation would effectively address the impact.	Excavation of a limited quantity of soil near the berm area requires a short timeframe and limited effort and cost. Activities would be coordinated with Yakama Nation to address potential cultural resources. Excavation of soil near the berm is implementable.	**Yes**
	Thermal Extraction	Low Temperature Thermal Heating - Electrical Resistance Heating (ERH)	There is a limited nature and extent of hydrocarbons in soil between ground surface and the water table. The limited residual hydrocarbons in unsaturated soil are not significantly collocated with saturated zone LNAPL targeted by low temperature heating. Based on the nature and extent of hydrocarbons in soil between ground surface and the water table, low temperature heating is not an effective approach to remove isolated and low concentrations of shallow residual hydrocarbons in the unsaturated zone.	Temperatures below the boiling point of water would not be suitable to remove the limited residual hydrocarbons in the unsaturated zone. High energy use, low soil moisture content, and heat losses to the surface and the isolated nature of residual hydrocarbons in unsaturated soil make implementation of low temperature heating for the unsaturated zone impracticable.	No
		High Temperature Thermal Heating - Thermal Conductive Heating (TCH)	There is a limited nature and extent of hydrocarbons in soil between ground surface and the water table. The limited residual hydrocarbons in unsaturated soil are not significantly collocated with saturated zone LNAPL targeted for remediation. Based on the nature and extent of hydrocarbons in soil between ground surface and the water table, high temperature heating is not an effective approach to remove isolated and low concentrations of shallow residual hydrocarbons in the unsaturated zone.	High energy use, low soil moisture content, and heat losses to the surface and the isolated nature of residual hydrocarbons in unsaturated soil make implementation of high temperature heating for the unsaturated zone impracticable.	No
		Radio-Frequency Heating (RFH)	There is a limited nature and extent of hydrocarbons in soil between ground surface and the water table. The limited residual hydrocarbons in unsaturated soil are not significantly collocated with saturated zone LNAPL targeted for remediation. Based on the nature and extent of hydrocarbons in soil between ground surface and the water table, radio-frequency heating is not an effective approach to remove isolated and low concentrations of shallow residual hydrocarbons in the unsaturated zone.	High energy use, low soil moisture content, and heat losses to the surface and the isolated nature of residual hydrocarbons in unsaturated soil make implementation of radio frequency heating for the unsaturated zone impracticable.	No
		Steam Enhanced Extraction	There is a limited nature and extent of hydrocarbons in soil between ground surface and the water table. The limited residual hydrocarbons in unsaturated soil are not significantly collocated with saturated zone LNAPL targeted for remediation. Based on the nature and extent of hydrocarbons in soil between ground surface and the water table, steam extraction is not an effective approach to remove isolated and low concentrations of shallow residual hydrocarbons in the unsaturated zone.	The potential for high temperature steam and volatilized constituents of concern migrating to the surface water body and condensing there creates an unacceptable risk.	No
In-Situ Treatment	Physical/Chemical	In-Situ Soil Mixing (Solidification/Stabilization/ Chemical Destruction)	There is a limited nature and extent of hydrocarbons in soil between ground surface and the water table. Stabilization with Portland cement or destruction with chemical oxidants mixed into the soils would provide additional protection from constituents of concern leaching to groundwater, but may not increase protection to site workers if soils are excavated in the future.	Mixing of soils in the area of the berm would introduce Portland cement and/or chemical oxidants into the subsurface in close proximity to the Columbia River, resulting in potentially unacceptable pH and groundwater chemistry conditions adjacent to the river. Mix designs using chemical oxidants without Portland cement could destabilize the berm and increase the risk for berm failure making this alternative unacceptable.	No
	Thermal Destruction	In-Situ Smoldering Technology: Self-Sustaining Treatment for Active Remediation (STAR)	There is a limited nature and extent of hydrocarbons in soil between ground surface and the water table. Limited residual hydrocarbons in unsaturated soil are not collocated with saturated zone LNAPL targeted for remediation. STAR is not an effective approach to combust isolated and low (residual) concentrations of hydrocarbons in the unsaturated zone because smoldering would not be sustained.	Insufficient fuel and energy is available in the isolated residual hydrocarbons in unsaturated soil. Implementation of STAR for the unsaturated zone is not possible.	No

DETAILED SCREENING OF REMEDIAL TECHNOLOGIES
BNSF Wishram Railyard

Groundwater					
Groundwater Impacts Occurring as LNAPL, Submerged LNAPL, and Dissolved-Phase Diesel Fuel and Oil					
LNAPL/Submerged LNAPL Remedial Alternatives					
Summary of LNAPL/Submerged LNAPL Conditions:	LNAPL has been observed primarily near the southern end of the site near the former underground oil pipelines and the former Power House. Mobility and migration evaluation in soil cores indicates LNAPL is classified as pooled (present at saturations above residual). The formation of Lake Celilo caused a rapid and permanent increase in groundwater elevation, submerging the LNAPL below the water table. The increased pore entry pressure of the submerged LNAPL minimizes the potential for the submerged viscous LNAPL to migrate horizontally or vertically without induced forces. The specific gravity of the LNAPL (0.96) and observation of LNAPL in the vicinity of the water table indicate that the submerged LNAPL does not exhibit the potential to migrate vertically downward into the bedrock without induced forces. LNAPL properties and investigation data collected over time (including the absence of LNAPL in river berm monitoring wells) indicate LNAPL is not migrating laterally beneath the site.				
General Response Action	**Remedial Technology**	**Remedial Alternative**	**Effectiveness**	**Implementability**	**Retained (Yes / No)**
Natural Source Zone Depletion (NSZD)	NSZD	NSZD	LNAPL is readily degraded through natural processes, particularly when sufficient oxygen is present. The quantity and extent of LNAPL affects the timeline of degradation and the overall effectiveness of NSZD within a defined timeframe. Carbon trap sampling estimates NSZD rates between 350 and 6,000 gallons/acre/year in the vicinity of the submerged LNAPL body, indicating NSZD would be an effective technical approach.	Limited change in existing monitoring infrastructure required. Respirometry testing to track progress is easily performed and compatible with expected long-term groundwater monitoring program.	**Yes**
Containment	Containment	Physical Containment	No active treatment of source area. Without removal, LNAPL would remain for and be allowed to naturally degrade (NSZD). Timeframe for LNAPL degradation would potentially be longer than the no action alternative as inflow of oxygenated groundwater from the river would be eliminated by the barrier. Based on LNAPL properties and hydrogeologic conditions indicating LNAPL migration is unlikely, a containment barrier would effectively separate LNAPL from potential downgradient receptors, but also would not significantly change the potential for LNAPL migration. Dissolved phase containment considerations are described below.	Installation of physical containment using a sealed sheet pile or slurry wall would require complex and difficult construction methods. Construction is further complicated by the variable bedrock surface. Groundwater monitoring expected in perpetuity if LNAPL is not removed. However, a physical barrier is implementable.	**Yes**
		Hydraulic Containment	The variable hydrogeologic environment (losing vs. gaining stream) and location relative to the Columbia River makes hydraulic containment impracticable. Hydraulic containment via groundwater extraction in proximity to the Columbia River requires significant water extraction rates and involves significant uncertainty in effectiveness of the hydraulic barrier. Water containing petroleum hydrocarbons and some LNAPL would be generated with groundwater extraction, increasing the efforts for effluent treatment and disposal, and increasing risks for exposure to site workers and the environment.	A significant volume of water containing petroleum hydrocarbons and some LNAPL would be generated, requiring operation of a large aboveground treatment unit. Hydraulic containment approaches would require permanent operation and maintenance of the system, expending a potentially valuable resource (groundwater) with little to no benefit towards remediating the site. Long-term treatment and disposal is impracticable. Results in larger influx of water from the Columbia River.	No
Removal	Excavation	Excavation with off-site disposal	Excavation would potentially remove the LNAPL and associated impacted soils. Sheet piling would be required to conduct excavations to 80 feet bgs; or caissons and large diameter augers could be used to remove the LNAPL and impacted soil. Confirmation samples could not be collected to confirm extent or that remediation removes all LNAPL and residual hydrocarbons.	Flowing sands identified during RI well installation operations and the uneven bedrock surface indicate that removal by caisson/large diameter auger is likely impracticable. Due to the depth below groundwater surface and proximity to the Columbia River, excavation of soil using sheet piles would require significant I-beam bracing, making excavation of the impacted material difficult and compaction of the backfill impracticable. The lack of geotechnical stability of the backfill in the middle of a railyard makes this option impracticable. Proximity of the excavation to the mainline track would pose significant safety concerns for rail traffic.	No
	Extraction	Vacuum Extraction	Recoverable LNAPL can be removed periodically (not a continuous operation) by vacuum extraction using a drop tube or stinger to specifically target LNAPL and remove in batches. The non-recoverable fraction of LNAPL will remain in the subsurface and degrade biologically. Reduction of LNAPL thickness and the creation of additional LNAPL surface area as LNAPL drains from soil pore space and is replaced by an inflow of oxygenated groundwater results in increased biological degradation.	Vacuum extraction has been used successfully on site wells in the past and more effectively limits the proportion of water removed with LNAPL. Vacuum removal will generate a temporary induced hydraulic gradient towards the well during removal events. High viscosity LNAPL will have low recharge rates, limiting the recovery of LNAPL during individual events. Frequency of extractions is established by LNAPL thickness monitoring, allowing for adaptive management to adjust removal frequency and approach. Vacuum extraction has been demonstrated to be implementable.	**Yes**
		Conventional/Passive Skimming	Recoverable LNAPL can be removed by skimming. The non-recoverable fraction of LNAPL will remain in the subsurface and degrade biologically. Reduction of LNAPL thickness and the creation of additional LNAPL surface area as LNAPL drains from soil pore space and is replaced by an inflow of oxygenated groundwater results in increased biological degradation. Continuous skimming is expected to be less effective compared to vacuum extraction due to the high viscosity of the LNAPL and the passive nature of the alternative.	High viscosity LNAPL will have low recharge rates, limiting the recovery of LNAPL by continuous passive physical removal methods. The submerged, high viscosity LNAPL is not expected to migrate at reasonable rates towards extraction wells as no hydraulic gradient is induced in the well by skimming.	No
		Vacuum Enhanced Skimming	Application of a vacuum at the top of the extraction well casings to enhance hydrocarbon movement during physical removal by skimming is effective and commonly used for floating LNAPL. However, the submerged condition of the LNAPL at the site renders the addition of vacuum to mobilize LNAPL ineffective.	Adding vacuum to a recovery well is easily implementable but will not increase recoverability of the submerged LNAPL.	No
		Multi-Phase Extraction (MPE) / Total Fluids Extraction (TFE)	Submerged LNAPL can be removed through MPE/TFE by continuous pumping of total fluids. Continuous operation of MPE/TFE in proximity to the Columbia River will result in significant water extraction rates. However, recovery rates of the high viscosity LNAPL are expected to diminish quickly, making the alternative less effective with time.	Operation of MPE/TFE near the Columbia River is expected to result in high water extraction volumes. The high viscosity of the LNAPL will result in diminishing returns being reached quickly increasing the water/oil ratio of the effluent. Long-term treatment and disposal is impracticable.	No

DETAILED SCREENING OF REMEDIAL TECHNOLOGIES
BNSF Wishram Railyard

Groundwater					
Groundwater Impacts Occurring as LNAPL, Submerged LNAPL, and Dissolved-Phase Diesel Fuel and Oil					
LNAPL/Submerged LNAPL Remedial Alternatives					
General Response Action	**Remedial Technology**	**Remedial Alternative**	**Effectiveness**	**Implementability**	**Retained (Yes / No)**
Removal (continued)	Thermal Extraction	Hot Water Flooding	Increased subsurface temperatures reduce LNAPL viscosity and mobility and enhance biological degradation. LNAPL migration is controlled hydraulically via inward hydraulic gradients. Pulling oxygenated water through the LNAPL area will increase biological degradation. Continuous extraction will result in preferential flow paths, resulting in areas of high viscosity LNAPL not being removed by fluid flow.	Operation of a large aboveground treatment unit would be required for a long time period. Variable hydrogeologic environment (losing vs. gaining stream) and location relative to the Columbia River makes containment difficult and increases risks of LNAPL migrating to the Columbia River.	No
		Steam Enhanced Extraction (SEE)	SEE increases the effectiveness of LNAPL removal due to high temperatures that reduce LNAPL viscosity and increase mobility. Steam delivery is difficult to control and can result in unanticipated preferential pathways for both steam and LNAPL reducing effectiveness for removal and creating uncertainty in system performance. Localized temperatures above 100 °C can cause volatilization of water and hydrocarbons resulting in unpredictable vapor-phase migration in close proximity to the Columbia River, potentially leaving LNAPL condensate in unexpected locations.	SEE requires significant energy use. High pressures are required for injection of steam at depth to address deep submerged LNAPL observed at the site. Circulation and extraction of steam through deep zones and uncertainty of maintaining hydraulic control of deep zone LNAPL close to the Columbia River makes SEE high risk and impractical.	No
		Low Temperature Thermal Heating - Electrical Resistance Heating (ERH)	Increasing subsurface temperatures to 50 to 70 °C would reduce LNAPL viscosity and increase extraction effectiveness. Maintaining temperatures below 100 ° C is important to avoid vaporization and uncontrolled migration of vapor-phase components. ERH creates more uniform and effective heating profile throughout the subsurface without high temperature hot spots compared to other thermal technologies. Residual heat improves biological degradation following cessation of active removal.	Implementation of Low Temperature Thermal using ERH requires installation of complex systems and careful operation to deliver electrical current to the subsurface to achieve resistance heating. ERH uses significant energy. Maintaining temperatures below the boiling point of water is important for control of LNAPL recovery. Recovered fluids and water can be treated on-site and disposed, or transported off-site.	**Yes**
		High Temperature Thermal Heating - Thermal Conductive Heating (TCH)	High Temperature Thermal Heating reduces LNAPL viscosity and increases the effectiveness of LNAPL mobility. Typical high temperature applications rely on complete volatilization of water and LNAPL and complete drying of the subsurface for recovery in the vapor phase. High temperature thermal is not expected to volatilize higher-chain hydrocarbons and is expected to result in significant residual mass remaining. Vaporization of water and LNAPL can cause unpredictable migration of vapor-phase hydrocarbons in close proximity to the Columbia River, potentially leaving LNAPL condensate in unexpected locations.	High Temperature Thermal Heating requires significant energy use, fluid and vapor recovery system and aboveground treatment of extracted fluids and vapors. Vaporization of water and petroleum hydrocarbons will result in gas generation and migration. Capillary entry pressure barriers and lithological stratification prevent upward migration of gasses to the vadose zone for collection allowing fugitive gasses to potentially escape the treatment area via submerged lateral preferential pathways. Influx of cool water from Columbia River makes complete heating of southern LNAPL area problematic/uncertain. Uncertainty related to implementation and ability to control potential migration in proximity to the Columbia River makes High Temperature Thermal impractical, relative to other thermal options.	No
		Radio-Frequency Heating (RFH)	RHF heats the subsurface to vaporize water and LNAPL through application of electromagnetic radiation similar to a microwave. Heating can be uneven based on the distribution of the electromagnetic field resulting in hotspots above 100 °C and vaporization of water and LNAPL, and other areas where heating is inefficient. Vaporization of water and LNAPL can cause unpredictable migration of vapor-phase hydrocarbons in close proximity to Columbia River, potentially leaving LNAPL condensate in unexpected locations.	RFH is less easily controlled than other options. Localized temperatures above 100 °C can cause volatilization of water and hydrocarbons. Localized cool zones results in less effective removal. May interfere with communications equipment necessary for railroad operations.	No
In-Situ Treatment	Physical/Chemical	In-Situ Chemical Oxidation (ISCO)	In-situ treatment requires contact between submerged LNAPL and treatment reagents. Chemical oxidation requires multiple injections throughout the entire volume and may be limited by residual hydrocarbons in inaccessible soil pore space. While an effective technology for some hydrocarbon releases, the high viscosity of the LNAPL, low solubility compounds, and a highly variable hydrogeologic environment limit the effectiveness of ISCO.	Requires injecting fluids into the subsurface near the Columbia River. Design constraints will include a buffer zone between the injection area and the Columbia River, resulting in an untreated fraction of the LNAPL. Injection of strong oxidants and associated alkaline or chemical activators near the Columbia River present potential risks to the environment that do not outweigh benefits given uncertainty regarding effectiveness.	No
		In-Situ Geochemical Stabilization	In-situ treatment requires contact between submerged LNAPL and treatment reagents. Geochemical mineralization to treat and encapsulate LNAPL in place requires multiple injections throughout the entire volume and may be limited by residual hydrocarbons in inaccessible pore space, The highly variable hydrogeologic environment and distribution of the LNAPL limit th effectiveness of geochemical stabilization.	Requires injecting fluids into the subsurface near the Columbia River. Design constraints will include a buffer zone between the injection area and the Columbia River, resulting in an untreated fraction of the LNAPL. Injection of strong oxidants near the Columbia River present potential risks to the environment that do not outweigh benefits given uncertainty regarding effectiveness.	No
	Thermal Destruction	In-Situ Smoldering Technology: Self-Sustaining Treatment for Active Remediation (STAR)	STAR combusts LNAPL in situ and requires ignition of submerged LNAPL using ignition points to raise temperatures to create combustion and smoldering. Requires air injection to manage oxygen for combustion and vapor recovery and treatment for mobilized vapor. STAR may be ineffective where water content of the LNAPL prevents ignition or full combustion and gaps in LNAPL distribution can limit migration of the combustion front through the LNAPL, requiring a high density of ignition points to be effective.	Success depends on effective delivery of heat and air to ignite and maintain combustion, and LNAPL connectivity in subsurface to pass combustion through target area. A high density of ignition points and significant energy use are assumed for the site due to the distribution of LNAPL in the subsurface and the hydrogeologic conditions adjacent to the Columbia River. Vaporization of water and petroleum hydrocarbons will result in gas generation and migration, though less volatilization of hydrocarbons is expected as compared to TCH, as combustion of hydrocarbons in place is the primary expected mechanism for LNAPL reduction. Capillary entry pressure barriers and lithological stratification prevent upward migration of gasses to the vadose zone for collection allowing fugitive gasses to potentially escape the treatment area via submerged lateral preferential pathways. Uncertainty related to implementation and ability to control potential migration in proximity to the Columbia River makes STAR impractical, relative to other thermal options.	No

TABLE 4

DETAILED SCREENING OF REMEDIAL TECHNOLOGIES
BNSF Wishram Railyard

Groundwater					
Groundwater Impacts Occurring as LNAPL, Submerged LNAPL, and Dissolved-Phase Diesel Fuel and Oil					
LNAPL/Submerged LNAPL Remedial Alternatives					
General Response Action	**Remedial Technology**	**Remedial Alternative**	**Effectiveness**	**Implementability**	**Retained (Yes / No)**
In-Situ Treatment (continued)	Biological	Biosparging	LNAPL is readily degraded through natural processes, particularly when sufficient oxygen is present. The quantity and extent of petroleum hydrocarbon sources relative to the magnitude of aerobic biological activity, as controlled by the availability of oxygen, effects the timeline of degradation and the overall effectiveness of biological processes. The addition and control of oxygen to promote biological processes is a proven effective means of degrading heavy end, long chain petroleum hydrocarbons in place. Variable hydrogeologic conditions, including regular inflow of oxygenated surface water from the Columbia River will aid in keeping elevated oxygen levels in treatment area. Biosparging in the LNAPL body may result in limited LNAPL mobilization and would generally be more effective when preceded by physical removal of the mobile LNAPL.	Requires installation of biosparging wells and operation of blowers or compressors to deliver atmospheric air to the subsurface. Operation can be adaptively managed based on performance monitoring of geochemical conditions to optimize the delivery of oxygen to specific locations and to apply the needed effort to accomplish remediation goals.	**Yes**
		Enhanced Bioremediation	Enhanced Bioremediation via injection of fluids containing nutrients and oxygen releasing compounds to promote biological degradation is generally most effective for lower concentration dissolved phase conditions and is not typically applied where significant LNAPL is present as biological degradation only occurs along the LNAPL surface.	Requires injecting fluids into the subsurface near the Columbia River, increasing potential risks to surface water. Potentially long timeframes and large amendment injection volumes due to large LNAPL mass present.	No
Ex-Situ Treatment	Aboveground Treatment	Aboveground Vapor Treatment	Due to low volatility of long chain LNAPL, only applicable to treatment of vaporized water and LNAPL during alternatives such as High Temperature Heating that rely on volatilization of hydrocarbons. Vapors can be condensed and combined with liquid waste stream for treatment.	May be implemented as a component of some alternatives.	**Yes**
		Oil/Water Separation	Extracted LNAPL and groundwater are physically separated. LNAPL is recycled/disposed. Separated water may require further physical or chemical treatment for residual and dissolved phase concentrations prior to discharge to Columbia River under NPDES or to POTW. Oil/Water Separation and additional physical/chemical treatment is effective as an effluent treatment component of the remedy.	May be implemented as a component of some alternatives.	**Yes**

DETAILED SCREENING OF REMEDIAL TECHNOLOGIES
BNSF Wishram Railyard

Groundwater					
Groundwater Impacts Occurring as LNAPL, Submerged LNAPL, and Dissolved-Phase Diesel Fuel and Oil					
Dissolved Phase Petroleum Hydrocarbon Remedial Alternatives					
Summary of Dissolved Phase Groundwater Conditions:	Dissolved phase DRO and ORO concentrations reported above their CULs typically occur in the southern and central portions of the site in the wells near the former oil pipelines, western portion of the berm, and the former Engine House, and in wells west of the Maintenance Shop.				
General Response Action	**Remedial Technology**	**Remedial Alternative**	**Effectiveness**	**Implementability**	**Retained (Yes / No)**
Monitored Natural Attenuation (MNA)	Monitored Natural Attenuation (MNA)	Monitored Natural Attenuation	Dissolved phase petroleum hydrocarbons are readily degraded through natural processes, particularly when sufficient oxygen is present. The quantity and extent of petroleum hydrocarbon sources affects the timeline of degradation and the overall effectiveness of MNA within a defined timeframe.	Limited change in existing monitoring infrastructure required. Easily performed and consistent with expected long-term monitoring program.	**Yes**
Containment	Barrier	Physical Containment	Effectiveness of physical containment for dissolved phase constituents using a sheet pile wall will be reduced by the variable bedrock surface at the base of the alluvial material, and ability to completely seal sheet pile joints. Containment using a slurry wall may be more effective. Performance of containment technologies for dissolved phase constituents would be reduced by variable and difficult to control hydraulic gradients due to daily changes in Columbia River elevation at Lake Celilo. Natural attenuation of dissolved phase hydrocarbons would continue, but at a potentially reduced rate due to isolation from surrounding groundwater flow containing relatively more oxygenated water.	Installation of physical containment using a sealed sheet pile or slurry wall would require complex and difficult construction methods. Installation of a slurry wall is highly problematic given the geotechnical conditions of the deep alluvial materials (flowing sands). Construction is further complicated by the variable bedrock surface. Additionally, the dissolved phase plume extends closer to the shoreline and adjacent berm than the area of submerged LNAPL evaluated above. Construction of containment features within the berm would be further complicated or not practical to fully contain the dissolved phase plume extents.	No
Removal	Extraction	Groundwater Extraction/Hydraulic Containment	Extraction and treatment for both cleanup and hydraulic containment via pump and treat in proximity to the Columbia River requires significant extraction rates and involves significant uncertainty in effectiveness of capturing target areas based on the variable hydrogeologic conditions beneath the site, as described in the RI Report. The rate of mass transfer of target compounds is a function of concentration gradients, which as mass removal progresses become smaller and less effective through groundwater extraction. A fraction of residual hydrocarbons will remain sorbed or trapped in soil pore space and is inaccessible for removal. Pump and treat systems require long time frames and result in inefficient and incomplete treatment.	Significant volume of water from an area immediately adjacent to the Columbia River needs to be extracted to address dissolved phase impacts. Results in larger influx of water from the Columbia River. Long-term treatment and disposal is impracticable.	No
In-Situ Treatment	Physical/Chemical	In-Situ Chemical Oxidation (ISCO)	In-situ treatment requires contact between dissolved phase target chemicals in groundwater and treatment reagents. Chemical oxidation requires multiple injections throughout the entire volume and may be limited by residual hydrocarbons in inaccessible soil pore space. While an effective technology for some hydrocarbon releases, the presence of high viscosity LNAPL, low solubility compounds, and a highly variable hydrogeologic environment limit the effectiveness of ISCO.	Requires injecting fluids into the subsurface near the Columbia River. Design constraints will include a buffer zone between the injection area and the Columbia River, resulting in an untreated fraction of the dissolved plume. Injection of strong oxidants and associated alkaline or chemical activators near the Columbia River present potential risks to the environment that do not outweigh benefits given uncertainty regarding effectiveness.	No
		Air Sparging/Soil Vapor Extraction	AS/SVE primarily relies on stripping of target compounds from soil and groundwater to be mobilized in vapor phase for extraction, collection, and treatment. AS/SVE is less effective for long chain, high viscosity oils due to the limited volatility of heavy end and weathered compounds. AS/SVE also has physical limitations, particularly where LNAPL is present in the vicinity due to the formation of preferential pathways in the subsurface. Oxygen addition from sparging is beneficial, but as a combined approach AS/SVE is not expected to effectively remove the long-chain hydrocarbons from groundwater.	Requires installation of sparging and extraction wells on grid basis across dissolved-phase plume area and construction of a system for treatment of extracted vapors. Due to the low volatility of the target compounds at the site, implementation may require a significant increase in the number of sparge wells, compared to typical designs. SVE may be ineffective at removing long-chain hydrocarbons from soil gas.	No
	Biological	Biosparging	Dissolved phase petroleum hydrocarbons are readily degraded through natural processes, particularly when sufficient oxygen is present. The quantity and extent of petroleum hydrocarbon sources relative to the magnitude of aerobic biological activity, as controlled by the availability of oxygen, affects the timeline of degradation and the overall effectiveness of biological processes. The addition and control of oxygen to promote biological processes is a proven effective means of degrading heavy end, long chain petroleum hydrocarbons in place. Variable hydrogeologic conditions, including regular inflow of oxygenated surface water from the Columbia River will aid in keeping elevated oxygen levels in the treatment area.	Requires installation of biosparging wells and operation of blowers or compressors to deliver atmospheric air to the subsurface. Operation can be adaptively managed based on performance monitoring of geochemical conditions to optimize the delivery of oxygen to specific locations and to apply the needed effort to accomplish remediation goals.	**Yes**
Ex-Situ Treatment	Aboveground Treatment	Aboveground Vapor Treatment	Due to low volatility of long chain LNAPL, only applicable to treatment of vaporized water and LNAPL during alternatives such as High Temperature Heating that rely on volatilization of hydrocarbons. Vapors can be condensed and combined with liquid waste stream for treatment.	May be implemented as a component of some alternatives.	**Yes**
		Oil/Water Separation	Extracted LNAPL and groundwater are physically separated. LNAPL is recycled/disposed. Separated water may require further physical or chemical treatment for residual and dissolved phase concentrations prior to discharge to Columbia River under NPDES or to POTW. Oil/Water Separation and additional physical/chemical treatment is effective as an effluent treatment component of the remedy.	May be implemented as a component of some alternatives.	**Yes**

TABLE 5

SUMMARY OF REMEDIAL ALTERNATIVES
BNSF Wishram Railyard

Remedial Alternative	Description
Alternative 1 - Physical LNAPL Removal, Focused Biosparge, MNA, and Targeted Excavation	
Excavate Shallow Impacted Soils	Excavate impacted soils in the vicinity of soil boring B-16-01, located to the south of the former power house. Total excavation volume of approximately 600 cubic yards. Laboratory testing to evaluate reuse of non-impacted soil on railyard and transport and offsite disposal of impacted soil, assumed to be non-hazardous waste.
Remove Mobile LNAPL in eastern LNAPL area	Periodically extract LNAPL from eastern portion of LNAPL body using approximately 15 new recovery wells and three existing OHM wells, allowing adequate time for recharge of LNAPL into extraction points between events. Monitor presence and amount of LNAPL. Offsite disposal of extracted fluids during implementation. NSZD of residual impacts in source area after drainable LNAPL is removed.
Focused biosparging in western LNAPL area.	Contingent on MNA assessment, install shallow and paired shallow and deep (between 20 and 40 feet bgs) biosparging wells in the western LNAPL area. Sparge air to stimulate biological degradation of LNAPL impacts in the western LNAPL area. Groundwater monitoring will be performed during operation of biosparging system. NSZD of residual impacts in western LNAPL area after cessation of biosparging.
Groundwater MNA and NSZD of Residual Petroleum Hydrocarbons	Conduct MNA assessment for dissolved phase petroleum in the mainline track area, beneath the former Engine House, and south of the eastern LNAPL area (just north of the river berm). Monitor groundwater for natural attenuation parameters to assess degradation of dissolved-phase petroleum hydrocarbons. MNA and NSZD used as polishing step following cessation of active treatment (biosparging and LNAPL removal). Compliance groundwater monitoring will be implemented at the site following MNA.
Alternative 2 - Institutional Controls (ICs) and Environmental Covenants (ECs) with Compliance Groundwater Monitoring	
Institutional Controls and Environmental Covenants	Develop institutional controls for the site and file environmental covenants to limit exposures to potential receptors (onsite workers, visitors, and nearby residents). Compliance groundwater monitoring will be implemented in selected wells. Constituent concentrations gradually decrease via natural source zone depletion and natural attenuation.
Alternative 3 - LNAPL Containment, Biosparge, MNA, and Targeted Excavation	
Excavate Shallow Impacted Soils	Excavate impacted soils in the vicinity of soil boring B-16-01, located to the south of the former power house. Total excavation volume of approximately 600 cubic yards. Laboratory testing to evaluate reuse of non-impacted soil on railyard and transport and offsite disposal of impacted soil, assumed to be non-hazardous waste.
Sheet Pile Wall	Install a sheet pile wall from ground surface to bedrock along three sides (eastern, southern, western) of the LNAPL areas to provide physical containment. No active treatment of source area. A Groundwater Covenant will be enacted to restrict future use of site groundwater.
Natural Source Zone Depletion (NSZD) of LNAPL	NSZD monitoring of residual petroleum hydrocarbons and LNAPL within contained area.
Biosparging mainline track area and former Engine House	Contingent on MNA assessment, install shallow (25 feet bgs) biosparging wells in the mainline track area and beneath the former Engine House, and sparge air to stimulate biological degradation of dissolved-phase petroleum hydrocarbons. Groundwater monitoring will be performed during operation of biosparging system.
Groundwater Monitored Natural Attenuation (MNA)	Following installation of the sheet pile containment wall, monitor groundwater for degradation of dissolved-phase petroleum hydrocarbons. MNA used as polishing step following cessation of active treatment (biosparging). Compliance groundwater monitoring will be implemented at the site following MNA.
Alternative 4 - Physical LNAPL Removal, Biosparge, MNA, and Targeted Excavation	
Excavate Shallow Impacted Soils	Excavate impacted soils in the vicinity of soil boring B-16-01, located to the south of the former power house. Total excavation volume of approximately 600 cubic yards. Laboratory testing to evaluate reuse of non-impacted soil on railyard and transport and offsite disposal of impacted soil, assumed to be non-hazardous waste.
Remove Mobile LNAPL in eastern LNAPL area	Periodically extract LNAPL from eastern portion of LNAPL body using approximately 15 new recovery wells and three existing OHM wells, allowing adequate time for recharge of LNAPL into extraction points between events. Monitor presence and amount of LNAPL. Offsite disposal of extracted fluids during implementation. NSZD of residual impacts in source area after drainable LNAPL is removed . Biosparging may be needed following cessation of LNAPL removal to stimulate further degradation of residual hydrocarbons, if groundwater remains impacted.
Biosparging mainline track area, former Engine House, western LNAPL area and south of eastern LNAPL area	Contingent on MNA assessment, install shallow (between 20 and 40 feet bgs) biosparging wells in the mainline track area, beneath the former Engine House and in the western LNAPL area, and install paired shallow (25 feet bgs) and deep (60 feet bgs) biosparging wells south of the eastern LNAPL area (just north of the river berm). Sparge air to stimulate biological degradation of LNAPL impacts (in the western LNAPL area) and dissolved-phase petroleum hydrocarbons. Groundwater monitoring will be performed during operation of biosparging system. NSZD of residual impacts in western LNAPL area after cessation of biosparging.
Groundwater MNA and NSZD of Residual Petroleum Hydrocarbons	Monitor groundwater for natural attenuation parameters to assess degradation of dissolved-phase petroleum hydrocarbons. MNA and NSZD used as polishing step following cessation of active treatment (biosparging and LNAPL removal). Compliance groundwater monitoring will be implemented at the site following MNA.
Alternative 5 - Low-Temperature Thermal Removal (LTTR), Biosparge, MNA, and Targeted Excavation	
Excavate Shallow Impacted Soils	Excavate impacted soils in the vicinity of soil boring B-16-01, located to the south of the former power house. Total excavation volume of approximately 600 cubic yards. Laboratory testing to evaluate reuse of non-impacted soil on railyard and transport and offsite disposal of impacted soil, assumed to be non-hazardous waste.
Low-Temperature Subsurface Heating and Mobile LNAPL Removal	Heat eastern portion of LNAPL body to approximately 50 to 70°C to reduce viscosity. Install stainless steel multiphase extraction wells for LNAPL recovery. Aboveground treatment of extracted fluids, off-site disposal of recovered LNAPL (or total fluids). Elevated subsurface temperatures will increase biological degradation through thermogenic bacteria. NSZD of residual impacts in source area after drainable LNAPL is removed and system cools to ambient temperatures. Biosparging may be used as a contingency remedy following cessation of LNAPL removal to increase oxygen concentrations in saturated interval and further stimulate degradation of residual hydrocarbons.
Biosparging mainline track area, former Engine House, western LNAPL area and south of eastern LNAPL area	Contingent on MNA assessment, install shallow (between 20 and 40 feet bgs) biosparging wells in the mainline track area, beneath the former Engine House and in the western LNAPL area, and install paired shallow (25 feet bgs) and deep (60 feet bgs) biosparging wells south of the eastern LNAPL area (just north of the river berm). Sparge air to stimulate biological degradation of LNAPL impacts (in the western LNAPL area) and dissolved-phase petroleum hydrocarbons. Groundwater monitoring will be performed during operation of biosparging system. NSZD of residual impacts in western LNAPL area after cessation of biosparging.
Groundwater MNA and NSZD of Residual Petroleum Hydrocarbons	Monitor groundwater for natural attenuation parameters to assess degradation of dissolved-phase petroleum hydrocarbons. MNA and NSZD used as polishing step following cessation of active treatment (biosparging and LNAPL removal). Compliance groundwater monitoring will be implemented at the site following MNA.

TABLE 6

ALTERNATIVES ANALYSIS SUMMARY
BNSF Wishram Railyard

Remedial Alternative	Protectiveness	Permanence	Cost	Long-Term Effectiveness	Short-term Risk	Ability to Implement	Restoration Timeframe	Total Score
Alternative 1 - Physical LNAPL Removal, Focused Biosparge, MNA and Targeted Excavation	5	7	6	7	8	8	6	**47**
Alternative 2 - ICs and ECs with Compliance GWM	2	2	9	3	9	9	1	**35**
Alternative 3 - LNAPL Containment, Biosparge, MNA and Targeted Excavation	4	3	5	4	3	5	1	**25**
Alternative 4 - Physical LNAPL Removal, Biosparge, MNA and Targeted Excavation	6	7	5	9	8	8	6	**49**
Alternative 5 - LTTR, Biosparge, MNA and Targeted Excavation	7	7	1	9	4	6	8	**42**

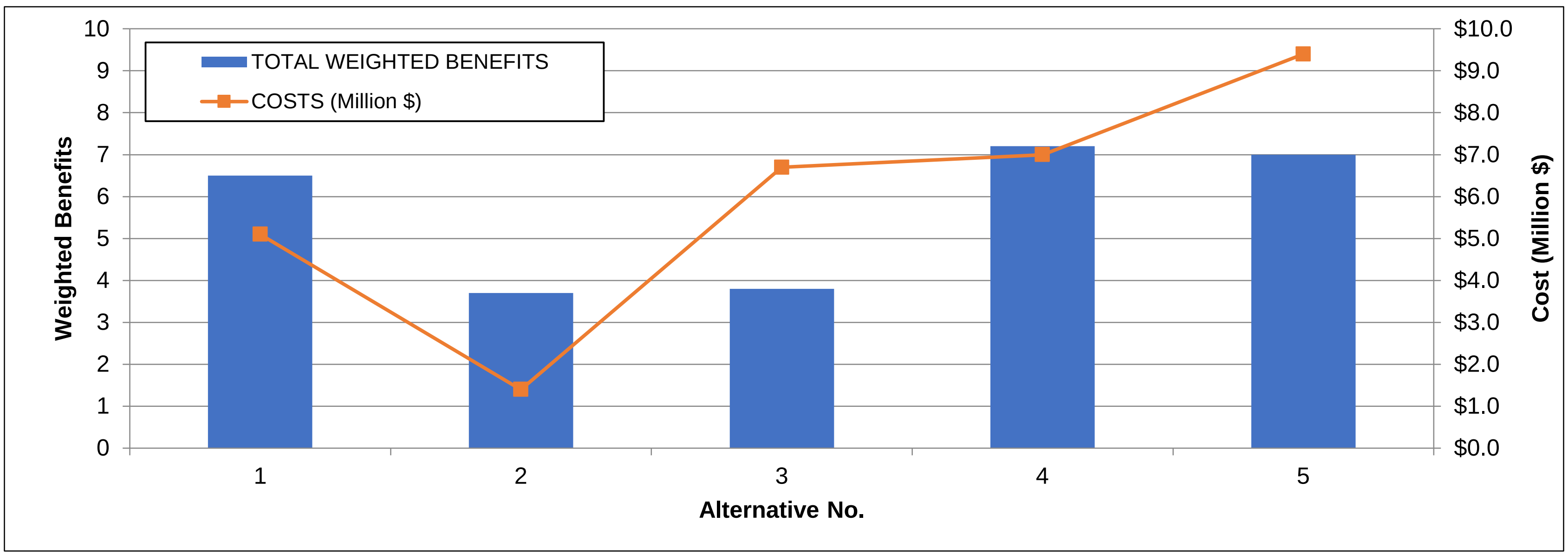
Abbreviations

ICs and ECs with Compliance GWM = Institutional Controls and Environmental Covenants with Compliance Groundwater Monitoring
LNAPL = light non-aqueous phase liquid
MNA = Monitored Natural Attenuation
LTTR = Low-Temperature Thermal Removal

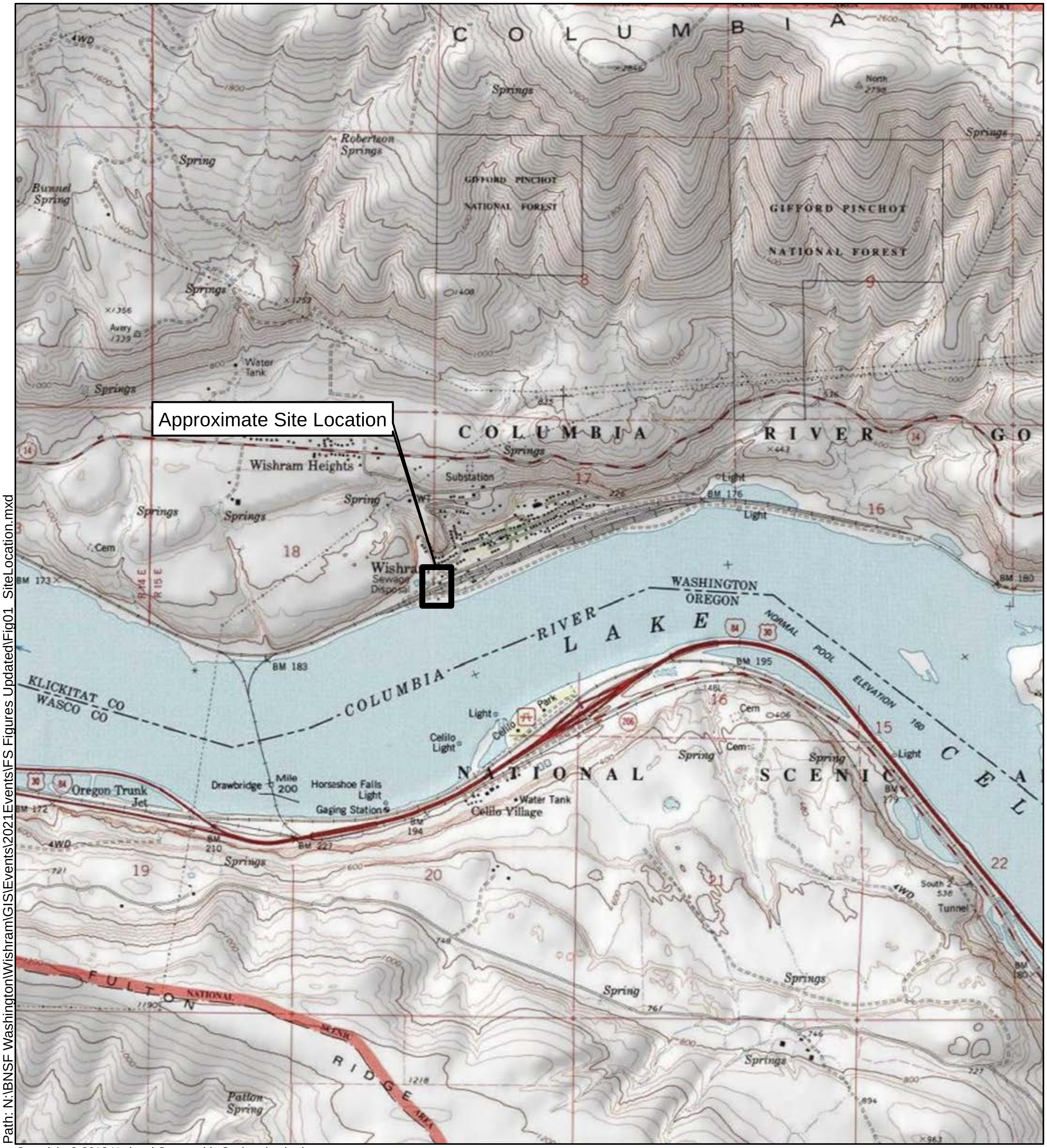
TABLE 7

BENEFIT/COST ANALYSIS
BNSF Wishram Railyard

		Disproportionate Cost Analysis				
BENEFITS	**Weighting Factor**	**Alternative 1**	**Alternative 2**	**Alternative 3**	**Alternative 4**	**Alternative 5**
Protectiveness	30%	5	2	4	6	7
Permanence	20%	7	2	3	7	7
Long-Term Effectiveness	20%	7	3	4	9	9
Short-term Risk	10%	8	9	3	8	4
Ability to Implement	10%	8	9	5	8	6
Consideration of public concerns	10%	6	3	4	6	7
TOTAL WEIGHTED BENEFITS	**100%**	**6.5**	**3.7**	**3.8**	**7.2**	**7.0**
COSTS (Million $)	**--**	**$5.1**	**$1.4**	**$6.7**	**$7.0**	**$9.4**
BENEFIT/COST RATIO		1.3	2.6	0.6	1.0	0.7
BENEFIT/COST RATIO Relative to Most Permanent Alternative (Alternative 1)		1.0	2.1	0.4	0.8	0.6



Figures



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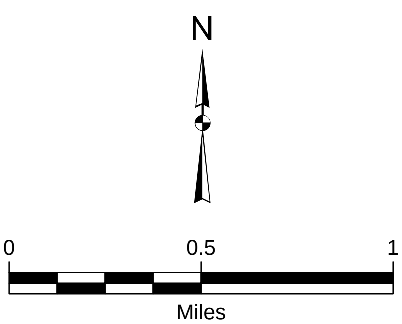

Note:
1. Locations are approximate.

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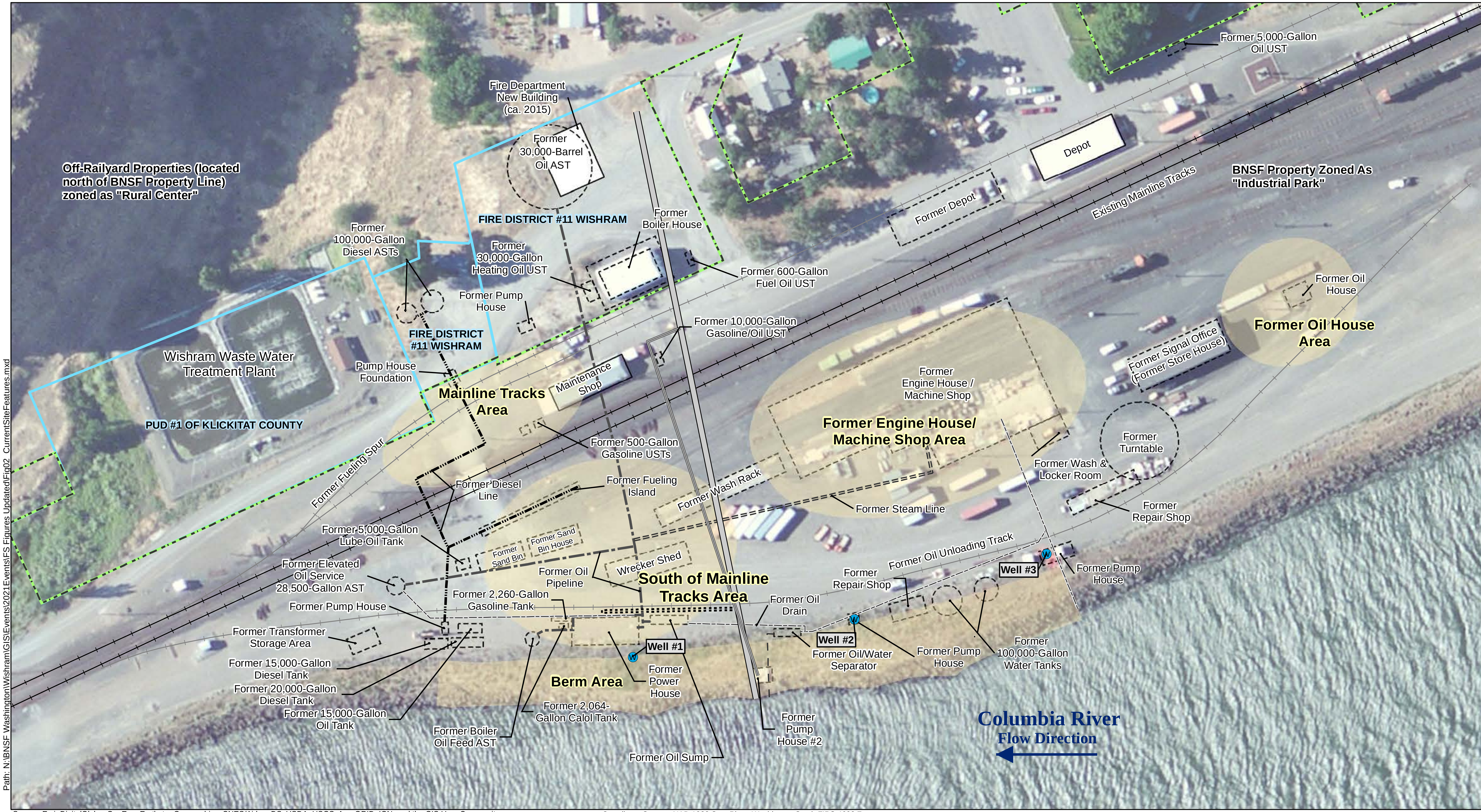
BNSF Wishram Railyard
Wishram, Washington

Site Location Map

2196120*06
December 2021

Figure 1



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Coordinate System: NAD 1983 StatePlane Washington South FIPS 4602 Feet

Legend

- Former Water Supply Well (Approximate)
- Approximate BNSF Property Line
- Existing Site Feature
- Former Site Feature
- Former Bunker Fuel / Oil Pipeline
- Former Oil Drain
- Former Oil Trough
- Former Sewer Line (Potential)
- Stormwater Underdrain (A portion removed from service circa 1960)
- Stormwater Underdrain (Rerouted portion circa 1960)
- Former Diesel Line
- Former Steam Line
- Off-Railyard Parcel Boundaries

Note:
1. Locations are approximate.

N

0 50 100

Scale: Feet

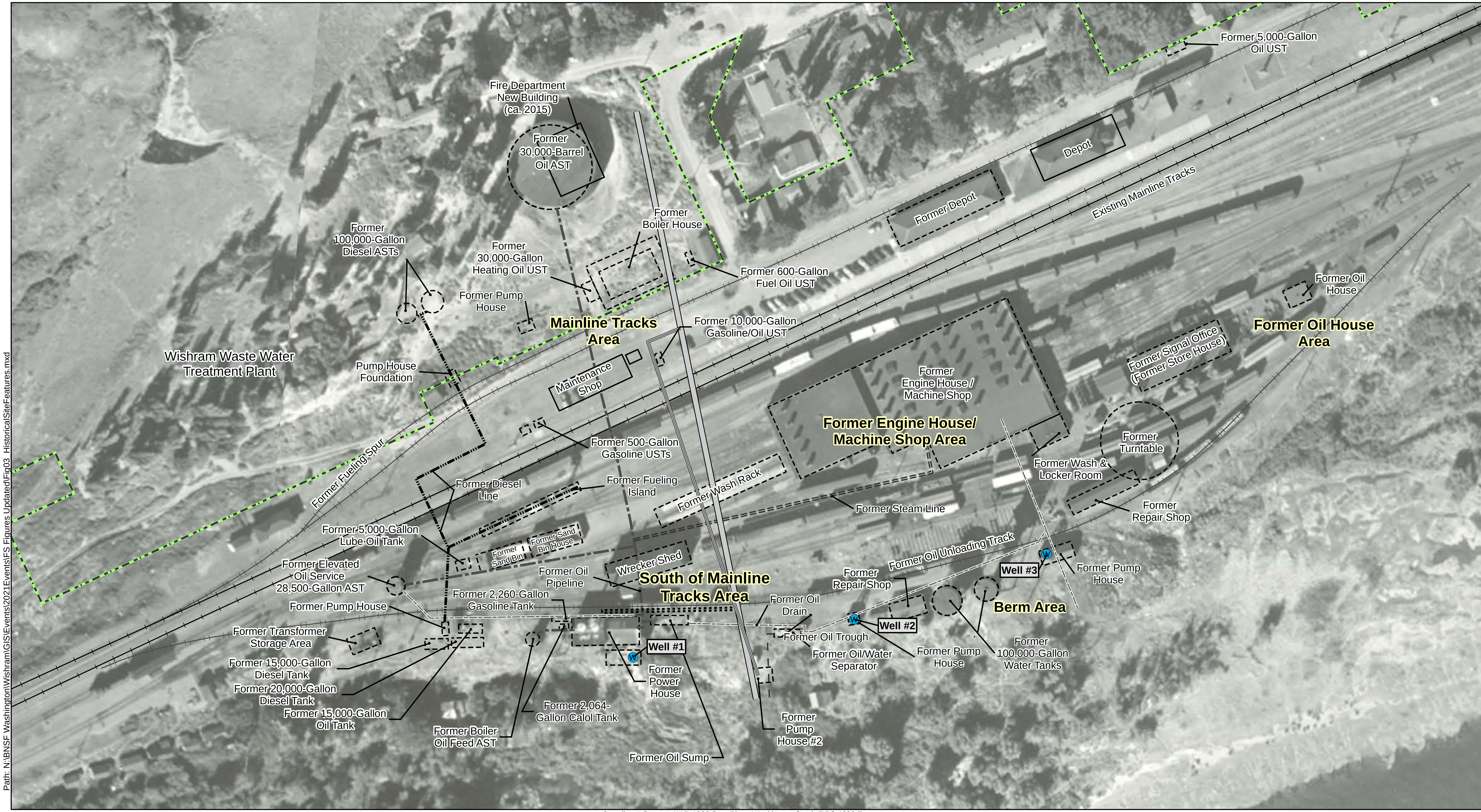
Kennedy/Jenks Consultants

BNSF Wishram Railyard
Wishram, Washington

Current and Historical Site Features

2196120*06
May 2022

Figure 2



Path: N:\BNSF Washington\Wishram\GIS\Events\2021Events\FS Figures Updated\Fig03_HistoricalSiteFeatures.mxd

Coordinate System: NAD 1983 StatePlane Washington South FIPS 4602 Feet

Legend

- W Former Water Supply Well (Approximate)
- Approximate BNSF Property Line
- Former Railroad Tracks
- Former Bunker Fuel / Oil Pipeline
- Former Oil Drain
- Former Oil Trough
- Former Sewer Line (Potential)
- Stormwater Underdrain (A portion removed from service circa 1960)
- Stormwater Underdrain (Rerouted portion circa 1960)
- Former Diesel Line
- Former Steam Line
- Existing Site Feature
- Former Site Feature

Notes:
1. Locations are approximate.
2. Background image from U.S. Army Corps of Engineers, 1951.

N

0 50 100
Scale: Feet

Kennedy/Jenks Consultants

BNSF Wishram Railyard
Wishram, Washington

Historical Site Features

2196120*06
December 2021

Figure 3

Path: N:\BNSF Washington\Wishram\GIS\Events\2021Events\FS Figures Updated\Fig04_CurrentSiteFeatures_east.mxd

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Coordinate System: NAD 1983 StatePlane Washington South FIPS 4602 Feet

Legend

- Approximate BNSF Property Line
- Former Bunker Fuel / Oil Pipeline
- Former Oil Drain
- Former Oil Trough
- Former Sewer Line (Potential)
- Stormwater Underdrain
- Stormwater Underdrain
- Existing Site Feature
- Former Site Feature

Note:
1. Locations are approximate.

N

0 50 100

Scale: Feet

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BNSF Wishram Railyard
Wishram, Washington

Current and Historical Site Features - East Area

2196120*06
December 2021

Figure 4

Coordinate System: NAD 1983 StatePlane Washington South FIPS 4602 Feet

Legend

- Approximate BNSF Property Line
- Existing Site Feature
- Former Site Feature

Notes:
1. Locations are approximate.
2. Background image from U.S. Army Corps of Engineers, 1962.

N

0 50 100

Scale: Feet

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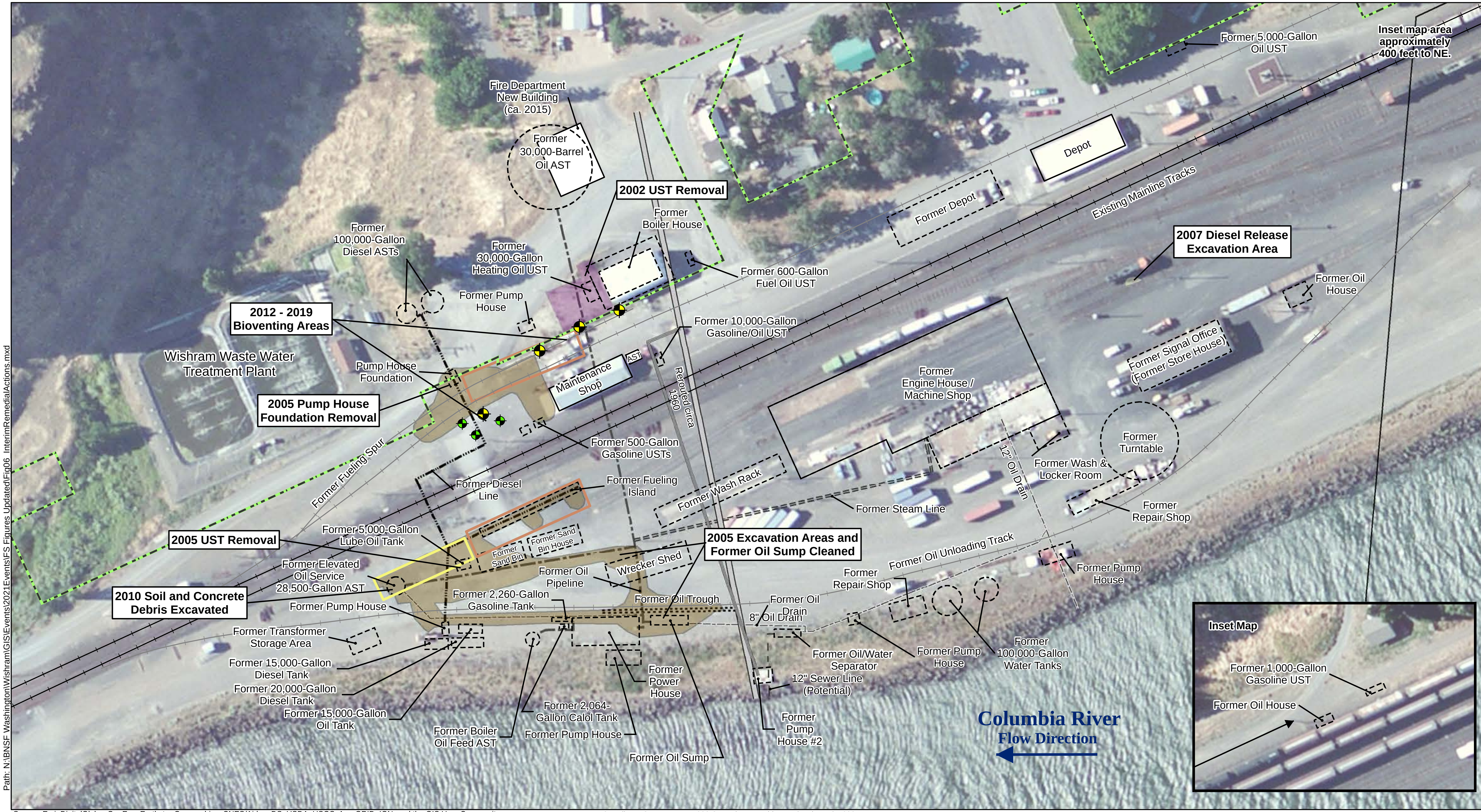
Wishram, Washington

Historical Site Features - East Area

2196120*06
December 2021

Figure 5



Path: N:\BNSF Washington\Wishram\GIS\Events\2021Events\FS Figures Updated\Fig06_InterimRemedialActions.mxd

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Coordinate System: NAD 1983 StatePlane Washington South FIPS 4602 Feet

Legend

- Bioventing Injection Well
- Air Sparge (AS) Well
- Approximate BNSF Property Line
- Former Bunker Fuel / Oil Pipeline
- Former Oil Drain
- Former Oil Trough
- Former Sewer Line (Potential)
- Stormwater Underdrain (A portion removed from service circa 1960)
- Stormwater Underdrain (Rerouted portion circa 1960)
- Former Diesel Line
- Former Steam Line
- Suspected Diesel Fueling Area
- Suspected Oil Fueling Area
- Approximate Previous Excavation Area
- Approximate Previous Excavation Area
- Approximate Previous Excavation Area
- Existing Site Feature
- Former Site Feature

Note:
1. Locations are approximate.

N

0 50 100

Scale: Feet

Kennedy/Jenks Consultants

BNSF Wishram Railyard
Wishram, Washington

Previous Interim Remedial Actions

2196120*06
December 2021

Figure 6

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Coordinate System: NAD 1983 StatePlane Washington South FIPS 4602 Feet

Legend

- LNAPL Observed in Boring

LIF Response (Diesel, Oil and/or Mixed)

- Inferred Diesel/Oil-Like LNAPL (> 60% RE)
- Residual LNAPL (20 to 60 % RE)
- No LNAPL or Residual LNAPL (< 20% RE)
- Inferred Lateral Extent of Shallow (at water table) Diesel-Like LNAPL Impacts
- Inferred Lateral Extent of Shallow (at water table) Oil-Like LNAPL Impacts
- Approximate BNSF Property Line

Notes:
1. Locations are approximate.
2. LNAPL = light non-aqueous phase liquid
3. Inferred lateral extent of potentially mobile Diesel- or Oil-Like LNAPL based on interpretation of LIF waveforms (July 2013) and soil boring logs.

N

0 30 60

Scale: Feet

Kennedy/Jenks Consultants

BNSF Wishram Railyard
Wishram, Washington

Combined Inferred Shallow LNAPL Extent Map

2196120*06
December 2021

Figure 7

Path: N:\BNSF Washington\Wishram\GIS\Events\2021Events\FS Figures Updated\Fig08_LIF_Dx_SUB.mxd

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Coordinate System: NAD 1983 StatePlane Washington South FIPS 4602 Feet

Legend

- ● LNAPL Observed in Boring

LIF Response (Diesel, Oil and/or Mixed)

- ● Inferred Diesel/Oil-Like LNAPL (> 60 %RE)
- ● Residual LNAPL (20 to 60 % RE)
- ● No LNAPL or Residual LNAPL (< 20 %RE)
- Inferred Lateral Extent of Submerged (below water table) Diesel-Like LNAPL Impacts
- Inferred Lateral Extent of Submerged (below water table) Oil-Like LNAPL Impacts
- Approximate BNSF Property Line

Notes:
1. Locations are approximate.
2. LNAPL = light non-aqueous phase liquid
3. Inferred lateral extent of potentially mobile Diesel- or Oil-Like LNAPL based on interpretation of LIF waveforms (July 2013) and soil boring logs.

N

0 30 60

Scale: Feet

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BNSF Wishram Railyard
Wishram, Washington

Combined Inferred Submerged LNAPL Extent Map

2196120*06
December 2021

Figure 8

Path: N:\BNSF Washington\Wishram\GIS\Events\2021Events\FS Figures Updated\Fig09_Soil_TPHDx_AWT_wExc.mxd ©2021 Kennedy/Jenks Consultants

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Coordinate System: NAD 1983 StatePlane Washington South FIPS 4602 Feet

Legend

DRO Result / ORO Result

- Result is above MTCA Method A CUL
- Result is below MTCA Method A CUL
- Result is below laboratory reporting limit

Notes:
1. Locations are approximate.
2. DRO = Diesel-Range Organics.
   ORO = Oil-Range Organics.
3. Results present for soil samples collected between 2002 and 2018.
4. MTCA Method A Cleanup level for diesel- and oil-range organics (DRO and ORO) in soil is 2,000 milligrams per kilogram (mg/kg).
5. Unsaturated depths are from approximately 0 to 10 feet below ground surface (bgs).

N

0 50 100

Scale: Feet

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BNSF Wishram Railyard
Wishram, Washington

DRO/ORO in Subsurface Soil (Unsaturated) - Main Area

2196120*06
December 2021

Figure 9

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Coordinate System: NAD 1983 StatePlane Washington South FIPS 4602 Feet

Path: N:\BNSF Washington\Wishram\GIS\Events\2021Events\FS Figures Updated\Fig10 Soil TPHDx BWT wExc.mxd

Legend

DRO Result / ORO Result

- Result is above MTCA Method A CUL
- Result is below MTCA Method A CUL
- Result is below laboratory reporting limit
- LNAPL Observed in Boring

Notes:
1. Locations are approximate.
2. DRO = Diesel-Range Organics.
   ORO = Oil-Range Organics.
3. Results present for soil samples collected between 2002 and 2018.
4. MTCA Method A Cleanup level for diesel- and oil-range organics (DRO and ORO) in soil is 2,000 milligrams per kilogram (mg/kg).
5. Saturated depths are from approximately 10 feet below ground surface (bgs) to bedrock.
6. Not all points are labeled. See Figures 6B, 7, and 25 in Uplands Remedial Investigation Report.

N

0 50 100

Scale: Feet

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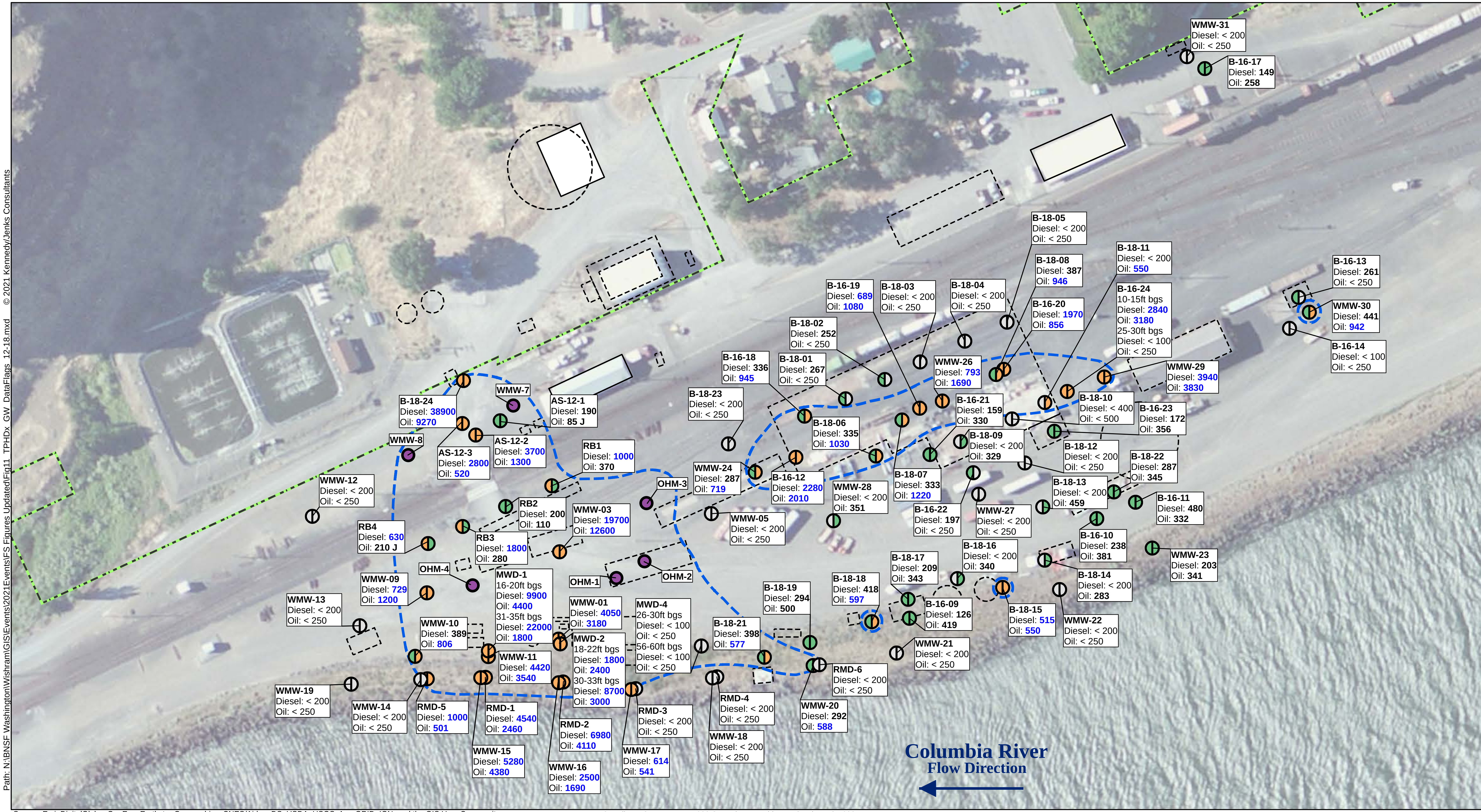
Wishram, Washington

DRO/ORO in Subsurface Soil (Saturated) - Main Area

2196120*06
December 2021

Figure 10



Path: N:\BNSF Washington\Wishram\GIS\Events\2021Events\FS Figures Updated\Fig11_TPHDx_GW_DataFlags_12-18.mxd

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Coordinate System: NAD 1983 StatePlane Washington South FIPS 4602 Feet

Legend

DRO Result — ORO Result

Approximate Lateral Extent of Dissolved Phase Diesel and/or Oil

- Result is above MTCA Method A CUL
- Result is below MTCA Method A CUL
- Result is below laboratory reporting limit
- LNAPL observed, well not sampled

Note:
1. Locations are approximate.
2. "Diesel" = Diesel-Range Organics.
   "Oil" = Oil-Range Organics.
3. MTCA Method A Cleanup levels (CULs) for diesel- and oil-range organics (DRO and ORO) in groundwater is 500 micrograms per liter (µg/l).
4. Reconnaissance groundwater samples from 2012, 2014, 2016, and 2018 are shown. Samples from 2012 and 2014, and some samples from 2016, were analyzed with silica gel cleanup. Monitoring well sample resutls from August 2018 are shown.
5. Bold font indicates result reported above the laboratory reporting limit, blue font indicates result reported above the MTCA Method A CUL.

N

0 50 100

Scale: Feet

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Wishram, Washington

Groundwater Sampling Results DRO and ORO (2012 - 2018) - Main Area

2196120*06
December 2021

Figure 11

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Coordinate System: NAD 1983 StatePlane Washington South FIPS 4602 Feet

Legend

- Total TPH-Dx Concentration Above MTCA Method A CUL
- Total TPH-Dx Concentration Below MTCA Method A CUL
- Total TPH-Dx Concentration Below Laboratory Reporting Limit
- LNAPL Observed, Well Not Sampled
- Approximate Lateral Extent of Dissolved Phase Diesel and/or Oil

Note:
1. Locations are approximate.
2. MTCA Method A Cleanup level (CUL) for total petroleum hydrocarbons (TPH) in groundwater is 500 micrograms per liter (µg/l).
3. Total TPH-Dx = Sum of diesel-range and oil-range organics results.
4. Reconnaissance groundwater samples from 2012, 2014, 2016, and 2018 are shown. Samples from 2012 and 2014, and some samples from 2016, were analyzed with silica gel cleanup. Monitoring well sample resutls from August 2018 are shown.
5. Bold font indicates result reported above the laboratory reporting limit, blue font indicates result reported above the MTCA Method A CUL.

N

0 50 100

Scale: Feet

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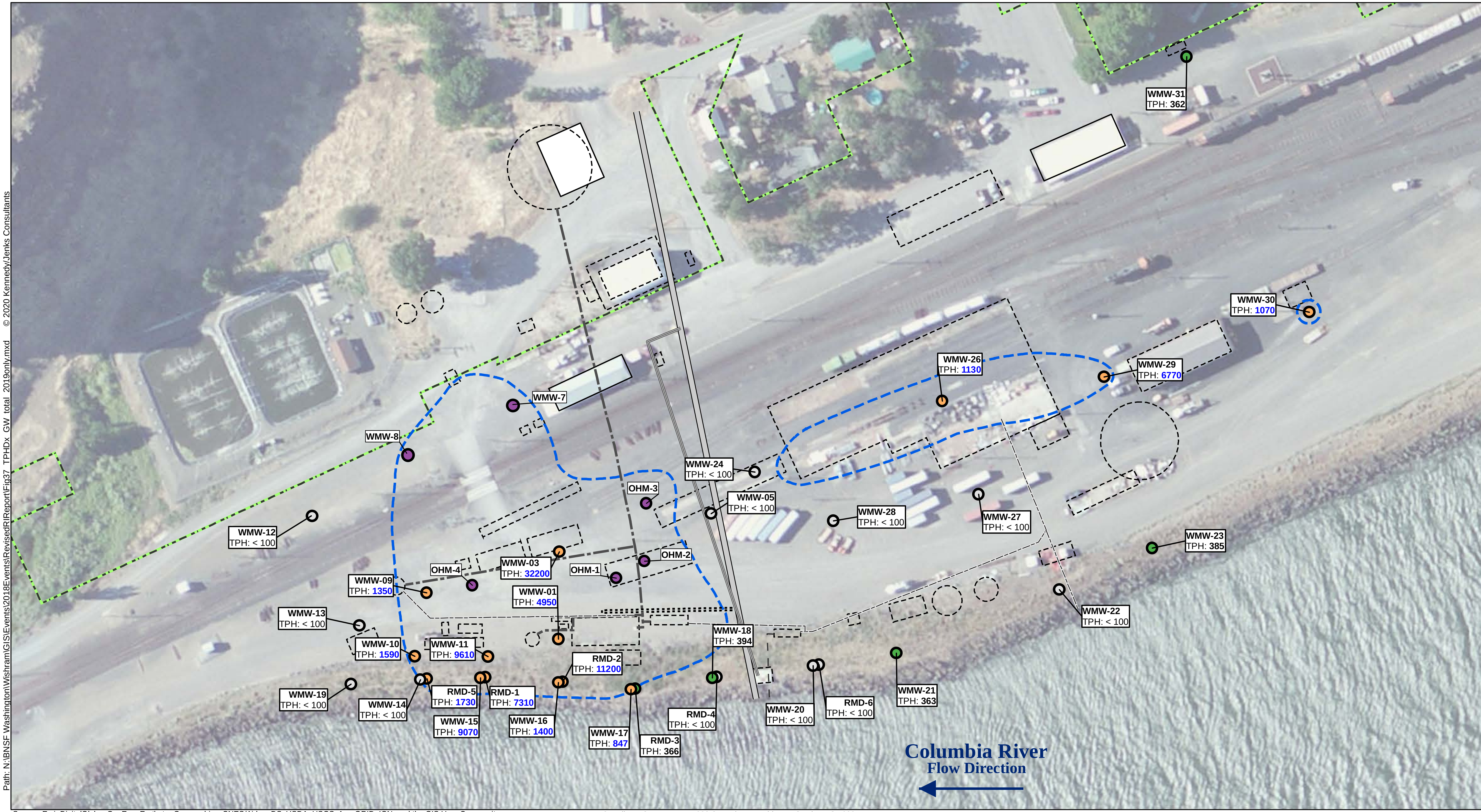
Wishram, Washington

Groundwater Sampling Results Total TPH-Dx (2012 - 2018) - Main Area

2196120*06
December 2021

Figure 12



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Coordinate System: NAD 1983 StatePlane Washington South FIPS 4602 Feet

Legend

- Total TPH-Dx Concentration Above MTCA Method A CUL
- Total TPH-Dx Concentration Below MTCA Method A CUL
- Total TPH-Dx Concentration Below Laboratory Reporting Limit
- LNAPL Observed, Well Not Sampled

Note:
1. Locations are approximate.
2. MTCA Method A Cleanup level (CUL) for total petroleum hydrocarbons (TPH) in groundwater is 500 micrograms per liter (µg/l).
3. Total TPH-Dx = Sum of diesel-range and oil-range organics results.
4. Monitoring well sample results from August 2019 are shown.
5. Bold font indicates result reported above the laboratory reporting limit, blue font indicates result reported above the MTCA Method A CUL.

N

0 50 100

Scale: Feet

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Wishram, Washington

Groundwater Sampling Results Total TPH-Dx (2019) - Main Area

1696120.02
July 2020

Figure 13

Path: N:\BNSF Washington\Wishram\GIS\Events\2018Events\DraftRIReport\Fig40_TPHDx_GW_DataFlags_12-18E.mxd

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Coordinate System: NAD 1983 StatePlane Washington South FIPS 4602 Feet

Legend

DRO Result / ORO Result

Result is above MTCA Method A CUL

Result is below MTCA Method A CUL

Result is below laboratory reporting limit

LNAPL observed, well not sampled

Approximate Lateral Extent of Dissolved Phase Diesel and/or Oil

Note:
1. Locations are approximate.
2. "Diesel" = Diesel-Range Organics.
   "Oil" = Oil-Range Organics.
3. MTCA Method A Cleanup levels for diesel- and oil-range organics (DRO and ORO) in groundwater is 500 micrograms per liter (µg/l).
4. Reconnaissance groundwater samples from 2012, 2014, 2016, and 2018 are shown. Samples from 2012 and 2014, and some samples from 2016, were analyzed with silica gel cleanup. Monitoring well sample results from August 2018 are shown.
5. Bold font indicates result reported above the laboratory reporting limit, blue font indicates result reported above the MTCA Method A CUL.

N

0 50 100

Scale: Feet

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Wishram, Washington

Groundwater Sampling Results DRO and ORO (2012 - 2018) - East Area

1696120.02
October 2021

Figure 14

Path: N:\BNSF Washington\Wishram\GIS\Events\2018Events\RevisedRIReport\Fig40_TPHDx_GW_total_Aug18_E_labels.mxd

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Coordinate System: NAD 1983 StatePlane Washington South FIPS 4602 Feet

Legend

- Total TPH-Dx Concentration Above MTCA Method A CUL
- Total TPH-Dx Concentration Below MTCA Method A CUL
- Total TPH-Dx Concentration Below Laboratory Reporting Limit
- LNAPL Observed, Well Not Sampled
- Approximate Lateral Extent of Dissolved Phase Diesel and/or Oil

Note:
1. Locations are approximate.
2. MTCA Method A Cleanup level (CUL) for total petroleum hydrocarbons (TPH) in groundwater is 500 micrograms per liter (µg/l).
3. Total TPH-Dx = Sum of diesel-range and oil-range organics results.
4. Reconnaissance groundwater samples from 2012, 2014, 2016, and 2018 are shown. Samples from 2012 and 2014, and some samples from 2016, were analyzed with silica gel cleanup. Monitoring well sample resutls from August 2018 are shown.
5. Bold font indicates result reported above the laboratory reporting limit, blue font indicates result reported above the MTCA Method A CUL.

N

0 50 100

Scale: Feet

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Wishram, Washington

Groundwater Sampling Results Total TPH-Dx (2012 - 2018) - East Area

1696120.02
October 2021

Figure 15

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Coordinate System: NAD 1983 StatePlane Washington South FIPS 4602 Feet

Legend

- Total TPH-Dx Concentration Above MTCA Method A CUL
- Total TPH-Dx Concentration Below MTCA Method A CUL
- Total TPH-Dx Concentration Below Laboratory Reporting Limit
- LNAPL Observed, Well Not Sampled

Note:
1. Locations are approximate.
2. MTCA Method A Cleanup level (CUL) for total petroleum hydrocarbons (TPH) in groundwater is 500 micrograms per liter (µg/l).
3. Total TPH-Dx = Sum of diesel-range and oil-range organics results.
4. Monitoring well sample results from August 2019 are shown.
5. Bold font indicates result reported above the laboratory reporting limit, blue font indicates result reported above the MTCA Method A CUL.

N

0 50 100

Scale: Feet

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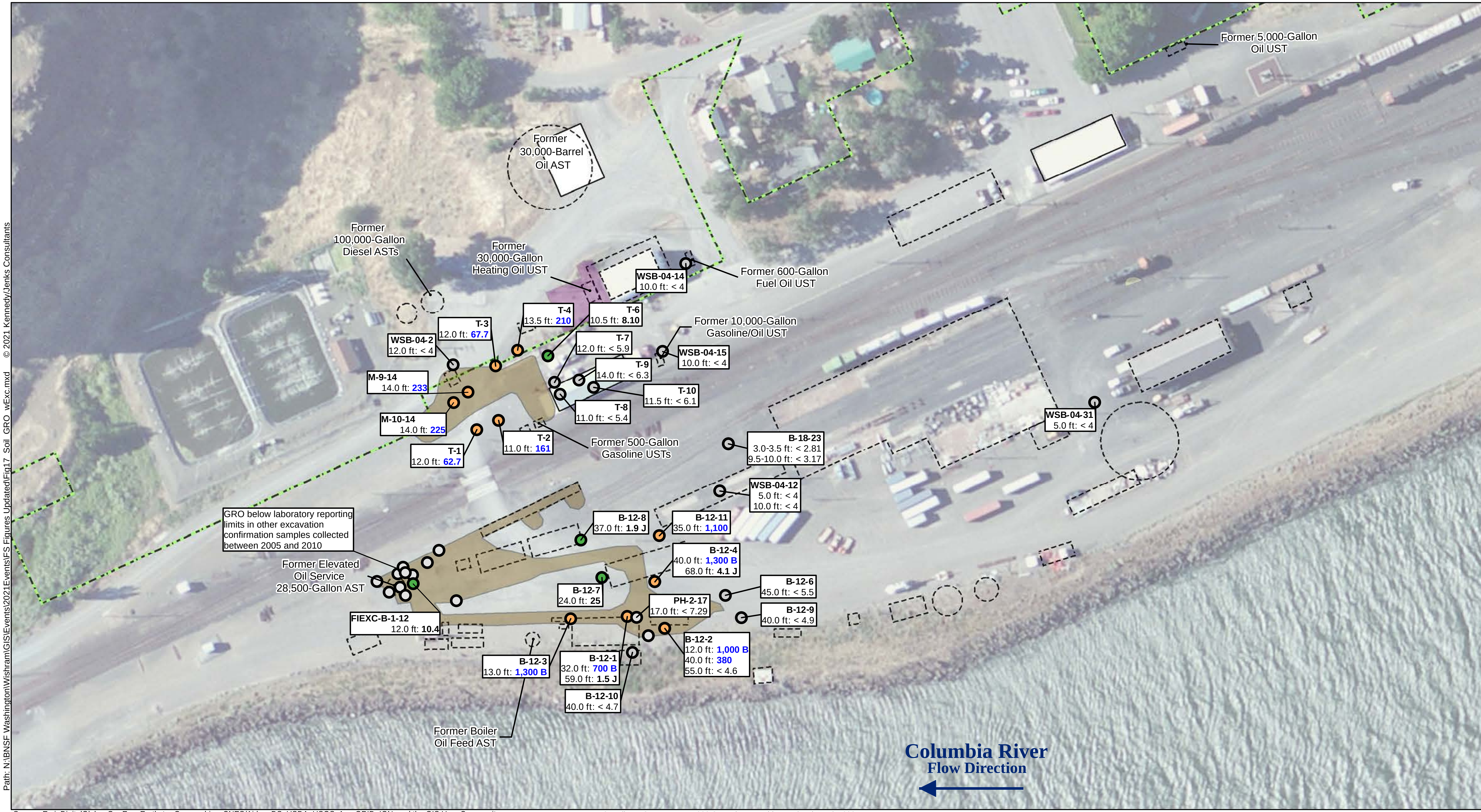
Wishram, Washington

Groundwater Sampling Results Total TPH-Dx (2019) - East Area

1696120.02
August 2020

Figure 16



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Coordinate System: NAD 1983 StatePlane Washington South FIPS 4602 Feet

Legend

- GRO Concentration Above MTCA Method A
- GRO Concentration Below MTCA Method A
- GRO Concentration Below Laboratory Reporting
- Approximate Previous Excavation Area
- Approximate Previous Excavation Area

Note:
1. Locations are approximate.
2. GRO = Gasoline-Range Organics.
3. Soil sample results from 2004 - 2018 are shown.
4. Only locations analyzed for GRO are shown.
5. Samples from areas later excavated are not shown.

N

0 50 100
Scale: Feet

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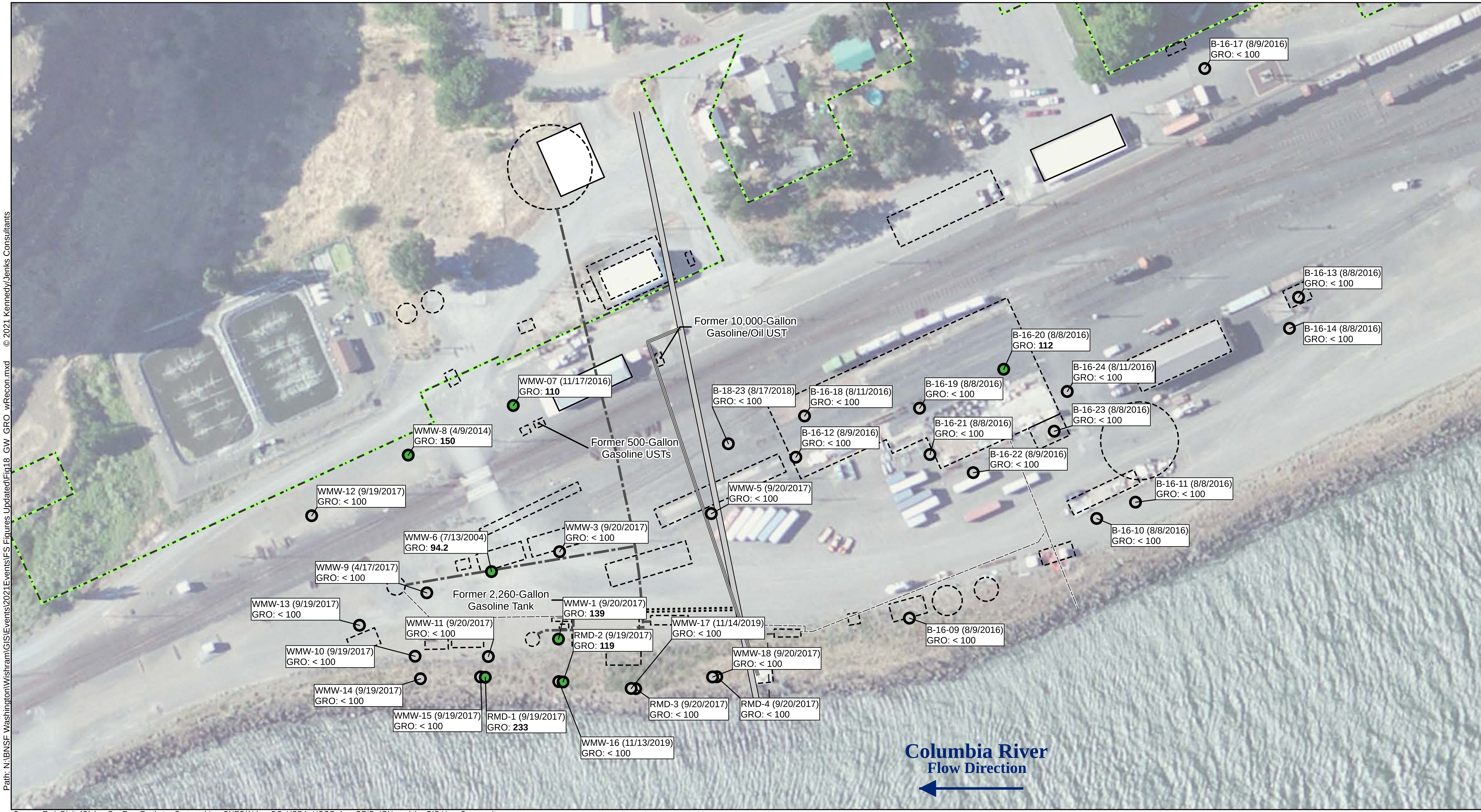
Wishram, Washington

Soil Sampling Results GRO (2004 - 2018) - Main Area

2196120*06
December 2021

Figure 17



Path: N:\BNSF Washington\Wishram\GIS\Events\2021Events\FS Figures Updated\Fig18_GW_GRO_wRecon.mxd © 2021 Kennedy/Jenks Consultants

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Coordinate System: NAD 1983 StatePlane Washington South FIPS 4602 Feet

Legend

- GRO Concentration Above MTCA Method A
- GRO Concentration Below MTCA Method A CUL
- GRO Concentration Below Laboratory Reporting Limit

Note:
1. Locations are approximate.
2. GRO = Gasoline-Range Organics.
3. Most recent monitoring well and reconnaissance groundwater sample results from 2004 through 2019 are shown.
4. Only locations analyzed for GRO are shown.
5. Results from up to eight previous sampling events are shown.

N

0 50 100

Scale: Feet

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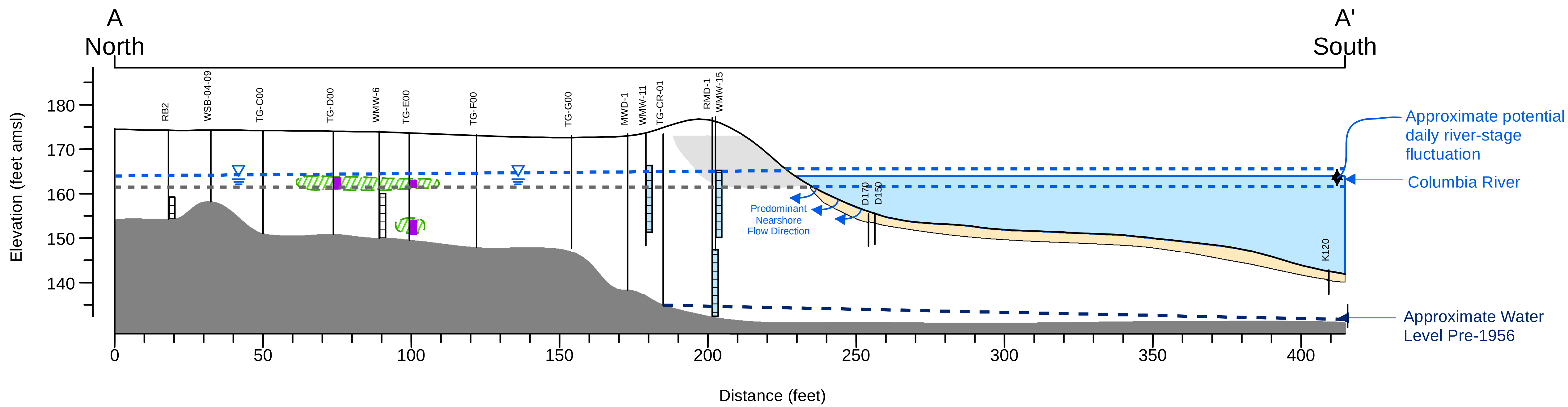
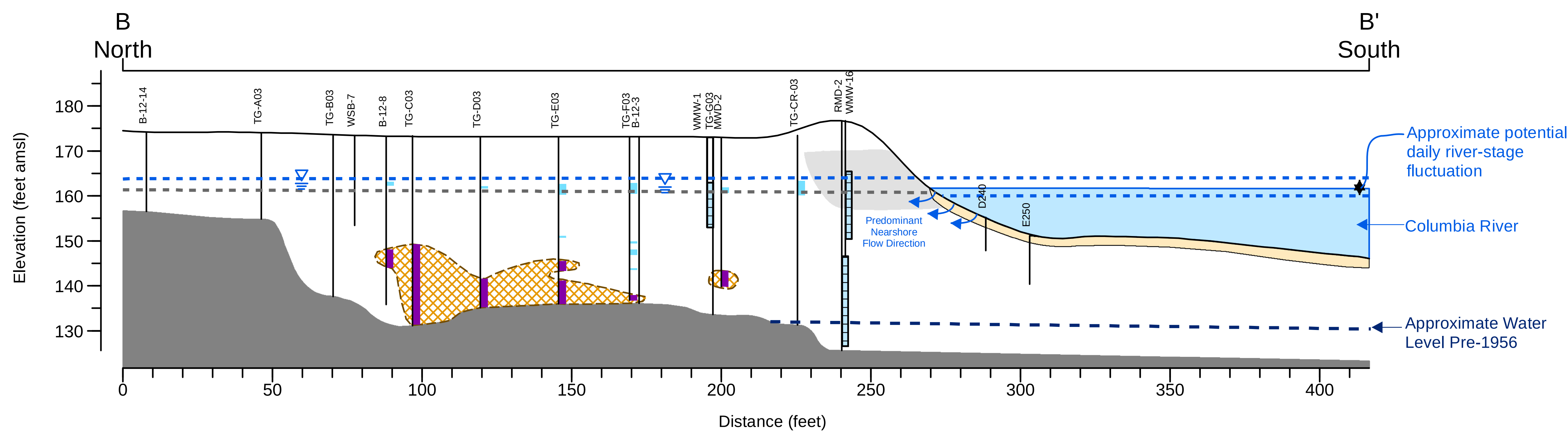
Wishram, Washington

Groundwater Sampling Results GRO (2004 - 2019) - Main Area

2196120*06
December 2021

Figure 18





Notes:
1. All locations and depths are approximate. Lithologic interpretation inferred from boring logs, historical documents, maps, and/or field observations.
2. AMSL = above mean sea level.
3. MTCA = Washington Model Toxics Control Act.
4. LNAPL = light non-aqueous phase liquid
5. TPH = total petroleum hydrocarbon
6. LIF = laser-induced fluorescence
7. Inferred LNAPL/residual TPH extent from interpretation of LIF waveforms and LNAPL field observations in soil borings.

Legend

- Inferred Maximum Measured Groundwater Elevation
- Inferred Minimum Measured Groundwater Elevation
- River Sediment (Interpreted)
- Columbia River

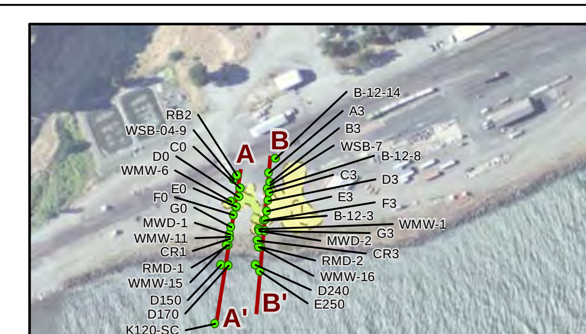
Lithology

- Gravelly Sand Fill Material
- Sand and Sand with Silt
- Gravel and Gravel with Sand
- Clay and Silty Clay
- Basalt Bedrock

- Well screen interval
- Well screen interval, blue shading indicates dissolved concentrations of diesel-range and/or oil-range organics in groundwater are above MTCA Method A cleanup levels (500 µg/L).

Inferred LNAPL/Residual TPH Extent

- Inferred Zone of Oil-like LNAPL
- Inferred Zone of Diesel-like LNAPL
- Inferred LNAPL in Boring
- Inferred Residual LNAPL in Boring

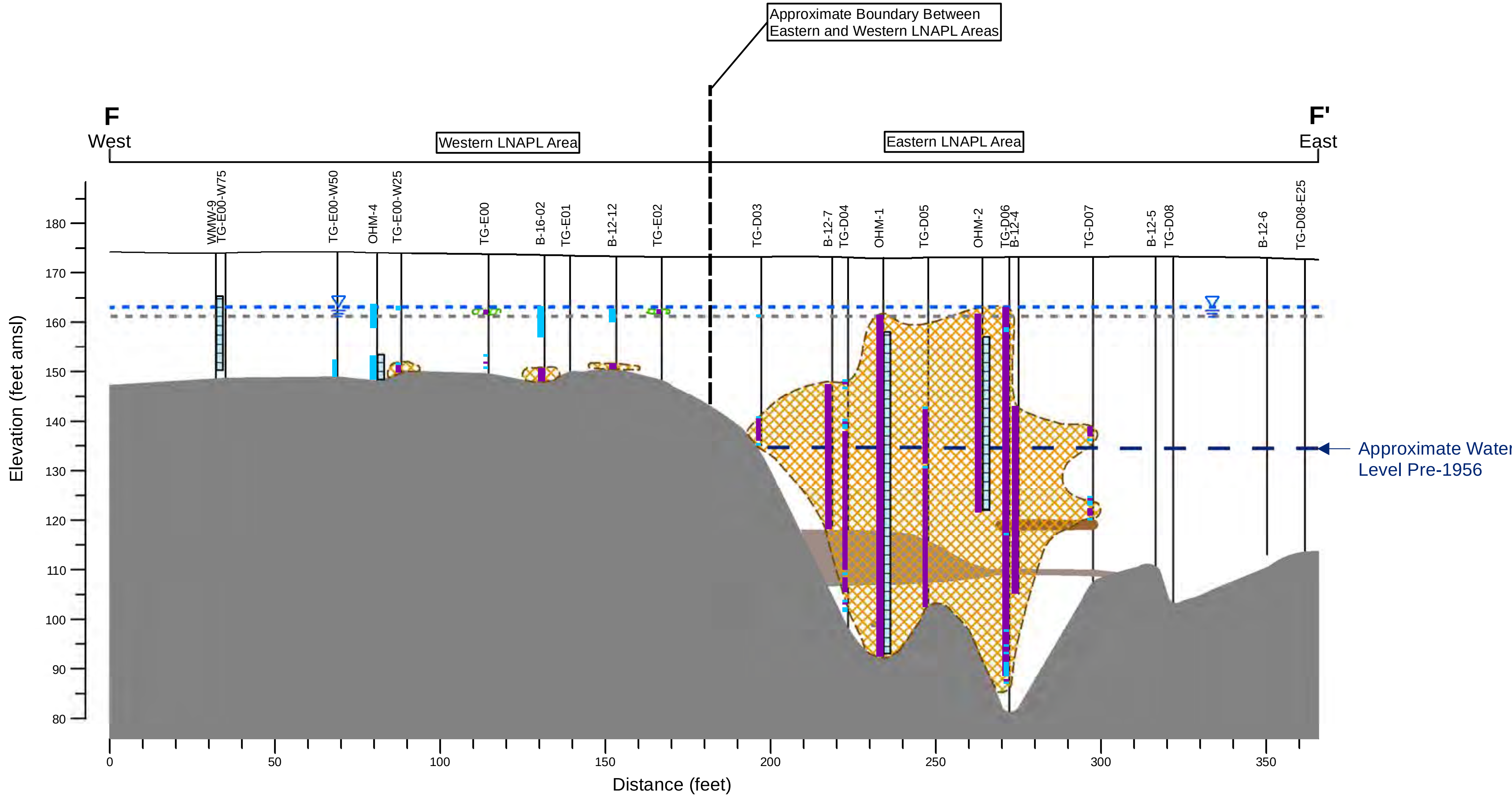


Kennedy/Jenks Consultants

BNSF Wishram Railyard
Wishram, Washington

Hydrogeologic Cross Section Transect A to A' and Transect B to B'

Figure 19



Notes:
1. All locations and depths are approximate. Lithologic interpretation inferred from boring logs, historical documents, maps, and/or field observations.
2. AMSL = above mean sea level.
3. MTCA = Washington Model Toxics Control Act
4. LNAPL = light non-aqueous phase liquid
5. TPH = total petroleum hydrocarbon
6. LIF = laser-induced fluorescence
7. Inferred LNAPL/residual TPH extent from interpretation of LIF waveforms and LNAPL field obervations in soil borings.

Legend

- Inferred Maximum Measured Groundwater Elevation
- Inferred Minimum Measured Groundwater Elevation
- River Sediment (Interpreted)
- Columbia River

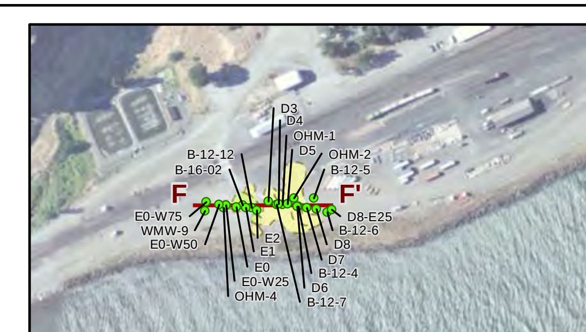
Lithology

- Gravelly Sand Fill Material
- Sand and Sand with Silt
- Gravel and Gravel with Sand
- Clay and Silty Clay
- Basalt Bedrock

- Well screen interval
- Well screen interval, blue shading indicates dissolved concentrations of diesel-range and/or oil-range organics in groundwater are above MTCA Method A cleanup levels (500 µg/L).

Inferred LNAPL/Residual TPH Extent

- Inferred Zone of Oil-like LNAPL
- Inferred Zone of Diesel-like LNAPL
- Inferred LNAPL in Boring
- Inferred Residual LNAPL in Boring



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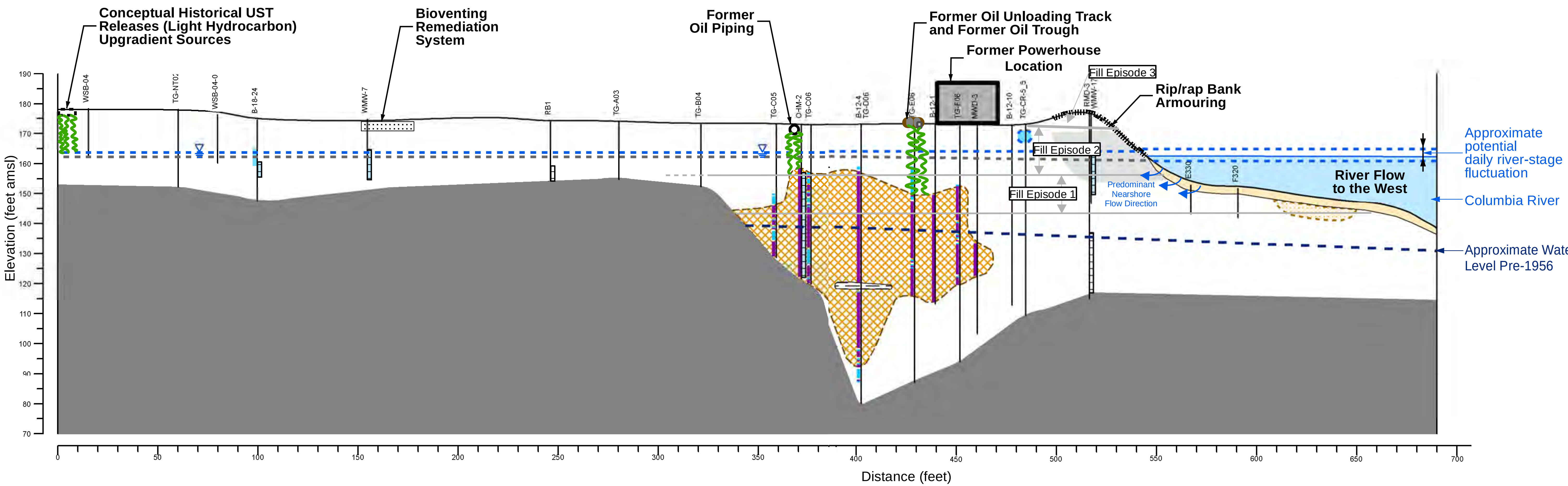
BNSF Wishram Railyard
Wishram, Washington

Hydrogeologic Cross Section Transect F to F'

Figure 20



Notes:

1. All locations and depths are approximate. Lithologic interpretation inferred from boring logs, historical documents, maps, and/or field observations.
2. AMSL = above mean sea level.
3. MTCA = Washington Model Toxics Control Act
4. LNAPL = light non-aqueous phase liquid
5. TPH = total petroleum hydrocarbon
6. LIF = laser-induced fluorescence
7. Inferred LNAPL/residual TPH extent from interpretation of LIF waveforms and LNAPL field observations in soil borings.

Legend

- Inferred Maximum Measured Groundwater Elevation
- Inferred Minimum Measured Groundwater Elevation
- River Sediment (Interpreted)
- Columbia River

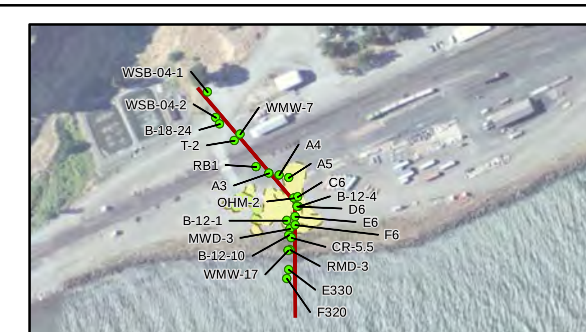
Lithology

- Gravelly Sand Fill Material
- Sand and Sand with Silt
- Gravel and Gravel with Sand
- Clay and Silty Clay
- Basalt Bedrock

- Well screen interval
- Well screen interval, blue shading indicates dissolved concentrations of diesel-range and/or oil-range organics in groundwater are above MTCA Method A cleanup levels (500 µg/L).

Inferred LNAPL/Residual TPH Extent

- Shallow Soil Diesel/Oil Impacts
- Inferred Zone of Oil-like LNAPL
- Inferred Zone of Oil-like LNAPL (Inundated Lands)
- Inferred LNAPL in Boring
- Inferred Residual TPH in Boring

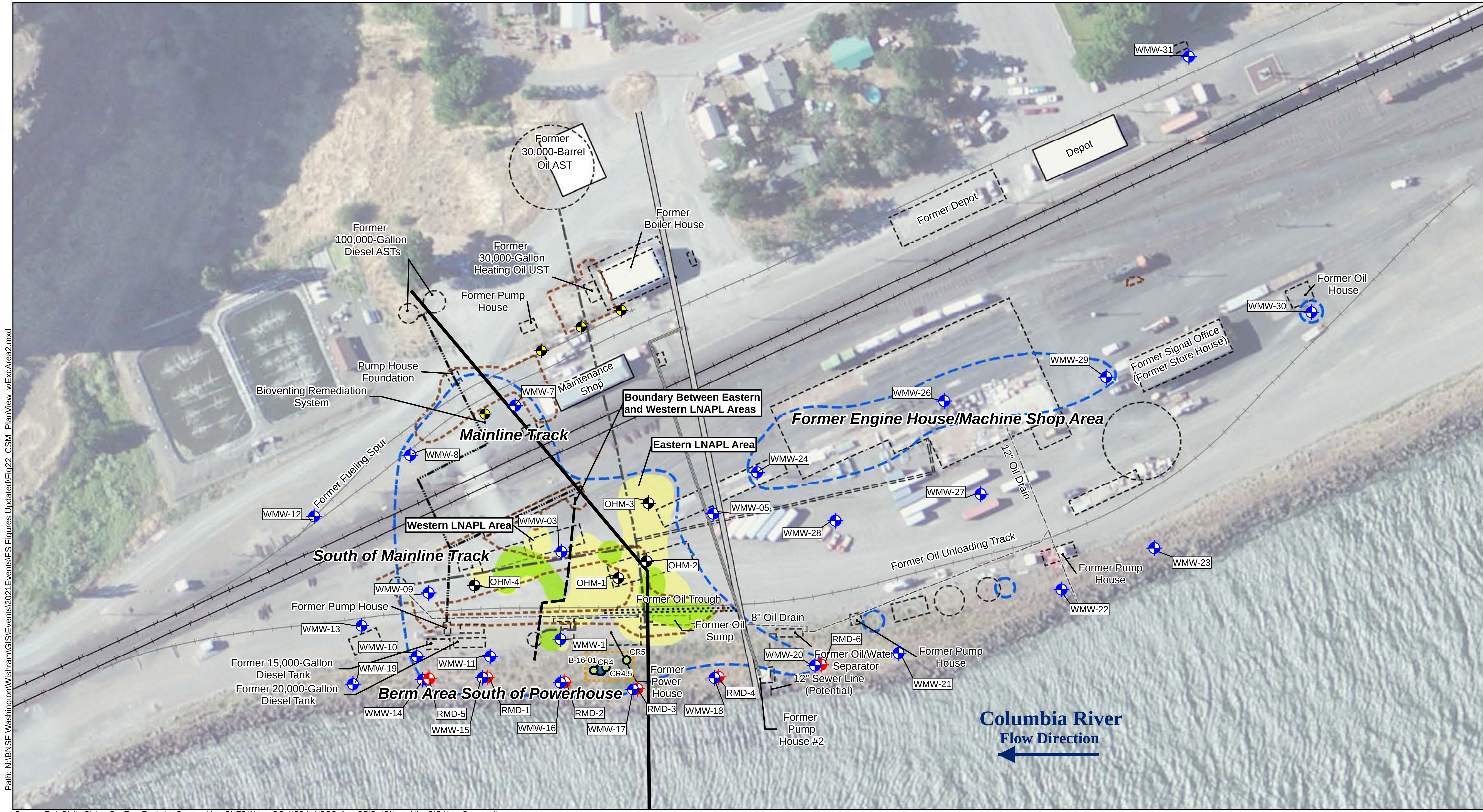


Kennedy/Jenks Consultants

BNSF Wishram Railyard
Wishram, Washington

Conceptual Site Model

Figure 21



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Coordinate System: NAD 1983 StatePlane Washington South FIPS 4602 Feet

Legend

- Former Bunker Fuel / Oil Pipeline
- Former Oil Drain
- Former Oil Trough
- Former Sewer Line (Potential)
- Stormwater Underdrain
- Stormwater Underdrain
- Former Diesel Line
- Former Steam Line
- Existing Site Feature
- Former Site Feature
- Approximate Lateral Extent of Submerged Diesel and/or Oil Impacts
- Approximate Lateral Extent of Smear Zone Diesel and/or Oil Impacts
- Approximate Lateral Extent of Dissolved Phase Diesel and/or Oil Impacts Above MTCA Method A CUL
- Approximate Previous Excavation Areas (2002-2010)
- Soil Boring
- LIF Location
- Shallow Berm Excavation
- CSM Cross Section Line

Note:
1. Locations are approximate.

N

0 50 100
Scale: Feet

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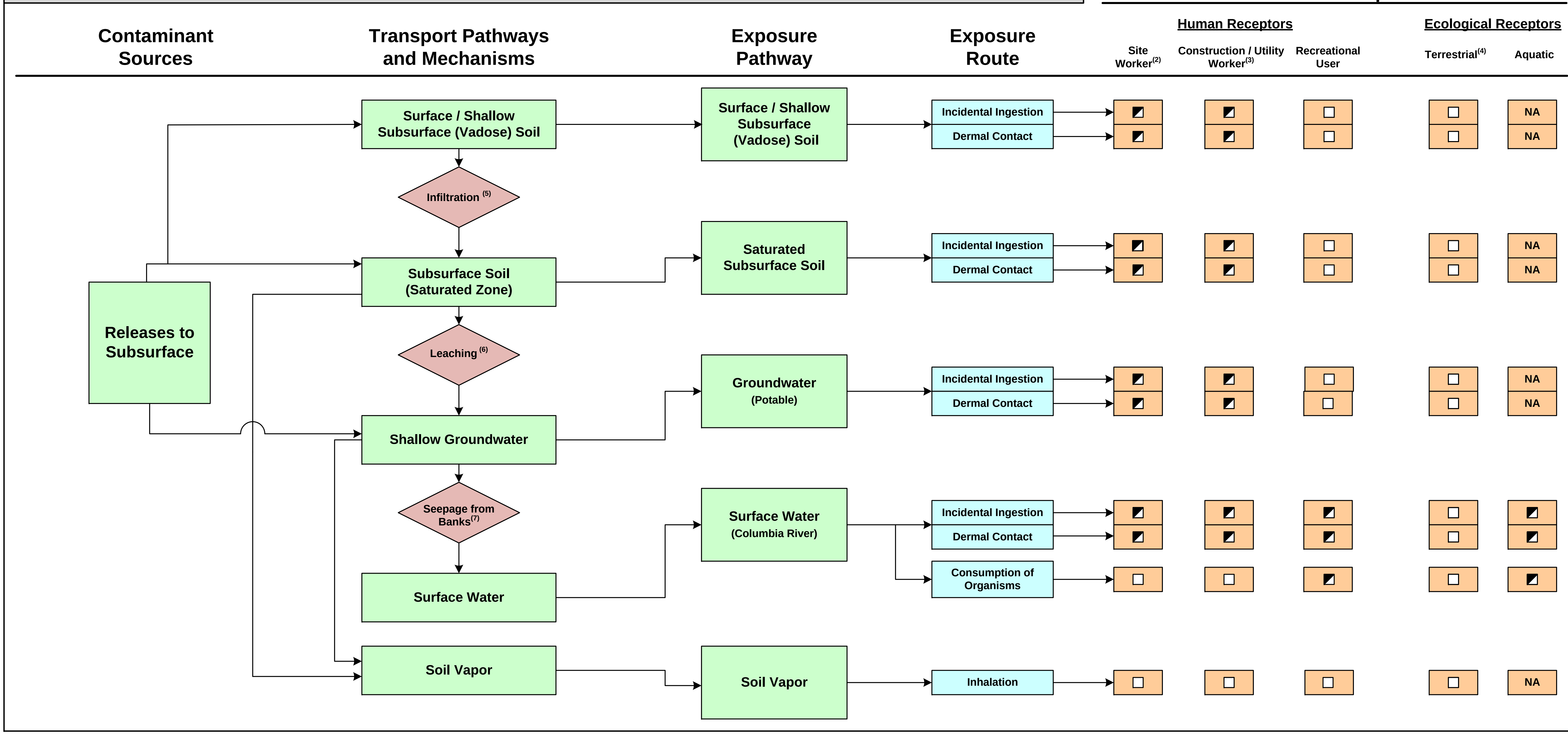
BNSF Wishram Railyard
Wishram, Washington

Conceptual Site Model (CSM) Plan View Map

2196120*06
December 2021

Figure 22

Conceptual Site Exposure Model based on Current Site Uses and Conditions [1]



Legend:

- ■ Complete exposure pathway.
- □ Incomplete exposure pathway.
- ◩ Potentially complete exposure pathway or insufficient information.
- NA Exposure pathway considered not applicable for the listed receptors.

Notes:

1. Potential exposure pathways may differ after remediation and/or redevelopment of the site.
2. Onsite employees performing routine tasks.
3. Onsite construction and/or utility workers performing invasive activities; workers performing environmental investigation or sampling activities.
4. Based on the Terrestrial Ecological Evaluation performed for the site.
5. Precipitation and infiltration through vadose soil to shallow groundwater.
6. Leaching of contaminants in soil to groundwater and downgradient dissolved-phase transport in shallow groundwater.
7. Seepage from groundwater to surface water along bank area adjacent to the Columbia River. This is expected to be minimal as the river is a losing stream approximately 10 months a year.

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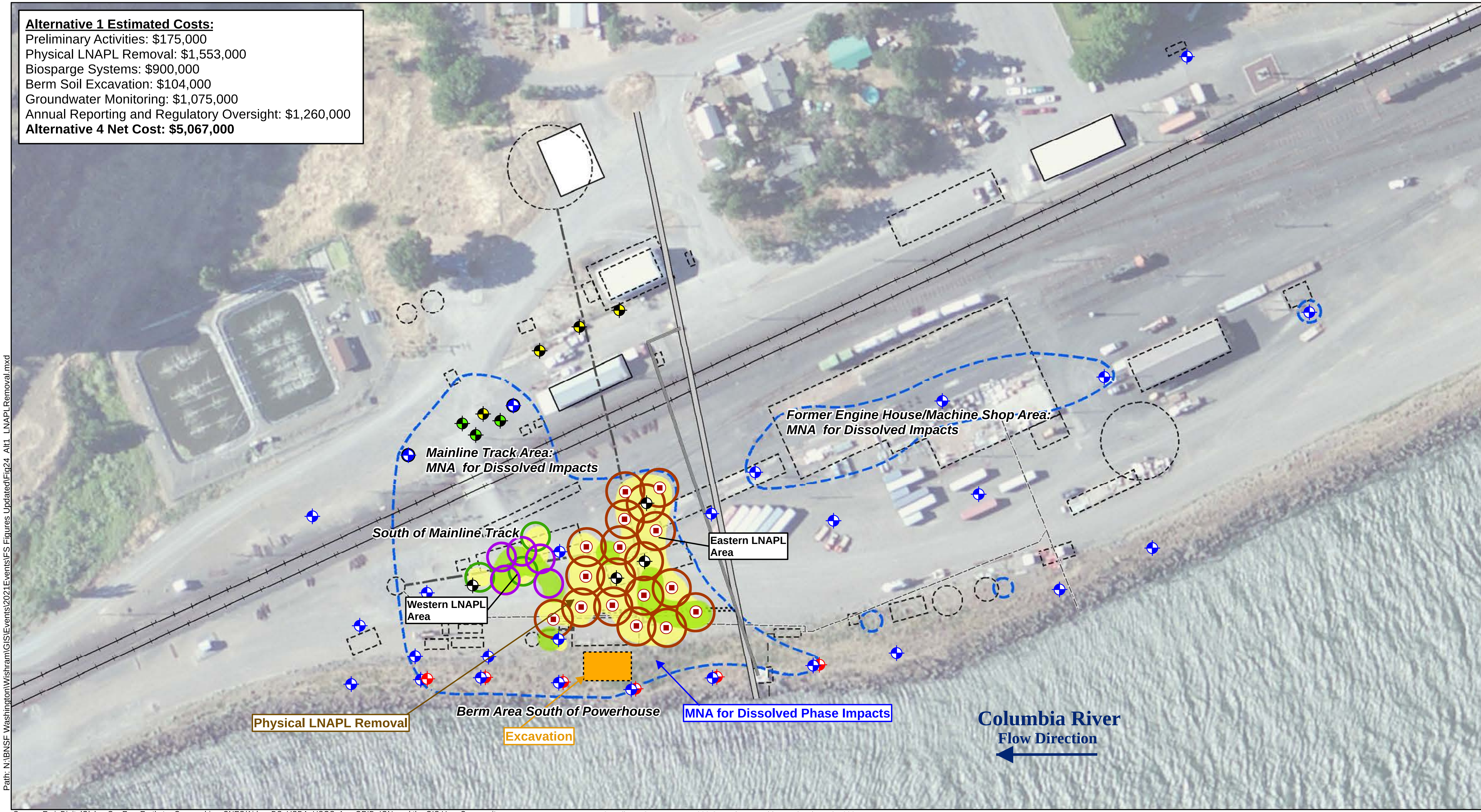
Wishram, Washington

Conceptual Site Exposure Model Diagram

2196120.00
December 2021

Figure 23



Path: N:\BNSF Washington\Wishram\GIS\Events\2021Events\FS Figures Updated\Fig24_Alt1_LNAPLRemoval.mxd

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Coordinate System: NAD 1983 StatePlane Washington South FIPS 4602 Feet

Legend

- Shallow Monitoring Well
- Deep Monitoring Well
- Oil Head Monitoring Well
- Bioventing Injection Well
- Air Sparge (AS) Well
- Former Bunker Fuel / Oil Pipeline
- Former Oil Drain
- Former Oil Trough
- Former Sewer Line (Potential)
- Stormwater Underdrain
- Stormwater Underdrain
- Existing Site Feature
- Former Site Feature
- Approximate Lateral Extent of Dissolved Phase Diesel and/or Oil Impacts Above MTCA Method A CUL
- Inferred Lateral Extent of Submerged Diesel and/or Oil Impacts
- Inferred Lateral Extent of Smear Zone Diesel and/or Oil Impacts
- Shallow Berm Excavation
- Proposed LNAPL Removal Well
- Shallow Biosparge Well: 15 foot ROI
- Paired Shallow and Deep Biosparge Well: 15 foot ROI
- LNAPL Removal Well: 20 foot ROI

Notes:
1. Locations are approximate.
2. MNA = monitored natural attenuation; LNAPL = light non-aqueous phase liquid.

N

0 50 100

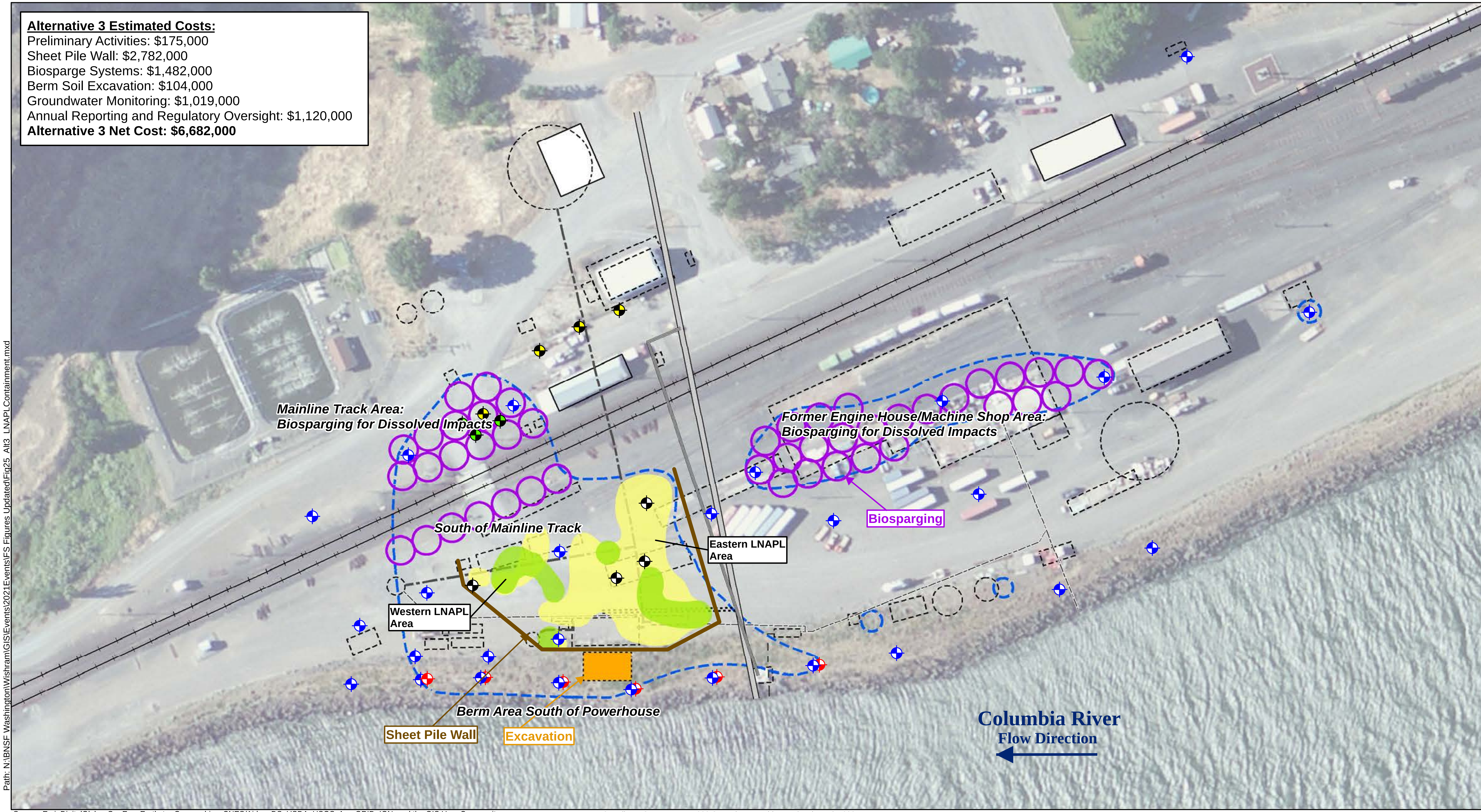
Scale: Feet

Kennedy/Jenks Consultants

BNSF Wishram Railyard
Wishram, Washington

Alternative 1:
Physical LNAPL Removal, Focused Biosparge, MNA, and Targeted Excavation

Figure 24



Path: N:\BNSF Washington\Wishram\GIS\Events\2021Events\FS Figures Updated\Fig25_Alt3_LNAPLContainment.mxd

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Coordinate System: NAD 1983 StatePlane Washington South FIPS 4602 Feet

Legend

- Shallow Monitoring Well
- Deep Monitoring Well
- Oil Head Monitoring Well
- Bioventing Injection Well
- Air Sparge (AS) Well
- Former Bunker Fuel / Oil Pipeline
- Former Oil Drain
- Former Oil Trough
- Former Sewer Line (Potential)
- Stormwater Underdrain
- Stormwater Underdrain
- Existing Site Feature
- Former Site Feature
- Approximate Lateral Extent of Dissolved Phase Diesel and/or Oil Impacts Above MTCA Level A CUL
- Inferred Lateral Extent of Submerged Diesel and/or Oil Impacts
- Inferred Lateral Extent of Smear Zone Diesel and/or Oil Impacts
- Sheet Pile Wall
- Shallow Berm Excavation
- Shallow Biosparge Well: 15 foot ROI

Notes:
1. Locations are approximate.
2. MNA = monitored natural attenuation

N

0 50 100

Scale: Feet

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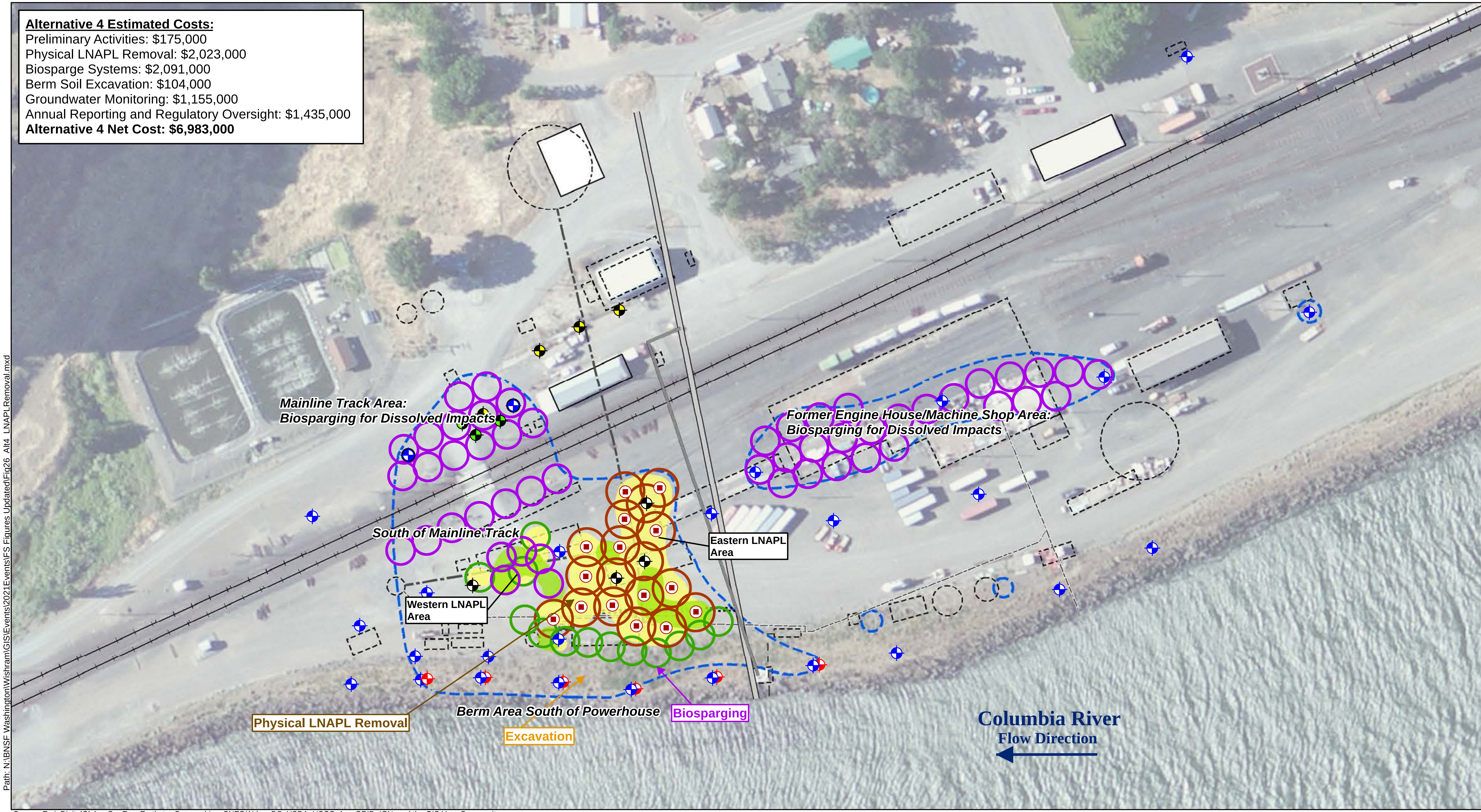
Alternative 3:
LNAPL Containment, Biosparge, MNA, and Targeted Excavation

Figure 25



Path: N:\BNSF Washington\Wishram\GIS\Events\2021Events\FS Figures Updated\Fig26_Alt4_LNAPLRemoval.mxd

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Coordinate System: NAD 1983 StatePlane Washington South FIPS 4602 Feet

Legend

- Shallow Monitoring Well
- Deep Monitoring Well
- Oil Head Monitoring Well
- Bioventing Injection Well
- Air Sparge (AS) Well
- Former Bunker Fuel / Oil Pipeline
- Former Oil Drain
- Former Oil Trough
- Former Sewer Line (Potential)
- Stormwater Underdrain
- Stormwater Underdrain
- Existing Site Feature
- Former Site Feature
- Approximate Lateral Extent of Dissolved Phase Diesel and/or Oil Impacts Above MTCA Method A CUL
- Inferred Lateral Extent of Submerged Diesel and/or Oil Impacts
- Inferred Lateral Extent of Smear Zone Diesel and/or Oil Impacts
- Shallow Berm Excavation
- Proposed LNAPL Removal Well
- Shallow Biosparge Well: 15 foot ROI
- Paired Shallow and Deep Biosparge Well: 15 foot ROI
- LNAPL Removal Well: 20 foot ROI

Notes:
1. Locations are approximate.
2. MNA = monitored natural attenuation; LNAPL = light non-aqueous phase liquid.

N

0 50 100

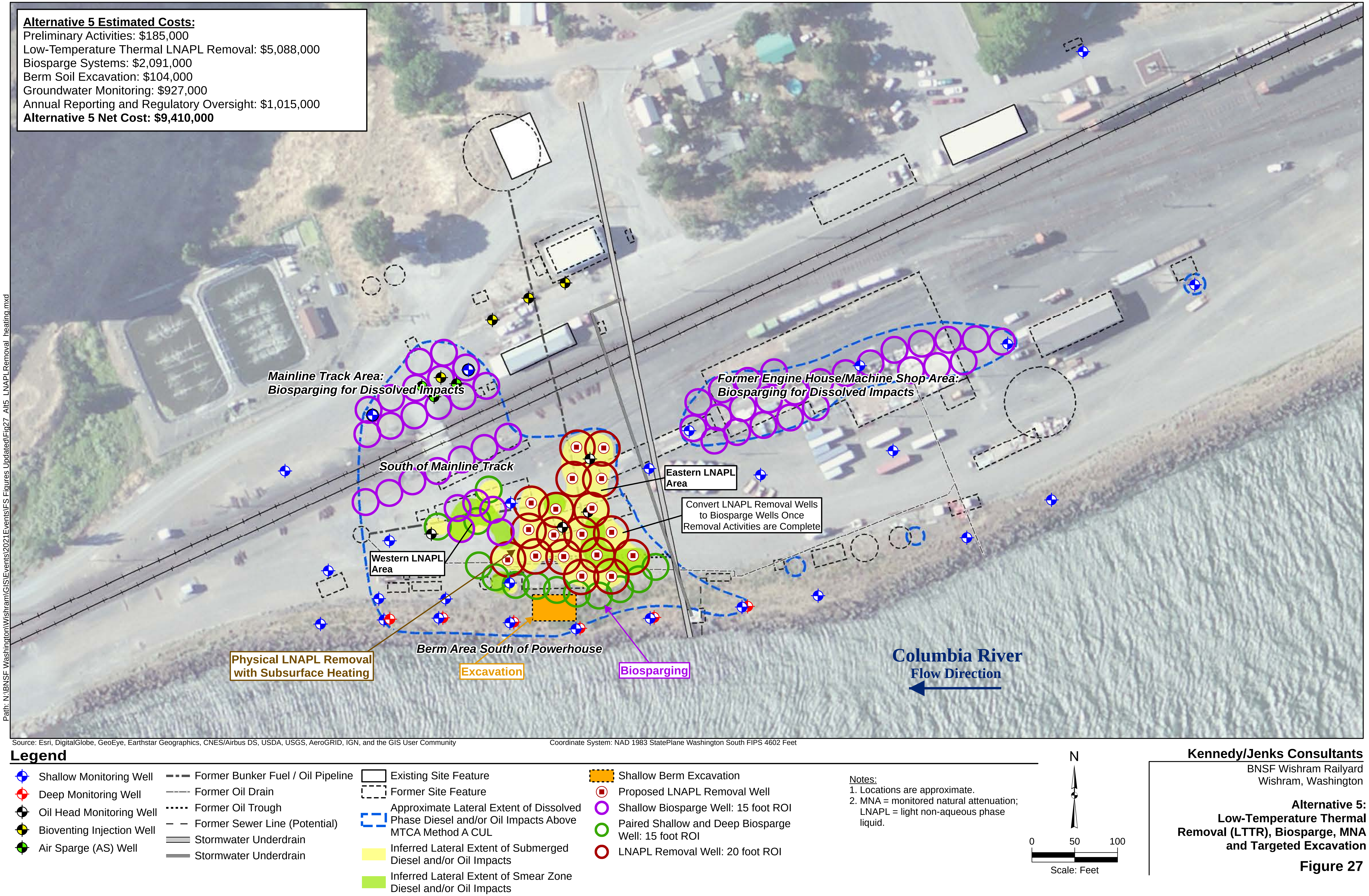
Scale: Feet

Kennedy/Jenks Consultants

BNSF Wishram Railyard
Wishram, Washington

Alternative 4:
Physical LNAPL Removal, Biosparge, MNA, and Targeted Excavation

Figure 26



Alternative 5 Estimated Costs:
Preliminary Activities: $185,000
Low-Temperature Thermal LNAPL Removal: $5,088,000
Biosparge Systems: $2,091,000
Berm Soil Excavation: $104,000
Groundwater Monitoring: $927,000
Annual Reporting and Regulatory Oversight: $1,015,000
Alternative 5 Net Cost: $9,410,000
Mainline Track Area: Biosparging for Dissolved Impacts
Former Engine House/Machine Shop Area: Biosparging for Dissolved Impacts
South of Mainline Track
Eastern LNAPL Area
Convert LNAPL Removal Wells to Biosparge Wells Once Removal Activities are Complete
Western LNAPL Area
Berm Area South of Powerhouse
Physical LNAPL Removal with Subsurface Heating
Excavation
Biosparging
Columbia River
Flow Direction
Path: N:\BNSF Washington\Wishram\GIS\Events\2021Events\FS Figures Updated\Fig27_Alt5_LNAPLRemoval_heating.mxd
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
Coordinate System: NAD 1983 StatePlane Washington South FIPS 4602 Feet
Legend
Shallow Monitoring Well
Deep Monitoring Well
Oil Head Monitoring Well
Bioventing Injection Well
Air Sparge (AS) Well
Former Bunker Fuel / Oil Pipeline
Former Oil Drain
Former Oil Trough
Former Sewer Line (Potential)
Stormwater Underdrain
Stormwater Underdrain
Existing Site Feature
Former Site Feature
Approximate Lateral Extent of Dissolved Phase Diesel and/or Oil Impacts Above MTCA Method A CUL
Inferred Lateral Extent of Submerged Diesel and/or Oil Impacts
Inferred Lateral Extent of Smear Zone Diesel and/or Oil Impacts
Shallow Berm Excavation
Proposed LNAPL Removal Well
Shallow Biosparge Well: 15 foot ROI
Paired Shallow and Deep Biosparge Well: 15 foot ROI
LNAPL Removal Well: 20 foot ROI
Notes:
1. Locations are approximate.
2. MNA = monitored natural attenuation; LNAPL = light non-aqueous phase liquid.
N
0 50 100
Scale: Feet
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Wishram, Washington
Alternative 5: Low-Temperature Thermal Removal (LTTR), Biosparge, MNA and Targeted Excavation
Figure 27

Appendix A

Summary of Bioventing and NSZD Testing Field Work and Hydraulic Gradient Monitoring

Summary of Bioventing and NSZD Testing Field Work

Summary of Bioventing and NSZD Testing Field Work

BNSF Wishram Railyard

Kennedy/Jenks Consultants, Inc. (KJ) has prepared this summary to document the results from bioventing and natural source zone depletion (NSZD) testing field work conducted in 2019 at the BNSF Wishram Railyard (site) located in Wishram, Washington. The railyard and historical site features are shown on Figure A1.

A1. Background

On 18 July 2019, Washington State Department of Ecology (Ecology) granted conditional approval of the *LNAPL Transmissivity, Bioventing Respirometry and NSZD Testing Work Plan* (Work Plan) submitted by BNSF. The final Work Plan was submitted to Ecology on 30 September 2019. Field work associated with the Work Plan was substantially conducted between July 2019 and September 2019.

The objectives of the field activities in the Work Plan were to 1) evaluate transmissivity of light non-aqueous phase liquid (LNAPL), 2) assess the performance of the existing bioventing system operating in the vicinity of the Maintenance Shop, 3) assess potential for bioventing in the vicinity of the submerged LNAPL south of the mainline, and 4) evaluate occurrence of NSZD. The procedures and results from the LNAPL transmissivity baildown tests were summarized in the *Uplands Remedial Investigation Report* (Uplands RI Report, KJ 2020). The results from the remaining activities are presented below.

A2. Bioventing Respirometry and NSZD Evaluation

Bioventing and NSZD evaluations were performed using several approaches to demonstrate and quantify biological degradation of hydrocarbons in the vadose and smear zones using multiple lines of evidence.

- A respirometry test in the vicinity of the existing bioventing system near the Maintenance Shop (north of the mainline tracks) was performed to compare conditions during and following operation and to evaluate performance.

- Soil gas measurements were collected from test and monitoring wells at multiple locations across the site, as shown on Figure A2, to evaluate current conditions.

- A bioventing injection test was performed south of the mainline tracks, near the submerged LNAPL (Submerged LNAPL area) (Figure A2). Test activities included 1) baseline soil gas measurements from select monitoring wells, 2) an air injection test to approximate system ROI, and 3) a respirometry test (following the injection test).

- Carbon traps were deployed at locations shown on Figure A2 and analyzed to evaluate NSZD using CO_2 flux related to hydrocarbon degradation.

Testing methods and results from each evaluation element are presented below followed by overall conclusions based on the combined lines of evidence.

A3. Soil Gas Measurement Methods

A common component of the bioventing and NSZD evaluations was the collection of soil gas measurements from test and monitoring wells. Measurements included oxygen (O_2), carbon dioxide (CO_2), hydrogen sulfide, methane (CH_4), and volatile organic compounds (VOCs). An RKI Eagle 2 multi-gas meter was used for soil gas measurements. Soil gas VOC concentrations were measured using a photoionization detector (PID). Monitoring wells were fitted with vapor monitoring well plugs or modified well caps with barbed fittings at least 1 day prior to soil gas measurements. Measurements were collected using the low purge volume well head method (Sweeney and Ririe 2017).

A4. Existing Bioventing System – Respirometry Test

A bioventing system operated between June 2012 and July 2019 to address residual petroleum hydrocarbons in soil north of the mainline tracks near the Maintenance Shop. The bioventing system operated by injecting ambient air into the unsaturated zone through four wells (SVE-12-1 through SVE-12-4) (Figure A2). The bioventing system operated in continuous mode (24 hours a day, 7 days a week) between June 2012 and April 2017, when the system blower failed. The blower was replaced on 28 November 2017, and continuous operation of the bioventing system was restarted. System operational data collected between November 2017 and May 2019 were summarized in the Work Plan, including an estimated radius of influence (ROI) of the system of 90 feet, based on measurements of induced pressures in wells WMW-7 and WMW-8, near injection well SVE-12-1 (see Figure A3).

The bioventing system was shut down on 24 July 2019 at 9:00 AM in preparation for the respirometry test. Immediately prior to system shutdown, soil gas (oxygen, carbon dioxide, hydrogen sulfide, and methane) and VOCs measurements were collected from injection wells SVE-12-1 through SVE-12-4 and monitoring wells WMW-7, WMW-8, and WMW-12. Wells SVE-12-1 through SVE-12-4 and monitoring wells WMW-7 and WMW-8 are located within the system's estimated ROI of 90 feet. Monitoring well WMW-12 is not located within the ROI but was included to provide background data for comparison. Soil gases were measured using the meters and methods described above. Soil gas measurements were collected at increasing time intervals following system shutdown through 29 July 2019 [approximately 122 hours (5 days) after shutdown] with an additional round of data collected on 8 August 2019 [approximately 369 hours (15 days) after shutdown]. Soil gas measurements are included in Table A1.

Respirometry test results were evaluated to estimate biodegradation rates based on oxygen utilization rates as described in Leeson and Hinchee (1996). Soil gas measurements from injection wells SVE-12-1 through SVE-12-4 and monitoring wells WMW-7, WMW-8, and WMW-12 indicated that oxygen levels remained high and carbon dioxide levels remained low for over 2 weeks after the system was shut off. Table A1 includes soil gas measurements from, well WMW-3 (located south of the mainline tracks outside of the pressure ROI), as a decrease in oxygen levels was observed between 26 July and 8 August.

Biodegradation rates (K_b) were calculated based on oxygen utilization rates (K_o) provided in Table A1. K_b values were calculated using the following equation (Leeson and Hinchee1996):

$$K_b = (- K_o /100) * (\theta_a * \rho O_2 * C /\rho_k)$$

Wherein:

θ_a = air-filled porosity = 0.32 for sand, assuming an effective porosity of 0.37 and residual water content of 0.05.

ρO_2= O_2 density = 1,365 milligrams per liter (mg/L), assuming standard temperature and pressure.

C = hydrocarbon to O_2 ratio = 0.2888, assuming a hydrocarbon molecular weight (MW) based on the hexadecane equivalent (MW = 226) (Leeson and Hinchee 1996).

ρ_k = soil dry bulk density = 1.6 grams per cubic centimeter (g/cm^3), sand.

The calculated average biodegradation rate was 0.065 mg hexadecane-equivalent/kg/day, and the calculated average oxygen utilization rate was 0.082 percent per day (%/day) (Table A1). According to the U.S. Environmental Protection Agency (EPA) (1995) bioventing design guidance documents, oxygen utilization rates greater than 1.0 %/day indicate bioventing may be feasible at a given site. Based on the respirometry test results, with an average calculated oxygen utilization rate more than an order of magnitude less than 1.0 %/day, the subsurface environment is sufficiently oxygenated for aerobic biodegradation to occur, and bioventing is no longer necessary in this area. The bioventing system remained off following the respirometry testing in July 2019.

A5. Sitewide Soil Gas Results

Soil gas conditions were measured in the Maintenance Shop, Submerged LNAPL, and former Engine House/Machine Shop areas without the influence of the existing bioventing system (shutdown 15 days earlier) on 8 August 2019 and are presented in Table A2 and on Figure A4. Measurements included oxygen, carbon dioxide, hydrogen sulfide, methane and VOCs using the methods described above.

Oxygen concentrations were generally between 19 and 20.9% oxygen, except for well WMW-3, which contained 18.1% oxygen. Carbon dioxide concentrations were generally less than 1%, other than wells WMW-3 and WMW-9, which contained 2.9% and 1.5% carbon dioxide, respectively. Methane and hydrogen sulfide concentrations were 0% of the lower explosive limit (LEL) and 0 parts per million (ppm), respectively, in the wells measured. VOC concentrations ranged from 0.10 ppm (well WMW-1) to 1.90 ppm (well WMW-29). Soil gas data indicate that the vadose zone contains oxygen at near-atmospheric concentrations, and limited or no carbon dioxide. These results further indicate that bioventing is no longer necessary in the Maintenance Shop area, as oxygen concentrations remained high (approximately 20%) 15 days after system shutdown, and that bioventing is not necessary to increase vadose zone oxygen concentrations in other site areas.

A6. Submerged LNAPL Area Bioventing Injection and Respirometry Tests

A bioventing injection test was performed south of the mainline tracks, near submerged LNAPL areas (Figure A2) in August 2019. Test activities included 1) an initial soil gas survey of select monitoring wells, 2) an air injection test to approximate system ROI, and 3) a respirometry test (following the injection test).

Monitoring well WMW-11 was used as the bioventing injection test well due to the availability of open screen interval above the groundwater table (approximately 4 feet), proximity to inferred LNAPL and residual total petroleum hydrocarbon (TPH) impacts, presence of dissolved phase TPH concentrations above MTCA Method A CULs, proximity to other monitoring wells, and its location in a limited traffic and easy access area.

An air injection test was performed at well WMW-11 to assess air injection into the formation and the optimum injection flow rate for the multi-day injection test. A regenerative blower was used to apply four different injection flow rates for approximately 1 hour each: approximately 16 standard cubic feet per minute (scfm), 20 scfm, 31 scfm, and 35 scfm. Induced pressure responses were measured in wells located in the vicinity of WMW-11: WMW-1, WMW-3, WMW-10, WMW-14, WMW-15, WMW-16, and WMW-17. Pressure response was measured in the wells identified above at approximately 30-minute intervals during the step tests with a differential pressure gage.

After the completion of step testing, a 30-hour continuous injection test was conducted at well WMW-11 using an injection rate of approximately 35 scfm as identified during the step testing. A portable generator was used to supply power to the injection blower during the test. The injection test was shut down on 28 August 2019 and soil gas measurements were collected at increasing time intervals through 31 August 2019 [approximately 64 hours (2.6 days) after shutdown].

A.6.1. Injection Test Results

Pressure responses greater than 0.1 inches of water were measured in wells WMW-11 (injection well) and well WMW-15 during the injection step testing. Pressure responses greater than 0.001 inches of water, but less than 0.1 inches of water were observed in wells WMW-10, WMW-14, WMW-16, and WMW-17 during the injection tests. The calculated ROI from well WMW-11 ranged from 38 feet during the 20 cfm step test to 48 feet during the 31 cfm step test. During the 30-hour step test at 35 cfm, a ROI of 47 feet was calculated (Figure A4). Results from the injection step tests are presented in Table A3, and a summary of the injection test results is presented in Table A5.

A.6.2. Respirometry Test Results

In the submerged LNAPL area, baseline soil gas oxygen concentrations (measured prior to the air injection test) were high (19 to 20% oxygen) and carbon dioxide concentrations were low (less than 1%). Respirometry test results did not show a significant change in soil gas concentrations in the wells monitored (see Table A3). Wells WMW-10, WMW-11, WMW-14, and

WMW-16 displayed a slight increase in oxygen concentrations and a slight decrease in carbon dioxide concentrations following the bioventing injection test.

The calculated average biodegradation rate was 0.05 mg hexadecane-equivalent/kg/day, and the average calculated oxygen utilization rate was 0.06 %/day as shown in Table A4. The results from the baseline soil gas measurement and bioventing and respirometry testing, with a calculated average oxygen utilization rate significantly lower than the 1.0 %/day criteria, indicate bioventing does not enhance biological degradation in the tested area.

A.6.3. Bioventing Tests Summary

Results from the respirometry test performed near the existing bioventing system in the Maintenance Shop area and the injection and respirometry test performed in the vicinity of the submerged LNAPL area are summarized in Table A5. The calculated injection ROIs in both site areas (approximately 90 feet in the Maintenance Shop area and approximately 47 feet in the submerged LNAPL area) indicate the vadose zone lithology is suitable for bioventing. However, baseline soil gas measurements of oxygen at near-atmospheric concentrations and calculated oxygen utilization rates in both areas less than 1.0 %/day criteria (EPA 1995), indicate bioventing is not necessary to increase vadose zone oxygen and is not an appropriate remedial technology for vadose zone conditions or submerged and residual LNAPL at the site.

A7. Carbon Traps NSZD Test

At sites impacted with petroleum hydrocarbons, LNAPL losses can occur through natural biodegradation processes such as methanogenesis (Amos et al. 2005), in which CO_2 and CH_4 are generated by an anaerobic process during natural degradation of organic materials such as petroleum hydrocarbons. As both these gases are transported from the LNAPL source toward the atmosphere, CH_4 encounters atmospheric O_2 and, through aerobic processes, generates CO_2 in the shallow surface soil layer and the vadose zone. Field screening tools have been developed to quantify biodegradation rates and estimate NSZD over time.

CO_2 flux was measured by trapping CO_2 and storing it for laboratory analysis, using a technology developed at Colorado State University Center for Contaminant Hydrology (CCH), and now commercialized by E-Flux, LLC (E-Flux). The E-Flux method measures carbon (to estimate total CO_2 flux) and carbon isotopes (i.e., ^{14}C) to estimate the contribution of petroleum hydrocarbon degradation to the total carbon flux from the soil to the ground surface (Zimbron et al. 2011). This process was used to assess and estimate natural LNAPL losses from biodegradation (i.e., NSZD). Research performed by CCH shows LNAPL losses on the order of thousands of gallons per acre per year at petroleum-impacted sites can be identified by measuring CO_2 flux. See the attached Standard Operating Procedure (SOP) for additional information about the CO_2 trap technology (Attachment A).

A.7.1. Carbon Trap Results

Carbon traps were deployed in 11 locations in the Maintenance Shop, Submerged LNAPL, and former Engine House/ Machine Shop areas on 12 and 13 August 2019 and retrieved on

21 August 2019 (Figure A2). Each trap consisted of two sorbent elements: the bottom captured CO_2 from surface soil and the top intercepted atmospheric CO_2. CO_2 passing through the trap reacts to form carbonates. The sorbent elements were analyzed by the laboratory for total carbonate mass, and CO_2 flux was estimated by dividing the carbonate mass by the cross-sectional area on the trap, taking into account the time the trap was deployed in the field. The estimated CO_2 flux was then converted to an estimated LNAPL biodegradation rate using the stoichiometric ratio between CO_2 and LNAPL. (Note: LNAPL biodegradation rates were corrected to subtract out background rates of CO_2 quantified by background sampling in a travel blank (TB) sample and/or ^{14}C analysis).

The carbon trap results are summarized on Figure A5 and in further detail in the E-Flux summary report, included in Attachment A. Detections of fossil fuel CO_2 in the carbon traps from locations 1 to 10 ranged from 0.02 grams (g) at location 8 (on the berm near well WMW-16) to 3.51 g at location 4 (located in the western LNAPL area). Fossil fuel CO_2 flux ranged from 0.07 micromole per square meter per second (µmol m^{-2} s^{-1}) at location 8 to 12.47 µmol m^{-2} s^{-1} at location 4. Calculated equivalent NSZD rates, based on a flux equivalence of 492.7 gallons/acre/year assuming an LNAPL density of 0.966 grams/milliliter (g/mL) and a 4-inch receiver pipe, ranged from 35 gallons/acre/year at location 8 (above dissolved phase petroleum impacts) to 6,146 gallons/acre/year at location 4 (above smear zone and submerged LNAPL).

Fossil fuel CO_2 was not detected (ND) at location 11 (located adjacent to well WMW-26 in the former Engine House). The results in the E-Flux report show while the total CO_2 content at location 11 (16.85%) and total CO_2 flux (27.82 µmol m^{-2} s^{-1}) were high compared to other samples, the CO_2 content was 98.3 % modern carbon (i.e., biological degradation of new sources of carbon, possibly from higher organic content in the backfill used in this area), and 1.7% old carbon (i.e., from biodegradation of low concentrations of dissolved petroleum hydrocarbons). The fossil fuel CO_2 results for location 11 were less than the estimated background (travel blank) sample, therefore the result was reported as ND.

As shown on Figure A5, the lower calculated equivalent NSZD rates (between ND and 147 gallons/acre/year) were measured in areas with dissolved phase petroleum impacts only (locations 2, 8, 9, and 11) or no dissolved phase or LNAPL impacts (locations 1 and 3). The higher calculated equivalent NSZD rates (between 364 and 6,146 gallons/acre/year) were measured in areas near or above the inferred extents of smear zone and/or submerged LNAPL (locations 4, 5, 6, 7, and 10). The carbon trap results provide evidence of biological activity (production of CO_2) from both petroleum hydrocarbon and natural sources; and show that biodegradation of petroleum hydrocarbons (i.e., NSZD) is occurring at measurable rates in areas where significant petroleum hydrocarbon mass exists in the subsurface.

A8. Conclusions

Soil gas measurements and bioventing testing results performed in the Maintenance Shop, Submerged LNAPL, and former Engine House/Machine Shop areas indicate the vadose zone across the site contains elevated oxygen (near-atmospheric concentrations) and low concentrations of carbon dioxide (generally less than 1%). Therefore, delivering additional oxygen using bioventing or soil vapor extraction is not expected to increase or enhance aerobic biological degradation of residual petroleum hydrocarbons in the vadose and smear zones. As a result, interim remedial measure bioventing operations were discontinued at the site. The results of the carbon trap evaluation indicated NSZD is occurring, with the highest responses in test locations near/above the inferred extents of smear zone and submerged LNAPL.

Multiple lines of evidence indicate aerobic biological degradation is currently effectively remediating the remaining residual petroleum hydrocarbons in vadose and smear zone soils without the active addition of oxygen via bioventing.

Enclosures:

Table A1: Maintenance Shop Existing Bioventing System Respirometry Results
Table A2: Baseline Soil Gas Data
Table A3: Injection Step Test Results
Table A4: Injection Test Respirometry Results
Table A5: Summary of Bioventing System Data

Figure A1: Current and Historical Site Features
Figure A2: Bioventing and NSZD Test Locations
Figure A3: Bioventing System Data
Figure A4: Sitewide Soil Gas Concentrations (8 August 2019)
Figure A5: Carbon Trap NSZD Estimates

Attachment A: E-Flux CO2 Flux and NSZD Rate Results
Attachment B: Field Forms and Supplemental Data

References

Kennedy/Jenks Consultants. 2019. LNAPL Transmissivity, Bioventing Respirometry, and NSZD Testing Work Plan BNSF Wishram Railyard, Wishram, Washington. Prepared by Kennedy/Jenks Consultants for BNSF Railway Company. 30 September 2019.

Kennedy/Jenks Consultants. 2020. Uplands Remedial Investigation Report BNSF Wishram Railyard (Ecology Site Name BNSF Track Switching Facility) Wishram, Washington. Prepared by Kennedy/Jenks Consultants for BNSF Railway Company. 20 October 2020.

Leeson, A., and R.E. Hinchee. 1996. Principles and Practices of Bioventing. Volume 1: Bioventing Principles and Volume 2: Bioventing Design. Battelle Memorial Institute. September.

Sweeney, R.E. and G.T. Ririe. 2017 Small Purge Method to Sample Vapor from Groundwater Monitoring Wells Screened Across the Water Table. National Ground Water Association.

Zimbron, J., T. Sale, and M. Lyverse. 2011. Gas Flux Measurement Using Traps, Pending US Patent, Submitted to the US Patent Office 3 August 2011.

Tables

MAINTENANCE SHOP EXISTING BIOVENTING SYSTEM RESPIROMETRY RESULTS
BNSF Wishram Railyard

SYSTEM SHUT DOWN
7/24/19 9:00

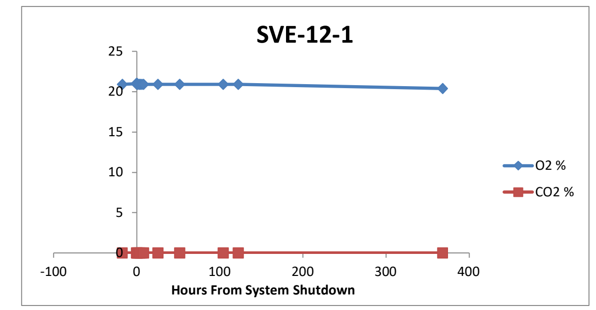
SOIL PARAMETERS	
Air-filled porosity of soil (unitless)[(a)]	0.32
Density of O2 @ STP (mg/L)	1,365
Ratio of O2 required to mineralize hexadecane	0.2888
Dry Soil Bulk Density (g/cc)[(a)]	1.6

AVERAGE	
Ko - Oxygen Utilization Rate (%/day)	Kb - Biodegradation Rate (mg Hexadecane Equivalent/kg/day)
0.082	0.065
Wells WMW-7, WMW-8, WMW-3 only	
0.175	0.138

Oxygen Utilization Rate < 1 %/day
O2 > 20% in most wells after 5 days

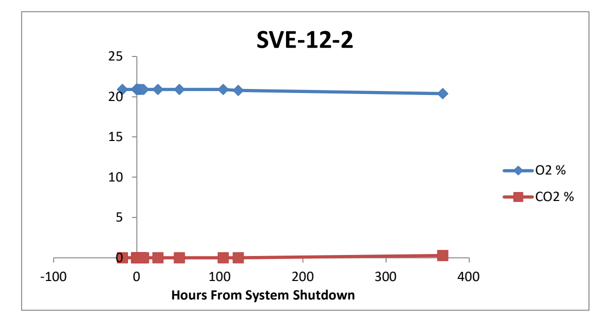
Injection Well #N/A

Well ID	Depth to Water (feet bgs)	Well Diameter (inch)	Date/Time	Duration System Off (hrs)	O_2 %	CO_2 %	CH4 % (LEL)	VOCs	Inches of H_2O	Ko - Oxygen Utilization Rate (%/day)	Kb - Biodegradation Rate (mg Hexadecane Equivalent/kg/day)
SVE-12-1	Dry	4	7/23/19 15:35	-17.4	20.9	0.0	0	0.0	6.40	0.031	0.025
			7/24/19 8:43	-0.3	21.0	0.0	0	0.0	6.60		
			7/24/19 9:08	0.1	20.9	0.0	1	0.0	0.00		
			7/24/19 9:34	0.6	21.0	0.0	0	0.0	0.00		
			7/24/19 10:33	1.5	20.9	0.0	0	0.1	0.00		
			7/24/19 12:11	3.2	20.9	0.0	0	1.4	0.00		
			7/24/19 13:10	4.2	20.9	0.0	0	1.4	0.00		
			7/24/19 15:08	6.1	20.9	0.0	0	1.5	0.00		
			7/24/19 17:17	8.3	20.9	0.0	0	1.6	0.00		
			7/25/19 10:21	25	20.9	0.0	0	1.6	0.00		
			7/26/19 12:55	52	20.9	0.0	0	1.3	0.00		
			7/28/19 17:01	104	20.9	0.0	0	1.1	0.00		
			7/29/19 11:09	122	20.9	0.0	0	0.9	0.00		
			8/8/19 17:07	368	20.4	0.0	0	0.7	0.00		



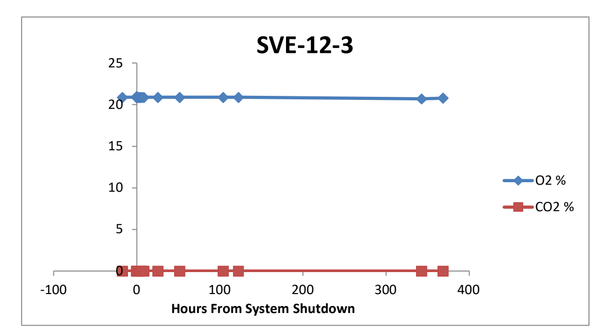
Injection Well #N/A

Well ID	Depth to Water (feet bgs)	Well Diameter (inch)	Date/Time	Duration System Off (hrs)	O_2 %	CO_2 %	CH4 % (LEL)	VOCs	Inches of H_2O	Ko - Oxygen Utilization Rate (%/day)	Kb - Biodegradation Rate (mg Hexadecane Equivalent/kg/day)
SVE-12-2	8.83	4	7/23/19 15:45	-17.3	20.9	0.0	0	0.0	8.40	0.015	0.012
			7/24/19 8:45	-0.2	20.9	0.0	0	0.0	9.20		
			7/24/19 9:02	0.0	21.0	0.0	1	0.0	0.00		
			7/24/19 9:40	0.7	20.9	0.0	1	0.5	0.00		
			7/24/19 10:37	1.6	20.9	0.0	0	0.5	0.00		
			7/24/19 12:13	3.2	20.9	0.0	0	1.1	0.00		
			7/24/19 13:12	4.2	20.9	0.0	0	1.4	0.00		
			7/24/19 15:10	6.2	20.9	0.0	0	1.3	0.00		
			7/24/19 17:20	8.3	20.9	0.0	0	1.3	0.00		
			7/25/19 10:23	25	20.9	0.0	0	0.9	0.00		
			7/26/19 12:33	52	20.9	0.0	0	1.2	0.00		
			7/28/19 17:06	104	20.9	0.0	0	0.5	0.00		
			7/29/19 11:15	122	20.8	0.0	0	0.5	0.00		
			8/8/19 17:17	368	20.4	0.3	0	0.3	0.00		



Injection Well #N/A

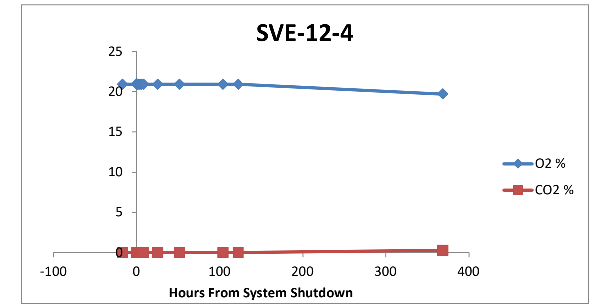
Well ID	Depth to Water (feet bgs)	Well Diameter (inch)	Date/Time	Duration System Off (hrs)	O_2 %	CO_2 %	CH4 % (LEL)	VOCs	Inches of H_2O	Ko - Oxygen Utilization Rate (%/day)	Kb - Biodegradation Rate (mg Hexadecane Equivalent/kg/day)
SVE-12-3	Dry	4	7/23/19 15:50	-17.2	20.9	0.0	0	0.0	12.60	0.014	0.011
			7/24/19 8:47	-0.2	20.9	0.0	0	0.0	13.20		
			7/24/19 9:04	0.1	21.0	0.0	1	0.0	0.00		
			7/24/19 9:46	0.8	20.9	0.0	1	0.2	0.00		
			7/24/19 10:40	1.7	20.9	0.0	0	0.1	0.00		
			7/24/19 12:15	3.2	20.9	0.0	0	1.0	0.00		
			7/24/19 13:14	4.2	20.9	0.0	0	1.1	0.00		
			7/24/19 15:13	6.2	20.9	0.0	0	1.0	0.00		
			7/24/19 17:22	8.4	20.9	0.0	0	1.4	0.00		
			7/25/19 10:26	25	20.9	0.0	0	0.8	0.00		
			7/26/19 12:35	52	20.9	0.0	0	1.2	0.00		
			7/28/19 17:08	104	20.9	0.0	0	1.1	0.00		
			7/29/19 11:19	122	20.9	0.0	0	0.5	0.00		
			8/7/19 15:55	343	20.7	0.0	0	0.5	0.00		
			8/8/19 17:31	369	20.8	0.0	0.0	0.3	0.00		



MAINTENANCE SHOP EXISTING BIOVENTING SYSTEM RESPIROMETRY RESULTS
BNSF Wishram Railyard

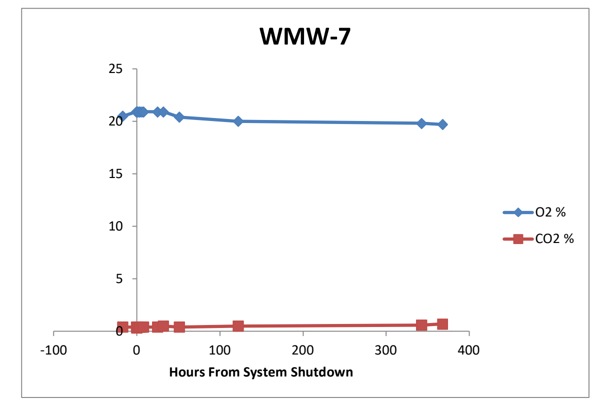
Injection Well #N/A

Well ID	Depth to Water (feet bgs)	Well Diameter (inch)	Date/Time	Duration System Off (hrs)	O_2 %	CO_2 %	CH4 % (LEL)	VOCs	Inches of H_2O	Ko - Oxygen Utilization Rate (%/day)	Kb - Biodegradation Rate (mg Hexadecane Equivalent/kg/day)
SVE-12-4	Dry	4	7/23/19 15:55	-17.1	20.9	0.0	0	0.0	15.20	0.004	0.003
			7/24/19 8:49	-0.2	20.9	0.0	0	0.0	15.80		
			7/24/19 9:06	0.1	21.0	0.0	1	0.0	0.00		
			7/24/19 9:52	0.9	20.9	0.0	0	0.0	0.00		
			7/24/19 10:44	1.7	20.9	0.0	0	0.1	0.00		
			7/24/19 12:18	3.3	20.9	0.0	0	1.3	0.00		
			7/24/19 13:16	4.3	20.9	0.0	0	0.8	0.00		
			7/24/19 15:15	6.2	20.9	0.0	0	2.8	0.00		
			7/24/19 17:24	8.4	20.9	0.0	0	1.4	0.00		
			7/25/19 10:28	25	20.9	0.0	0	1.1	0.00		
			7/26/19 12:37	52	20.9	0.0	0	1.0	0.00		
			7/28/19 17:11	104	20.9	0.0	0	0.7	0.00		
			7/29/19 11:19	122	20.9	0.0	0	0.5	0.00		
			8/8/19 17:37	369	19.7	0.3	0.0	1.2	0.00		



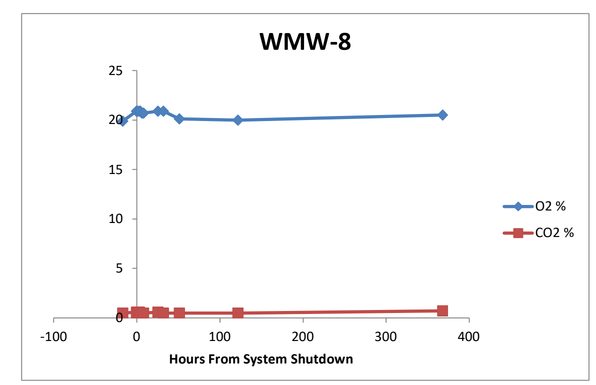
WMW-7: 33 feet from injection well SVE-12-1. Inside Pressure ROI. Screen Interval: 10 - 20 feet bgs

Well ID	Depth to Water (feet bgs)	Well Diameter (inch)	Date/Time	Duration System Off (hrs)	O_2 %	CO_2 %	CH4 % (LEL)	VOCs	Inches of H_2O	Ko - Oxygen Utilization Rate (%/day)	Kb - Biodegradation Rate (mg Hexadecane Equivalent/kg/day)
WMW-7	12.09	2	7/23/19 15:58	-17.0	20.5	0.4	0	1.5	0.80	0.184	0.145
			7/24/19 8:30	-0.5	20.9	0.4	0	1.1	0.90		
			7/24/19 9:00	0.0	20.9	0.3	0	0.4	0.00		
			7/24/19 10:22	1.4	20.9	0.4	0	1.0	0.00		
			7/24/19 11:59	3.0	20.9	0.4	0	1.0	0.00		
			7/24/19 13:00	4.0	20.9	0.4	0	1.2	0.00		
			7/24/19 15:00	6.0	20.9	0.4	0	1.6	0.00		
			7/24/19 17:08	8.1	20.9	0.4	0	1.3	0.00		
			7/25/19 10:10	25	20.9	0.4	0	1.2	0.00		
			7/25/19 17:04	32	20.9	0.5	0	2.0	0.00		
			7/26/19 12:13	51	20.4	0.4	0	1.9	0.00		
			7/29/19 11:06	122	20.0	0.5	0	1.0	0.00		
			8/7/19 15:46	343	19.8	0.6	0	0.8	0.00		
			8/8/19 17:05	368	19.7	0.7	0	0.3	0.00		



WMW-8: 91 feet from injection well SVE-12-1. Inside Pressure ROI. Screen Interval: 7 - 22 feet bgs

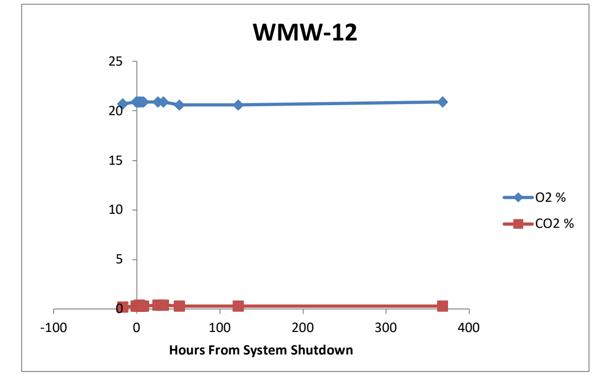
Well ID	Fluid Depth/Probe Depth (ft)	Well Diameter (inch)	Date/Time	Duration System Off (hrs)	O_2 %	CO_2 %	CH4 % (LEL)	VOCs	Inches of H_2O	Ko - Oxygen Utilization Rate (%/day)	Kb - Biodegradation Rate (mg Hexadecane Equivalent/kg/day)
WMW-8	11.62	2	7/23/19 16:04	-16.9	19.9	0.5	0	1.2	0.12	0.184	0.145
			7/24/19 8:21	-0.7	20.9	0.6	0	2.0	0.10		
			7/24/19 9:10	0.2	20.9	0.5	1	1.8	0.00		
			7/24/19 10:25	1.4	20.9	0.6	0	1.6	0.00		
			7/24/19 12:02	3.0	20.9	0.6	0	1.7	0.00		
			7/24/19 13:03	4.0	20.9	0.5	0	1.5	0.00		
			7/24/19 15:02	6.0	20.7	0.5	0	1.6	0.00		
			7/24/19 17:10	8.2	20.7	0.5	0	1.6	0.00		
			7/25/19 10:13	25	20.9	0.6	1	1.5	0.00		
			7/25/19 17:07	32	20.9	0.5	0	2.4	0.00		
			7/26/19 12:15	51	20.1	0.5	0	2.2	0.00		
			7/29/19 10:55	122	20.0	0.5	0	1.2	0.00		
			8/8/19 17:00	368	20.5	0.7	0	0.6	0.00		



MAINTENANCE SHOP EXISTING BIOVENTING SYSTEM RESPIROMETRY RESULTS
BNSF Wishram Railyard

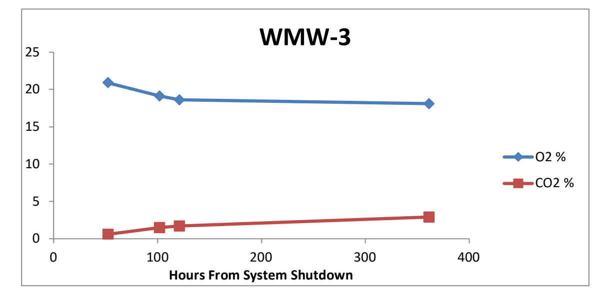
WMW-12: 212 feet from injection well SVE-12-1. Outside of Pressure ROI. Screen Interval: 6 - 22 feet bgs

Well ID	Fluid Depth/Probe Depth (ft)	Well Diameter (inch)	Date/Time	Duration System Off (hrs)	O_2 %	CO_2 %	CH4 % (LEL)	VOCs	Inches of H_2O	Ko - Oxygen Utilization Rate (%/day)	Kb - Biodegradation Rate (mg Hexadecane Equivalent/kg/day)
WMW-12	11.06	2	7/23/19 16:04	-16.9	20.7	0.2	0	4.4	0.03	0.068	0.054
			7/24/19 8:16	-0.7	20.9	0.3	0	3.8	0.00		
			7/24/19 9:12	0.2	20.9	0.3	1	2.6	0.00		
			7/24/19 10:28	1.5	20.9	0.3	0	2.5	0.00		
			7/24/19 12:05	3.1	20.9	0.4	0	2.7	0.00		
			7/24/19 13:06	4.1	20.9	0.3	0	2.7	0.00		
			7/24/19 15:05	6.1	20.9	0.3	0	3.5	0.00		
			7/24/19 17:13	8.2	20.9	0.3	0	3.4	0.00		
			7/25/19 10:18	25	20.9	0.4	1	2.6	0.00		
			7/25/19 17:10	32	20.9	0.4	0	3.5	0.00		
			7/26/19 12:19	51	20.6	0.3	0	4.2	0.00		
			7/29/19 10:59	122	20.6	0.3	0	1.9	0.00		
			8/8/19 16:55	368	20.9	0.3	0	0.8	0.00		



WMW-3: 168 feet from injection well SVE-12-1. Outside of Pressure ROI - Response in O2 measurements Screen Interval: 10 - 20 feet bgs

Well ID	Fluid Depth/Probe Depth (ft)	Well Diameter (inch)	Date/Time	Duration System Off (hrs)	O_2 %	CO_2 %	CH4 % (LEL)	VOCs	Inches of H_2O	Ko - Oxygen Utilization Rate (%/day)	Kb - Biodegradation Rate (mg Hexadecane Equivalent/kg/day)
WMW-3	10.80	2	7/26/19 13:20	52	20.9	0.6	1	2.9	0.00	0.158	0.125
			7/28/19 14:45	102	19.1	1.5	0	2.8	0.00		
			7/29/19 10:09	121	18.6	1.7	0	2.2	0.00		
			8/8/19 10:09	361	18.1	2.9	0	0.3	0.00		



Notes:
(a) Literature values assumed for porosity and dry bulk density.
Tan shading indicates background data collected prior to study step testing.
Blue shading indicates data recorded prior to shut down of blower.
Green shading indicates data used for estimating biodegradation.

-- = not measured
mg/L = milligrams per liter
g/cc = grams per cubic centimeter
ft = feet
hrs = hours
% O_2 = percent oxygen
STP = standard temperature and pressure
% CO_2 = percent carbon dioxide
H_2O = water
%/day = percent per day
mg = milligram
kg/day = kilograms per day
NA = not applicable

TABLE A2 BASELINE SOIL GAS DATA
BNSF Wishram Railyard

Well ID	Measurement Date(s)	Average of O_2 %	Average of CO_2 %	Average of CH_4 % (LEL)	Average of H_2S (ppm)	Average of VOCs (ppm)
Fueling Area South of Mainline						
WMW-01	8/8/2019	20.9	0.2	0.0	0.0	0.10
WMW-03	8/8/2019	18.1	2.9	0.0	0.0	0.30
WMW-09	8/8/2019	19.2	1.5	0.0	0.0	0.60
WMW-10	8/8/2019	20.9	0.4	0.0	0.0	1.70
WMW-11	8/8/2019	20.4	0.9	0.0	0.0	0.60
WMW-13	8/8/2019	20.9	0.3	0.0	0.0	0.10
WMW-14	8/8/2019	20.8	0.7	0.0	0.0	0.60
WMW-15	8/8/2019	20.5	0.8	0.0	0.0	1.10
WMW-16	8/8/2019	19.7	0.9	0.0	0.0	0.20
WMW-17	8/8/2019	20.9	0.6	0.0	0.0	0.30
Former Engine House						
WMW-26	8/8/2019	20.5	0.7	0.0	0.0	0.20
WMW-27	8/8/2019	20.8	0.5	0.0	0.0	0.10
WMW-28	8/8/2019	20.8	0.4	0.0	0.0	1.40
WMW-29	8/8/2019	20.5	0.7	0.0	0.0	1.90
Maintenance Shop Area / Existing Bioventing System (15 days after shutdown)						
WMW-07	8/8/2019	20.4	0.0	0.0	0.0	0.70
WMW-08	8/8/2019	20.4	0.3	0.0	0.0	0.30
WMW-12	8/8/2019	20.8	0.0	0.0	0.0	0.30
SVE-12-1	8/8/2019	19.7	0.3	0.0	0.0	1.20
SVE-12-2	8/8/2019	19.7	0.7	0.0	0.0	0.30
SVE-12-3	8/8/2019	20.5	0.7	0.0	0.0	0.60
SVE-12-4	8/8/2019	20.9	0.3	0.0	0.0	0.80

Notes:
O_2 = oxygen
CO_2 = carbon dioxide
CH_4 = methane
% = percent
LEL = lower explosive limit
H_2S = hydrogen sulfide
VOC = volatile organic compound
ppm = parts per million

TABLE A3

INJECTION STEP TEST RESULTS
BNSF Wishram Railyard

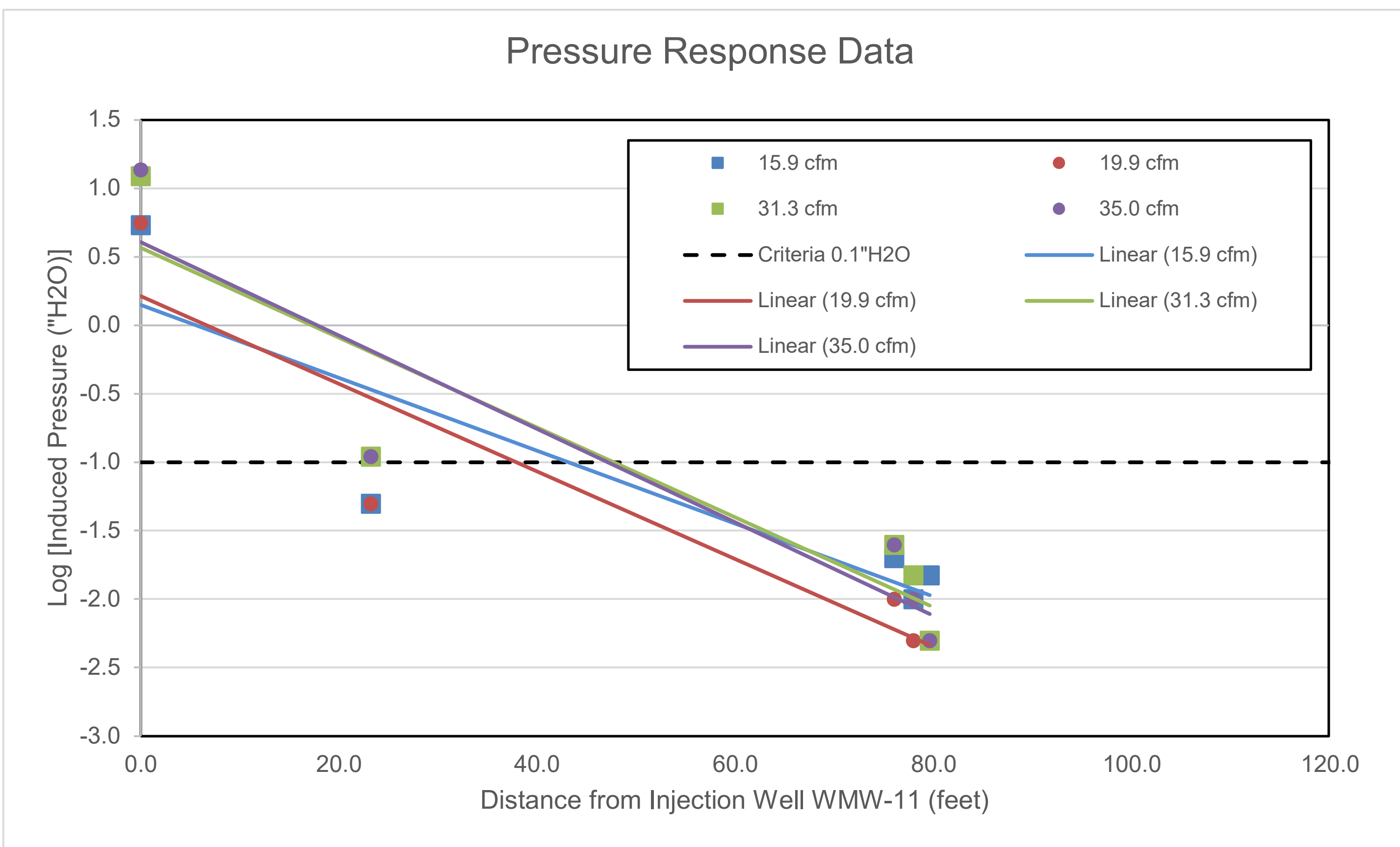
Injection Well	Step Start	Step End	Step #	Manifold Measurements			Pressure Response at Monitoring Wells (inches of H_2O)								Calculated ROI
				Temp (°F)	Pres. ("H_2O)	Flow (cfm)	WMW-1	WMW-3	WMW-10	WMW-11	WMW-14	WMW-15	WMW-16	WMW-17	
Distance from Injection Well WMW-11 (feet)							77.1	135.1	78.0	0.0	76.1	23.3	79.7	156.0	(feet)
WMW-11	10:00	10:57	1	89.1	8.1	15.9	0	0	0.01	5.4	0.02	0.05	0.015	0.015	43
	8:09	9:45	2	88.3	8.4	19.9	0	0	0.005	5.6	0.01	0.05	0.005	0.005	38
	10:57	16:10	3	107.4	24.2	31.3	0.001	0	0.015	12.3	0.025	0.11	0.005	0.001	48
	Approx 24 hrs		4	110.0	25.7	35.0	0	0	0.01	13.7	0.025	0.11	0.005	0.01	47

Notes:

Highlighted rows correspond to symbols in chart below.

10.8	Pressure response >= 0.1 inches of H_2O
0.08	Pressure response >= 0.05 inches of H_2O

Date	Flow rate (cfm)	Log P	WMW-10	WMW-11	WMW-14	WMW-15	WMW-16
8/28/2019	15.9		-2.0	0.7	-1.7	-1.3	-1.8
8/27/2019	19.9		-2.3	0.7	-2.0	-1.3	-2.3
8/27/2019	31.3		-1.8	1.1	-1.6	-1.0	-2.3
8/27/2019	35.0		-2.0	1.1	-1.6	-1.0	-2.3



15.9 cfm			31.3 cfm	
intercept	0.1497		intercept	0.5676
slope	-0.0266		slope	-0.0328
0.1"H_2O	43.2		0.1"H_2O	47.8
19.9 CFM			35 cfm	
intercept	0.2124		intercept	0.6074
slope	-0.0320		slope	-0.0341
0.1"H_2O	37.9		0.1"H_2O	47.2
X	0	200		
log(0.1)	-1	-1		

TABLE A4

INJECTION TEST RESPIROMETRY RESULTS
BNSF Wishram Railyard

SYSTEM SHUT DOWN
8/28/19 16:13

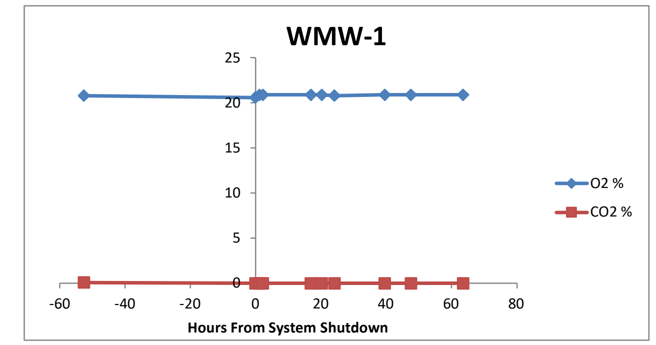
SOIL PARAMETERS	
Air-filled porosity of soil (unitless)[a]	0.32
Density of O2 @ STP (mg/L)	1,365
Ratio of O2 required to mineralize hexadecane	0.2888
Dry Soil Bulk Density (g/cc)[a]	1.6

AVERAGE	
Ko - Oxygen Utilization Rate (%/day)	Kb - Biodegradation Rate (mg Hexadecane Equivalent/kg/day)
0.06	0.05

Oxygen Utilization Rate < 1 %/day
Baseline O2 > 20% in most wells

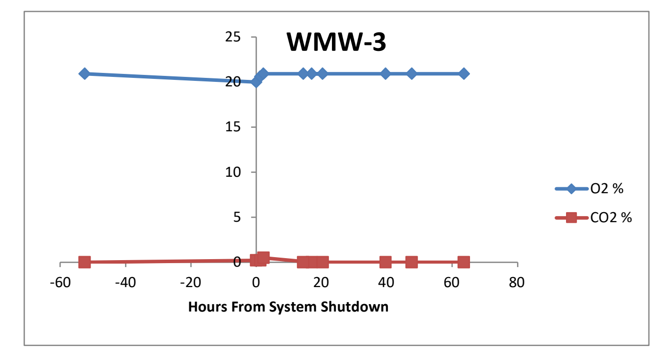
WMW-1: 77 feet from Injection well WMW-11. Screen Interval: 10 - 20 feet bgs

Well ID	Depth to Water (feet bgs)	Well Diameter (inch)	Date/Time	Duration System Off (hrs)	O_2 %	CO_2 %	CH4 % (LEL)	H_2S (ppm)	VOCs (ppm)	Inches of H_2O	Ko - Oxygen Utilization Rate (%/day)	Kb - Biodegradation Rate (mg Hexadecane Equivalent/kg/day)
WMW-1	10.30	2	8/26/19 11:38	-52.58	20.8	0.1	0	0	0.7	0.00	NA - no change	NA
			8/28/19 16:07	-0.10	20.6	0.0	0	0	1.8	0.00		
			8/28/19 17:25	1.20	20.9	0.0	0	0	1.3	0.00		
			8/28/19 18:24	2.18	20.9	0.0	0	0	1.4	0.00		
			8/29/19 9:06	16.88	20.9	0.0	0	0	1.4	0.00		
			8/29/19 12:29	20.27	20.9	0.0	0	0	0.5	0.00		
			8/29/19 16:22	24.15	20.8	0.0	0	0	1.5	0.00		
			8/30/19 7:46	39.55	20.9	0.0	0	0	0.6	--		
			8/30/19 15:45	47.53	20.9	0.0	0	0	1.4	--		
			8/31/19 7:43	63.50	20.9	0.0	0.0	0.0	0.4	--		



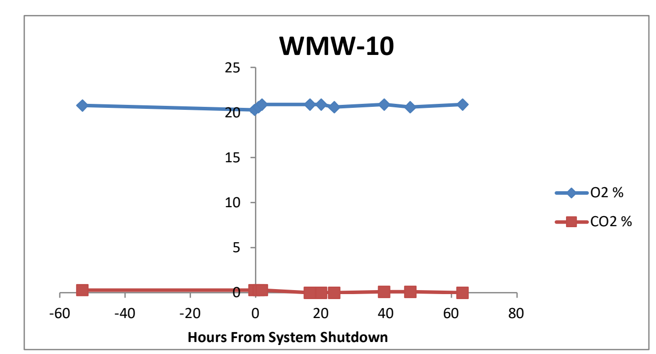
WMW-3: 135 feet from Injection well WMW-11. Screen Interval: 10 - 20 feet bgs

Well ID	Depth to Water (feet bgs)	Well Diameter (inch)	Date/Time	Duration System Off (hrs)	O_2 %	CO_2 %	CH4 % (LEL)	H_2S (ppm)	VOCs	Inches of H_2O	Ko - Oxygen Utilization Rate (%/day)	Kb - Biodegradation Rate (mg Hexadecane Equivalent/kg/day)
WMW-3	10.80	2	8/26/19 11:42	-52.52	20.9	0.0	0	0	0.5	0.00	NA - no change	NA
			8/28/19 16:10	-0.05	20.0	0.2	0	0	2.6	0.00		
			8/28/19 17:27	1.23	20.6	0.2	0	0	2.2	0.00		
			8/28/19 18:27	2.23	20.9	0.5	0	0	2.1	0.00		
			8/29/19 9:10	16.95	20.9	0.0	0	0	1.4	0.00		
			8/29/19 12:31	20.30	20.9	0.0	0	0	0.9	0.00		
			8/29/19 6:35	14.37	20.9	0.0	0	0	0.7	0.00		
			8/30/19 7:50	39.62	20.9	0.0	0	0	0.9	--		
			8/30/19 15:48	47.58	20.9	0.0	0	0	1.3	--		
			8/31/19 7:46	63.55	20.9	0.0	0.0	0.0	0.7	--		



WMW-10: 78 feet from Injection well WMW-11. Screen Interval: 7.5 - 22.5 feet bgs

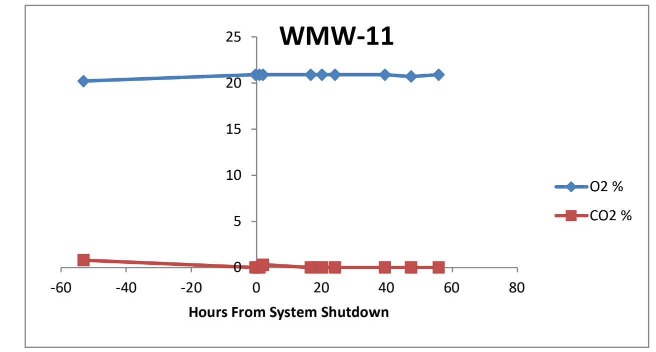
Well ID	Depth to Water (feet bgs)	Well Diameter (inch)	Date/Time	Duration System Off (hrs)	O_2 %	CO_2 %	CH4 % (LEL)	H_2S (ppm)	VOCs	Inches of H_2O	Ko - Oxygen Utilization Rate (%/day)	Kb - Biodegradation Rate (mg Hexadecane Equivalent/kg/day)
WMW-10	10.90	2	8/26/19 11:10	-53.05	20.8	0.3	0	0	0.6	0.00	0.03	0.02
			8/28/19 15:54	-0.32	20.3	0.3	0	0	0.9	0.15		
			8/28/19 17:08	0.92	20.6	0.3	0	0	0.7	0.005		
			8/28/19 18:09	1.93	20.9	0.3	0	0	0.6	0.005		
			8/29/19 8:50	16.62	20.9	0.0	0	0	0.7	0.00		
			8/29/19 12:16	20.05	20.9	0.0	0	0	0.6	0.00		
			8/29/19 16:17	24.07	20.6	0.0	0	0	1.3	0.00		
			8/30/19 7:33	39.33	20.9	0.1	0	0	0.9	--		
			8/30/19 15:32	47.32	20.6	0.1	0	0	1.6	--		
			8/31/19 7:33	63.33	20.9	0.0	0.0	0.0	0.5	--		



INJECTION TEST RESPIROMETRY RESULTS
BNSF Wishram Railyard

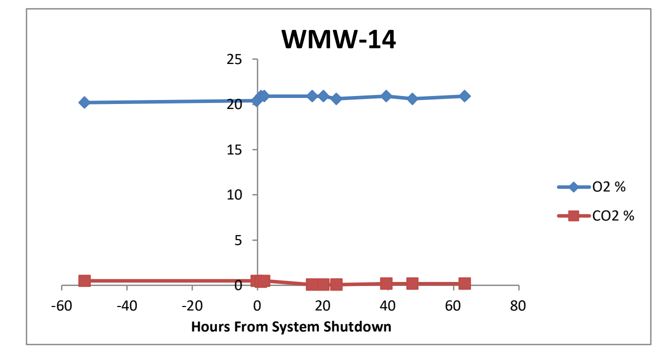
Injection Well — Screen Interval: 7 - 22 feet bgs

Well ID	Depth to Water (feet bgs)	Well Diameter (inch)	Date/Time	Duration System Off (hrs)	O_2 %	CO_2 %	CH4 % (LEL)	H_2S (ppm)	VOCs	Inches of H_2O	Ko - Oxygen Utilization Rate (%/day)	Kb - Biodegradation Rate (mg Hexadecane Equivalent/kg/day)
WMW-11	10.74	2	8/26/19 11:05	-53.13	20.2	0.8	0	0	0.3	0.00	0.04	0.03
			8/28/19 15:51	-0.37	20.9	0.0	0	0	4.0	12.30		
			8/28/19 17:02	0.82	20.9	0.0	0	0	3.3	0.015		
			8/28/19 18:09	1.93	20.9	0.3	0	0	3.2	0.005		
			8/29/19 8:48	16.58	20.9	0.0	0	0	1.8	0.000		
			8/29/19 12:14	20.02	20.9	0.0	0	0	0.7	0.000		
			8/29/19 16:14	24.02	20.9	0.0	0	0	1.4	0.000		
			8/30/19 7:30	39.28	20.9	0.0	0	0	0.6	--		
			8/30/19 15:30	47.28	20.7	0.0	0	0	1.8	--		
			8/31/19 0:00	55.78	20.9	0.0	0.0	0.0	0.5	--		



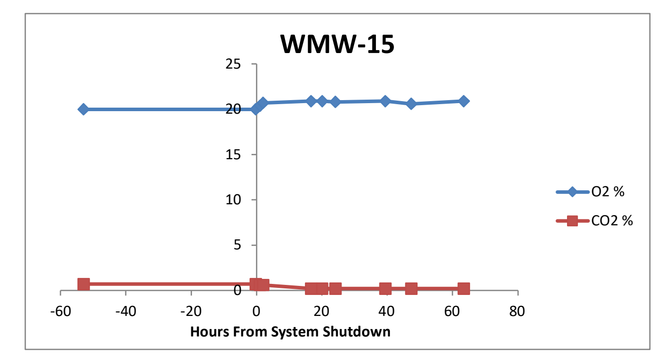
WMW-14: 76 feet from Injection well WMW-11. — Screen Interval: 12 - 27 feet bgs

Well ID	Depth to Water (feet bgs)	Well Diameter (inch)	Date/Time	Duration System Off (hrs)	O_2 %	CO_2 %	CH4 % (LEL)	H_2S (ppm)	VOCs	Inches of H_2O	Ko - Oxygen Utilization Rate (%/day)	Kb - Biodegradation Rate (mg Hexadecane Equivalent/kg/day)
WMW-14	14.69	2	8/26/19 11:14	-52.98	20.2	0.5	0	0	0.6	0.00	0.04	0.03
			8/28/19 15:57	-0.27	20.4	0.5	0	0	1.8	0.025		
			8/28/19 17:12	0.98	20.9	0.4	0	0	1.4	0.00		
			8/28/19 18:13	2.00	20.9	0.5	0	0	0.4	0.00		
			8/29/19 8:54	16.68	20.9	0.1	0	0	0.7	0.00		
			8/29/19 12:19	20.10	20.9	0.1	0	0	0.5	0.00		
			8/29/19 16:20	24.12	20.6	0.1	0	0	1.3	0.00		
			8/30/19 7:36	39.38	20.9	0.2	0	0	0.9	--		
			8/30/19 15:35	47.37	20.6	0.2	0	0	1.3	--		
			8/31/19 7:35	63.37	20.9	0.2	0.0	0.0	0.3	--		



WMW-15: 23 feet from Injection well WMW-11. — Screen Interval: 12 - 27 feet bgs

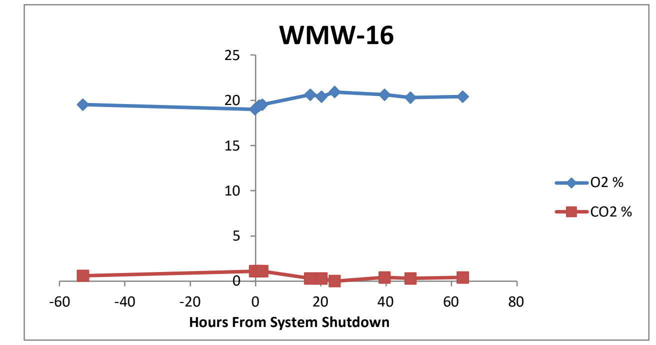
Well ID	Depth to Water (feet bgs)	Well Diameter (inch)	Date/Time	Duration System Off (hrs)	O_2 %	CO_2 %	CH4 % (LEL)	H_2S (ppm)	VOCs	Inches of H_2O	Ko - Oxygen Utilization Rate (%/day)	Kb - Biodegradation Rate (mg Hexadecane Equivalent/kg/day)
WMW-15	14.52	2	8/26/19 11:17	-52.93	20.0	0.7	0	0	1.0		NA	NA
			8/28/19 16:00	-0.22	20.0	0.7	0	0	0.8	0.025		
			8/28/19 17:17	1.07	20.4	0.6	0	0	2.9	0.00		
			8/28/19 18:15	2.03	20.7	0.6	0	0	3.6	0.00		
			8/29/19 8:56	16.72	20.9	0.2	0	0	1.5	0.00		
			8/29/19 12:21	20.13	20.9	0.2	0	0	1.4	0.00		
			8/29/19 16:23	24.17	20.8	0.2	0	0	1.5	0.00		
			8/30/19 7:39	39.43	20.9	0.2	0	0	1.1	--		
			8/30/19 15:37	47.40	20.6	0.2	0	0	1.6	--		
			8/31/19 7:37	63.40	20.9	0.2	0.0	0.0	1.2	--		



INJECTION TEST RESPIROMETRY RESULTS
BNSF Wishram Railyard

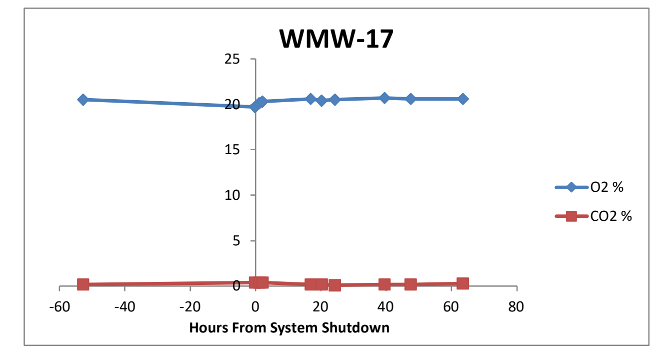
WMW-16: 80 feet from Injection well WMW-11. Screen Interval: 11.33 - 26.33 feet bgs

Well ID	Depth to Water (feet bgs)	Well Diameter (inch)	Date/Time	Duration System Off (hrs)	O_2 %	CO_2 %	CH4 % (LEL)	H_2S (ppm)	VOCs	Inches of H_2O	Ko - Oxygen Utilization Rate (%/day)	Kb - Biodegradation Rate (mg Hexadecane Equivalent/kg/day)
WMW-16	15.10	2	8/26/19 11:24	-52.82	19.5	0.6	0	0	0.6	0.00	0.14	0.11
			8/28/19 16:02	-0.18	19.0	1.1	0	0	1.0	0.005		
			8/28/19 17:19	1.10	19.4	1.1	0	0	2.9	0.000		
			8/28/19 18:18	2.08	19.5	1.1	0	0	0.6	0.000		
			8/29/19 9:00	16.78	20.6	0.3	0	0	0.6	0.000		
			8/29/19 12:24	20.18	20.4	0.3	0	0	0.2	0.000		
			8/29/19 16:26	24.22	20.9	0.0	0	0	0.4	0.000		
			8/30/19 7:42	39.48	20.6	0.4	0	0	0.0	--		
			8/30/19 15:40	47.45	20.3	0.3	0	0	0.6	--		
			8/31/19 7:39	63.43	20.4	0.4	0.0	0.0	0.1	--		



WMW-17: 156 feet from Injection well WMW-11. Screen Interval: 12 - 27 feet bgs

Well ID	Depth to Water (feet bgs)	Well Diameter (inch)	Date/Time	Duration System Off (hrs)	O_2 %	CO_2 %	CH4 % (LEL)	H_2S (ppm)	VOCs	Inches of H_2O	Ko - Oxygen Utilization Rate (%/day)	Kb - Biodegradation Rate (mg Hexadecane Equivalent/kg/day)
WMW-17	14.20	2	8/26/19 11:26	-52.78	20.5	0.2	0	0	1.0	0.00	NA	NA
			8/28/19 16:04	-0.15	19.7	0.4	0	0	1.5	0.001		
			8/28/19 17:22	1.15	20.1	0.4	0	0	1.2	0.00		
			8/28/19 18:21	2.13	20.3	0.4	0	0	1.2	0.00		
			8/29/19 9:04	16.85	20.6	0.2	0	0	1.1	0.00		
			8/29/19 12:26	20.22	20.4	0.2	0	0	0.3	0.00		
			8/29/19 16:29	24.27	20.5	0.1	0	0	1.3	0.00		
			8/30/19 7:42	39.48	20.7	0.2	0	0	0.4	--		
			8/30/19 15:42	47.48	20.6	0.2	0	0	1.3	--		
			8/31/19 7:42	63.48	20.6	0.3	0.0	0.0	0.2	--		



Notes:
(a) Literature values assumed for porosity and dry bulk density.
Tan shading indicates background data collected prior to study step testing.
Blue shading indicates data recorded prior to shut down of blower.
Green shading indicates data used for estimating biodegradation.
Grey shading indicates data not used in respirometry estimates.

-- = not measured
mg/L = milligrams per liter
g/cc = grams per cubic centimeter
ft = feet
hrs = hours
% O_2 = percent oxygen
STP = standard temperature and pressure
% CO_2 = percent carbon dioxide
H_20 = water
%/day = percent per day
mg = milligram
kg/day = kilograms per day
NA = not applicable

SUMMARY OF BIOVENTING SYSTEM DATA
BNSF Wishram Railyard

Existing Bioventing System Summary

Injection Flow Rate	Induced Pressure Response	Calculated ROI	Oxygen Utilization Rate (%/day)	Biodegradation Rate (mg Hexadecane Equivalent/kg/day)
Range 6-29 cfm (avg 17 cfm)	0.9 "H2O at 33 feet, 0.1 "H2O at 91 feet	89-92 feet	0.082	0.065
		Wells WMW-7, WMW-8, and WMW-3 Only:	0.175	0.138

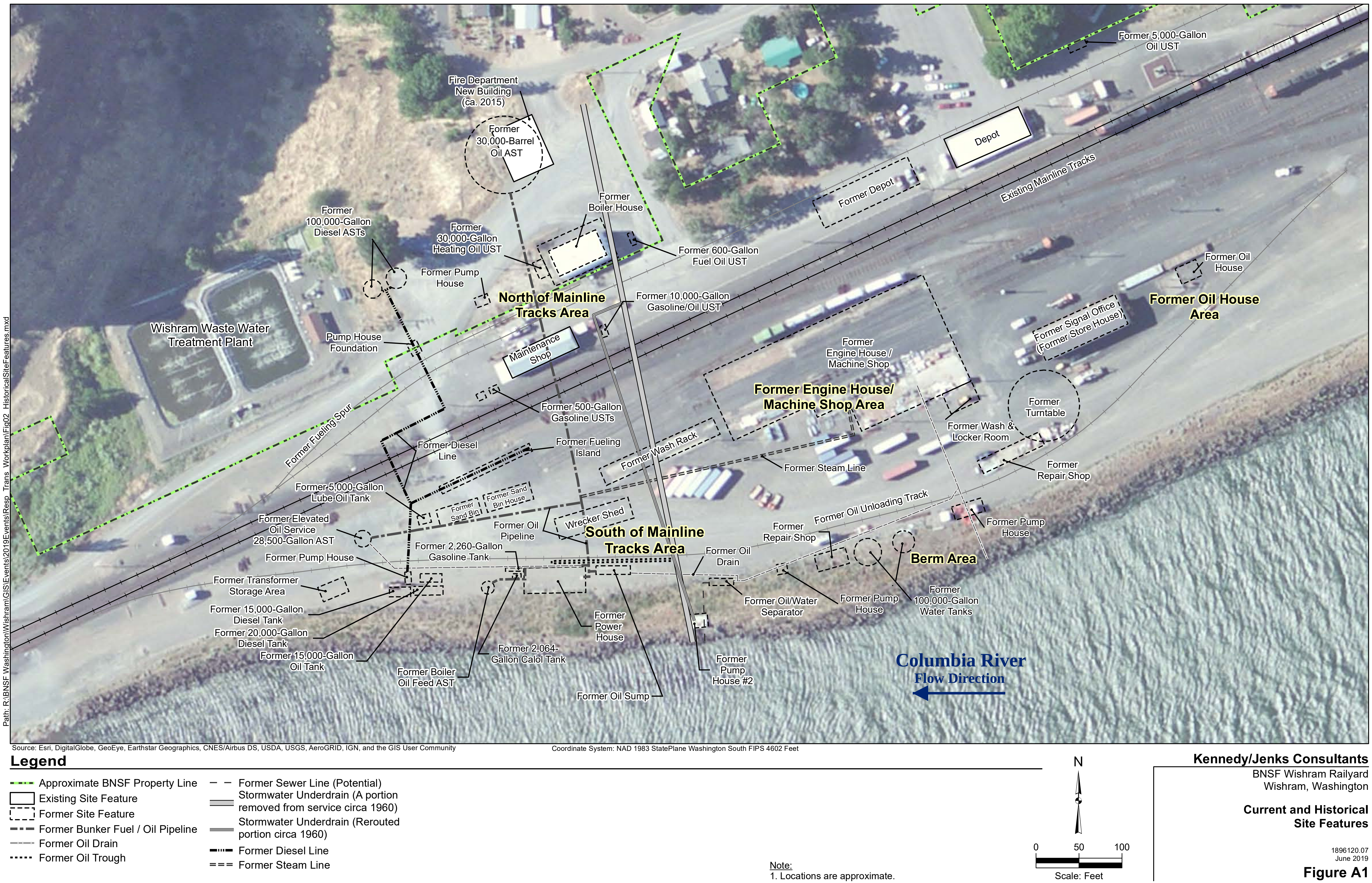
Results: O_2 Utilization rate less than 1%/day; O_2 after 5 days approx 19-20%. Recommend discontinuing operation.
System operating since 2013 (blower replaced in 2017). Operated 24/7 through July 2019, when shutdown.
Injection wells: SVE-12-1 to SVE-12-4.
Monitor wells: WMW-7, WMW-8, WMW-12 (& O_2 response at WMW-3).
Wells WMW-7 and WMW-8 frequently contain sheen in purge water, but no measurable LNAPL > 0.01 feet.
WMW-3 elevated dissolved phase DRO and ORO, decline in % O_2 observed.

Bioventing Injection Test Summary

Injection Flow Rate	Induced Pressure Response	Calculated ROI	Oxygen Utilization Rate (%/day)	Biodegradation Rate (mg Hexadecane Equivalent/kg/day)
31-35 cfm	0.11 "H2O at 23.3 feet, 0.015" H2O at 78 feet	47-48 feet	0.061	0.048

Results: O_2 Utilization rate less than 1%/day; O_2 at 19-20% baseline and after 3 days approx 20%. Bioventing not practicable or needed in tested areas (note, vadose zone/smear zone LNAPL not present in most tested areas).
Test Injection Well: WMW-11.
Monitor Wells: WMW-1, WMW-3, WMW-10, WMW-14, WMW-15, WMW-16, WMW-17.
Boring logs for WMW-11, WMW-16 and WMW-17 indicate petroleum sheen/odors below static water levels (submerged) but not in vadose zone.

Figures



Kennedy/Jenks Consultants

BNSF Wishram Railyard
Wishram, Washington

Current and Historical Site Features

1896120.07
June 2019

Figure A1

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Coordinate System: NAD 1983 StatePlane Washington South FIPS 4602 Feet

Path: N:\BNSF Washington\Wishram\GIS\Events\2019Events\Resp_Trans_Workplan\Fig1_GWMonWells.mxd

Legend

- Inferred Lateral Extent of Smear Zone Diesel and/or Oil Impacts
- Inferred Lateral Extent of Submerged Diesel and/or Oil Impacts
- Approximate Lateral Extent of Dissolved Phase Diesel and/or Oil
- Shallow Monitoring Well
- Deep Monitoring Well
- Oil Head Monitoring Well
- Air Sparge Well
- Soil Vapor Extraction Well
- Carbon Trap Location
- WMW-16 Well included in bioventing/NSZD testing
- WMW-7 Well included in respirometry study

Note:
1. Locations are approximate.

N

0 50 100

Scale: Feet

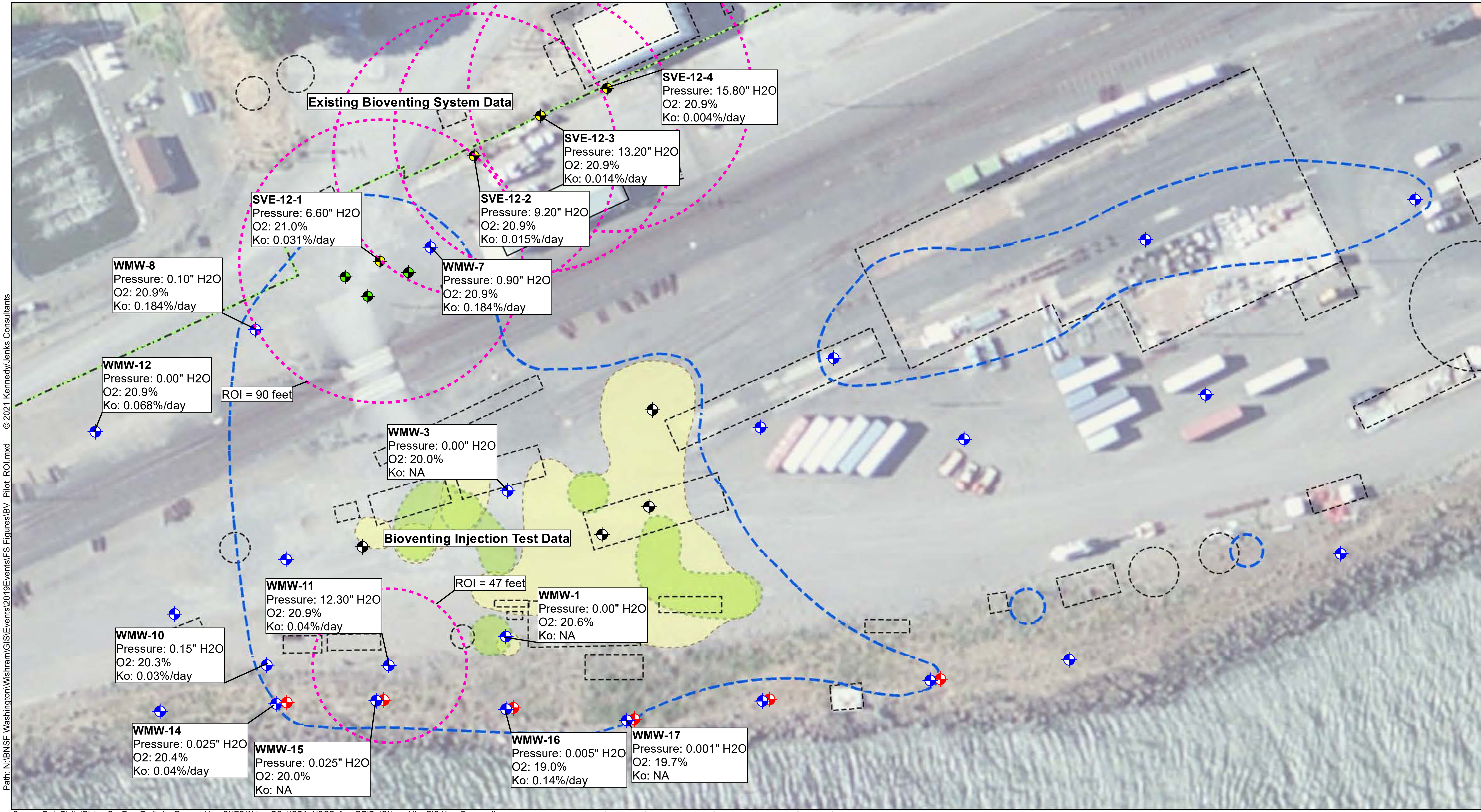
Kennedy/Jenks Consultants

BNSF Wishram Railyard
Wishram, Washington

Bioventing and NSZD Test Locations

1996120*07
April 2021

Figure A2



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Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Coordinate System: NAD 1983 StatePlane Washington South FIPS 4602 Feet

Legend

- Shallow Monitoring Well
- Deep Monitoring Well
- Oil Head Monitoring Well
- Air Sparge Well
- Soil Vapor Extraction Well
- Approximate Bioventing Radius of Influence
- Inferred Lateral Extent of Smear Zone Diesel and/or Oil Impacts
- Inferred Lateral Extent of Submerged Diesel and/or Oil Impacts
- Approximate Lateral Extent of Dissolved Phase Diesel and/or Oil
- Approximate BNSF Property Line

Notes:
1. Locations are approximate.
2. LNAPL = light non-aqueous phase liquid
3. TPH = total petroleum hydrocarbons
4. Ko = oxygen utilization rate
5. Inferred lateral extent of Diesel- or Oil-Like LNAPL based on interpretation of LIF waveforms (July 2013) and soil boring logs.
5. Existing bioventing system measurements collected on 24 July 2019 prior to system shutdown.
Bioventing test measurements collected on 28 August 2019 after approximately 24 hours of system operation.

N

0 30 60

Scale: Feet

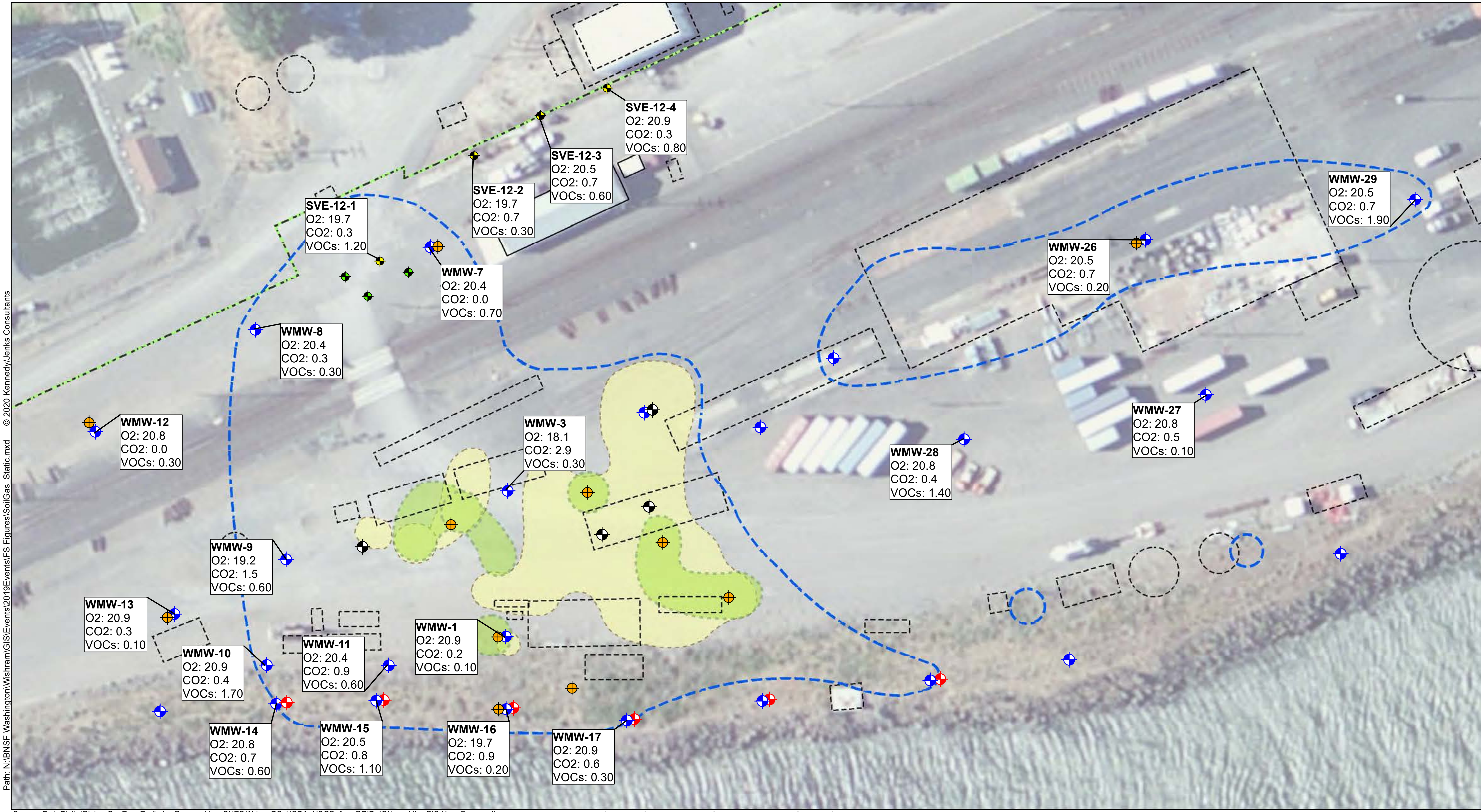
Kennedy/Jenks Consultants

BNSF Wishram Railyard
Wishram, Washington

Bioventing Systems Data

1996120.00
April 2021

Figure A3



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Coordinate System: NAD 1983 StatePlane Washington South FIPS 4602 Feet

Legend

- Shallow Monitoring Well
- Deep Monitoring Well
- Oil Head Monitoring Well
- Air Sparge Well
- Soil Vapor Extraction Well
- Carbon Trap Location
- Inferred Lateral Extent of Smear Zone Diesel and/or Oil Impacts
- Inferred Lateral Extent of Submerged Diesel and/or Oil Impacts
- Approximate Lateral Extent of Dissolved Phase Diesel and/or Oil
- Approximate BNSF Property Line

Notes:
1. Locations are approximate.
2. LNAPL = light non-aqueous phase liquid
3. TPH = total petroleum hydrocarbons
4. Inferred lateral extent of Diesel- or Oil-Like LNAPL based on interpretation of LIF waveforms (July 2013) and soil boring logs.
5. All soil gas measurements collected on August 8, 2019. Bioventing system shutdown on July 24, 2019.

N

0 30 60

Scale: Feet

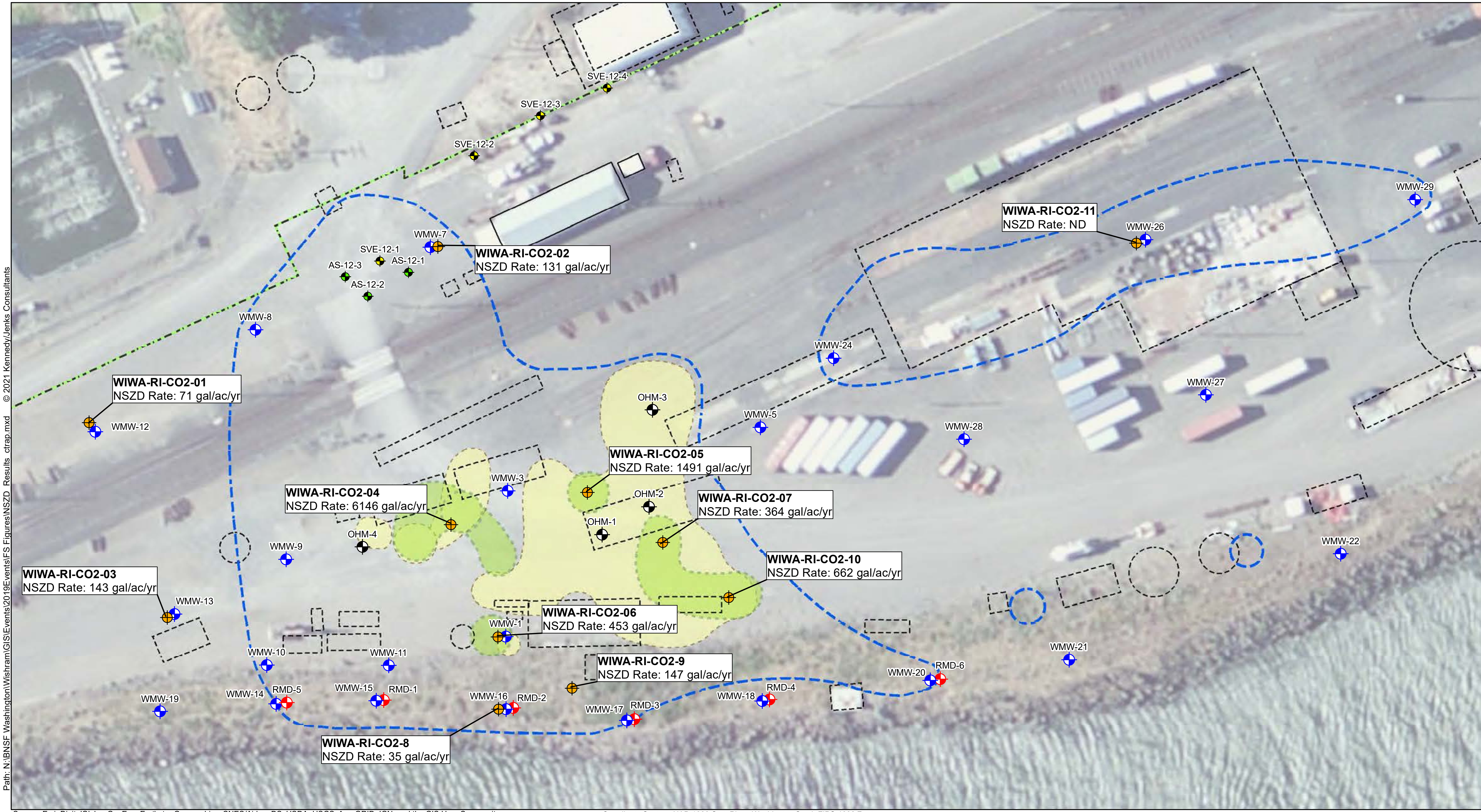
Kennedy/Jenks Consultants

BNSF Wishram Railyard
Wishram, Washington

Sitewide Soil Gas Concentrations (8 August 2019)

1996120.00
December 2020

Figure A4



Path: N:\BNSF Washington\Wishram\GIS\Events\2019Events\FS Figures\NSZD_Results_ctrap.mxd

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Coordinate System: NAD 1983 StatePlane Washington South FIPS 4602 Feet

Legend

- Shallow Monitoring Well
- Deep Monitoring Well
- Oil Head Monitoring Well
- Air Sparge Well
- Soil Vapor Extraction Well
- Carbon Trap Location
- Inferred Lateral Extent of Smear Zone Diesel and/or Oil Impacts
- Inferred Lateral Extent of Submerged Diesel and/or Oil Impacts
- Approximate Lateral Extent of Dissolved Phase Diesel and/or Oil
- Approximate BNSF Property Line

Notes:
1. Locations are approximate.
2. LNAPL = light non-aqueous phase liquid
3. TPH = total petroleum hydrocarbons
4. NSZD = natural source-zone depletion
5. ND = not detected
6. Inferred lateral extent of Diesel- or Oil-Like LNAPL based on interpretation of LIF waveforms (July 2013) and soil boring logs.
7. NSZD estimates based on carbon trap site-specific flux results.

N

0 30 60

Scale: Feet

Kennedy/Jenks Consultants

BNSF Wishram Railyard
Wishram, Washington

Carbon Trap NSZD Estimates

1996120.00
April 2021

Figure A5

Attachment A

E-Flux CO2 Flux and NSZD Rate Results

E·FLUX

Confidential Report
CO_2 Flux and NSZD Rate Results

RYAN HULTGREN
KENNEDY JENKS
PROJECT: WISHRAM, WA
SAMPLING DATES:
8/12/2019 - 8/21/2019

For technical support questions contact:

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3185-A Rampart Road, Room D214
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jzimbron@soilgasflux.com

Report Date: 9/23/2019

The purpose of this document is to provide sample calculations for the reported results and to explain the method for differentiating petroleum hydrocarbon-derived CO_2 from that produced from natural soil respiration processes. The value of the ^{14}C analysis, site-specific study results and applicable notes, calculation explanations, and references are included.

The Value of the ^{14}C Analysis

How to differentiate between petroleum hydrocarbon-derived CO_2 and natural process-derived CO_2 using CO_2 flux traps:

Unimpacted soils naturally produce CO_2 due to microbial root zone activity and/or the degradation of natural organic matter. Thus, the total measured CO_2 flux at an impacted location is a function of the rates of both natural soil respiration and LNAPL degradation (Sihota and Mayer, 2012). The latter, which is caused by Natural Source Zone Depletion (NSZD), can be estimated by subtracting measured CO_2 fluxes at unimpacted locations from the total measured CO_2 fluxes at LNAPL-impacted locations (Sihota and Mayer, 2012). This spatial "background correction" assumes that bio-based CO_2 fluxes are similar at both impacted and unimpacted locations. This approach is complicated to implement, given that at many industrial facilities it is difficult to find unimpacted areas and vegetation cover can vary across a site. Alternatively, carbon isotope analysis can be used to carry out a location-specific correction for total measured CO_2 fluxes, and this approach effectively overcomes the limitations of the background correction.

Theory of Carbon Isotope Analysis:

Our method for NSZD rate estimation relies on the analysis of ^{14}C, an unstable carbon isotope with an absolute half-life of 5,730 years. ^{14}C is generated by cosmic rays in the atmosphere and is quickly oxidized to $^{14}CO_2$; thus, bio-based living carbon is ^{14}C-rich, while ancient fossil fuel carbon is completely ^{14}C-depleted. Additionally, bio-based organic carbon and the atmosphere have the same characteristic amount of ^{14}C. The short half-life of ^{14}C only allows for dating of samples younger than 60,000 years using accelerator mass spectrometry (Stuiver and Polach, 1977). ^{14}C analysis can therefore be used to differentiate between anthropogenic (i.e., fossil fuel) and natural sources of atmospheric carbon (see Klouda and Connolly, 1995; Levin et al., 1995; Avery et al., 2006), and this analysis is the basis for ASTM D6866-18.

For samples that contain both bio-based and fossil fuel-derived carbon, such as E-Flux's fossil fuel traps, measurement of ^{14}C enables quantitation of *both* source contributions. The fossil fuel-derived percentage of the sample (ff_{sample}) and the bio-based percentage ($1-ff_{sample}$, or bb_{sample}) are related by the following two-component mass balance (modified from Avery, Jr. et al., 2006):

$$Fm_{sample} = (ff_{sample})(Fm_{ff}) + (1 - ff_{sample})(Fm_{atm})$$

Here, Fm_x represents the fraction modern, a measure of how close the present $^{14}C/^{12}C$ ratio of the sample is to the ratio from 1950, which is derived from a pre-industrial era standard. Fm_{sample} is the total measured fraction modern of the sample. Fm_{ff} is the fraction modern of only the fossil fuel portion of the sample. This number is 0, as there is no ^{14}C in fossil fuel-derived CO_2. Fm_{atm} is the fraction modern of the part of the sample derived from natural soil respiration processes. This value, currently equal to **1.02** (Cerling et al., 2016, Larsen et al., 2018), has been experimentally determined and is a fixed value at each point in time. By convention, the results of carbon isotope analysis are reported based on a 1950 NBS oxalic acid standard, and so Fm_{sample} is reported as if the analysis took place in 1950. Due to nuclear testing, current ^{14}C atmospheric levels are now higher than they were in 1950. This means that Fm_{atm} is counter-intuitively larger than 1, as the $^{14}C/^{12}C$ sample ratio is higher now than it would have been in 1950.

^{14}C Calculations:

Conversion of Fraction Modern Carbon to Fossil Fuel Carbon:

The equation for calculating the percentage of fossil fuel carbon (ff_{sample}) is derived from the following mass balance:

$$Fm_{sample} = (ff_{sample})(Fm_{ff}) + (1 - ff_{sample})(Fm_{atm})$$

Solving for ff_{sample} yields:

$$ff_{sample} = 1 - \frac{Fm_{sample}}{Fm_{atm}}$$

Fraction modern (Fm_{sample}, from ^{14}C analysis) is reported by convention based on ^{14}C levels from 1950. Because of atomic testing, current environmental ^{14}C levels are approximately 2% higher than they were in 1950 (Cerling et al., 2016, Larsen et al., 2018) and Fm_{atm} is equal to 1.02. This equation then becomes:

$$ff_{sample} = 1 - \frac{Fm_{sample}}{1.02}$$

As percentages must add to 1, the percentage of bio-based carbon ($bb_{sample.}$) can then be calculated using the following equivalence:

$$bb_{sample} = 1 - ff_{sample} = 1 - \left(1 - \frac{Fm_{sample}}{1.02}\right) = \frac{Fm_{sample}}{1.02}$$

Converting Carbon Flux to Equivalent LNAPL Loss Rate:

The intermediate reactions for LNAPL mineralization include methanogenesis, leading to production of methane and CO_2, and the subsequent aerobic oxidation of methane into CO_2:

$$C_8H_{18} + 3.5\ H_2O \rightarrow 6.25\ CH_4 + 1.75\ CO_2 \text{ (methanogenesis)}$$

$$6.25\ CH_4 + 12.5\ O_2 \rightarrow 6.25\ CO_2 + 12.5\ H_2O \text{ (methane oxidation)}$$

$$C_8H_{18} + 12.5\ O_2 \rightarrow 9H_2O + 8\ CO_2 \text{ (overall reaction)}$$

Note: Example conversion factor for gasoline LNAPL

Assuming a conservative LNAPL density of 0.77 g mL^{-1} (upper range of gasoline) and using the molecular weight of C_8H_{18} (octane, 114.23 g mol^{-1}), µmol m^{-2} s^{-1} of CO_2 can then be converted into gal. acre^{-1} yr^{-1} of LNAPL:

$$1\ \frac{\mu\text{mol CO}_2}{\text{m}^2\ \text{s}} \cdot \left(\frac{1\ \mu\text{mol C}_8\text{H}_{18}}{8\ \mu\text{mol CO}_2}\right)\left(\frac{1\ \text{mol C}_8\text{H}_{18}}{1 \times 10^6\ \mu\text{mol C}_8\text{H}_{18}}\right)\left(\frac{114\ \text{g C}_8\text{H}_{18}}{1\ \text{mol C}_8\text{H}_{18}}\right)\left(\frac{1\ \text{mL C}_8\text{H}_{18}}{0.77\ \text{g C}_8\text{H}_{18}}\right)$$
$$\left(\frac{1\ \text{L}}{1000\text{mL}}\right)\left(\frac{1\ \text{gal.}}{3.785\ \text{L}}\right)\left(\frac{4{,}046\ \text{m}^2}{1\ \text{acre}}\right)\left(\frac{3600\ \text{s}}{1\ \text{h}}\right)\left(\frac{24\ \text{h}}{1\ \text{d}}\right)\left(\frac{365\ \text{d}}{1\ \text{yr}}\right).$$
$$= 625.2\ \frac{\text{gal. C}_8\text{H}_{18}}{\text{acre} \cdot \text{yr}}$$

Note that both the LNAPL formula and its density are assumed, and so this conversion is subject to uncertainty. However, site-specific data can be used if available. Using alternative representative hydrocarbon formulas and densities generally results in conversion factors that are within 10-15% of 625.2 gal. acre^{-1} yr^{-1}. Therefore, the uncertainty associated with these values does not preclude an acceptable estimate.

Expected Results and Recommendations:

^{14}C-based techniques offer a built-in, location-specific correction as an alternative to the standard background location correction. Early work on a limited number of samples suggested that ^{14}C-corrected results are equivalent to background-corrected results (Sihota and Mayer, 2012; McCoy et al., 2015). However, a more recent comparison spanning 4 different sites suggests that measured carbon fluxes can differ by up to five times among different locations within the same site (Zimbron and Kasyon, 2015). Depending on the location, the resulting difference between background-corrected and ^{14}C-corrected NSZD rate estimates can be up to one order of magnitude. In contrast, the background correction assumes that the non-fossil fuel CO_2 flux is constant across an entire site; large errors in final estimated NSZD rates might therefore be introduced if the background correction is used. Because the ^{14}C measurement is co-located with the CO_2 flux measurement, it is unbiased by spatial uncertainties related to the background location(s) (e.g., vegetation, lithology, unknown impacts, different gas transport regimes, soil moisture).

The fossil fuel CO_2 content of unexposed sorbent as used in the traps is typically around 30% (as of today) and likely results from material processing and handling (e.g., exposure to fossil fuel fumes). This small mass of fossil fuel CO_2 is removed from samples by carrying out a ^{14}C travel blank correction. ^{14}C analysis is performed on CO_2 sorbent sub-samples after homogenization of the entire bottom sorbent layer (see McCoy et al., 2015). The mass of fossil fuel CO_2 in the unexposed travel blank trap (TB) is then subtracted from the mass of fossil fuel CO_2 in each field-deployed trap.

The results in this report are based on proprietary technology used to measure soil gas efflux. All information contained herein is strictly confidential to the customer.

Easy set-up. Expert results.

This report contains Confidential Information and is to be delivered only to the indicated Customer.

Project: Wishram, WA
Customer: Kennedy Jenks
Customer Contact: Ryan Hultgren
Report Date: 23-Sep-2019

Sample ID	Sampling Information			Raw Results[a]				Final CO_2 Results[b]			^{14}C Results[a]			NSZD Results[b]				
	Deployed	Retrieved	Days in Field	Moisture content (%)	Dry Sorbent Mass (g)	Avg. % CO_2[c]	CV[d] CO_2 (%)	CO_2 content (%)	CO_2 mass (g)	CO_2 Flux (μmol m^{-2} s^{-1})	Fm_{sample} As Reported[e]	bb_{sample} As of Today[f]	ff_{sample} As of Today[f]	Bio-based CO_2 Flux (μmol m^{-2} s^{-1})	ff_{sample} As of Today (TB-corrected)	Fossil Fuel CO_2 (g)	Fossil Fuel CO_2 Flux (μmol m^{-2} s^{-1})	Equivalent NSZD Rate (gal. $acre^{-1}$ yr^{-1})
WIWA-R1-CO2-TB	N/A	N/A	N/A	21.5%	40.31	0.95%	0.72%	-	-	-	67.53	66.21%	33.79%	-	-	-	-	-
WIWA-R1-CO2-01	8/13/19 9:09	8/21/19 16:48	8.32	4.7%	42.15	6.42%	3.53%	5.46%	2.30	8.98	95.49	93.62%	6.38%	8.84	1.60%	0.04	0.14	71
WIWA-R1-CO2-02	8/13/19 9:38	8/21/19 16:54	8.30	7.4%	40.03	1.60%	0.19%	0.65%	0.26	1.02	70.73	69.34%	30.66%	0.75	26.06%	0.07	0.26	131
WIWA-R1-CO2-03	8/12/19 12:48	8/21/19 16:40	9.16	8.1%	40.52	1.71%	0.62%	0.76%	0.31	1.09	70.74	69.35%	30.65%	0.80	26.70%	0.08	0.29	143
WIWA-R1-CO2-04	8/12/19 13:20	8/21/19 16:36	9.14	8.6%	42.05	10.86%	4.44%	9.91%	4.17	14.79	20.51	20.11%	79.89%	2.32	84.32%	3.51	12.47	6146
WIWA-R1-CO2-05	8/12/19 15:58	8/21/19 16:09	9.01	9.6%	41.35	3.94%	0.32%	2.99%	1.24	4.45	41.1	40.29%	59.71%	1.43	67.96%	0.84	3.03	1491
WIWA-R1-CO2-06	8/12/19 13:47	8/21/19 16:30	9.11	14.6%	41.21	2.38%	0.86%	1.43%	0.59	2.10	61.39	60.19%	39.81%	1.18	43.82%	0.26	0.92	453
WIWA-R1-CO2-07	8/13/19 7:55	8/21/19 16:03	8.34	8.3%	40.31	1.96%	3.50%	1.01%	0.41	1.58	60.73	59.54%	40.46%	0.84	46.77%	0.19	0.74	364
WIWA-R1-CO2-08	8/12/19 14:18	8/21/19 16:24	9.09	4.6%	40.58	2.34%	0.47%	1.39%	0.56	2.02	85.89	84.21%	15.79%	1.95	3.47%	0.02	0.07	35
WIWA-R1-CO2-09	8/12/19 14:42	8/21/19 16:18	9.07	6.3%	41.23	2.15%	3.38%	1.20%	0.49	1.77	77.13	75.62%	24.38%	1.47	16.91%	0.08	0.30	147
WIWA-R1-CO2-10	8/12/19 15:20	8/21/19 15:57	9.03	7.2%	41.15	2.42%	1.24%	1.47%	0.60	2.17	50.18	49.20%	50.80%	0.83	61.83%	0.37	1.34	662
WIWA-R1-CO2-11	8/12/19 12:12	8/21/19 15:52	9.15	1.4%	46.57	17.81%	0.59%	16.85%	7.85	27.82	100.26	98.29%	1.71%	27.85	ND	ND	ND	ND

- The flux equivalence is **1** μmol m^{-2} s^{-1} = **492.7** gallons $acre^{-1}$ yr^{-1}, assuming a representative hydrocarbon density of **0.966** g mL^{-1} with the formula $\mathbf{C_{22}H_{46}}$.Trap cross-sectional area is $\mathbf{8.11 \times 10^{-3}}$ m^2 (based on a **4-inch** receiver pipe).
- Carbonate analysis of each trap/sample is based on method ASTM 4373-14, which does do not provide acceptable variability (CV) standards. Similar methods (e.g., ASTM D513-16) allow typical errors of ≤ 20%. Analysis is therefore conducted in duplicate if the coefficient of variation (CV) of the duplicates is < 5%. If CV ≥ 5%, duplicate analyses are repeated until CV < 5%.
- NA = Not Applicable; ND = Not Detectable.

Docosane reactions (C22H46), surrogate for Bunker C:

C22H46 + 10.5 H2O → 16.75 CH4 + 5.25 CO2 (methanogenesis)

16.75CH4 + 33.5 O2 → 16.75 CO2 + 33.5 H2O (methane oxidation)

C22H46 + 33.5 O2 → 22 CO2 + 23 H2O (overall reaction)

a. Raw and ^{14}C Results are not TB-corrected.
b. Final CO_2 and NSZD Results are TB-corrected.
c. Refers to the measured weight percentage of CO_2 with respect to the total dry sorbent mass.
d. Refers to the coefficient of variation of CO_2 measurements for each sample: CV = [standard deviation of %CO_2 measurements] / [average %CO_2 measurement]
e. Refers to the reported fraction modern (Fm_{sample}). As is standard in radiocarbon reporting, this value has not been corrected to account for present-day ^{14}C atmospheric levels. This number is originally reported as pMC (percent modern carbon) and is converted into *Fm* for our calculations using the relation 100.0 pMC = 1.0 *Fm* = 100% *Fm*.
f. "As of Today" means that the value has been adjusted to account for the difference between atmospheric ^{14}C levels from the 1950s and today (Stenström et al., 2011). bb_{sample} is the percentage of the total CO_2 that is derived from bio-based (non-fossil fuel) sources. ff_{sample} refers to the percentage of CO_2 that is derived from fossil fuels. The values reported in the ^{14}C Results section are not TB-corrected, but those in the NSZD Results section are.

Results Snapshot:

- The Travel Blank (TB) concentration is **0.95%**; typically, this number is < 2%.
- Trap tops are not saturated with CO_2 (sorbent saturation is 30%). The maximum measured (raw) top concentration is ***6.06%*** (sample **WIWA-R1-CO2-11 top**).
- Bio-based carbon fluxes represent the CO_2 contributions from natural soil respiration processes to the total carbon flux; the ^{14}C analysis corrects for this contribution. Average bio-based CO_2 flux is **4.39** µmol m^{-2} s^{-1}, and the coefficient of variation is **185%**. The range of bio-based CO_2 fluxes is between **0.75** and **27.85** µmol m^{-2} s^{-1}. If these interferences were not removed using the results of the radiocarbon analysis, the errors in the NSZD rate estimates would be between **370** and **13723** gallons acre^{-1} yr^{-1}.
- Sample **WIWA-R1-CO2-11** shows non-detectable (ND) fossil fuel CO_2 flux. The entire CO_2 flux for this sample is likely derived from non-fossil fuel sources.

Site-specific Sample Calculations:

Grams of Fossil Fuel CO_2:

The mass of fossil fuel-derived CO_2 in each trap is calculated by subtracting the total fossil fuel CO_2 in the travel blank (TB) from the total fossil fuel CO_2 in the trap. Only data that are ***not*** TB-corrected (i.e., ff_{sample} As of Today and raw % CO_2) are used in this calculation. Using Sample 1 as an example:

$$\left(\mathrm{g\ CO_{2(ff)}}\right)_{sample\ 1} = \mathrm{g_{sorbent}} \cdot \left[\left((\%\ \mathrm{CO_2})_{\mathrm{sample}}\left(ff_{sample}\right)\right) - \left((\%\ \mathrm{CO_2})_{\mathrm{TB}}\left(ff_{TB}\right)\right)\right]$$

$$\left(\mathrm{g\ CO_{2(ff)}}\right)_{sample\ 1} = \mathbf{42.15}\ \mathrm{g} \cdot \left[(\mathbf{6.42}\ \% \cdot \mathbf{6.38}\ \%) - (\mathbf{0.95}\ \% \cdot \mathbf{33.79}\ \%)\right]$$

$$\left(\mathrm{g\ CO_{2(ff)}}\right)_{sample\ 1} = \mathbf{0.0369}\ \mathrm{g}$$

Here, $g_{sorbent}$ is the mass of sorbent used in the bottom layer of the trap, $(\%CO_2)_{sample}$ is the average weight percentage of CO_2 in the sample, ff_{sample} is the percentage of carbon in the sample derived from fossil fuels, $(\%CO_2)_{TB}$ is the average weight percentage of CO_2 in the travel blank, and ff_{TB} is the percentage of carbon in the travel blank that is derived from fossil fuels. In this example, Sample 1 contains **0.0369 g** of fossil-fuel derived CO_2.

Fossil Fuel CO_2 Flux:

Converting grams of CO_2 to CO_2 flux requires the cross-sectional area of the receiver (**8.11 × 10^{-3}** m^2 for a **4**-inch receiver), the number of days that the trap was deployed in the field, and the molecular weight of CO_2 (44 g mol^{-1}). Using Site 1 as an example:

$$\text{Fossil Fuel CO}_2\text{ Flux} = \frac{\text{g fossil fuel CO}_2 \cdot \dfrac{1\ \text{mol CO}_2}{44\ \text{g CO}_2} \cdot \dfrac{1{,}000{,}000\ \mu\text{mol CO}_2}{1\ \text{mol CO}_2}}{\text{days in the field} \cdot \dfrac{24\ \text{hr}}{\text{day}} \cdot \dfrac{3600\ \text{s}}{\text{hr}} \cdot (\text{receiver area})}$$

$$\text{Fossil Fuel CO}_2\text{ Flux} = \frac{\mathbf{0.0369}\ \text{g fossil fuel CO}_2 \cdot \dfrac{1\ \text{mol CO}_2}{44\ \text{g CO}_2} \cdot \dfrac{1{,}000{,}000\ \mu\text{mol CO}_2}{\text{mol CO}_2}}{\mathbf{8.32}\ \text{days} \cdot \dfrac{24\ \text{hr}}{\text{day}} \cdot \dfrac{3600\ \text{s}}{\text{hr}} \cdot (\mathbf{8.11} \times \mathbf{10^{-3}}\ \text{m}^2)}$$

$$\text{Fossil Fuel CO}_2\text{ Flux} = \mathbf{0.14}\ \frac{\mu\text{mol CO}_2}{\text{m}^2 \cdot \text{s}}$$

References

ASTM (2014) Method D4373-14, Rapid Determination of Carbonate Content of Soils.

ASTM (2016) Method D513-16, Total and Dissolved Carbon Dioxide in Water.

ASTM (2018) Method D6866-18, Determining the Biobased Content in Solids, Liquid, and Gaseous Samples Using Radiocarbon Analysis.

Avery, Jr. G. B., Wiley J. D. and Kieber R. J. (2006) Carbon isotopic characterization of dissolved organic carbon in rainwater: Terrestrial and marine influences. *Atmospheric Environment* **40(39)**, 7539-7545.

Cerling T. E., Barnette J. E., Chesson L. A., Douglas-Hamilton I., Gobush K. S., Uno K. T., Wasser S. K. and Xu X. (2016) Radiocarbon dating of seized ivory confirms rapid decline in African elephant populations and provides insight into illegal trade. *Proceedings of the Natural Academy of Sciences* **114(47)**, 13330-13335.

Klouda G. A. and Connolly M. V. (1995) Radiocarbon (^{14}C) measurements to quantify sources of atmospheric carbon monoxide in urban air. *Atmospheric Environment* **29(22)**, 3309-3318.

Larsen T., Yokoyama Y. and Fernandes R. (2018) Radiocarbon in ecology: Insights and perspectives from aquatic and terrestrial studies. *Methods in Ecology and Evolution* **9**, 181-190.

Levin I., Graul R. and Trivett N. B. A. (1995) Long-term observations of atmospheric CO_2 and carbon isotopes at continental sites in Germany. *Tellus B, Chemical and Physical Meteorology* **47**, 23-34.

McCoy K., Zimbron J., Sale T. and Lyverse M. (2015) Measurement of Natural Losses of LNAPL Using CO_2 Traps. *Groundwater* **53(4)**, 658-667. doi:10.1111/gwat.12240

Sihota N. J. and Mayer K. U. (2012) Characterizing vadose zone hydrocarbon biodegradation using carbon dioxide effluxes, isotopes, and reactive transport modeling. *Vadose Zone Journal* **11(4)**, doi:10.2136/vzj2011.0204

Stenström K. E., Skog G., Georgiadou E., Genberg J. and Johansson A. (2011) A guide to radiocarbon units and calculations. Lund University Internal Report, LUNFD6(NFFR-3111)/1-17/(2011).

Stuiver M. and Polach H. A. (1977) Discussion: Reporting of ^{14}C data. *Radiocarbon* **19(3)**, 355–363.

Zimbron J. and Kasyon E. (2015) Combined Use of Isotope Analysis and Passive CO_2 Flux Traps to Estimate Field Rates of Hydrocarbon Degradation. Battelle Remediation Conference, D-002(abstr.), Miami FL.

E-FLUX

CO2 TRAP SHIPMENT AND INSTALLATION LOG
LNAPL NATURAL ATTENUATION STUDY

E-FLUX

Date: / /2018

Date Returned to E-Flux: ____________

Contaminant Type	Deployment Location	Retrieval Location	Identification on Outside of Trap Box	Trap Placed in Field		Trap Recovered from Field		Comments	Depth to Ground Water	LNAPL Thickness in Well	Smear Zone Thickness	
4				Date	Time	Date	Time				Vadose Zone	Groundwater
Trap Data												
PHC	NMW-26		WIWA-R1-CO2-~~01~~ 11	8/12/19	1212	8/21/19	1552		10.53	—		
↓	WMW-7		WIWA-R1-CO2-02	8/13/19	0938	↓	1654		11.43	—		
↓	WMW-13		WIWA-R1-CO2-03	8/12/19	1248	↓	1640		11.00	—		
↓	04		WIWA-R1-CO2-04	8/12/19	1320	↓	1636					
↓	05		WIWA-R1-CO2-05	8/12/19	1558	↓	1609					
↓	WMW-1		WIWA-R1-CO2-06	8/12/17	1347	↓	1630		9.87	—		
↓	07		WIWA-R1-CO2-07	8/13/19	0755	↓	1603					
↓	WMW-16		WIWA-R1-CO2-08	8/12/19	1418	↓	1624		14.30	—		
↓	09		WIWA-R1-CO2-09	8/12/19	1442	↓	1618					
↓	10		WIWA-R1-CO2-10	8/12/19	1520	↓	1557					
↓	WMW-12		WIWA-R1-CO2-~~11~~ 01	8/13/19	0909	↓	1648		10.68	—		
			WIWA-R1-CO2-12					NOT DEPLOYED				
Travel Blanks												
				Date Received		Date Returned						
Travel Blank			WIWA-R1-CO2-TB									

Installation Steps - KEEP TRAPS UPRIGHT - CAUTION, CONTAINS CAUSTIC MATERIAL

1- Find the appropriate trap for the location chosen (see map). Remove housing from over Receiver.
2- Remove screw-in caps (top and bottom). Add rain cover to top. Keep trap upright.
3- Place trap on receiver in ground using 4 in rubber coupler. Tighten hose clamps on rubber coupler.
4- At end of monitoring period, reverse steps. Cap both top and bottom of the trap.
5- Keep upright while handing and shipping.

Return Traps to: E-Flux, LLC
(970) 492-4360
200 West Lake St, RIC Room D230
Fort Collins, CO 80521-0922
Attn: E-Flux Receiving

Technician Name:

Easy set-up. Expert results.

Attachment B

Field Forms and Supplemental Data

System Parameter Field Form

Project: BNSF Wishram

System: Bioventing

Date: 7/23/19

Screening Equipment: TSI VelociCalc 9565, Diff Press/Mag Gauges

Well ID	Well Screen Depth (ft)	Well Diameter (inch)	Date/Time	Injection Flow Rate (cfm)	Injection Pressure (inches H_2O)	Wellhead Vacuum/ Pressure (inches H_2O)	
SVE-12-1	5.5 - 8.5	4"	7/23/19 1430	27.5 14:46	7.6 14:41	6.6 1430	
SVE-12-2	5 - 9	4"	↓	5.97 14:47	8.9 14:43	8.8 1432	
SVE-12-3	6.4 - 10.4	4"	↓	22.3 14:48	~~[illegible] 14:42~~ 18.5 14:42	12.7 1435	
SVE-12-4	6.1 - 10.1	4"	↓	~~27.5 14:46~~	~~7.6 14:41~~ 14:44	13.3 1438	
WMW-7	10 - 20	2"	↓	9.75 14:49		0.8 1456	
WMW-8	7 - 22	2"	↓			0.12 1458	
WMW-12	6 - 21	2"	↓ 1501			0.02 1501	
		TEMP °F					%O₂R
SVE-12-1	5.5 - 8.5	114.3°F	7/24/19 0743	28.6 cfm	8.0 0742	6.6	9.1
SVE-12-2	5 - 9	95.6	7/24/19 0747	6.42 cfm	9.9 0748		18.7
SVE-12-3	6.4 - 10.4	118.6	7/24/19 0750	23.0 cfm	14.2 0749		8.1
SVE-12-4	6.1 - 10.1	115.4	7/24/19 0752	8.70 cfm	16.4 0751		9.3
WMW-7	10 - 20		7/24/19 0823			0.9 0823	
WMW-8	7 - 22		7/24/19 0821			0.1 0821	
WMW-12	6 - 21		7/24/19 0816			0.0 0816	

CALIBRATION FIELD FORM
BNSF WISHRAM

Calibration Field Form

Project: Wishram

Date: ______________

PID CALIBRATION					
Date	Time	Calibration Gas Type	Calibration Value	Meter Response	Notes
7/23/19	~~1500~~ 1540	Isobutylene	100	100	zeroed
7/24/19	0825	Isobutylene	100	100	zeroed
7/25/19	0940	"	100	99.9	"
7/26/19	0801	"	100	100.0	"
7/26/19	1230	"	100	100.3	Non resp. PID
7/28/19	1312	"	100	100.0	
7/29/19	0926	"	100	101.9	

	MULTI GAS METER CALIBRATION										
			Calibration Values				Meter Response				
...nceDate	Date	Time	O_2 (%)	CO_2 (%)	CH_4 (% LEL)	H_2S (%)	O_2 (%)	CO_2 (%)	CH_4 (% LEL)	H_2S (%)	Notes
1/2/19	7/23/19	1500	~~11.8~~ 12	~~0.0~~ —	50	—	11.7	0.0	67	0.0	
5/7/19	7/23/19	1510	12	—	50	—	11.1	1.0	49	0.0	
5/7/19	7/23/19	1515	—	5.0	—	—	4.1	3.3	0	0.0	
2/1/19	7/23/19	1520	12	—	50	—	13.9	0.0	55	0.0	
7/7/19	7/23/19	1523	—	5.0	—	—		4.3			
1/2/19	7/23/19	1535	—	5.0	—	—		5.0			Took meter into shop, out of wind
~~1/2/19~~	~~7/23/19~~	~~1537~~	~~12~~	~~—~~	~~50~~	~~—~~					
5/7/19	7/24/19	0750	—	5.0	—	—		4.9			Recal CO_2
5/7/19	7/24/19	0750	12	—	50	—	11.8	—	54	0.0	
5/7/19	7/25/19	0946	~~11.8~~ 12	5.0	50	—	12.0	5.0	48	0.0	
5/7/19	7/26/19	0804	12	5.0	50	—	12.9	~~4~~5.1	46	0.0	

26 @0828 5/7/19 Gas meter reading 21.5% O_2 in ambient air. Other gas meter reading 20.9% O_2 but 9% LEL. Cal gas ran out.

RKI Eagle 2

			Cal Value			Meter Reading			
#	Date	Time	% OXY	% LEL CH4	% CO2	OXY	CH4	CO2	Notes
0581	7/26/19	1152	20.9	50	0.5	20.9	49	0.5	
6669	7/26/19	1155	20.9	50	0.5	20.9	52	0.6	Recal'd CH4
0581	7/28/19	1300	20.9	50	0.5	20.9	48	0.5	
0581	7/29/19	0928	20.9	50	0.5	20.9	51	0.4	Recal'd CH4

BIOVENTING WELLHEAD MEASUREMENTS
BNSF WISHRAM

System Parameter Field Form
Project: WISHRAM
System: BIOVENTING
Date: 7/23/19

Meter: RKI Eagle 2 S/N E2H491
Screening Equipment: Mini Rae Lite
Purging Equipment: Keter pumps
Purging Flowrate:

Tubing depth	Well ID/Depth	Date/Time	Depth to Water (feet btoc)	Purge Time (minutes)	Vacuum/ Pressure (inches H_2O)	O_2 (%)	CO_2 (%)	CH_4 (% LEL)	H_2S ~~(%)~~ ppm	VOCs (ppm)	Notes
	SVE-12-1	7/23 1535	NM	2	+6.4	20.9	0.0	0	0.0	0.0	SYSTEM ON
	SVE-12-1	7/24 0843	NM	3	+6.6	21	0.0	0	0.0	0.0	SYSTEM ON
	SVE-12-1	7/24 0908	NM	2	0.0	20.9	0.0	1	0.0	0.0	SYSTEM OFF
~8 *	SVE-12-1	7/24 0934	NM	3	0.0	21.0	0.0	0	0.0	0.0	SYSTEM OFF
	SVE-12-1	7/24 1033	NM	2	0.0	20.9	0.0	0	0.0	0.1	SYSTEM OFF
	SVE-12-2	7/23 1545	NM	2	+8.4	20.9	0.0	0	0.0	0.0	SYSTEM ON
	SVE-12-2	7/24 0845	NM	2	9.2	20.9	0.0	0	0.0	0.0	SYSTEM ON
	SVE-12-2	7/24 0902	NM	2	0.0	21.0	0.0	1	0.0	0.0	SYSTEM OFF
~9 *	SVE-12-2	7/24 0940	NM	3	0.0	20.9	0.0	0	0.0	0.5	SYSTEM OFF
	SVE-12-2	7/24 1037	NM	2	0.0	20.9	0.0	0	0.0	0.5	SYSTEM OFF
	SVE-12-3	7/23 1550	NM	2	+12.6	20.9	0.0	0	0.0	0.0	SYSTEM ON
	SVE-12-3	7/24 0847	NM	2	13.2	20.9	0.0	0	0.0	0.0	SYSTEM ON
	SVE-12-3	7/24 0904	NM	2	0.0	21.0	0.0	1	0.0	0.0	SYSTEM OFF
~9 *	SVE-12-3	7/24 0946	NM	3	0.0	20.9	0.0	0.0	0.0	0.2	SYSTEM OFF
	SVE-12-3	7/24 1040	NM	2	0.0	20.9	0.0	0	0.0	0.1	SYSTEM OFF
	SVE-12-4	7/23 1555	NM	2	+15.2	20.9	0.0	0	0.0	0.0	SYSTEM ON
	SVE-12-4	7/24 0849	NM	2	15.8	20.9	0.0	0	0.0	0.0	SYSTEM ON
	SVE-12-4	7/24 0906	NM	2	0.0	21.0	0.0	1	0.0	0.0	SYSTEM OFF
~9 *	SVE-12-4	7/24 0952	NM	3	0.0	20.9	0.0	0	0.0	0.0	SYSTEM OFF
	SVE-12-4	7/24 1044	NM	2	0.0	20.9	0.0	0	0.0	0.1	SYSTEM OFF

* Tubing installed

BIOVENTING WELLHEAD MEASUREMENTS
BNSF WISHRAM

System Parameter Field Form
Project: Wishram
System: Bioventing
Date: 7/24/19

Meter: Eagle 2 / PID
Screening Equipment:
Purging Equipment: Meters
Purging Flowrate:

Well ID/Depth	Date/Time	Depth to Water (feet btoc)	Purge Time (minutes)	Vacuum/ Pressure (inches H_2O)	O_2 (%)	CO_2 (%)	CH_4 (% LEL)	H_2S (%)	VOCs (ppm)	Notes
SVE-12-1	7/24 1211	NM	3	0.0	20.9	0.0	0	0.0	1.4	SYSTEM OFF
SVE-12-1	7/24 1310	NM	2	0.0	20.9	0.0	0	0.0	1.4	"
SVE-12-1	7/24 1508	NM	2	0.0	20.9	0.0	0	0.0	1.5	"
SVE-12-1	7/24 1717	NM	2	0.0	20.9	0.0	0	0.0	1.6	"
SVE-12-1	7/25 1021	NM	2	0.0	20.9	0.0	0	0.0	1.6	"
SVE-12-2	7/24 1213	NM	2	0.0	20.9	0.0	0	0.0	1.1	SYSTEM OFF
SVE-12-2	7/24 1312	NM	2	0.0	20.9	0.0	0	0.0	1.4	"
SVE-12-2	7/24 1510	NM	2	0.0	20.9	0.0	0	0.0	1.3	"
SVE-12-2	7/24 1720	NM	2	0.0	20.9	0.0	0	0.0	1.3	"
SVE-12-2	7/25 1023	NM	2	0.0	20.9	0.0	0	0.0	0.9	"
SVE-12-3	7/24 1215	NM	2	0.0	20.9	0.0	0	0.0	1.0	SYSTEM OFF
SVE-12-3	7/24 1314	NM	2	0.0	20.9	0.0	0	0.0	1.1	"
SVE-12-3	7/24 1513	NM	2	0.0	20.9	0.0	0	0.0	1.0	"
SVE-12-3	7/24 1722	NM	2	0.0	20.9	0.0	0	0.0	1.4	"
SVE-12-3	7/25 1026	NM	2	0.0	20.9	0.0	0	0.0	0.8	"
SVE-12-4	7/24 1218	NM	2	0.0	20.9	0.0	0	0.0	1.3	SYSTEM OFF
SVE-12-4	7/24 1316	NM	2	0.0	20.9	0.0	0	0.0	0.8	"
SVE-12-4	7/24 1515	NM	2	0.0	20.9	0.0	0	0.0	2.0	"
SVE-12-4	7/24 1724	NM	2	0.0	20.9	0.0	0	0.0	1.4	"
SVE-12-4	7/25 1028	NM	2	0.0	20.9	0.0	0	0.0	1.1	"
SVE-12-1	7/25 1714	NM	2	0.0	21.6	0.0	0	0.0	1.1	"
SVE-12-2	7/25 1719	NM	2	0.0	21.5	0.0	0	0.0	0.7	"
SVE-12-3	7/25 1721	NM	2	0.0	21.6	0.0	0	0.0	1.5	"
SVE-12-4	7/25 1723	NM	2	0.0	21.4	0.0	0	0.0	1.1	"

BIOVENTING WELLHEAD MEASUREMENTS
BNSF WISHRAM

System Parameter Field Form
Project: Wishram
System: BV
Date: 7/26/19

Meter: RKI Eagle 2 / PID
Screening Equipment:
Purging Equipment:
Purging Flowrate:

Well ID/Depth	Date/Time	Depth to Water (feet btoc)	Purge Time (minutes)	Vacuum/ Pressure (inches H_2O)	O_2 (%)	CO_2 (%)	CH_4 (% LEL)	H_2S (%)	VOCs (ppm)	Notes
SVE-12-1	7/26 1225	NM	2	0.0	20.9	0.0	0	0.0	1.3	SYSTEM OFF
SVE-12-1	7/28 1701	NM	2	0.0	20.9	0.0	0	0.0	1.1	"
SVE-12-1	7/29 1109	NM	2	0.0	20.9	0.0	0	0.0	0.9	"
SVE-12-1										
SVE-12-1										
SVE-12-2	7/26 1233	NM	2	0.0	20.9	0.0	0	0.0	1.2	SYSTEM OFF
SVE-12-2	7/28 1706	NM	2	0.0	20.9	0.0	0	0.0	0.5	"
SVE-12-2	7/29 1115	NM	2	0.0	20.8	0.0	0	0.0	0.5	"
SVE-12-2										
SVE-12-2										
SVE-12-3	7/26 1235	NM	2	0.0	20.9	0.0	0	0.0	1.2	SYSTEM OFF
SVE-12-3	7/28 1708	NM	2	0.0	20.9	0.0	0	0.0	1.1	"
SVE-12-3	7/29 1119	NM	2	0.0	20.9	0.0	0	0.0	0.5	"
SVE-12-3										
SVE-12-3										
SVE-12-4	7/26 1237	NM	2	0.0	20.9	0.0	0	0.0	1.0	SYSTEM OFF
SVE-12-4	7/28 1711	NM	2	0.0	20.9	0.0	0	0.0	0.7	"
SVE-12-4	7/29 1121	NM	2	0.0	20.7	0.0	0	0.0	0.6	"
SVE-12-4										
SVE-12-4										

BIOVENTING WELLHEAD MEASUREMENTS
BNSF WISHRAM

System Parameter Field Form

Project: WISHRAM

System: BIOVENTING

Date: 7/23/19 –

Meter: RKI EAGLE 2 S/N E2H491

Screening Equipment: MINI RAE LITE S/N 590-905052

Purging Equipment: METERS

Purging Flowrate:

Well ID/Depth	Date/Time	Depth to Water (feet btoc)	Purge Time (minutes)	Vacuum/ Pressure (inches H_2O)	O_2 (%)	CO_2 (%)	CH_4 (% LEL)	H_2S (%)	VOCs (ppm)	Notes
WMW-7	7/23 1558	NM	3	0.8	20.5	0.4	0	0.0	1.5	SYSTEM ON
WMW-7	7/24	NM	3	0.9	20.9	0.4	0	0.0	1.1	SYSTEM ON
WMW-7	7/24 0900	NM	3	0.0	20.9	0.3	0	0.0	0.4	SYSTEM OFF
WMW-7	7/24 1022	NM	2	0.0	20.9	0.4	0	0.0	1.0	SYSTEM OFF
WMW-7	7/24 1159	NM	2	0.0	20.9	0.4	0	0.0	1.0	SYSTEM OFF
WMW-8	7/23 1604	NM	3	0.12	19.9	0.5	0	0.0	1.2	SYSTEM ON
WMW-8	7/24 0821	NM	3	0.1	20.9	0.6	0	0.0	2.0	SYSTEM ON
WMW-8	7/24 0910	NM	3	0.0	20.9	0.5	1	0.0	1.8	SYSTEM OFF
WMW-8	7/24 1025	NM	2	0.0	20.9	0.6	0	0.0	1.46	SYSTEM OFF
WMW-8	7/24 1202	NM	2	0.0	20.9	0.6	0	0.0	1.7	SYSTEM OFF
WMW-12	7/23 1604	NM	3	0.03	~~19.9~~ 20.7	~~0.5~~ 0.2	0	0.0	~~1.2~~ 4.4	SYSTEM ON
WMW-12	7/24 0816	NM	3	0.0	20.9	0.3	0	0.0	~~0.0~~ 3.8 MRP	SYSTEM ON
WMW-12	7/24 0912	NM	3	0.0	20.9	0.3	1	0.0	2.6	SYSTEM OFF
WMW-12	7/24 1028	NM	2	0.0	20.9	0.3	0	0.0	2.5	SYSTEM OFF
WMW-12	7/24 1205	NM	2	0.0	20.9	0.4	0	0.0	2.7	SYSTEM OFF

BIOVENTING WEL[illegible]EAD MEASUREMENTS
BNSF WISHRAM

System Parameter Field Form
Project: Wishram
System: Bioventing
Date: 7/24/19 + 7/25/19

Meter: RKI Eagle 2 / PID
Screening Equipment:
Purging Equipment:
Purging Flowrate:

Well ID/Depth	Date/Time	Depth to Water (feet btoc)	Purge Time (minutes)	Vacuum/ Pressure (inches H_2O)	O_2 (%)	CO_2 (%)	CH_4 (% LEL)	H_2S (%)	VOCs (ppm)	Notes
WMW-7	7/24 1300	NM	2	0.0	20.9	0.4	0	0.0	1.2	SYSTEM OFF
WMW-7	7/24 1500	NM	2	0.0	20.9	0.4	0	0.0	1.6	"
WMW-7	7/24 1708	NM	3	0.0	20.9	0.4	0	0.0	1.3	"
WMW-7	7/25 1010	NM	2	0.0	20.9	0.4	0	0.0	1.2	"
WMW-7										
WMW-8	7/24 1303	NM	2	0.0	20.9	0.5	0	0.0	1.5	SYSTEM OFF
WMW-8	7/24 1502	NM	2	0.0	20.7	0.5	0	0.0	1.6	"
WMW-8	7/24 1710	NM	2	0.0	20.7	0.5	0	0.0	1.6	"
WMW-8	7/25 1013	NM	2	0.0	20.9	0.6	1	0.0	1.5	"
WMW-8										
WMW-12	7/24 1306	NM	2	0.0	20.9	0.3	0	0.0	2.7	SYSTEM OFF
WMW-12	7/24 1505	NM	2	0.0	20.9	0.3	0	0.0	3.5	"
WMW-12	7/24 1713	NM	2	0.0	20.9	0.3	0	0.0	3.4	"
WMW-12	7/25 1018	NM	2	0.0	20.9	0.4	1	0.0	2.6	"
WMW-12										

7/25 @1010 Area around WMW-8 & WMW-12 v. active, starting exavation near WMW-12

BIOVENTING WELLHEAD MEASUREMENTS
BNSF WISHRAM

System Parameter Field Form
Project: Wishram
System: BV
Date: 7/25/19

Meter: RKI Eagle 2 / PID
Screening Equipment:
Purging Equipment: Meters
Purging Flowrate:

Well ID/Depth	Date/Time	Depth to Water (feet btoc)	Purge Time (minutes)	Vacuum/ Pressure (inches H_2O)	O_2 (%)	CO_2 (%)	CH_4 (% LEL)	H_2S (%)	VOCs (ppm)	Notes
WMW-7	7/25 1704	NM	2	0.0	20.9	0.5	0	0.0	2.0	SYSTEM OFF
WMW-7	7/26 1213	NM	2	0.0	20.4	0.4	0	0.0	1.9	"
WMW-7	7/28 1652	NM	2	0.0	20.9	~~0.3~~ 0.4	0	0.0	1.1	"
~~WMW-7~~ WMW-8	7/29 1055	NM	2	0.0	20.0	0.5	0	0.0	1.2	"
WMW-7										
WMW-8	7/25 1707	NM	2	0.0	20.9	0.5	0	0.0	2.4	SYSTEM OFF
WMW-8	7/26 1215	NM	2	0.0	20.1	0.5	0	0.0	2.2	"
WMW-8	7/28 1654	NM	2	0.0	20.8	0.4	0	0.0	1.4	"
~~WMW-8~~ WMW-7	7/29 1106	NM	2	0.0	20.0	0.5	0	0.0	1.0	"
WMW-8										
WMW-12	7/25 1710	NM	2	0.0	20.9	0.4	0	0.0	3.5	SYSTEM OFF
WMW-12	7/26 1219	NM	2	0.0	20.6	0.3	0	0.0	4.2	"
WMW-12	7/28 1656	NM	2	0.0	20.9	~~0.2~~ 0.3	0	0.0	2.2	"
WMW-12	7/29 1059	NM	2	0.0	20.6	0.3	0	0.0	1.9	"
WMW-12										

BIOVENTING WELLHEAD MEASUREMENTS
BNSF WISHRAM

System Parameter Field Form
Project: Wishram
System: Bioventing
Date: 8/7/19

Meter: RKI Eagle 2 / PID
Screening Equipment:
Purging Equipment:
Purging Flowrate:

Well ID/Depth	Date/Time	Depth to Water (feet btoc)	Purge Time (minutes)	Vacuum/ Pressure (inches H_2O)	O_2 (%)	CO_2 (%)	CH_4 (% LEL)	H_2S (~~%~~ ppm)	VOCs (ppm)	Notes
WMW-7	8/7/19 1546	NM	3	0.0	19.8	0.6	0	0	0.8	
WMW-7	8/8/19 1705	NM	2	0.0	19.7	0.7	0	0	0.3	
WMW-7										
WMW-7										
WMW-7										
WMW-8	8/8/19 1700	NM	2	0.0	20.5	0.7	0	0.0	0.6	
WMW-8										
WMW-8										
WMW-8										
WMW-8										
WMW-12	8/8/19 1655	NM	2	0.0	20.9	0.3	0	0.0	0.8	
WMW-12										
WMW-12										
WMW-12										
WMW-12										
SVE-12-3	8/7/19 1555	NM	3	0.0	20.7	0.0	0	0	0.5	
SVE-12-1	8/8/19 1707	NM	2	0.0	20.4	0.0	0	0	0.7	
SVE-12-2	↓ 1717	NM	2	0.0	20.4	0.3	0	0	0.3	
SVE-12-3	↓ 1731	NM	2	0.0	20.8	0.0	0	0	0.3	
SVE-12-4	↓ 1737	NM	2	0.0	19.7	0.3	0	0	1.2	

SOIL GAS WELLHEAD MEASUREMENTS
BNSF WISHRAM

System Parameter Field Form
Project: Wishram
System:
Date: 7/26/19

Meter: RKI Eagle 2/PID
Screening Equipment:
Purging Equipment:
Purging Flowrate:

Well ID/Depth	Date/Time	Depth to Water (feet btoc)	Purge Time (minutes)	Vacuum/ Pressure (inches H_2O)	O_2 (%)	CO_2 (%)	CH_4 (% LEL)	H_2S (%)	VOCs (ppm)	Notes
WMW-1	7/26/19									
WMW-1	7/28/19	NM	2	0.0	20.9	0.2	0	0.0	2.2	*
WMW-1	7/29/19 0935	NM	2	0.0	20.9	~~0.0~~ 0.1	0	0.0	0.4	
WMW-1										
WMW-3	7/26/19									
WMW-3	7/28/19	NM	2	0.0	19.1	1.5	0	0.0	2.8	*
WMW-3	7/29/19 1009	NM	2	0.0	18.6	1.7	0	0.0	2.2	
WMW-3										
WMW-9	7/26/19 1300	NM	2	0.0	19.3	1.2	0	0.0	1.7	*
WMW-9	7/28/19 1452	NM	2	0.0	19.4	1.2	0	0.0	1.3	
WMW-9	7/29/19 1024	NM	2	0.0	19.1	1.2	0	0.0	1.1	
WMW-9										
WMW-10										
WMW-10	7/28/19 1507	NM	2	0.0	20.9	0.2	0	0.0	2.4	
WMW-10	7/29/19 0956	NM	2	0.0	20.8	0.3	0	0.0	2.6	
WMW-10	7/26/19 1255	NM	2	0.0	20.9	0.1	0	0.0	3.3	*
WMW-11	7/26/19 1310	NM	2	0.0	20.1	0.7	0	0.0	1.8	*
WMW-11	7/28/19 1501	NM	2	0.0	20.8	0.7	0	0.0	1.6	
WMW-11	7/29/19 0959	NM	2	0.0	20.0	0.8	0	0.0	1.2	
WMW-11										
WMW-13	7/26/19 1250	NM	2	0.0	20.9	0.1	0	0.0	1.5	* silicon tubing quickconnect (on all)
WMW-13	7/28/19 1538	NM	2	0.0	20.9	0.2	0	0.0	1.5	
WMW-13	7/29/19 1018	NM	2	0.0	20.9	0.2	0	0.0	1.2	
WMW-13										
WMW-14	7/26/19 1315	NM	2	0.0	20.9	0.4	0	0.0	1.3	*
WMW-14	7/28/19 1510	NM	2	0.0	20.9	0.3	0	0.0	1.6	

SOIL GAS WELLHEAD MEASUREMENTS
BNSF WISHRAM

Well	Date	DTW	Purge T	Vacuum	O_2	CO_2	CH_4	H_2S	VOCs	Notes
WMW-15 ~~WMW-14~~ KT	7/26/19 1320	NM	2	0.0	20.6	0.6	0	0.0	3.1	*
WMW-14	7/29/19 0951	NM	2	0.0	20.4	0.6	0	0.0	0.9	WMW-14
WMW-15	7/28/19 1504	NM	2	0.0	20.7	0.6	0	0.0	2.9	
WMW-15	7/29/19 0947	NM	2	0.0	20.1	0.7	0	0.0	1.2	
WMW-15										
WMW-15										
WMW-16	7/26/19 1325	NM	2	0.0	19.9	0.5	0	0.0	1.8	*
WMW-16	7/28/19 1425	NM	2	0.0	20.8	0.3	0	0.0	1.2	
WMW-16	7/29/19 0939	NM	2	0.0	~~20.9~~ 20.1	~~0.0~~ 0.4	0	0.0	0.4	KT
WMW-16										
WMW-17	7/26/19 1330	NM	2	0.0	20.9	0.2	0	0.0	2.0	*
WMW-17	7/28/19 1432	NM	2	0.0	20.9	0.2	0	0.0	1.6	
WMW-17	7/29/19 0944	NM	2	0.0	20.4	~~0.3~~ 0.4	0	0.0	0.7	
WMW-17	~~7/29/19~~									
WMW-26	7/26/19									
WMW-26	7/28/19 1355	NM	2	0.0	20.1	0.5	0	0.0	2.3	*
WMW-26	7/29/19 1030	NM	2	0.0	20.4	0.5	0	0.0	1.0	
WMW-26										
WMW-27	7/26/19									
WMW-27	7/28/19 1400	NM	2	0.0	20.4	0.4	0	0.0	1.7	*
WMW-27	7/29/19 1030	NM	2	0.0	20.7	0.4	0	0.0	0.9	
WMW-27										
WMW-28	7/26/19									
WMW-28	7/28/19 1549	NM	2	0.0	20.9	0.3	0	0.0	2.0	
WMW-28	7/29/19 1047	NM	2	0.0	20.7	0.2	0-1	0.0	1.9	
WMW-28										
WMW-29	7/26/19									
WMW-29	7/28/19 1350	NM	2	0.0	20.1	0.7	0	0.0	3.0	*
WMW-29	7/29/19 1035	NM	2	0.0	20.4	~~0.6~~ 0.7	0	0.0	2.4	
WMW-29										

SOIL GAS WELLHEAD MEASUREMENTS
BNSF WISHRAM

System Parameter Field Form

Project: ____________________

System: ____________________

Date: ____________________

Meter: ____________________

Screening Equipment: ____________________

Purging Equipment: ____________________

Purging Flowrate: ____________________

Well ID/Depth	Date/Time	Depth to Water (feet btoc)	Purge Time (minutes)	Vacuum/ Pressure (inches H_2O)	O_2 (%)	CO_2 (%)	CH_4 (% LEL)	H_2S (%)	VOCs (ppm)	Notes
WMW-1	7-26 1316	NM	2min	—	20.9	0.0	1	0	2.8	
WMW-1										
WMW-1										
WMW-1										
WMW-3	7-26 13:20	NM	2min	—	20.9	0.6	1	0	2.9	
WMW-3										
WMW-3										
WMW-3										
WMW-9										
WMW-9										
WMW-9										
WMW-9										
WMW-10										
WMW-10										
WMW-10										
WMW-10										
WMW-11										
WMW-11										
WMW-11										
WMW-11										
WMW-13										
WMW-13										
WMW-13										
WMW-13										
WMW-14										
WMW-14										

SOIL GAS WELLHEAD MEASUREMENTS

BNSF WISHRAM

	Date/time	DTW	Purge time	Vac/press	O_2	CO_2	CH_4	H_2S	VOCs	Notes
WMW-14					20.9	0.2	0	0		
WMW-14										
WMW-15										
WMW-15										
WMW-15										
WMW-15										
WMW-16										
WMW-16										
WMW-16										
WMW-16										
WMW-17										
WMW-17										
WMW-17										
WMW-17										
WMW-26	7-26 12:56	NM	2min	—	20.9	0.3	0	0	2.2	
WMW-26										
WMW-26										
WMW-26										
WMW-27	7-26 13:00	NM	2min	—	20.9	0.1	0	0	1.6	
WMW-27										
WMW-27										
WMW-27										
WMW-28	7-26 13:08	NM	2.5min	—	20.9	0.1	1	0	2.6	
WMW-28										
WMW-28										
WMW-28										
WMW-29	7-26 12:45	NM	2min	—	20.9	0.2	0	0	4.2	
WMW-29										
WMW-29										
WMW-29										

SOIL GAS WELLHEAD MEASUREMENTS
BNSF WISHRAM

System Parameter Field Form
Project: Wishram
System: NA
Date: 8/8/19

Meter: RKI Eagle2/PID
Screening Equipment:
Purging Equipment:
Purging Flowrate:

Well ID/Depth	Date/Time	Depth to Water (feet btoc)	Purge Time (minutes)	Vacuum/ Pressure (inches H_2O)	O_2 (%)	CO_2 (%)	CH_4 (% LEL)	H_2S (~~%~~ ppm)	VOCs (ppm)	Notes
WMW-1	0959	NM	2	0.0	20.9	0.2	0	0.0	0.1	
MW-3 ~~WMW-1~~	1009	NM	3	0.0	18.1	2.9	0	0.0	0.3	
WMW-1										
WMW-1										
WMW-3										
WMW-3										
WMW-3										
WMW-3										
WMW-9	1554	NM	2	0.0	19.2	1.5	0	0.0	0.6	
WMW-9										
WMW-9										
WMW-9										
WMW-10	1056	NM	2	0.0	20.9	0.4	0	0.0	1.7	
WMW-10										
WMW-10										
WMW-10										
WMW-11	1059	NM	2	0.0	20.4	0.9	0	0.0	0.6	
WMW-11										
WMW-11										
WMW-11										
WMW-13	1548	NM	2	0.0	20.9	0.3	0	0.0	0.1	
WMW-13										
WMW-13										
WMW-13										
WMW-14	1053	NM	~~0.0~~ 2	0.0	20.8	0.7	0	0.0	0.6	
WMW-14										

SOIL GAS WELLHEAD MEASUREMENTS
BNSF WISHRAM

	Time	DTW	Purge	Vac	O_2	CO_2	CH_4	H_2S	VOCs	Notes
WMW-14										
WMW-14										
WMW-15	1049	NM	2	0.0	20.5	0.8	0	0.0	1.1	
WMW-15										
WMW-15										
WMW-15										
WMW-16	1046	NM	2	0.0	19.7	0.9	0	0.0	0.2	
WMW-16										
WMW-16										
WMW-16										
WMW-17	1042	NM	3	0.0	20.9	0.6	0	0.0	0.3	
WMW-17										
WMW-17										
WMW-17										
WMW-26	1532	NM	2	0.0	20.5	0.7	0	0.0	0.2	
WMW-26										
WMW-26										
WMW-26										
WMW-27	1519	NM	2	0.0	20.8	0.5	0	0.0	0.1	
WMW-27										
WMW-27										
WMW-27										
WMW-28	1515	NM	2	0.0	20.8	0.4	0	0.0	1.4	
WMW-28										
WMW-28										
WMW-28										
WMW-29	1523	NM	2	0.0	20.5	0.7	0	0.0	1.9	
WMW-29										
WMW-29										
WMW-29										

ATTACHMENT B1
SOIL GAS DATA
BNSF Wishram Railyard

Well ID	Date/Time	O_2 %	CO_2 %	CH4 % (LEL)	H_2S (ppm)	VOCs (ppm)
WMW-01	7/26/19 13:16	20.9	0.0	1	0	0.0
WMW-01	7/28/19 14:40	20.9	0.2	0	0	2.2
WMW-01	7/29/19 9:35	20.9	0.1	0	0	0.4
WMW-01	8/8/19 9:59	20.9	0.2	0	0	0.1
WMW-03	7/26/19 13:20	20.9	0.6	1	0	2.9
WMW-03	7/28/19 14:45	19.1	1.5	0	0	2.8
WMW-03	7/29/19 10:09	18.6	1.7	0	0	2.2
WMW-03	8/8/19 10:09	18.1	2.9	0	0	0.3
WMW-09	7/26/19 13:00	19.3	1.2	0	0	1.7
WMW-09	7/28/19 14:52	19.4	1.2	0	0	1.3
WMW-09	7/29/19 10:24	19.1	1.2	0	0	1.1
WMW-09	8/8/19 15:54	19.2	1.5	0	0	0.6
WMW-10	7/26/19 12:55	20.9	0.1	0	0	3.3
WMW-10	7/28/19 15:07	20.9	0.2	0	0	2.4
WMW-10	7/29/19 9:56	20.8	0.3	0	0	2.6
WMW-10	8/8/19 10:56	20.9	0.4	0	0	1.7
WMW-11	7/26/19 13:10	20.1	0.7	0	0	1.8
WMW-11	7/28/19 15:01	20.8	0.7	0	0	1.6
WMW-11	7/29/19 9:59	20.0	0.8	0	0	1.2
WMW-11	8/8/19 10:59	20.4	0.9	0	0	0.6
WMW-13	7/26/19 12:50	20.9	0.1	0	0	1.5
WMW-13	7/28/19 15:38	20.9	0.2	0	0	1.5
WMW-13	7/29/19 10:18	20.9	0.2	0	0	1.2
WMW-13	8/8/19 15:48	20.9	0.3	0	0	0.1
WMW-14	7/26/19 13:15	20.9	0.4	0	0	1.3
WMW-14	7/28/19 15:10	20.9	0.3	0	0	1.6
WMW-14	7/29/19 9:51	20.4	0.6	0	0	0.9
WMW-14	8/8/19 10:53	20.8	0.7	0	0	0.6
WMW-15	7/26/19 13:20	20.6	0.6	0	0	3.1
WMW-15	7/28/19 15:04	20.7	0.6	0	0	2.9
WMW-15	7/29/19 9:47	20.1	0.7	0	0	1.2
WMW-15	8/8/19 10:49	20.5	0.8	0	0	1.1
WMW-16	7/26/19 13:25	19.9	0.5	0	0	1.8
WMW-16	7/28/19 14:25	20.8	0.3	0	0	1.2
WMW-16	7/29/19 9:39	20.1	0.4	0	0	0.4
WMW-16	8/8/19 10:46	19.7	0.9	0	0	0.2
WMW-17	7/26/19 13:30	20.9	0.2	0	0	2.0
WMW-17	7/28/19 14:32	20.9	0.2	0	0	1.6
WMW-17	7/29/19 9:44	20.4	0.4	0	0	0.7
WMW-17	8/8/19 10:42	20.9	0.6	0	0	0.3
WMW-26	7/26/19 12:56	20.9	0.3	0	0	2.2
WMW-26	7/28/19 13:55	20.1	0.5	0	0	2.3
WMW-26	7/29/19 10:38	20.4	0.5	0	0	1.0
WMW-26	8/8/19 15:32	20.5	0.7	0	0	0.2
WMW-27	7/26/19 13:00	20.9	0.1	0	0	1.6
WMW-27	7/28/19 14:00	20.4	0.4	0	0	1.7
WMW-27	7/29/19 10:30	20.7	0.4	0	0	0.9
WMW-27	8/8/19 15:19	20.8	0.5	0	0	0.1
WMW-28	7/26/19 13:08	20.9	0.1	1	0	2.6
WMW-28	7/28/19 15:49	20.9	0.3	0	0	2.0
WMW-28	7/29/19 10:47	20.7	0.2	0	0	1.9
WMW-28	8/8/19 15:15	20.8	0.4	0	0	1.4
WMW-29	7/26/19 12:45	20.9	0.2	0	0	4.2
WMW-29	7/28/19 13:50	20.1	0.7	0	0	3.0
WMW-29	7/29/19 10:35	20.4	0.7	0	0	2.4
WMW-29	8/8/19 15:23	20.5	0.7	0	0	1.9

Notes:
Soil gas measurements collected following installation of vapor well plugs / well caps in areas outside existing bioventing system.
August 8, 2019 measurements for baseline soil gas conditions in natural source zone depletion and respirometry evaluations.

0900 KET arrive at Discover Rentals in The Dalles to pick up generator.
0915 Drive to site. Pick up gas can & fill w/ gas on the way
1000 Arrive on site. Don PPE. Meet GG.
1030 Call RH to discuss BV pilot test scope.
1100 Calibrate gas meters & start background soil gas msmts.
1143 DTW WMW-11 = 10.12
1146 DTW WMW-1 = 9.68
1115-1135 KET perform bank inspection. Observed sheen between wells WMW-17 & WMW-18. Sheen ~5' long (E-W) & 0.5' wide, no oil droplets observed. Floated E & into bank. Weather 74° F, wind 4 mph NNW
1200 Start setting up for BV test on WMW-11
1215 GG off site to Home Depot for pipe fittings
1343 GG back on site

Scale: 1 square = ______

1345 Start blower on WMW-11
Velocicalc flow reading
flow = 10.10 - 10.20 cfm
temp = 102.9° F
1355 Start pressure msmts. No bubbles in river.
1415 No sheen on river
1445 Velocicalc reading
flow = 9.95 - 10.00 cfm
temp = 104.5° F
1450 Increase flow for 2nd step
Velocicalc reading
flow = 14.99 - 15.15 cfm
temp = 107.2° F
1535 Check flow on velocicalc
flow = 15.05 - 15.17 cfm
temp = 108.6° F
1550 Increase flow for 3rd step
flow = 20.06 - 20.17 cfm
temp = 108.7° F
1700 Increase flow. Dilution valve closed completely
flow = 33.71 - 33.79 cfm
temp = 114.6° F
1730 Start round of pressure msmts

Scale: 1 square = ______

Well	(in H_2O) Pressure	Time	O_2	CO_2	CH_4	H_2S	VOCs	Notes	Purge Time
WMW-11 (wellhead)	7.4	1730	NM	NM	NM	NM	NM		NA
WMW-11 (blower)	18.8	1731							
WMW-10	0.01	1732							
WMW-14	0.02	1734							
WMW-15	0.09	1735							
WMW-16	0	1736							
WMW-17	0	1737							
WMW-1	0	1740							
WMW-3	0.001	1742							
WMW-10	0.015	1753	20.9	0.2	0	0	0.7		2
WMW-14	0.02	1757	21.2	0.1	0	0	0.2		2
WMW-15	0.08	1759	20.9	0.4	0	0	0.6		2
WMW-16	0	1803	20.9	0.4	0	0	0.2		2
WMW-17	0	1807	20.9	0	0	0	0.2		2
WMW-1	0	1811	20.9	0	0	0	0.3		2
WMW-3	0	1815	20.5	0.4	0	0	0.7		2

1830 RH calls. Generator stops working. Gas gauge indicates full. Discuss leaving blower overnight & take measurements every 4 hrs tomorrow.

1845 Fill generator w/ gas (~10L). Gas gauge may be broken. Still indicates full. Generator started up again w/ 311.5 hrs

19:10 KET off site

Scale: 1 square = ________

Scale: 1 square = ________

Rite in the Rain

0700 KET arrive on site. Don PPE.
Generator not running. Gas
gauge reads empty.
Add gas to generator.
0735 Generator powered up. Hour
reading = 316.5
Operating at ~123 V
0745 Blower flow reading 36.90-37.05
CFM. Temp = 74.2 °F
0805 Set blower to 20.27-20.35 CFM
Temp = 80.7 °F
0820-0830 Bank inspection. No sheen.
River v. calm. 61°F wind WNW 1 mph
0900 observe several (~7-8) areas of
sheen floating on river between
wells WMW-14 & WMW-16. 5-10' from
bank. Two areas of sheen appear to
have oil droplets. Ea. area ~1' or
smaller. Weather 65° F, wind
NW 1 mph, river v. calm. Sheen
floating slowly east.
0943 Blower flow rate reading =
19.78-19.85 CFM
temp = 88.3

0945 Increase blower flow rate to
35.77-35.90 CFM
temp = 93.9 °F
Dilution valve closed
1000 KET off site to fill gas can & pick up velocicalc
1105 KET back on site
Bank inspection. No sheen.
1130 Check flow w/ velocicalc 9535 (KJ)
& 9565 (rental) 71
9535 - flow: 35.~~42~~ 35.98 CFM
temp: 104.4°F
9565 - flow: 31.96-32.25 CFM
temp: 98.8 °F
% rh: 16.8
Flow on 9565 less stable than on 9535
1217 Turn off generator to add more fuel
1228 Blower & generator back on
1240 Add duct tape to blower to reduce leaks
1255 Manifold pressure = 24.7 in H_2O
Sch. 80 PVC pipe pressure = 24.6 in H_2O
WMW-11 wellhead pressure = 12.4 in H_2O
1536 9535 - flow = 34.40-34.60 CFM
temp = 110.6
9565 - flow = 31.28-31.57 CFM
temp = 111.1
rh = 9.1

2/27/19

Well	Time	Pressure (in H_2O)	O_2(%)	CO_2(%)	CH_4(% LEL)	H_2S (ppm)	↑	Purge Time (min)	Notes
WMW-11 (blower)	0809	8.4							20 CFM
WMW-11 (wellhead)	0810	5.7							20 CFM
WMW-10	0815	0.005	20.9	0.3	0	0	0.2	2	20 CFM
WMW-14	0820	0.01	20.7	0.5	0	0	0.5	2	20 CFM
WMW-15	0830	0.04	20.4	0.6	0	0	1.3	2	20 CFM
WMW-16	0834	0.005	19.3	0.9	0	0	0.2	2	20 CFM
WMW-17	0839	0.005	20.1	0.3	0	0	0.8	2	20 CFM
WMW-1	0843	0.001	20.9	0.0	0	0	1.0	2	20 CFM
WMW-3	0846	0.0	20.7	0.4	0	0	1.8	2	20 CFM
WMW-11 (blower)	0855	8.4							↓
WMW-11 (wellhead)	0856	5.6							↓
WMW-10	0858	0.005							↓
WMW-14	0859	0.01							↓
WMW-15	0912	0.05							↓
WMW-16	0916	0.005							↓
WMW-17	0917	0.005							↓
WMW-1	0918	0.0							↓
WMW-3	0920	0.0							↓
WMW-16	0938	0.005	19.2	0.8	0	0	0.1	2	20 CFM
WMW-11 (blower)	1151	19.9							
WMW-11 (wellhead)	1152	10.8							
WMW-10	1159	0.01							
WMW-14	1200	0.02							

Scale: 1 square = ________

Scale: 1 square = ________

8/27/19

Well	Time	Pressure (in H2O)	O_2 (%)	CO_2 (%)	CH_4 (% LEL)	H_2S (ppm)	VOCs (ppm)	Purge (min)	Notes
WMW-15	1201	0.085							
WMW-16	1202	0.005							
WMW-17	1203	0.005							
WMW-1	1204	0.005							
WMW-3	1205	0.0							
WMW-11 (Manifold)	1541	24.5							
Sch 80 PVC	1542	24.4							
WMW-11 (Wellhead)	1543	12.4							
WMW-10	1545	0.02							
WMW-14	1546	0.03							
WMW-15	1547	0.10							
WMW-16	1549	0.0							
WMW-17	1550	0.0							
WMW-1	1553	0.0							
WMW-3	1554	0.001							
manifold	1641	23.5							
WMW-11 (Wellhead)	1643	12.8							
WMW-10	1645	0.02							
WMW-14	1646	0.02							
WMW-15	1647	0.11							
WMW-16	1648	0.0							
WMW-17	1649	0.0							
WMW-1	1651	0.0							
WMW-3	1652	0.001							

Scale: 1 square = ______

1730 Pressure on manifold = 23.9 in. H_2O

1736 Blower & generator off to refuel

1746 Blower & generator back on, hours on generator = 326.4
Generator refueled.

1800 KET off site

Scale: 1 square = ______

9/27/19 Wishram

1601 Turn off blower, remove 2" sch. 80 PVC section & connect hose directly to manifold.

1610 Turn blower back on.

1615 Gauge WLs

Well	DTW	Time
WMW-10	10.18	1617
WMW-14	14.40	1619
WMW-15	14.23	1621
WMW-16	14.05	1623
WMW-17	13.91	1625
WMW-1	9.62	1627
WMW-3	10.22	1629

Well	Time	% O_2	% CO_2	%LEL CH_4	ppm H_2S	ppm VOCs	(min) Purge	Notes
WMW-10	1702	20.6	0.2	0	0	1.0	2	
-14	1707	20.4	0.5	0	0	1.5	2	
-15	1711	20.1	0.6	0	0	1.8	2	
-16	1714	19.2	0.7	0	0	0.7	2	
-17	1717	19.4	0.4	0	0	1.2	2	
-1	1720	20.7	0.0	0	0	1.6	2	
-3	1723	20.1	0.2	0	0	1.7	2	
-11 (wellhead)	1725	20.9	0.6	0	0	2.7	2	

Scale: 1 square = ________

9/28/19 Wishram

0715 KET arrive on site. Don PPE. Generator off & gas gauge E. Add fuel to generator.

0735 Generator & blower running. Generator hours = 335.8

0740-0750 Bank inspection. No sheen observed. Weather: 63°F, no wind, water has small ripples, sunny

0800 Calibrate gas meters

0946 Turn off blower to add sch. 80 pipe back in

0952 Blower back on

0955 Blower flow = 15.56 - 15.66 CFM
temp = 82.9°F

1000 Start round of pressure msmts

1033 Flow = 15.66 - 15.73 CFM
Temp = 85.0 °F

1055 Flow = 15.77 - 15.86 CFM
Temp = 89.1 °F

1057 Close dilution valve.
Flow = 32.40 - 32.70 CFM
Temp = 90.6 °F
Manifold pressure = 24.7 " H_2O
Sch. 80 Pipe pressure = 24.7 " H_2O
WMW-11 wellhead pressure = 12.4 " H_2O

Scale: 1 square = ________

8/28/19

Well	Time	Pres. (in. H2O)	O_2 (%)	CO_2 (%)	CH_4 (LEL)	H_2S (ppm)	Purge (min)	~~Notes~~ VOCs
Manifold	0819	25.7						
WMW-11 wellhead	0821	13.7	20.9	0.0	0	0	2	1.3
WMW-10	0828	0.01	20.7	0.3	0	0	2	0.2
-14	0831	0.025	20.7	0.6	0	0	2	0.8
-15	0833	0.11	20.7	0.7	0	0	2	1.3
-16	0837	0.005	19.1	1.2	0	0	2	0.3
-17	0841	0.01	19.5	0.5	0	0	2	0.9
-1	0845	0	20.9	0.0	0	0	2	0.9
-3	0848	0	20.6	0.2	0	0	2	1.2

15 CFM STEP 0955 – 1055

Well	Time	Pres.
Manifold	1000	~~6.7~~ 8.0
sch 80	1001	8.0
WMW-11 wellhead	1003	5.3
WMW-10	1007	0.01
-14	1008	0.015
-15	1009	0.05
-16	1010	0.01
-17	1011	0.015
-1	1013	0.0
-3	1014	0.0
Manifold	1021	8.1
sch. 80	1022	8.1
WMW-11 wellhead	1023	5.3
WMW-10	1024	0.005

Scale: 1 square = ________

8/28/19

Well	Time	Pres. (in. H2O)	O_2 %	CO_2 %	CH_4 LEL	H_2S ppm	VOCs ppm	Purge mins
WMW-14	1026	0.02						
-15	1027	0.06						
-16	1028	0.015						
-17	1029	0.015						
-1	1030	0.0						
-3	1031	0.0						
Manifold	1043	8.1						
sch 80	1044	8.1						
WMW-11 wellhead	1045	5.4						
WMW-10	1046	0.01						
-14	1047	0.02						
-15	1048	0.05						
-16	1049	0.015						
-17	1051	0.015						
-1	1052	0.0						
-3	1053	0.0	END OF STEP					
WMW-11 wellhead	1315	12.2						
WMW-10	1318	0.01						
-14	1319	0.025						
-15	1321	0.11						
-16	1322	0.005						
-17	1324	0.005						
-1	1331	0.0						
-3	1332	0.0						

Scale: 1 square = ________

1140 KET off site to ship velocicalc & get fuel for generator
1300 KET back on site.
1310 Flow = 32.08 - 32.25 CFM
Temp = 98.0
Manifold pressure = 24.5 "H_2O
Sch 80 pipe pressure = 24.4 "H_2O
1325 - 1340 Observe sheen in river. ~7 small areas, 5 in² or less, no oil droplets observed. ~5' off shore in front of concrete pad near WMW-18. Slowly floating & dissapating. River is calm
weather 92°F, wind WNW 4 mph
1350 GG arrive on site.
OHM-2 11.69 ft = DTP
@ 14:20, 8/28/2019
OHM-1 DTP = 9.40 ft
@ 14:25 8/28/2019
1433 OHM-3 DTP = 11.42 ft

1504 WMW-8 ~~0.03~~ 0.02
1512 WMW-12 ~~0.025~~ 0.01
1518 WMW-7 ~~0.015~~ 0.005
SVE-1 ~~0.010~~ ~~0.005~~ 0.0
SVE-2 0.0

Scale: 1 square = ______

1536 SVE-3 0.0
1537 SVE-4 0.0

Well	Time	Pres ("H_2O)	O_2 (%)	CO_2 (%)	CH_4 LEL	H_2S ppm	VOC ppm	Purge min
Manifold ~~1548~~	1549	24.2						
SCH80	1549	24.1						
well head WMW-11	1551	12.3	20.9	0	0	0	4.0	2
WMW-10	1554	.015	20.3	0.3	0	0	0.9	2
WMW-14	1557	.025	20.4	0.5	0	0	1.8	2
WMW-15	1600	.11	20.0	0.7	0	0	0.8	2
WMW-16	1602	.005	19.0	1.1	0	0	1.0	2
WMW-17	1604	.001	19.7	0.4	0	0	1.5	2
WMW-1	1607	.001	20.6	0	0	0	1.8	2
WMW-3	1610	0.0	20.0	0.2	0	0	2.6	2

1610 Flow = 31.21 - 31.44 CFM
Temp = 107.4 °F
1613 Blower off
Hours = 344.5
Pack up equipment, break down blower
1700 Soil gas reading
1800 Soil gas reading
1845 All off site

Scale: 1 square = ______

8/28/19

Well	Time	Pres. ("H_2O)	O_2 (%)	CO_2 (%)	CH_4 (LEL)	H_2S (ppm)	VOCs (ppm)	Purge (min)
WMW-11	1702	0.015	20.9	0.0	0	0	3.3	2
-10	1708	0.005	20.6	0.3	0	0	0.7	2
-14	1712	~~0.015~~ 0.0	20.9	0.4	0	0	1.4	2
-15	1717	0.0	20.4	0.6	0	0	2.9	2
-16	1719	0.0	19.4	1.1	0	0	0.8	2
-17	1722	0.0	20.1	0.4	0	0	1.2	2
-1	1725	0.0	20.9	0.0	0	0	1.3	2
-3	1727	0.0	20.6	0.2	0	0	2.2	2
-11	1805	0.005	20.9	0.0	0	0	3.2	2
-10	1809	0.005	20.9	0.3	0	0	0.6	2
-14	1813	0.0	20.9	0.5	0	0	0.4	2
-15	1815	0.0	20.7	0.6	0	0	3.6	2
-16	1818	0.0	19.5	1.1	0	0	0.6	2
-17	1821	0.0	20.3	0.4	0	0	1.2	2
-1	1824	0.0	20.9	0.0	0	0	1.4	2
-3	1827	0.0	20.9	0.5	0	0	2.1	2

Scale: 1 square = ________

8/29/2019

0820 GREN arrives on site donned PPE
0825 Start calibration of meters
Mini Rae reading 110.5 (inital)
After calibration reading 100.7
RKI Eagle intial reading CH_4 = 39%.
CO_2 = 0.3%
After Calibration CH_4: 50%. CO_2: 0.5%.
0845 Start soil gas reading

Well	Time	Pressure	O_2	CO_2	CH_4	H_2S	VOCs	Purge
WMW-11	0848	0	20.9	0	0	0	1.8	2
-10	0850	0	20.9	0	0	0	0.7	2
-14	0854	0	20.9	0.1	0	0	1.1	2
-15	0856	0	20.9	0.2	0	0	1.5	2
-16	0900	0	20.6	0.3	0	0	0.6	2
-17	0904	0	20.6	0.2	0	0	1.1	2
-1	0906	0	20.9	0	0	0	1.4	2
-3	0910	0	20.9	0	0	0	1.4	2

0920 OWI ~~well~~ probe to freeze w/ dry ice and water
0955 Frozen Probe in DHM-1
1004 Spoke with RH, measure soil-gas at 12/1p and 4 hours after that.

Scale: 1 square = ________

1025 start OHM-1 reading
1033 OHM-1 DTW = 18.25 ft
DTP = 9.43 ft
1040 Raining
1045 Probe to freeze
1110 Probe in OHM-2 waiting for it to thaw
1140 OHM-2 ~~DTP~~ DTW = 18.74 ft
DTP = 11.71 ft

Well	Time	Pressure ("H_2O)	O_2 (%)	CO_2 (%)	CH_4 (%)	H_2S (%)	VOCs (ppm)	Purge (min)
~~WMW~~								
WMW-11	1214	0	20.9	0.0	0	0	0.7	2
WMW-10	1216	0	20.9	0.0	0	0	0.6	2
-14	1219	0	20.9	0.1	0	0	0.5	2
-15	1221	0	20.9	0.2	0	0	1.4	2
-16	1224	0	20.4	0.3	0	0	0.2	2
-17	1226		20.4	0.2	0	0	0.3	2
-1	1229	0	20.9	0.0	0	0	0.5	2
-3	1231	0	20.9	0.0	0	0	0.9	2

1240 Frozen probe in OHM-3
1242-1252 Bank Inspection from WMW14 to WMW-18, no sheen present. Small waves, with precipitation going into the river
rain picking up again

Scale: 1 square = ______

1305 start measurement on OHM-3
1315 OHM-3 DTW = 14.50 ft
1325 DTP = 11.42 ft
1520-1530 Bank inspection, no sheen. stopped raining.
1535 adding silicone tubing to WMW-10 and WMW-3

Well	Time	Press. ("H_2O)	O_2 (%)	CO_2 (%)	CH_4 (%)	H_2S (%)	VOCs (ppm)	Purge (min)
WMW-11	1614	0	20.9	0	0	0	1.4	2
-10	1617	0	20.6	0	0	0	10.3	2
-14	1620	0	20.6	0.1	0	0	1.3	2
-15	1623	0	20.8	0.2	0	0	1.5	2
-16	1626	0	20.9	0	0	0	0.4	2
-17	1629	0	20.5	0.1	0	0	1.3	2
-1	1632	0	20.8	0	0	0	1.5	2
-3	1635	0	20.9	0	0	0	0.7	

1648 GIRG off site.

Scale: 1 square = ______

Rite in the Rain

8/30/14

0710 GRG arrives on site don PPE
0715 Turn on meters.
0725 RKI Eagle calibrated
Mini RAE calibrated

Well	Press ("H_2O)	Time	O_2 (%)	CO_2 (%)	CH_4 (%)	H_2S (%)	VOCs (ppm)	Purge (min)
MW-11	—	0730	20.9	0	0	0	0.6	2
-10	—	0733	20.9	0.1	0	0	0.9	2
-14	—	0736	20.9	0.2	0	0	0.5	2
-15	—	0739	20.9	0.2	0	0	1.1	2
-16	—	0742	20.6	0.4	0	0	0.0	2
-17	—	0742	20.7	0.2	0	0	0.4	2
-1	—	0746	20.9	0.0	0	0	0.6	2
-3	—	0750	20.9	0.0	0	0	0.9	2

0800 Spoke with RH yesterday (8/29) 06:00 and spoke about scope of work for the next two day. take readings 8 hrs apart on 8/30 and one final reading 8/31 Also take DTP measurements and, check DTW in SVE wells.
0806 A lot of activity on site
0808 Start measurement of OHM wells

0812 OHM-1 DTP = 9.37 ft.
0820 OHM-2 DTP = 11.69 ft
0825 OHM-3 DTP = 11.42
0830-0835 NO sheen in river.

Well	DTW (ft)	Time
SVE-1	N.W.	0842
SVE-2	8.83	0852
SVE-3	N.W.	0858
SVE-4	N.W	0902

Had to remove surface water from inside of SVE-2, could be from rain event yesterday.

1450 GRG back on site.
1500 Move drums over OHM wells.
1515 Prepare meters for readings
1516 Readings table on the back page

Well	Time	Press ("H_2O)	O_2 (%)	CO_2 (%)	CH_4 (%)	H_2S (%)	VOCs (ppm)	Purge (min)
WMW-11	1530	—	20.7	0.0	0	0	1.8	2
-10	1532	—	20.6	0.1	0	0	1.6	2
-14	1535	—	20.6	0.2	0	0	1.3	2
-15	1537	—	20.6	0.2	0	0	1.6	2
-16	1540	—	20.3	0.3	0	0	0.6	2
-17	1542	—	20.6	0.2	0	0	1.3	2
-1	1545	—	20.9	0.0	0	0	1.4	2
-3	1548	—	20.9	0.0	0	0	1.3	2

1555 GRG off site.

08/31/2019

0720 GRG on-site Don PPE

0721 RKI Eagle on

O_2 = 20.9

CH_4 = 50%

CO_2 = 0.5%

0723 MiniRAE on

100.3 ppm

Well	Time	Press	O_2	CO_2	CH_4	H_2S	VOCs	Purge
WMW-11	0730	—	20.9	0.0	0.0	0.0	0.5	2
-10	0733	—	20.9	0.1	0.0	0.0	0.5	2
-14	0735	—	20.9	0.2	0.0	0.0	0.3	2
-15	0737	—	20.9	0.2	0.0	0.0	1.2	2
-16	0739	—	20.4	0.4 gm	0.0	0.0	0.1	2
-17	0742	—	20.7 gm	0.3	0.0	0.0	0.2	2
-1	0743	—	20.9	0.0	0	0	0.4	2
-3	0746	—	20.9	0.0	0	0	0.7	2

0850 Meters stored away start closing up wells, etc.

Hydraulic Gradient Monitoring

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Coordinate System: NAD 1983 StatePlane Washington South FIPS 4602 Feet

Legend

- Shallow Monitoring Well
- Deep Monitoring Well
- OHM Well
- Abandoned Monitoring Well
- Former Bunker Fuel / Oil Pipeline
- Former Oil Drain
- Former Oil Trough
- Former Sewer Line (Potential)
- Stormwater Underdrain
- Stormwater Underdrain

Notes:
1. Locations are approximate.
2. Existing site monitoring wells will include semiannual collection of groundwater samples for NWTPH-Dx without silica gel cleanup (SGC) and Total Arsenic.
3. In 2021 only, existing site monitoring wells will also include semiannual collection of samples for cations, anions, arsenic (total and dissolved), and natural attenuation parameters.

N

0 50 100

Scale: Feet

Kennedy Jenks

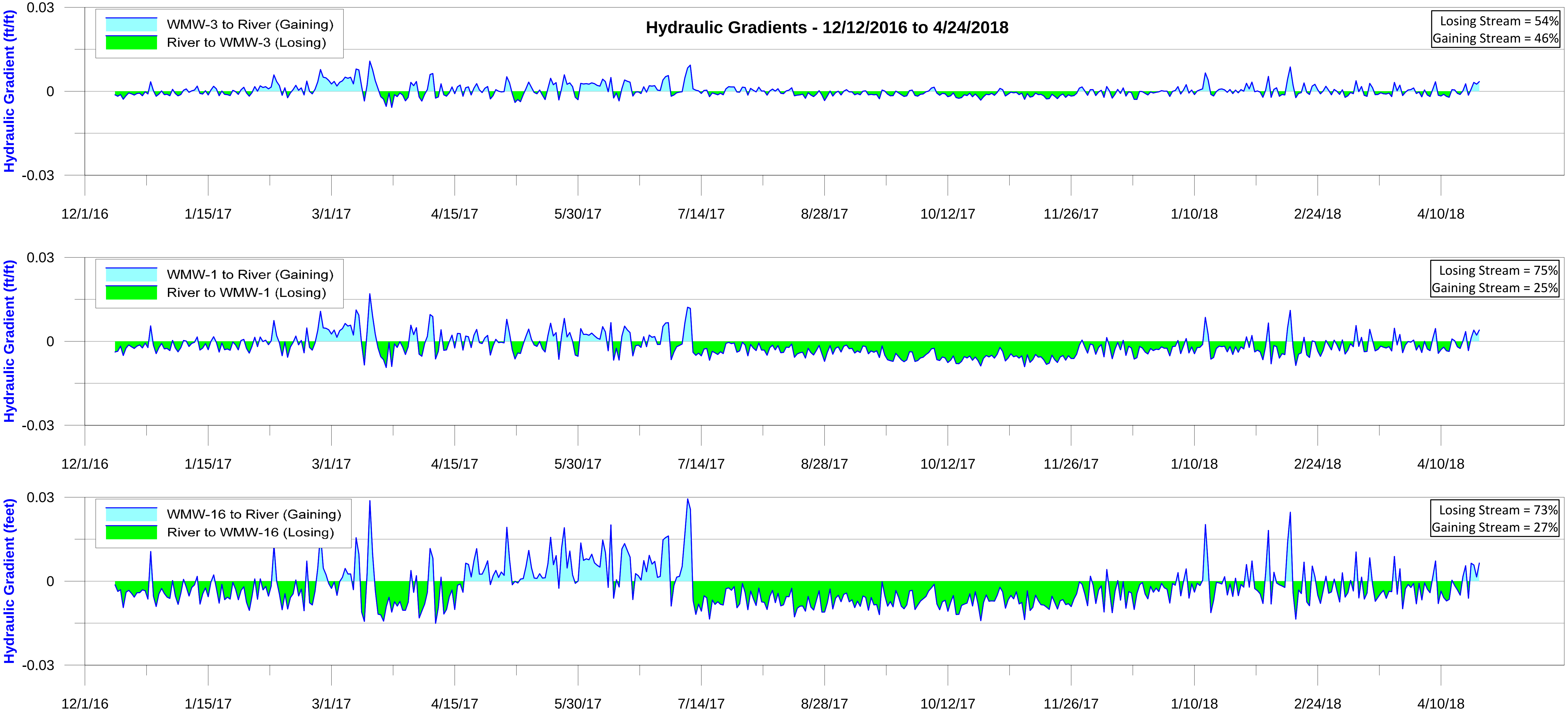
BNSF Wishram Railyard
Wishram, Washington

Monitoring Wells

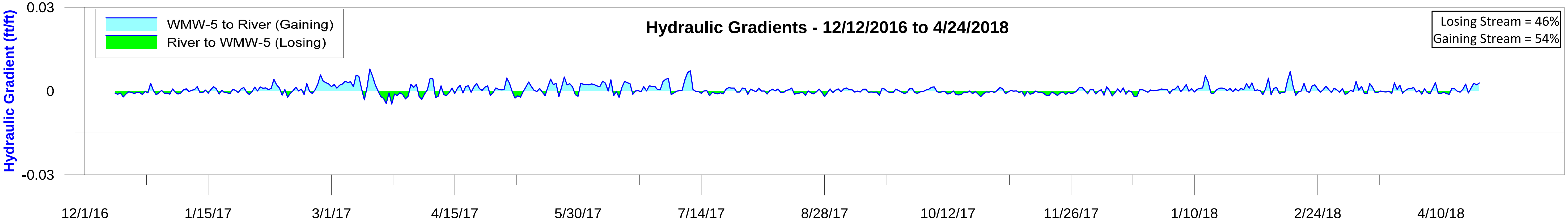
1996120.00
November 2020

Figure 1

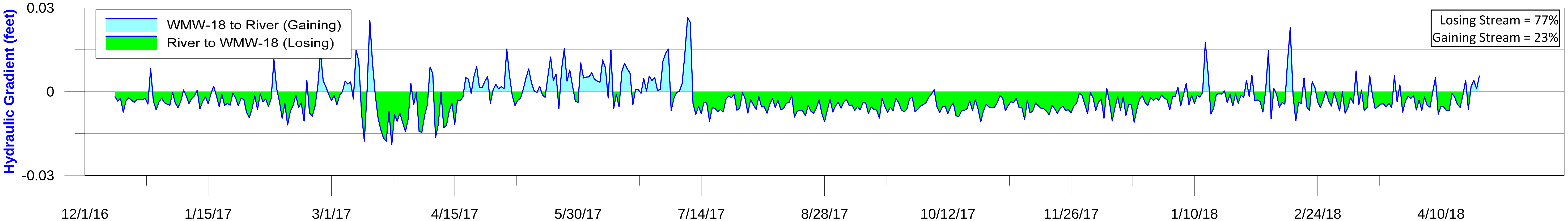

Hydraulic Gradients - 12/12/2016 to 4/24/2018
WMW-8 to River (Gaining)
River to WMW-8 (Losing)
Losing Stream = 52%
Gaining Stream = 48%
WMW-9 to River (Gaining)
River to WMW-9 (Losing)
Losing Stream = 62%
Gaining Stream = 38%
WMW-10 to River (Gaining)
River to WMW-10 (Losing)
Losing Stream = 77%
Gaining Stream = 23%
WMW-14 to River (Gaining)
River to WMW-14 (Losing)
Losing Stream = 75%
Gaining Stream = 25%
Hydraulic Gradient (ft/ft)
0.03
0
-0.03
12/1/16
1/15/17
3/1/17
4/15/17
5/30/17
7/14/17
8/28/17
10/12/17
11/26/17
1/10/18
2/24/18
4/10/18



Hydraulic Gradients - 12/12/2016 to 4/24/2018
WMW-3 to River (Gaining)
River to WMW-3 (Losing)
Losing Stream = 54%
Gaining Stream = 46%
Hydraulic Gradient (ft/ft)
0.03
0
-0.03
12/1/16
1/15/17
3/1/17
4/15/17
5/30/17
7/14/17
8/28/17
10/12/17
11/26/17
1/10/18
2/24/18
4/10/18
WMW-1 to River (Gaining)
River to WMW-1 (Losing)
Losing Stream = 75%
Gaining Stream = 25%
Hydraulic Gradient (ft/ft)
0.03
0
-0.03
12/1/16
1/15/17
3/1/17
4/15/17
5/30/17
7/14/17
8/28/17
10/12/17
11/26/17
1/10/18
2/24/18
4/10/18
WMW-16 to River (Gaining)
River to WMW-16 (Losing)
Losing Stream = 73%
Gaining Stream = 27%
Hydraulic Gradient (feet)
0.03
0
-0.03
12/1/16
1/15/17
3/1/17
4/15/17
5/30/17
7/14/17
8/28/17
10/12/17
11/26/17
1/10/18
2/24/18
4/10/18



Hydraulic Gradients - 12/12/2016 to 4/24/2018
WMW-5 to River (Gaining)
River to WMW-5 (Losing)
Losing Stream = 46%
Gaining Stream = 54%
Hydraulic Gradient (ft/ft)
0.03
0
-0.03
12/1/16
1/15/17
3/1/17
4/15/17
5/30/17
7/14/17
8/28/17
10/12/17
11/26/17
1/10/18
2/24/18
4/10/18



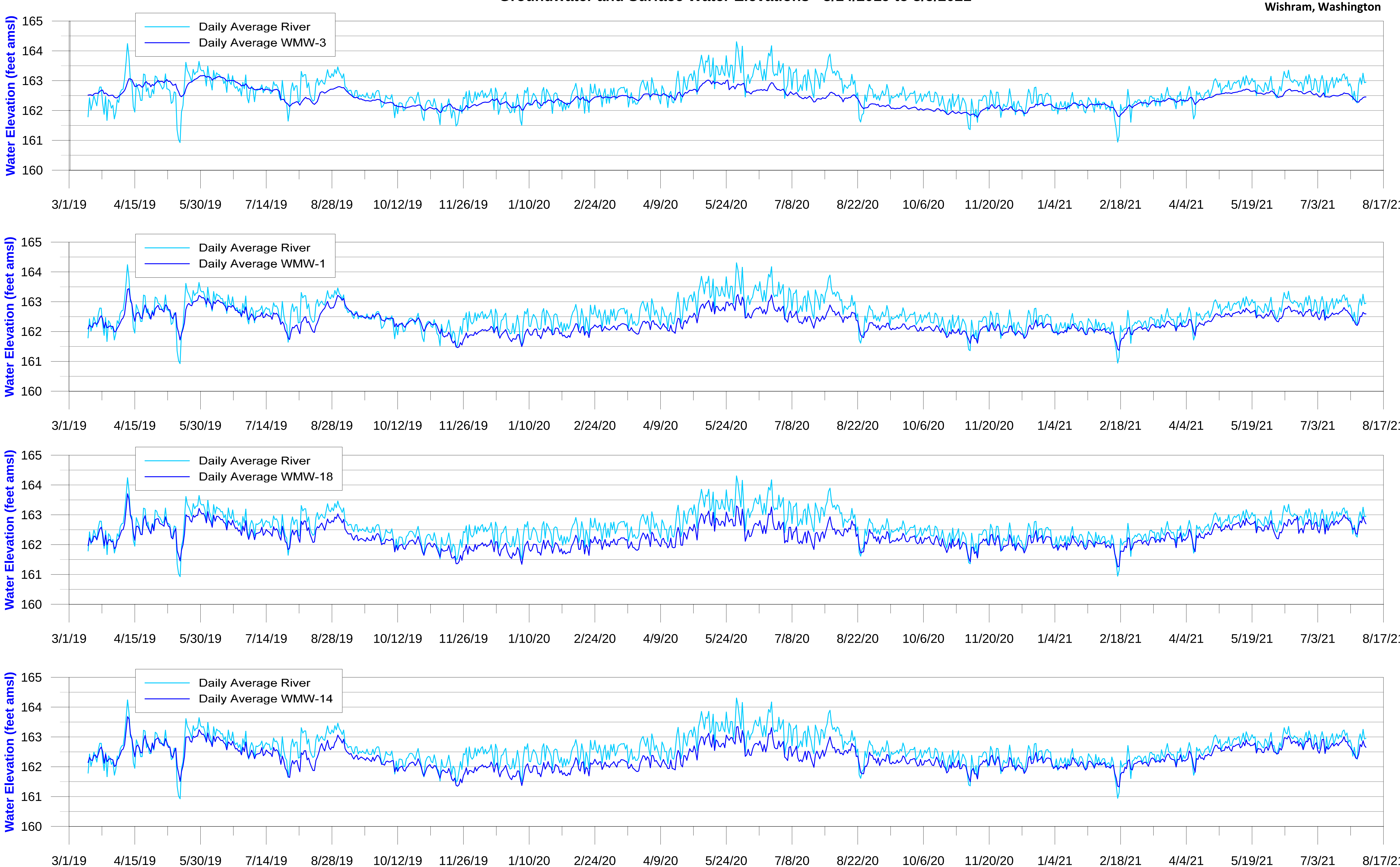
WMW-18 to River (Gaining)
River to WMW-18 (Losing)
Losing Stream = 77%
Gaining Stream = 23%
Hydraulic Gradient (feet)
0.03
0
-0.03
12/1/16
1/15/17
3/1/17
4/15/17
5/30/17
7/14/17
8/28/17
10/12/17
11/26/17
1/10/18
2/24/18
4/10/18

BNSF Wishram Railyard
Wishram, Washington

Hydraulic Gradients - 3/14/2019 to 8/5/2021

Groundwater and Surface Water Elevations - 3/14/2019 to 8/5/2021

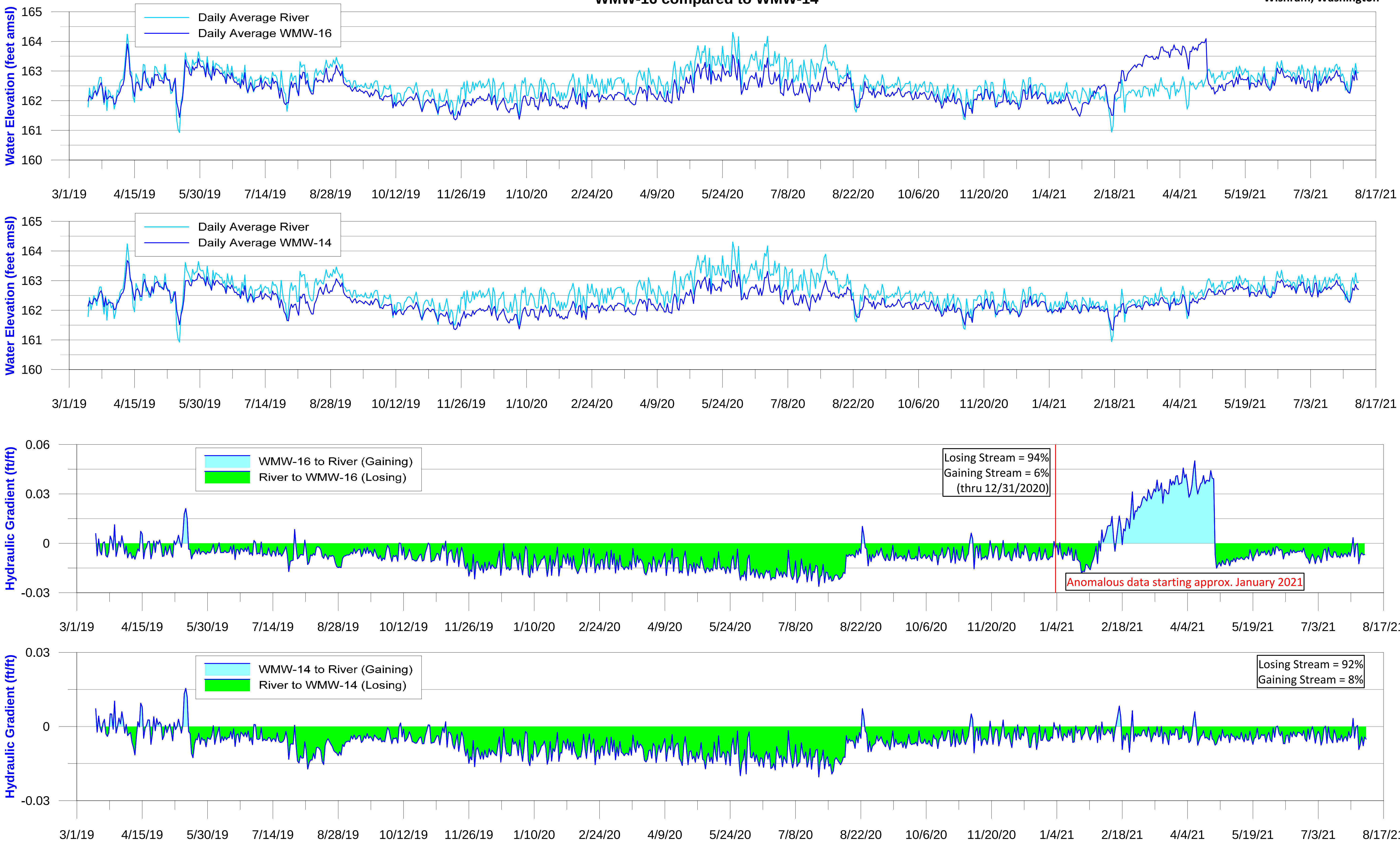
BNSF Wishram Railyard
Wishram, Washington



DRAFT

Groundwater and Surface Water Elevations and Hydraulic Gradients - 3/14/2019 to 8/5/2021: WMW-16 compared to WMW-14

BNSF Wishram Railyard
Wishram, Washington



Appendix B

Proposed CULs and Identification of COCs

Appendix B: Proposed CULs and Identification of COCs

B1. Introduction

This Appendix to the Uplands Feasibility Study Report (FS Report) summarizes the development of proposed cleanup levels (CULs) for groundwater, surface water, and soil and identifies constituents of concern (COCs) for the BNSF Wishram Railyard [Washington State Department of Ecology (Ecology) Site Name: BNSF Track Switching Facility] (site) in Wishram, Washington. Identification of COCs is based on comparison of soil and groundwater sampling results [presented in the *Uplands Remediation Investigation Report BNSF Wishram Railyard* (Uplands RI Report; Kennedy Jenks 2020)] and 2020 groundwater sampling results to the proposed CULs.

This summary has been prepared in response to Ecology's memorandum titled *Wishram Cleanup Site: Preliminary Cleanup Levels and Contaminants of Potential Concern for Groundwater, Surface Water and Upland Soils* (Ecology PCULs Memo) (Ecology 2021a), received by BNSF on 17 August 2021, Ecology's comments to the draft Uplands Feasibility Study Report, received by BNSF on 31 August 2021, and Ecology's comments to the revised draft Uplands Feasibility Study Report, received by BNSF on 15 and 16 March 2022.

B2. Current and Future Use

The Klickitat County, Washington zoning map [https://www.klickitatcounty.org/284/Zoning-Map; (Klickitat County Zoning Map)], indicates the railyard is zoned as an "Industrial Park." The area to the north of the railyard property boundary (illustrated as a green line on Figures B-1 and B-2), is zoned as "Rural Center".

BNSF Wishram Railyard Property

The BNSF Wishram Railyard Property (site) is currently used as a railyard and meets the definition of an industrial property in Washington Administrative Code (WAC) 173-340-200 and the applicability criteria of soil cleanup standards for industrial properties under WAC 173-340-745(1)(a)(i)(A) through (F). The railyard and areas north of the mainline track area (e.g., the maintenance shop and bullpen) have controlled access, including fencing between the existing depot and maintenance shop, a fenced-in bullpen north of the maintenance shop, and are patrolled by railroad police. The primary potential exposures to potentially impacted surface and subsurface soil, groundwater and adjacent surface water are to adult railroad, construction, and utility workers.

The site is fully developed as an industrial railyard where buildings, pavement, rail lines, and surfaces (comprising approximately 94 percent of the land area) are designed and managed per federal regulations to remove and control vegetation, limit the potential for vegetation with deep root zones and use by wildlife. The railyard surface areas, covered by gravel, asphalt, or other impervious structures (e.g., buildings) minimize potential exposure to the soil. Along the Columbia River, engineered embankments (forming the berm area) composed of large riprap protect the banks from erosion and restrict potential deeper soil contact by occupants and wildlife. Railroad operations control subsurface disturbance and can be formally established by institutional controls (ICs). The site is anticipated to remain a railyard for the foreseeable future, with railyard operations comprising of railcar switching on track spurs located south of the Depot (see Figure 2 in the FS Report).

Off-Railyard Properties

Areas to the north of the railyard property boundary (off-railyard properties) are zoned as Rural Center. Potential petroleum hydrocarbon impacts related to the railyard are limited to the vicinity of the former boiler house and former heating oil UST within this area. The UST and approximately 750 tons of petroleum hydrocarbon-impacted soil were removed in April 2002 (see Figure B-2 for approximate lateral extent of the excavation area). Petroleum hydrocarbon-impacted soils were excavated to the top of the bedrock surface (to the extent practicable) at a depth of approximately 16 feet below ground surface (bgs); groundwater was not encountered in the excavation. Confirmation samples from the north, east, and south sidewalls of the excavation indicated diesel- and oil-range petroleum hydrocarbon impacts remained in-place from approximately 14.5 to 15.5 feet bgs (see Figures 6, 9, and 10 in the FS Report).

Fire District #11 Wishram is listed as the property owner of the two property parcels located in this area (Figure B-2). Current features include two warehouse storage-type buildings used by the fire department in the eastern parcel and a U.S. Post Office in the western parcel. Surface areas covered by gravel or impervious structures (buildings) comprise approximately 65 percent of the land area between the two parcels and minimize potential exposure to the subsurface soil. The primary potential exposures to potentially impacted subsurface soil and groundwater are to adult construction and utility workers.

B3. Proposed CULs

Proposed site CULs for groundwater, surface water, and soil are based on Ecology's Model Toxics Control Act (MTCA), other applicable, relevant, and appropriate requirements (ARARs) and other relevant information pertinent to establishing site-specific remedial goals. Ecology's *Supporting Material for Cleanup Levels and Risk Calculation (CLARC) - Soil Cleanup Levels to Protect Groundwater* (CLARC Guidance) guidance document was used in the development of proposed groundwater, surface water, and soil CULs along with applicable sections of WAC 173-340. Available and applicable CULs and screening levels were obtained from Ecology's CLARC master data table (updated in July 2021) (Ecology 2021b).

MTCA requires sites to be cleaned up to the extent that they no longer pose an unacceptable threat to human health and the environment. Establishing CULs to meet that objective is described generally under WAC 173-340-700. The applicability of MTCA Methods A, B, and C cleanup levels, is summarized under WAC 173-340-704, -705, and -706, respectively. According to WAC 173-340-700(5)(a)-(c), except where institutional controls (ICs) are required by WAC 173-340-440(4), where cleanup meet Method A and/or Method B cleanup levels, a site may be used without future restrictions on the property. Site cleanups with Method C cleanup levels may have restrictions (ICs) placed on the property to ensure future protection of human health and the environment. Cleanup levels developed using Methods B and C must not be set at levels below the practical quantitation limit (PQL) in accordance with WAC 173-340-707 or background concentrations.

Method A cleanup levels may be used at sites that have few hazardous substances and are either undergoing a routine cleanup action as defined in WAC 173-340-200 or where numerical standards are available for all indicator hazardous substances in the media for which the

Method A cleanups levels are to be used. Method A cleanup levels for unrestricted land use (listed in MTCA Table 740-1) and for restricted (industrial) land use (listed in MTCA Table 745-1) are based on the protection of groundwater for drinking water beneficial uses.

Method B is applicable to all sites and can be used to develop cleanup levels unless one or more conditions for using Method A or Method C is demonstrated to exist and the person conducting the cleanup action elects to use that method. Method B cleanup levels are based on unrestricted land use and the protection of groundwater.

Method C cleanup levels are protective of human health and the environment for specified uses and conditions. Method C cleanup levels use exposure assumptions and risk levels for restricted land uses, including industrial land uses. A site (or portion of a site) that qualifies for Method C cleanup levels for one medium (e.g., soil), may not necessarily qualify for a Method C cleanup level in other media. As stated by Ecology (2016a), a key difference between Method B and Method C soil cleanup levels is that under Method C, the direct soil contact exposure pathway is based on healthy workers being exposed to soil contamination instead of children being exposed in a residential setting. Per WAC 173-340-745(4), Method C is the standard method for establishing soil cleanup levels at industrial sites and its use is conditioned upon the continued use of the site for industrial purposes. Soil CULs developed under Method C must still be protective of groundwater and surface water.

Groundwater and Surface Water CULs

Beneficial use designations for the Columbia River near the site include water supply, spawning and rearing aquatic life, wildlife, and miscellaneous such as recreation, aesthetics, hydroelectric power generation, and commercial navigation and transportation. In accordance with WAC 173-340-720, designated groundwater uses include potential drinking water source, although shallow groundwater at the site is not a current source of drinking water nor is it identified as a future drinking water source as potable water is supplied to the site by the City of Wishram. Proposed groundwater and surface water CULs protective of drinking water were based on Method B cleanup levels, Method A cleanup levels for select petroleum hydrocarbons [gasoline-range organics (GRO), diesel-range organics (DRO), oil-range organics (ORO), and total petroleum hydrocarbons – diesel range fraction (TPH-Dx, sum of DRO and ORO)], and ARARs. Surface water CULs were also selected to be protective of aquatic life.

Soil CULs - BNSF Wishram Railyard Property

Based on the current and future use of the site as a railyard, with activities continuing to meet the definition of an industrial property, proposed CULs for the unsaturated and saturated zone soil on railyard property are based on Methods A and C cleanup levels for industrial properties, along with consideration of soil concentrations protective of groundwater (e.g., leaching) including leaching with the potential to discharge to surface water.

Soil CULs - Off-Railyard Properties

The current use of the properties north of the maintenance shop area includes small business and commercial services uses (e.g., the U.S. Post Office and fire department storage buildings), although the zoning designation as “Rural Center” allows for other non-commercial uses including homes and eating/drinking establishments. Therefore, proposed CULs for the unsaturated and saturated zone soil in these areas are based on Methods A and B unrestricted cleanup levels, along with consideration of soil concentrations protective of groundwater (e.g., leaching). As this area is not adjacent to surface water, soil concentrations protective of groundwater discharging to surface water were not considered.

CUL Tables

Tables B-1, B-2, and B-3 present the proposed CULs for groundwater, surface water, and soil, respectively. The selection process of the CULs is discussed in the following sections. Because the soil CULs are based in part on protection of groundwater and surface water (via the soil leaching to groundwater pathway), groundwater and surface water CULs are presented first in the following sections. Constituents with one or more samples exceeding the applicable proposed CUL for that media are also identified as COCs in the tables. Table B-4 presents a summary of the CULs for identified COCs by matrix. The CULs for COCs will be further evaluated in the draft Cleanup Action Plan (CAP).

Preliminary PQLs included in Tables B-1, B-2, and B-3 were based on one of the following: (1) recommended PQLs as available from Table 7.3 of Ecology's *Guidance for the Remediation of Petroleum Contaminated Sites* (Ecology 2016a); (2) PQLs provided in the Ecology PCULs Memo; or (3) PQLs and method reporting limits (MRLs) provided by Pace Analytical for its laboratories in Mount Juliet, Tennessee, and Minneapolis, Minnesota. Identification of PQLs for constituents in the draft CAP will include evaluation of MRLs and method detection limits (MDLs) (which may change on at least an annual basis) provided by several Washington State-Accredited laboratories.

B3-1. Remedial Investigation Data

Soil and groundwater sampling results presented in the Uplands RI Report and groundwater sampling results from 2020 were used in the evaluation of COCs by media.

Groundwater Data. Results from groundwater sampling events of monitoring wells conducted between November 2016 and August 2020 were selected as representative data for current dissolved phase groundwater conditions. Depending on monitoring well installation date (pre-2016, 2016, or 2018), groundwater samples were collected from monitoring wells during five events (deep wells installed in 2018 and sampled semiannually) and 15 events (shallow wells installed in 2016 along the berm). Screening "grab" reconnaissance groundwater (RGW) samples were collected from temporary wells as a component of Uplands RI field investigation activities in 2016 and 2018; however, the evaluation of groundwater sampling results for identifying COCs considers monitoring well samples only, as they are reproducible and representative of current groundwater conditions.

Evaluation of the RGW groundwater data indicated that, other than four metals, constituents identified at concentrations above drinking water standards in the RGW samples were also identified in the samples collected from monitoring wells. Total metals results for barium, cadmium, chromium, and/or lead in fifteen (15) 2016 RGW samples were above respective CULs; however, dissolved metals results in the 2016 and 2018 RGW samples were below CULs. As discussed in Section 2.3.3.3.7 of the Uplands RI Report, it was determined that dissolved metals (and not total metals) concentrations in reconnaissance groundwater samples from temporary wells from 2016 and 2018 are representative of site conditions. The RGW samples with total and/or dissolved metals results above CULs are generally within approximately 50 to 100 feet of a cross-gradient or downgradient monitoring well. The monitoring wells bound the lateral extent of the dissolved-phased constituents that exceeded applicable screening levels in RGW samples.

Additional considerations for select constituents are summarized below, related to evaluation of CULs for soil and groundwater.

Total Chromium. As reported in the Uplands RI Report, there is no source for hexavalent chromium at the site. Therefore, as stated in the CLARC chemical-specific considerations – July 2021, "If chromium VI is NOT present at the site, then the site assessor may assume that the measured concentration of total chromium is the concentration of chromium III." Accordingly, the CULs proposed for chromium in soil, groundwater and surface water are the CULs for chromium III or total chromium, as available.

Carcinogenic PAHs. Ecology policies and procedures for implementing WAC 173-340-708(8)(e) in the MTCA rule requires that mixtures of cPAHs be considered a single hazardous substance (total cPAH) when establishing and determining compliance with cleanup levels. Results of the cPAH compounds [benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene, chrysene, dibenz(a,h)anthracene, and indeno(1,2,3-c,d)pyrene] were used to calculate total cPAH concentrations using the Toxicity Equivalency Factor (TEF) summation method. If an individual chemical was not detected, a value of one-half the method reporting limit (MRL) was used as the concentration in the calculation, except when all chemicals used in the calculation were not detected then one half the lowest MRL was used as the total concentration. Calculated total cPAH results are presented in tables in this Appendix for comparison to proposed CULs.

Total Naphthalenes. According to Ecology's *Guidance on Remediation of Petroleum-Contaminated-Sites* (Ecology 2016a) and MTCA Method A cleanup level Tables 720-1, 740-1, and 745-1, under the MTCA rule, "naphthalenes" for comparison to Method A cleanup levels are the total of naphthalene, 1-methylnaphthalene, and 2-methylnaphthalene. Results of the 1-methylnaphthalene, 2-methylnaphthalene, and naphthalene analyses (as available) were used to calculate total naphthalenes concentrations, which are presented in tables for soil and groundwater analytical results. Total naphthalenes were calculated by summing the individual naphthalenes concentrations. If an individual chemical was not detected, a value of one half the MRL was used as the concentration in the calculation, except when all chemicals used in the calculation were not detected, then one half the lowest MRL was used as the total concentration. Naphthalene, 1-methylnaphthalene, 2-methylnaphthalene and calculated total naphthalenes results are presented in Tables B-1, B-2, and B-3 in this Appendix for comparison to proposed CULs.

B3-2. Groundwater CULs and COCs

Beneficial use designations for the groundwater beneath the site include use as a potential drinking water source. Proposed groundwater CULs protective of drinking water were established from consideration of the following values:

- "Groundwater Target Cleanup Level for Soil to Ground Water Pathway" (groundwater target CUL), which is included in the CLARC tables and derived, as described in the CLARC Guidance, from evaluation of the groundwater Method B Cancer and Noncancer cleanup levels, ARARs including state and federal Maximum Contaminant Levels (MCLs), and/or adjustments to ARARs as applicable.

- Method A cleanup levels for groundwater for select constituents (e.g., GRO, DRO, ORO, and TPH-Dx).

- Background (for arsenic), and PQLs. The background concentration for arsenic is from MTCA Table 720-1 Method A CULs and is subject to change based on potential policy updates resulting from Ecology’s January 2022 publication *Natural Background Groundwater Arsenic Concentrations in Washington State Study Results*.

Proposed groundwater CULs are summarized in Table B-1, along with the source (e.g., Method A, Method B Cancer or Noncancer, ARARs, etc.) of the value. Constituents included in the table were detected in one or more groundwater samples collected from monitoring wells between November 2016 and August 2020, representative of current groundwater conditions. Dibenz(a,h)anthracene was detected in one sample from well WMW-30 in the 2016 to 2020 time period; the other six cPAH constituents were not detected in groundwater samples during this time period. All seven cPAHs are shown in Table B-1 along with Total cPAH based on the TEF summation method; the proposed groundwater CUL is for benzo(a)pyrene and Total cPAH in accordance with WAC 173-340-708(8)(e).

For groundwater, the total chromium federal and Washington State MCL is 100 micrograms per liter (µg/L). As reported in the Uplands RI Report, there are no known or potential sources of hexavalent chromium at the site; therefore, it is assumed that all the chromium is trivalent and the Method A concentration for total chromium is 100 µg/L.

Constituents reported in one or more groundwater monitoring well samples collected since November 2016 above the proposed CUL for groundwater are identified as COCs in Table B-1.

Identified groundwater COCs and respective proposed CULs (and their sources) are as follows:

- DRO – 500 µg/L as an unrestricted use goal (Method A CUL).

- ORO – 500 µg/L as an unrestricted use goal (Method A CUL).

- Total petroleum hydrocarbon (TPH-Dx) – 500 µg/L as an unrestricted use goal (Method A CUL).

- 1-methylnaphthalene – 1.5 µg/L (Method B Cancer CUL).

- Total arsenic – 5 µg/L (Background).

- Total barium – 2,000 µg/L (State and Federal MCL).

- Dissolved iron – 11,000 µg/L (Method B Noncancer CUL).

- Dissolved manganese – 750 µg/L (Method B Noncancer CUL).

Discussion. Total naphthalenes results in groundwater samples collected between November 2016 and August 2020 were less than the proposed CUL of 160 µg/L (Method A); however, results for the individual constituent 1-methylnaphthalene were above its proposed CUL of 1.5 µg/L (Method B Cancer) and therefore, 1-methylnaphthalene was identified as a groundwater COC. Based on review of results from groundwater sampling events between November 2016 and August 2020, GRO and Chromium (total) were not identified as COCs in

Table B-1. These constituents were included as COCs in Ecology's Comment No. 28 to the Draft FS. Ecology's process for identifying COCs for groundwater included comparing the maximum reported concentration for each constituent in groundwater samples to the Ecology preliminary CUL (PCUL). It does not appear that consideration was given to the age of the sample result, concentration trends or sampling artifacts as discussed below:

- GRO was reported at a concentration (1,790 µg/L) above its Method A CUL of 1,000 µg/L (GRO without presence of benzene in the sample) in the sample collected from monitoring well WMW-07 in July 2004. GRO results in samples collected from well WMW-07 since July 2007 have been below the CUL of 1,000 µg/L. GRO has not been reported above its CULs (800 µg/L with benzene or 1,000 µg/L without benzene present) in samples from other monitoring wells.

- Chromium (total) has not been reported above the proposed CUL of 100 µg/L in groundwater samples from monitoring wells. Total chromium (total) was reported at concentrations above the proposed CUL in four grab samples from temporary wells in 2016; dissolved chromium (total) was not reported above laboratory reporting limits in these four samples. As discussed in Section 2.3.3.3.7 of the Uplands RI Report, it was determined that dissolved metals (and not total metals) concentrations in reconnaissance groundwater samples from temporary wells from 2016 and 2018 are representative of site conditions.

B3-3. Surface Water CULs

Beneficial use designations for the Columbia River near the site include use as potential drinking water supply, along with spawning and rearing aquatic life, wildlife, and miscellaneous such as recreation, aesthetics, hydroelectric power generation, and commercial navigation and transportation. Proposed surface water CULs protective of drinking water and aquatic life were established from consideration of the following values and are summarized in Table B-2:

- "Surface Water Target Cleanup Level for Soil to Surface Water Pathway Fresh Water" (surface water target CUL), which is included in the CLARC tables and is derived from evaluation of surface water Method B Cancer and Noncancer cleanup levels and ARARs including fresh surface water concentrations that are protective of human health and protective of aquatic life under acute and chronic exposure conditions as established under state (WAC 173-201A-240) and federal laws [Section 304 of the Clean Water Act (CWA)].

- Environmental Effects-Based Concentrations (EEBCs) from Implementation Memo No. 23 (Ecology 2021c) for petroleum hydrocarbons (e.g., weathered diesel). As presented in the Uplands RI Report, NWTPH-Dx chromatograms from soil and groundwater samples collected from the site (areas north and south of the mainline tracks associated with historical fueling operations and along the berm) represent weathered diesel or a mixture of weathered diesel and/or weathered Bunker C.

- Method A CULs for select constituents (e.g., GRO, DRO, ORO, and TPH-Dx) for beneficial use as potable water.

- Surface water values for select constituents from the Risk Assessment Information System (RAIS) or from the Great Lakes Water Quality Initiative (GLWQI) Clearinghouse (https://www.epa.gov/gliclearinghouse) (if no surface water ecological ARAR is available).

- Background concentrations and PQLs.

Proposed surface water CULs are summarized in Table B-2. Constituents included in the table were detected in one or more groundwater samples collected from monitoring wells between November 2016 and August 2020. Samples collected in this timeframe are considered representative of current groundwater conditions and were used to identify COCs for surface water adjacent to the railyard.

Constituents reported above the proposed CUL for surface water in one or more groundwater samples collected since November 2016 from monitoring wells located along the berm separating the site from the Columbia River are identified as COCs in Table B-2. The berm wells include 10 shallow monitoring wells (WMW-14 through WMW-23) and six deep monitoring wells (RMD-1 through RMD-6).

The proposed surface water COCs and respective CULs (and their sources) for monitoring wells located along the berm are as follows:

- DRO – 500 µg/L as an unrestricted use goal (Method A CUL) for human health exposure considerations and 3,000 µg/L (EEBC weathered DRO) for ecological receptor exposure considerations.

- ORO – 500 µg/L as an unrestricted use goal (Method A CUL) for human health exposure considerations and 3,000 µg/L (EEBC weathered DRO) for ecological receptor exposure considerations.

- Total petroleum hydrocarbon (TPH-Dx) – 500 µg/L as an unrestricted use goal (Method A CUL) for human health exposure considerations and 3,000 µg/L (EEBC weathered DRO) for ecological receptor exposure considerations.

- 1-methylnaphthalene – 2.1 µg/L (RAIS).

- Total arsenic – 5 µg/L (Background).

- Total lead – 2.5 µg/L (Surface Water Aquatic Life Fresh/Chronic WAC 173-201A and CWA §304).

- Dissolved iron – 1,000 µg/L (Surface Water Aquatic Life Fresh/Chronic CWA §304).

- Dissolved manganese – 50 µg/L (Surface Water Human Health Fresh Water CWA §304).

Discussion. Between November 2016 and August 2020, total cPAHs were detected in one sample from one site well (WMW-30, not located on the shoreline berm), but not in the five subsequent samples from the well. Total cPAHs were not detected in the shoreline berm monitoring wells, and therefore, the groundwater to surface water pathway is not complete for total cPAHs. Similarly, total barium was reported above its proposed CUL in one of 74 groundwater samples from site wells (WMW-30, August 2019) at a concentration that appeared anomalous (16,500 µg/L) compared to other reported concentrations in samples from the same well before and after August 2019 (ranged 34.2 to 45.5 µg/L) and other site wells. Total barium was not reported above the proposed groundwater and surface water CULs in the shoreline berm wells, and therefore, the groundwater to surface water pathway is not complete. Total cPAHs and total barium do not merit further evaluation as COCs in surface water.

B3-4. Soil CULs

Based on the property zoning designations, the proposed unsaturated (vadose) and saturated zone soil CULs were established from either unrestricted or restricted (industrial) cleanup levels as available for protection of human health (direct contact), and soil protective of groundwater (for highest beneficial use) and soil protective of groundwater with potential to discharge to water (for highest beneficial use).

For off-railyard properties (rural center-zoned), direct contact cleanup levels were established from unrestricted cleanup levels. As the railyard meets the criteria for an industrial property (WAC 173-340-200 and WAC 173-340-745), direct contact cleanup levels for soil within the railyard property boundary were established from industrial cleanup levels. Points of compliance are presented below for soil.

Unsaturated (Vadose) Subsurface Soil [0 to 10 feet below ground surface (bgs)]

The standard point of compliance for soil based on human exposure via direct contact is sitewide to a depth of 15 feet bgs as the typical maximum depth of soil disturbing activities [WAC 173-340-740(6)(d)]. The unsaturated vadose zone within much of the railyard extends from the ground surface to 10 feet bgs and along the berm from the ground surface to approximately 15 feet bgs. As such, a conditional point of compliance for vadose zone soil at the site, with adoption of ICs, is the water table depth of 10 feet bgs within the railyard.

Vadose zone soil will be evaluated using:

- Applicable unrestricted Method A and B CULs for soil off-railyard property to the north of the maintenance shop (rural center zoned); or

- Applicable industrial Method A and C CULs for soil within the railyard (industrial park zoned).

For those constituents proven likely to leach from soil to groundwater, cleanup levels will be established from soil concentrations (calculated using the fixed parameter 3-phase partitioning model described in WAC 173-340-747(4) and MTCA Equation 747-1) for the vadose zone that are protective of groundwater and the groundwater to surface water pathway.

Saturated Subsurface Soil (10 to 15 feet bgs)

The depth to groundwater in much of the railyard is 10 feet bgs. Groundwater was not encountered in the 2002 excavation adjacent to the former boiler house. However, based on 2016 and 2018 soil borings near the former 30,000-barrel Oil AST and the Maintenance Shop area, the depth to groundwater in the off-railyard properties to the north of the railyard was estimated as 14 feet bgs in the Uplands RI Report. Soil between the groundwater table (approximately 10 feet bgs on the railyard and 14 feet bgs off-railyard) and 15 feet bgs will be evaluated as saturated zone soil using:

- Applicable unrestricted Method A and B CULs for soil off-railyard property to the north of the maintenance shop (rural center zoned); or

- Applicable industrial Method A and C CULs for soil within the railyard (industrial park zoned).

For those constituents proven likely to leach to groundwater, cleanup levels will be established using soil concentrations (calculated using the fixed parameter 3-phase partitioning model described in WAC 173-340-747(4) and MTCA Equation 747-1) for the saturated zone that are protective of groundwater and the groundwater to surface water pathway. Impact to groundwater from subsurface soil in the saturated zone will be evaluated based on direct measurement of groundwater conditions and remediation of soil in the saturated zone will be evaluated based on groundwater cleanup performance data.

As reported in Section 2.3.4 of the Uplands RI Report, the site qualified for completion of a Simplified Terrestrial Ecological Evaluation (TEE) from which it was determined that the site does not pose a substantial threat of significant adverse effects to terrestrial ecological receptors. As such, a TEE is excluded from this evaluation.

Proposed soil cleanup levels are presented in Table B-3A for samples collected above the groundwater table (i.e., vadose zone) and in Table B-3B for samples collected below the groundwater table (i.e., saturated zone). The proposed CULs were based on the following:

- Method A direct contact cleanup levels for unrestricted land use from Table 740-1 for unrestricted land use (areas north of the railyard property boundary) or from Table 745-1 for industrial (restricted) land use for selected petroleum hydrocarbon-related constituents (GRO, DRO, ORO, and TPH-Dx). The numerical values for the unrestricted (Table 740-1) and restricted (Table 745-1) Method A CULs for these constituents are equivalent.

- Lowest of Method B Cancer and Noncancer unrestricted land use direct contact cleanup levels from the CLARC tables.

- Lowest of Method C Cancer and Noncancer industrial land use direct contact cleanup levels from the CLARC tables.

- Calculated soil concentrations protective of potable groundwater (i.e., leaching) and protective of groundwater that may discharge to surface water in accordance with the CLARC Guidance document.

- Background concentrations and PQLs.

Empirical Demonstration

In accordance with WAC 173-340-747(9), an empirical demonstration is presented below to document that the measured soil concentrations of several constituents in the vadose zone and saturated zone at the site have not and will not cause an exceedance of the applicable groundwater cleanup levels. The requirements for an empirical demonstration as presented in Ecology's Implementation Memorandum No. 15, Frequently Asked Questions (FAQs) Regarding Empirical Demonstrations and Related Issues (Ecology June 2016b) include that:

- The measured groundwater concentrations must be less than or equal to the applicable groundwater cleanup levels; and

- The measured soil concentrations will not cause an exceedance of the applicable groundwater cleanup levels at any time in the future.

“This requires applicants to demonstrate a) that enough time has elapsed for hazardous substances to migrate from soil to groundwater, and b) that the characteristics of the site (e.g., depth to groundwater and infiltration) are representative of future site conditions.”

Railyard Former and Current Conditions. The operational history of the railyard was presented in the Uplands RI Report along with a summary of current site conditions based on extensive site investigations conducted since 2002. A summary is presented here, relative to the sources and estimated age of impacts.

Fueling of steam locomotives with Bunker-C oil was conducted at the site from approximately 1912 through 1956 and fueling of locomotives using diesel fuel was conducted from the early 1950s to the 1970s. Petroleum hydrocarbon impacts were identified in soil and groundwater in the vicinity of former USTs, former ASTs, and former infrastructure used to store and transfer fuel associated with former locomotive fueling operations. Where implemented, interim remedial measures (IRMs) conducted between 2002 and 2010 successfully removed petroleum hydrocarbons from unsaturated zone areas down to the water table or bedrock, as applicable, such that soil samples collected from 134 of 145 confirmation sampling locations in the unsaturated zone did not contain residual petroleum hydrocarbons. Based on the fueling and petroleum storage history of the site, these soil impacts were likely greater than 50 to 60 years old at the time of removal.

Groundwater monitoring has been conducted since 2003. Groundwater samples and/or depth to water/LNAPL measurements were collected from up to 41 groundwater monitoring wells during groundwater monitoring events. Groundwater monitoring data demonstrate that the average depth to groundwater is 10 feet bgs and varies by only 1 or 2 feet throughout the year. Submerged LNAPL is estimated to be greater than 60 years old based on known facility operations and the formation of Lake Celilo. The site is anticipated to remain a railyard for the foreseeable future. The railyard surface areas, covered by gravel, asphalt, or other impervious structures (e.g., buildings) are anticipated to remain the same for the future as well, minimizing changes to groundwater conditions (groundwater depth and infiltration) that may be affected by surface coverings.

Vertical infiltration rates through the unsaturated zone were calculated following guidance in Appendix 1 of Implementation Memorandum No. 15. Using a gravimetric water content of 5 percent (based on moisture content laboratory data in the Uplands RI Report), a bulk density of 1.49 grams per cubic centimeters (g/cc) (based on soil core data in Table 25 of the Uplands RI Report), and residual saturation and fully saturated values provided in Appendix 1 for sand, an effective saturation of 0.077 was calculated. Figure 4 of Appendix 1 was used to estimate a hydraulic conductivity of 1 centimeter per day (cm/day) (0.033 feet/day). The estimated time for impacts at the ground surface to reach the water table at a depth of 10 feet bgs (railyard property) is 0.8 years, and at a depth of 14 feet bgs (off-railyard properties) is 1.2 years.

Travel times for horizontal transport from saturated soil source material to a downgradient well were calculated without and with consideration for chemical retardation following guidance from Appendix 2 of Implementation Memorandum No. 15. Using an average estimated hydraulic conductivity of 6.39 feet per day (Table 12 of Uplands RI Report), an estimated hydraulic gradient of 0.003 feet/foot [average positive hydraulic gradient (toward the river) [1] from four wells (WMW-01, WMW-03, WMW-14, and WMW-18) between 14 March 2019 and 5 August 2021], and an effective porosity of 0.28 (average of soil core data in Table 25 of the Uplands RI Report), the calculated groundwater seepage velocity is 0.068 feet per day. Assuming no chemical retardation, travel times for dissolved phase impacts in groundwater would be 0.8 years to travel 20 feet or 4 years to travel 100 feet to a downgradient well.

Chemical properties of 1-methylnaphthalene were used to estimate the chemical retardation factor for petroleum hydrocarbon impacts to soil. Using an organic carbon/water partition coefficient of 2,530 milliliters per gram (mL/g) for 1-methylnaphthalene (CLARC tables), estimated fraction of organic carbon of 0.001 for sand aquifer material, bulk density of 1.49 grams per cubic centimeters (g/cc), and effective porosity of 0.28, the calculated retardation factor is 14.5. Dividing the groundwater seepage velocity by the retardation factor, the calculated chemical velocity is 0.0047 feet per day. At this velocity, travel times are approximately 12 years for 20 feet and 58 years for 100 feet.

Based on the estimated age of impacts to soil and groundwater (greater than 60 years), measured soil concentrations of potential COCs remaining in soil (both vadose zone and saturated zone) which have not already resulted in impacts to groundwater are not anticipated to cause an exceedance in the future.

The notation “Empirical” under the “3-Phase Model” headings in Tables B-3A and B-3B for select constituents indicates that the soil protective of groundwater and soil protective of groundwater to surface water pathways are not complete. For constituents with the empirical demonstration, proposed soil CULs were based on the human health direct contact exposure pathway. The empirical demonstration is based on one of the following (Additional notes have been added to the Empirical notation Tables 3A and 3B and below to clarify the basis for the empirical demonstration):

- Constituents without a cleanup level for indicated pathways. (“Empirical – No CUL”)

- Constituents detected in groundwater samples at concentrations below the respective proposed groundwater and surface water CULs. (“Empirical - Below GW&SW CUL”)

- Constituents detected in one or more soil samples from the vadose and/or saturated zone but not detected in groundwater samples. (“Empirical – ND in wells”)

- 1-Methylnaphthalene: The highest reported concentrations of 1-methylnaphthalene were in soil samples containing visible sheen and LNAPL collected at 12 feet bgs from borings advanced adjacent to LIF borings TG-D0 and TG-D1. Elevated 1-methylnaphthalene concentrations reported in wells south of these borings (RMD-1 and WMW-16) are attributed to dissolution from the LNAPL. 1-methylnaphthalene was also reported above the reporting limit in shallow samples from borings B-18-18 (1.5-2.0 feet bgs) and WMW-29 (2.0-2.5 feet bgs) but not in deeper soil samples from those two borings

[1] As presented in the Uplands RI Report (KJ 2020), the Columbia River is a losing stream more than 80 percent (10 months) of the year. The average hydraulic gradient was calculated from positive gradient values only - when the hydraulic gradient is toward the river (gaining stream).

(B-18-18 at 14.0-14.5 feet bgs and WMW-29 at 9.5-10.0 feet bgs). 1-methylnaphthalene was not reported in groundwater samples from monitoring well WMW-21, located approximately 40 feet south of soil boring B-18-18 nor in the well installed in boring WMW-29. Absence of 1-methylnaphthalene in the deeper soil samples from both borings and in groundwater samples from the two wells indicates that the leaching pathway from soil to groundwater is not complete. (“Empirical – Data Based”)

- Barium: As discussed previously, total barium was reported above the proposed groundwater CUL in one of 74 groundwater samples from site wells (WMW-30, August 2019) at an anomalous concentration compared to other reported concentrations in samples from the same well and other site wells. Total barium was below the CULs in groundwater samples from berm wells. Barium concentrations in soil samples from WMW-30 were below the soil concentration protective of groundwater indicating the soil leaching to groundwater pathway is not complete. (“Empirical – Data Based”)

Constituents reported in one or more soil samples above applicable (i.e., vadose or saturated zone) proposed soil CULs were identified as COCs. As shown in Table B-3A and Table B-3B, the proposed soil COCs were different for vadose and saturated zone conditions. The proposed soil COCs and respective CULs (and their sources) are as follows:

- GRO – 30 milligrams per kilogram (mg/kg) as an unrestricted use goal (Method A CUL); the unrestricted and restricted (industrial) CULs are the same. Applicable to saturated soil only.

- DRO – 2,000 mg/kg as an unrestricted use goal (Method A CUL); the unrestricted and restricted (industrial) CULs are the same. Vadose and saturated soil.

- ORO – 2,000 mg/kg as an unrestricted use goal (Method A CUL); the unrestricted and restricted (industrial) CULs are the same. Vadose and saturated soil.

- TPH-Dx – 2,000 mg/kg as an unrestricted use goal (Method A CUL); the unrestricted and restricted (industrial) CULs are the same. Vadose and saturated soil.

B3-5. Identification of COCs

Table B-4 summarizes COCs in groundwater, surface water, and soil (vadose and saturated zones for areas on- and off-railyard property), proposed CULs and their source, as identified in this appendix.

References

The Risk Assessment Information System. Ecological Benchmark Tool for Chemicals. https://rais.ornl.gov/tools/eco_search.php?select=chem. Accessed November 2021.

Kennedy/Jenks Consultants. 2020. Uplands Remedial Investigation Report BNSF Wishram Railyard (Ecology Site Name BNSF Track Switching Facility) Wishram, Washington. Prepared by Kennedy/Jenks Consultants for BNSF Railway Company. 20 October 2020.

Washington State Department of Ecology. 2016a. Guidance for Remediation of Petroleum Contaminated Sites. Toxics Cleanup Program. Publication No. 10-09-057. Revised June 2016.

Washington State Department of Ecology. 2016b. Frequently Asked Questions (FAQ's) Regarding Empirical Demonstrations and Related Issues Implementation Memorandum No. 15. Toxics Cleanup Program. Publication No. 16-09-047. 16 June 2016.

Washington State Department of Ecology. 2021a. Wishram Cleanup Site: Preliminary Cleanup Levels and Contaminants of Potential Concern for Groundwater, Surface Water and Upland Soils. Memorandum. 28 May 2021.

Washington State Department of Ecology. 2021b. Cleanup Levels and Risk Calculation (CLARC) Tables. July 2021. https://fortress.wa.gov/ecy/ezshare/tcp/CLARC/CLARC_Master.xlsx

Washington State Department of Ecology. 2021c. Implementation Memorandum No. 23: Concentrations of Gasoline and Diesel Range Organics Predicted to be Protective of Aquatic Receptors in Surface Waters. Publication No. 19-09-043. 25 August 2021.

Washington State Department of Ecology. 2022. Natural Background Groundwater Arsenic Concentrations in Washington State Study Results. Publication 14-09-044. January 2022.

Attachments

Table B-1: Proposed Groundwater Cleanup Levels
Table B-2: Proposed Surface Water Cleanup Levels
Table B-3A; Proposed Vadose Zone Soil Cleanup Levels
Table B-3B: Proposed Saturated Zone Soil Cleanup Levels
Table B-4: Summary of Constituents of Concern (COCs) and Proposed Cleanup Levels (CULs)
Figure B-1: Current and Historical Site Features and Previous Interim Remedial Actions
Figure B-2: Zoning Designations and Sample Locations (2002-2018) – Main Area

PROPOSED GROUNDWATER CLEANUP LEVELS
BNSF Wishram Railyard, Wishram, Washington

Chemical	cas_rn	Unit	Ground Water Method A (Table 720-1) (µg/L)	Ground Water Method B Lowest of Noncancer & Cancer (Eq. 720-1/720-2) (µg/L)	Ground Water Method C Lowest of Noncancer & Cancer (Eq. 720-1/720-2) (µg/L)	Lowest State & Federal Ground Water Maximum Contaminant Level (µg/L)	Ground Water Target Cleanup Level for Soil to Ground Water Pathway (µg/L)	Preliminary Practical Quantitation Limit (µg/L)	PQL Source	Proposed Groundwater CUL	Proposed Groundwater CUL Source	2016-2020 Groundwater Maximum Detection (µg/L)	2016-2020 Groundwater Sample with Maximum Detection	Maximum Detection Above Proposed CUL = COC (Yes / No)	Comments
NWTPH-Gx															
Gasoline-Range Organics (no benzene present)	unavailable08	µg/L	1000	--	--	--	--	250	(1)	1000	Method A	270	RMD-2-20161116	No	
NWTPH-Dx - without silica gel cleanup															
Diesel-Range Organics	unavailable09	µg/L	500	--	--	--	--	250	(1)	500	Method A	28600	WMW-16-20171130	Yes	
Oil-Range Organics	unavailable10	µg/L	500	--	--	--	--	250	(1)	500	Method A	12600	WMW-03-20180823	Yes	
Total TPH-Dx (HalfDL_WA)	unavailable09	µg/L	500	--	--	--	--	250	(1)	500	Method A	36300	WMW-16-20171130	Yes	
NWTPH-Dx - with silica gel cleanup															
Diesel-Range Organics	unavailable09	µg/L	500	--	--	--	--	250	(1)	500	Method A	21100	WMW-16-20171130	Yes	
Oil-Range Organics	unavailable10	µg/L	500	--	--	--	--	250	(1)	500	Method A	6080	WMW-03-20180823	Yes	
Total TPH-Dx (HalfDL_WA)	unavailable09	µg/L	500	--	--	--	--	250	(1)	500	Method A	24900	WMW-16-20171130	Yes	
BTEX															
Toluene	108-88-3	µg/L	1000	640	1400	1000	640	1	(1)	1000	Method A, MCL	7.11	WMW-32-20180827	No	
Polycyclic Aromatic Hydrocarbons (PAHs)															
1-Methylnaphthalene	90-12-0	µg/L	--	1.5	15	--	1.5	1	(1)	1.5	Method B Cancer	15	WMW-16-20181107	Yes	
2-Methylnaphthalene	91-57-6	µg/L	--	32	70	--	32	1	(1)	32	Method B Noncancer	1.95	WMW-16-20171130	No	
Naphthalene	91-20-3	µg/L	160	160	350	--	160	1	(1)	160	Method A	1.25	RMD-1-20190507	No	
Total Naphthalenes (HalfDL_WA)	91-20-3	µg/L	160	160	350	--	160	1	(1)	160	Method A	17.3	WMW-16-20181107	No	CUL for Total Naphthalenes
Benzo(a)anthracene	56-55-3	µg/L	--	--	--	--	--	0.05	(3)	--	--	--	--	No	
Benzo(a)pyrene	50-32-8	µg/L	--	--	--	--	--	0.05	(3)	--	--	--	--	No	
Benzo(b)Fluoranthene	205-99-2	µg/L	--	--	--	--	--	0.05	(3)	--	--	--	--	No	
Benzo(k)Fluoranthene	207-08-9	µg/L	--	--	--	--	--	0.05	(3)	--	--	--	--	No	
Chrysene	218-01-9	µg/L	--	--	--	--	--	0.05	(3)	--	--	--	--	No	
Dibenz(a,h)Anthracene	53-70-3	µg/L	--	--	--	--	--	0.05	(3)	--	--	0.0689	WMW-30-20180829	No	
Indeno(1,2,3-c,d)Pyrene	193-39-5	µg/L	--	--	--	--	--	0.05	(3)	--	--	--	--	No	
Total cPAH TEQ (HalfDL_WA)	50-32-8	µg/L	0.1	0.023	0.88	0.2	0.2	0.05	(3)	0.2	MCL	0.0421	WMW-30-20180829	No	CUL for Total cPAH
Acenaphthene	83-32-9	µg/L	--	480	1100	--	480	1	(2)	960	Method B Noncancer	1.36	WMW-16-20171130	No	
Acenaphthylene	208-96-8	µg/L	--	--	--	--	--	1	(2)	--	No Cleanup Level	0.103	RMD-1-20190507	No	
Anthracene	120-12-7	µg/L	--	2400	5300	--	2400	1	(2)	4800	Method B Noncancer	0.126	RMD-1-20170919	No	
Fluorene	86-73-7	µg/L	--	320	700	--	320	0.53	(2)	640	Method B Noncancer	1.35	RMD-1-20190507	No	
Pyrene	129-00-0	µg/L	--	240	530	--	240	0.53	(2)	480	Method B Noncancer	0.077	RMD-2-20170919 (dup)	No	
Monitored Natural Attenuation Metals															
Iron, Dissolved	7439-89-6	µg/L	--	11000	25000	--	11200	50	(3)	11000	Method B Noncancer	18400	WMW-16-20171130	Yes	
Manganese, Dissolved	7439-96-5a	µg/L	--	750	1600	--	747.2	0.5	(3)	750	Method B Noncancer	6750	WMW-03-20180823	Yes	
Metals															
Arsenic, Dissolved	7440-38-2	µg/L	5	0.058	0.58	10	5	0.5	(2)	5	Background	37	WMW-24-20180830	Yes	
Arsenic, Total	7440-38-2	µg/L	5	0.058	0.58	10	5	0.5	(2)	5	Background	35.5	WMW-24-20180830	Yes	
Barium, Dissolved	7440-39-3	µg/L	--	3200	7000	2000	2000	0.625	(2)	2000	MCL	152	WMW-29-20180831	No	
Barium, Total	7440-39-3	µg/L	--	3200	7000	2000	2000	0.625	(2)	2000	MCL	16500	WMW-30-20190820	Yes	
Chromium, total, Dissolved	7440-47-3	µg/L	100	24000	53000	100	24000	2	(3)	100	Method A, MCL	15	WMW-26-20190507	No	No hexavalent chromium source
Chromium, total, Total	7440-47-3	µg/L	100	24000	53000	100	24000	2	(3)	100	Method A, MCL	16.5	WMW-32-20200527	No	No hexavalent chromium source
Lead, Dissolved	7439-92-1	µg/L	15	--	--	15	15	0.5	(3)	15	MCL	5.69	WMW-30-20180829	No	
Lead, Total	7439-92-1	µg/L	15	--	--	15	15	0.5	(3)	15	MCL	9.68	WMW-23-20190508	No	
Selenium, Dissolved	7782-49-2	µg/L	--	80	180	50	50	1	(2)	50	MCL	3.01	WMW-32-20180827	No	
Selenium, Total	7782-49-2	µg/L	--	80	180	50	50	1	(2)	50	MCL	3.09	WMW-32-20180827	No	

Table presents proposed cleanup levels (CULs) and CUL sources for constituents detected in one or more groundwater samples from monitoring wells between 2016 and 2020.

Diesel-Range Organics — Detected constituents above the proposed CUL are shaded blue. These constituents are identified as Constituents of Concern (COCs) for groundwater.

Abbreviations and Symbols

" - -" denotes not measured, not available, or not applicable. µg/L = micrograms per liter

There are no known or potential sources of hexavalent chromium at the site; therefore, it is assumed that all of the chromium is trivalent and the Method A number for total chromium is 100 µg/L in accordance with WAC 246-290-310.

Total cPAHs = Possible total cPAHs are based on the relative toxicity of each cPAH to benzo(a)pyrene and were calculated by multiplying the individual cPAH concentrations by a toxicity equivalency factor (TEF) and summing the adjusted concentrations. Non-detects were included as noted.

Total Naphthalenes = Total Naphthalenes concentrations were calculated by summing 1-Methylnaphthalene, 2-Methylnaphthalene, and Naphthalene concentrations. Non-detects were included as noted.

(HalfDL_WA) = If an individual chemical was not detected, a value of one half the method reporting limit was used as the concentration in the calculation, except when all chemicals used in the calculation were not detected then one half the lowest method reporting limit was used as the total concentration.

Cleanup Levels

Cleanup level values based on Model Toxics Control Act (MTCA) Method B values (B Cancer or B Non Cancer) and MTCA Method A values for groundwater (Table 720-1) based on Washington State Administrative Code (WAC) 173-340-720 from Cleanup Levels and Risk Calculation (CLARC) tables (Accessed July 2021), and Washington State (246-290 WAC) and Federal (40 CFR 141) Maximum Contaminant Levels (MCLs).

Preliminary Practical Quantitation Limit (PQL) based on values provided in one of the following: (1) Table 7-3 of Ecology's Guidance for Remediation of Petroleum Contaminated Sites. Toxics Cleanup Program. Publication No. 10-09-057. Revised June 2016;
(2) Ecology Memorandum "Wishram Cleanup Site: Preliminary Cleanup Levels and Contaminants of Potential Concern for Groundwater, Surface Water and Upland Soils" dated 28 May 2021; or
(3) Method reporting limits (MRLs) provided by Pace Analytical for Pace Analytical National in Mount Juliet, TN (provided 4/27/2022) and Pace Analytical in Minneapolis, MN (provided 5/9/2022).

PROPOSED SURFACE WATER CLEANUP LEVELS
BNSF Wishram Railyard, Wishram, Washington

Chemical	cas_rn	Unit	Surface Water Method B Lowest of Cancer and Noncancer (µg/L)	Lowest Surface Water Aquatic Life Fresh Water / Acute & Chronic (µg/L)	Lowest Surface Water Human Health Fresh Water (µg/L)	Surface Water Target Cleanup Level for Soil to Surface Water Pathway Fresh Water (µg/L)	Surface Water Target Criterion Fresh Water	Other Ecological Value (µg/L)	Other Ecological Source	Preliminary Practical Quantitation Limit (µg/L)	PQL Source	Proposed Surface Water CUL (µg/L)	Proposed Surface Water CUL Source	2016-2020 Berm Well Groundwater Maximum Detection (µg/L)	2016-2020 Groundwater Sample from Berm Well with Maximum Detection	Maximum Detection Above Proposed CUL = COC (Yes / No)	Comments
NWTPH-Gx																	
Gasoline-Range Organics (no benzene present)	unavailable08	µg/L	1000	--	--	--	--	1000	EEBC	250	(1)	1000	EEBC	270	RMD-2-20161116	No	
NWTPH-Dx - without silica gel cleanup																	
Diesel-Range Organics	unavailable09	µg/L	500	--	--	--	--	3000	EEBC	250	(1)	500 / 3000	Method A / EEBC	28600	WMW-16-20171130	Yes	PCUL HH = 500, Eco = 3000
Oil-Range Organics	unavailable10	µg/L	500	--	--	--	--	3000	EEBC	250	(1)	500 / 3000	Method A / EEBC	7670	WMW-16-20171130	Yes	PCUL HH = 500, Eco = 3000
Total TPH-Dx (HalfDL_WA)	unavailable09	ug/L	500	--	--	--	--	3000	EEBC	250	(1)	500 / 3000	Method A / EEBC	36300	WMW-16-20171130	Yes	PCUL HH = 500, Eco = 3000
NWTPH-Dx - with silica gel cleanup																	
Diesel-Range Organics	unavailable09	µg/L	500	--	--	--	--	3000	EEBC	250	(1)	500 / 3000	Method A / EEBC	21100	WMW-16-20171130	Yes	PCUL HH = 500, Eco = 3000
Oil-Range Organics	unavailable10	µg/L	500	--	--	--	--	3000	EEBC	250	(1)	500 / 3000	Method A / EEBC	3810	WMW-16-20171130	Yes	PCUL HH = 500, Eco = 3000
Total TPH-Dx (HalfDL_WA)	unavailable09	ug/L	500	--	--	--	--	3000	EEBC	250	(1)	500 / 3000	Method A / EEBC	24900	WMW-16-20171130	Yes	PCUL HH = 500, Eco = 3000
BTEX																	
Toluene	108-88-3	µg/L	19000	--	57	57	WQC_HH	53	EEBC	1	(1)	53	EEBC			No	No detections in berm wells
Polycyclic Aromatic Hydrocarbons																	
1-Methylnaphthalene	90-12-0	µg/L	--	--	--	--	--	2.1	RAIS	1	(1)	2.1	RAIS	15	WMW-16-20181107	Yes	
2-Methylnaphthalene	91-57-6	µg/L	--	--	--	--	--	130	RAIS	1	(1)	130	RAIS	1.95	WMW-16-20171130	No	
Naphthalene	91-20-3	µg/L	4900	--	--	4938	Method B NC	490	RAIS	1	(1)	490	RAIS	1.25	RMD-1-20190507	No	
Total Naphthalenes (HalfDL_WA)	91-20-3	µg/L	4900	--	--	4938	Method B NC	490	RAIS	1	(1)	490	RAIS	17.3	WMW-16-20181107	No	CUL for total naphthalenes
Benzo(a)anthracene	56-55-3	µg/L	--	--	--	--	--	--	--	0.05	(3)	--	--			No	
Benzo(a)pyrene	50-32-8	µg/L	0.035	--	0.000016	0.000016	WQC_HH	--	--	0.05	(3)	--	--			No	
Benzo(b)Fluoranthene	205-99-2	µg/L	--	--	--	--	--	--	--	0.05	(3)	--	--			No	
Benzo(k)Fluoranthene	207-08-9	µg/L	--	--	--	--	--	--	--	0.05	(3)	--	--			No	
Chrysene	218-01-9	µg/L	--	--	--	--	--	--	--	0.05	(3)	--	--			No	
Dibenz(a,h)Anthracene	53-70-3	µg/L	--	--	--	--	--	--	--	0.05	(3)	--	--			No	
Indeno(1,2,3-c,d)Pyrene	193-39-5	µg/L	--	--	--	--	--	--	--	0.05	(3)	--	--			No	
Total cPAH TEQ (HalfDL_WA)	50-32-8	µg/L	0.035	--	0.000016	0.000016	WQC_HH	--	--	0.05	(3)	0.05	PQL			No	No detections in berm wells
Acenaphthene	83-32-9	µg/L	640	--	30	30	WQC_HH	23	RAIS	1	(2)	23	WQC_HH	1.36	WMW-16-20171130	No	
Acenaphthylene	208-96-8	µg/L	--	--	--	--	--	13	GLWQI	1	(2)	13	GLWQI	0.103	RMD-1-20190507	No	
Anthracene	120-12-7	µg/L	26000	--	100	100	WQC_HH	0.3	RAIS	1	(2)	1	PQL	0.126	RMD-1-20170919	No	
Fluorene	86-73-7	µg/L	3500	--	10	10	WQC_HH	19	GLWQI	0.53	(2)	10	WQC_HH	1.35	RMD-1-20190507	No	
Phenanthrene	85-01-8	µg/L	--	--	--	--	--	2.3	GLWQI	1	(2)	2.3	GLWQI	0.175	RMD-1-20180430	No	
Pyrene	129-00-0	µg/L	2600	--	8	8	WQC_HH	7	RAIS	0.53	(2)	7	WQC_HH	0.077	RMD-2-20170919 (dup)	No	
MNA Metals																	
Iron, Dissolved	7439-89-6	µg/L	--	1000	--	1000	WQC_AL	--	--	50	(3)	1000	WQC_AL	18400	WMW-16-20171130	Yes	
Manganese, Dissolved	7439-96-5a	µg/L	--	--	50	50	WQC_HH	93	GLWQI	0.5	(3)	50	WQC_HH	3360	RMD-2-20190821	Yes	
Metals																	
Arsenic, Dissolved	7440-38-2	µg/L	0.098	150	0.018	5	Background	--	--	0.5	(2)	5	Background	35.9	WMW-17-20171130 (dup)	Yes	
Arsenic, Total	7440-38-2	µg/L	0.098	150	0.018	5	Background	--	--	0.5	(2)	5	Background	34.9	WMW-17-20171130 (dup)	Yes	
Barium, Dissolved	7440-39-3	µg/L	--	--	1000	1000	WQC_HH	220	GLWQI	0.625	(2)	220	GLWQI	46.2	WMW-20-20180827	No	
Barium, Total	7440-39-3	µg/L	--	--	1000	1000	WQC_HH	220	GLWQI	0.625	(2)	220	GLWQI	47.9	WMW-20-20180827	No	No exceedances in berm wells
Chromium, total, Dissolved (Cr III)	16065-83-1	µg/L	240000	74	--	74	WQC_AL	--	--	2	(3)	74	WQC_AL			No	No detections in berm wells
Chromium, total, Total (Cr III)	16065-83-1	µg/L	240000	74	--	74	WQC_AL	--	--	2	(3)	74	WQC_AL			No	No detections in berm wells
Lead, Dissolved	7439-92-1	µg/L	--	2.5	--	2.5	WQC_AL	--	--	0.5	(3)	2.5	WQC_AL			No	No detections in berm wells
Lead, Total	7439-92-1	µg/L	--	2.5	--	2.5	WQC_AL	--	--	0.5	(3)	2.5	WQC_AL	9.68	WMW-23-20190508	Yes	
Selenium, Dissolved	7782-49-2	µg/L	2700	5	60	5	WQC_AL	--	--	1	(2)	5	WQC_AL			No	No detections in berm wells
Selenium, Total	7782-49-2	µg/L	2700	5	60	5	WQC_AL	--	--	1	(2)	5	WQC_AL			No	No detections in berm wells

Table presents proposed cleanup levels (CULs) and CUL sources for constituents detected in one or more groundwater samples from monitoring wells located along the Columbia River berm between 2016 and 2020.

Diesel-Range Organics — Detected constituents above the proposed CUL are shaded blue. These constituents are identified as Constituents of Concern (COCs) for surface water.

Abbreviations and Symbols

" - -" denotes not measured, not available, or not applicable. µg/L = micrograms per liter

There are no known or potential sources of hexavalent chromium at the site; therefore, it is assumed that all of the chromium is trivalent and the Method A number for total chromium is 100 µg/L in accordance with WAC 246-290-310.

Total cPAHs = Possible total cPAHs are based on the relative toxicity of each cPAH to benzo(a)pyrene and were calculated by multiplying the individual cPAH concentrations by a toxicity equivalency factor (TEF) and summing the adjusted concentrations. Non-detects were included as noted.

Total Naphthalenes = Total Naphthalenes concentrations were calculated by summing 1-Methylnaphthalene, 2-Methylnaphthalene, and Naphthalene concentrations. Non-detects were included as noted.

Total Xylenes = Total Xylenes concentrations were calculated by summing Xylene, m,p- and Xylene, o- concentrations. Non-detects were included as noted.

(HalfDL_WA) = If an individual chemical was not detected, a value of one half the method reporting limit was used as the concentration in the calculation, except when all chemicals used in the calculation were not detected then one half the lowest method reporting limit was used as the total concentration.

Cleanup Levels

Cleanup level values based on Washington State Department of Ecology (Ecology) Model Toxics Control Act (MTCA) Method B values (B Cancer or B Non Cancer), MTCA Method A values and other applicable, relevant, and appropriate requirements (ARARs) for surface water based on Washington State Administrative Code (WAC) 173-340-730 from Cleanup Levels and Risk Calculation (CLARC) tables (Accessed July 2021).

"WQC_HH" = Surface water quality cleanup level for Human Health. "WQC_AL" = Surface water quality cleanup level for Aquatic Life.

Other Ecological Sources include: Great Lakes Water Quality Initiative (GLWQI) Clearinghouse (https://www.epa.gov/gliclearinghouse), The Risk Assessment Information System (RAIS) (https://rais.ornl.gov/tools/eco_search.php),

"EEBC" = Environmental Effects-Based Concentrations, from *Concentrations of Gasoline and Diesel Range Organics Predicted to be Protective of Aquatic Receptors in Surface Waters, Implementation Memorandum No. 23 (* Ecology, August 25, 2021).

Preliminary Practical Quantitation Limit (PQL) based on values provided in one of the following: (1) Ecology's Guidance for Remediation of Petroleum Contaminated Sites. Toxics Cleanup Program. Publication No. 10-09-057. Revised June 2016;

(2) Ecology Memorandum "Wishram Cleanup Site: Preliminary Cleanup Levels and Contaminants of Potential Concern for Groundwater, Surface Water and Upland Soils" dated 28 May 2021; or

(3) Method reporting limits (MRLs) provided by Pace Analytical for Pace Analytical National in Mount Juliet, TN (provided 4/27/2022) and Pace Analytical in Minneapolis, MN (provided 5/9/2022).

PROPOSED VADOSE ZONE SOIL CLEANUP LEVELS
BNSF Wishram Railyard, Wishram, Washington

													Off-Railyard Property					BNSF Wishram Railyard Property				
Chemical	CAS Rn	Units	Soil Method A Industrial Properties (Table 745-1) (mg/kg)	Soil Method A Unrestricted Land Use (Table 740-1) (mg/kg)	Soil Method B Lowest Cancer & Noncancer (mg/kg)	Soil Method C Lowest Cancer & Noncancer (mg/kg)	Empirical Determination - Soil Protective of GW and GW to SW Pathways	3-Phase Model Soil Protective of GW Vadose @ 13 degrees C (Eq. 747-1) (mg/kg)	3-Phase Model Soil Protective of GW to SW Vadose @ 13 degrees C Fresh Water (Eq. 747-1) (mg/kg)	Natural Background (mg/kg)	Preliminary Practical Quantitation Limit (PQL) (mg/kg)	PQL Source	Proposed Unrestricted Vadose Zone Soil CUL (mg/kg)	Source Proposed Vadose Zone Soil CUL (0-10 feet bgs)	Maximum Detection (mg/kg)	Vadose Soil Sample(s) with Maximum Concentration	Maximum Detection Above Proposed Unrestricted Vadose Zone Soil CUL = COC (Yes / No)	Proposed Restricted / Industrial Vadose Zone Soil CUL (mg/kg)	Source Proposed Vadose Zone Soil CUL (Railyard 0-10 feet bgs, Berm 0-15 feet bgs)	Maximum Detection (mg/kg)	Vadose Soil Sample(s) with Maximum Concentration	Maximum Detection Above Proposed Restricted / Industrial Vadose Zone Soil CUL = COC (Yes / No)
NWTPH-Gx																						
Gasoline-Range Organics	unavailable25	mg/kg	30	30	--	--	Not applicable	--	--	--	5	(1)	30	Method A	ND		No	30	Method A	4.48	WSB-04-20-10	No
NWTPH-Dx - without silica gel cleanup																						
Diesel-Range Organics	unavailable09	mg/kg	2,000	2,000	--	--	Not applicable	--	--	--	25	(1)	2,000	Method A	ND		No	2,000	Method A	2,700	B-18-24(9.0-9.5)	Yes
Oil-Range Organics	unavailable10	mg/kg	2,000	2,000	--	--	Not applicable	--	--	--	100	(1)	2,000	Method A	113	B-16-06-05	No	2,000	Method A	3,790	B-18-03(2.0-2.5)	Yes
Total TPH-Dx (HalfDL_WA)	unavailable09	mg/kg	2,000	2,000	--	--	Not applicable	--	--	--	25	(1)	2,000	Method A	134	B-16-06-05	No	2,000	Method A	4,780	B-18-03(2.0-2.5)	Yes
NWTPH-Dx - with silica gel cleanup																						
Diesel-Range Organics	unavailable09	mg/kg	2,000	2,000	--	--	Not applicable	--	--	--	25	(1)	2,000	Method A	5,120	#2-11.5	Yes	2,000	Method A	50,200	#9-12	Yes
Oil-Range Organics	unavailable10	mg/kg	2,000	2,000	--	--	Not applicable	--	--	--	100	(1)	2,000	Method A	7,850	#2-11.5	Yes	2,000	Method A	62,900	#9-12	Yes
Total TPH-Dx (HalfDL_WA)	unavailable09	mg/kg	2,000	2,000	--	--	Not applicable	--	--	--	25	(1)	2,000	Method A	13,000	#2-11.5	Yes	2,000	Method A	113,000	#9-12	Yes
BTEX																						
Benzene	71-43-2	mg/kg	0.03	0.03	18	2,400	Empirical - ND in wells	Empirical	Empirical	--	0.005	(1)	18	Method B C	ND	--	No	2,400	Method C C	0.00301	WMW-29(2.0-2.5)	No
Ethylbenzene	100-41-4	mg/kg	6	6	8,000	350,000	Empirical - ND in wells	Empirical	Empirical	--	0.005	(1)	8,000	Method B NC	ND	--	No	350,000	Method C NC	0.687	WSB-2-14	No
Toluene	108-88-3	mg/kg	7	7	6,400	280,000	Empirical Below GW&SW CUL	Empirical	Empirical	--	0.005	(1)	6,400	Method B NC	ND	--	No	280,000	Method C NC	0.0401	WMW-29(2.0-2.5)	No
Xylene, m,p-	108-38-3	mg/kg	--	--	16,000	700,000	Empirical - ND in wells	Empirical	Empirical	--	0.0065	(3)	16,000	Method B NC	ND	--	No	700,000	Method C NC	0.0593	WMW-29(2.0-2.5)	No
Xylene, o-	95-47-6	mg/kg	--	--	16,000	700,000	Empirical - ND in wells	Empirical	Empirical	--	0.0065	(3)	16,000	Method B NC	ND	--	No	700,000	Method C NC	0.0193	RMD-5(7.5-8.0)	No
Total Xylenes (HalfDL_WA)	1330-20-7	mg/kg	9	9	16,000	700,000	Empirical - ND in wells	Empirical	Empirical	--	0.0065	(3)	16,000	Method B NC	ND	--	No	700,000	Method C NC	0.0739	WMW-29(2.0-2.5)	No
Xylene, total	1330-20-7	mg/kg	9	9	16,000	700,000	Empirical - ND in wells	Empirical	Empirical	--	0.0065	(3)	16,000	Method B NC	ND	--	No	700,000	Method C NC	1.36	WSB-4-10	No
Polycyclic Aromatic Hydrocarbons																						
1-Methylnaphthalene	90-12-0	mg/kg	--	--	34	4,500	Empirical - Data Based	Empirical	Empirical	--	0.5	(1)	34	Method B C	ND	--	No	4,500	Method C C	0.0949	B-18-18(1.5-2.0)	No
2-Methylnaphthalene	91-57-6	mg/kg	--	--	320	14,000	Empirical Below GW&SW CUL	Empirical	Empirical	--	0.5	(1)	320	Method B NC	ND	--	No	14,000	Method C NC	61.9	WSB-2-14	No
Naphthalene	91-20-3	mg/kg	5	5	1,600	70,000	Empirical Below GW&SW CUL	Empirical	Empirical	--	0.5	(1)	1,600	Method B NC	ND	--	No	70,000	Method C NC	23.8	WSB-2-14	No
Total Naphthalenes (HalfDL_WA)	91-20-3	mg/kg	5	5	1,600	70,000	Empirical Below GW&SW CUL	Empirical	Empirical	--	0.5	(1)	1,600	Method B NC	ND	--	No	70,000	Method C NC	85.7	WSB-2-14	No
Benzo(a)anthracene	56-55-3	mg/kg	--	--	--	--	--	--	--	--	0.05	(1)	--	--	ND	--	No	--	--	3.65	B-18-18(1.5-2.0)	No
Benzo(a)pyrene	50-32-8	mg/kg	--	--	--	--	--	--	--	--	0.05	(1)	--	--	ND	--	No	--	--	3.07	B-18-18(1.5-2.0)	No
Benzo(b)Fluoranthene	205-99-2	mg/kg	--	--	--	--	--	--	--	--	0.05	(1)	--	--	ND	--	No	--	--	4.24	B-18-18(1.5-2.0)	No
Benzo(k)Fluoranthene	207-08-9	mg/kg	--	--	--	--	--	--	--	--	0.05	(1)	--	--	ND	--	No	--	--	1.17	B-18-18(1.5-2.0)	No
Chrysene	218-01-9	mg/kg	--	--	--	--	--	--	--	--	0.05	(1)	--	--	ND	--	No	--	--	4.01	B-18-18(1.5-2.0)	No
Dibenz(a,h)Anthracene	53-70-3	mg/kg	--	--	--	--	--	--	--	--	0.05	(1)	--	--	ND	--	No	--	--	0.582	B-18-18(1.5-2.0)	No
Indeno(1,2,3-c,d)Pyrene	193-39-5	mg/kg	--	--	--	--	--	--	--	--	0.05	(1)	--	--	ND	--	No	--	--	1.72	B-18-18(1.5-2.0)	No
Total cPAH TEQ (HalfDL_WA)	50-32-8	mg/kg	2	0.1	0.19	130	Empirical Below GW&SW CUL	Empirical	Empirical	--	0.05	(1)	0.19	Method B C	ND	--	No	130	Method C C	4.25	B-18-18(1.5-2.0)	No
Acenaphthene	83-32-9	mg/kg	--	--	4,800	210,000	Empirical Below GW&SW CUL	Empirical	Empirical	--	0.0435	(2)	4,800	Method B NC	ND	--	No	210,000	Method C NC	0.508	B-18-18(1.5-2.0)	No
Anthracene	120-12-7	mg/kg	--	--	24,000	1,100,000	Empirical Below GW&SW CUL	Empirical	Empirical	--	0.0435	(2)	24,000	Method B NC	ND	--	No	1,100,000	Method C NC	0.798	B-18-18(1.5-2.0)	No
Benzo(g,h,i)Perylene	191-24-2	mg/kg	--	--	--	--	Empirical No CUL	Empirical	Empirical	--	0.05	(1)	--	--	0.0566	B-16-06-05	No	--	--	1.9	B-18-18(1.5-2.0)	No
Fluoranthene	206-44-0	mg/kg	--	--	3,200	140,000	Empirical - ND in wells	Empirical	Empirical	--	0.05	(1)	3,200	Method B NC	ND	--	No	140,000	Method C NC	6.61	B-18-18(1.5-2.0)	No
Fluorene	86-73-7	mg/kg	--	--	3,200	140,000	Empirical Below GW&SW CUL	Empirical	Empirical	--	0.02	(2)	3,200	Method B NC	ND	--	No	140,000	Method C NC	0.214	B-18-18(1.5-2.0)	No
Phenanthrene	85-01-8	mg/kg	--	--	--	--	Empirical No CUL	Empirical	Empirical	--	0.05	(1)	--	--	ND	--	No	--	--	41	WSB-2-14	No
Pyrene	129-00-0	mg/kg	--	--	2,400	110,000	Empirical Below GW&SW CUL	Empirical	Empirical	--	0.05	(1)	2,400	Method B NC	ND	--	No	110,000	Method C NC	18.1	WSB-2-14	No
Volatile Organic Compounds																						
1,1-Dichloropropene	563-58-6	mg/kg	--	--	--	--	Empirical - ND in wells	Empirical	Empirical	--	0.0025	(3)	--	--	--	--	No	--	--	0.0454	B-18-10(2.0-2.5)	No
1,2,3-Trimethylbenzene	526-73-8	mg/kg	--	--	800	35,000	Empirical - ND in wells	Empirical	Empirical	--	0.005	(3)	800	Method B NC	--	--	No	35,000	Method C NC	0.0192	B-18-18(1.5-2.0)	No
1,2,4-Trimethylbenzene	95-63-6	mg/kg	--	--	800	35,000	Empirical - ND in wells	Empirical	Empirical	--	0.005	(3)	800	Method B NC	--	--	No	35,000	Method C NC	0.021	B-18-18(1.5-2.0)	No
1,3,5-Trimethylbenzene	108-67-8	mg/kg	--	--	800	35,000	Empirical - ND in wells	Empirical	Empirical	--	0.005	(3)	800	Method B NC	--	--	No	35,000	Method C NC	0.00961	WMW-29(2.0-2.5)	No
Acetone	67-64-1	mg/kg	--	--	72,000	3,200,000	Empirical - ND in wells	Empirical	Empirical	--	0.015	(2)	72,000	Method B NC	--	--	No	3,200,000	Method C NC	0.106	B-18-29(2.0-2.5)	No
Chloroethane	75-00-3	mg/kg	--	--	--	--	Empirical - No CUL	Empirical	Empirical	--	0.005	(3)	--	--	--	--	No	--	--	0.0248	B-18-10(2.0-2.5)	No
Cymene (p-Isopropyltoluene)	99-87-6	mg/kg	--	--	--	--	Empirical - No CUL	Empirical	Empirical	--	0.005	(3)	--	--	--	--	No	--	--	0.011	B-18-18(1.5-2.0)	No
Dibromomethane	74-95-3	mg/kg	--	--	800	35,000	Empirical - ND in wells	Empirical	Empirical	--	0.001	(2)	800	Method B NC	--	--	No	35,000	Method C NC	0.00611	B-18-10(2.0-2.5)	No
Methyl ethyl ketone (2-Butanone)	78-93-3	mg/kg	--	--	48,000	2,100,000	Empirical - ND in wells	Empirical	Empirical	--	0.02	(2)	48,000	Method B NC	--	--	No	2,100,000	Method C NC	0.0566	B-18-23(3.0-3.5)	No
Naphthalene	91-20-3	mg/kg	5	5	1,600	70,000	Empirical Below GW&SW CUL	Empirical	Empirical	--	0.5	(1)	1,600	Method B NC	--	--	No	70,000	Method C NC	0.0551	B-18-18(1.5-2.0)	No
trans-1,3-Dichloropropene	542-75-6	mg/kg	--	--	10	1,300	Empirical - ND in wells	Empirical	Empirical	--	0.005	(3)	10	Method B C	--	--	No	1300	Method C C	0.00897	B-18-10(2.0-2.5)	No
Metals																						
Arsenic	7440-38-2	mg/kg	20	20	0.67	88	Above GW&SW CUL	2.9	2.9	20	4.5	(2)	20	Background	--	--	No	20	Background	9.65	B-18-18(1.5-2.0)	No
Barium	7440-39-3	mg/kg	--	--	16,000	700,000	Empirical - Data Based	Empirical	Empirical	--	0.5	(3)	16,000	Method B NC	--	--	No	700,000	Method C NC	6,500	WSB-2-14	No
Chromium, total (Cr III for soil)	16065-83-1	mg/kg	2,000	2,000	120,000	5,300,000	Empirical Below GW&SW CUL	Empirical	Empirical	42	0.5	(1)	120,000	Method B NC	--	--	No	5,300,000	Method C NC	28.8	B-18-03(2.0-2.5)	No
Lead	7439-92-1	mg/kg	1,000	250	--	--	Above SW CUL	3000	500	17	0.5	(3)	250	Method A	--	--	No	500	Protective GW-SW	387	WSB-2-8	No
Mercury	7439-97-6	mg/kg	2	2	--	--	Empirical - ND in wells	Empirical	Empirical	0.07	0.02	(2)	2	Method A	--	--	No	2	Method A	0.156	B-18-30(2.0-2.5)	No
Selenium	7782-49-2	mg/kg	--	--	400	18,000	Empirical Below GW&SW CUL	Empirical	Empirical	0.78	3	(2)	400	Method B NC	--	--	No	18,000	Method C NC	0.457	WSB-2-8	No

Table presents proposed cleanup levels (CULs) and CUL sources for constituents detected in one or soil samples collected between 2002 and 2018. Results include samples collected from unsaturated vadose zone soil.

Diesel-Range Organics — Detected constituents above the proposed CUL are shaded blue. These constituents are identified as Constituents of Concern (COCs) for unsaturated vadose zone soil.

Abbreviations and Symbols

" - -" denotes not measured, not available, or not applicable.

mg/kg = milligrams per kilogram

Where "Empirical" is listed in the row, it has been assumed that an empirical demonstration indicates that the contaminant is not reaching groundwater/surface water at values above what is considered protective; based on groundwater samples collected between November 2016 and August 2020.

Empirical Below CUL = constituent not reported above the proposed groundwater (GW) and/or surface water (SW) CUL in groundwater samples. Above CUL = constituent reported above the proposed groundwater CUL in one or more groundwater samples collected between November 2016 and August 2020. ND = constituent not detected in groundwater. No CUL = no CUL for constituent.

There are no known or potential sources of hexavalent chromium at the site; therefore, it is assumed that all of the chromium is trivalent and the Method A number for total chromium is 100 µg/L in accordance with WAC 246-290-310.

Total cPAHs = Possible total cPAHs are based on the relative toxicity of each cPAH to benzo(a)pyrene and were calculated by multiplying the individual cPAH concentrations by a toxicity equivalency factor (TEF) and summing the adjusted concentrations. Non-detects were included as noted.

Total Naphthalenes = Total Naphthalenes concentrations were calculated by summing 1-Methylnaphthalene, 2-Methylnaphthalene, and Naphthalene concentrations. Non-detects were included as noted.

Total Xylenes = Total Xylenes concentrations were calculated by summing Xylene, m,p- and Xylene, o- concentrations. Non-detects were included as noted.

(HalfDL_WA) = If an individual chemical was not detected, a value of one half the method reporting limit was used as the concentration in the calculation, except when all chemicals used in the calculation were not detected then one half the lowest method reporting limit was used as the total concentration.

Cleanup Levels

Cleanup level values based on Washington State Department of Ecology (Ecology) Model Toxics Control Act (MTCA) Method C values (Method C C = Cancer or Method C NC = Non Cancer) and MTCA Method A values for soil (Table 745-1) based on Washington State Administrative Code (WAC) 173-340-745 and 3-Phase Model Soil Protective of Groundwater Vadose (Eq. 747-1) and 3-Phase Model Soil Protective of Groundwater to Surface Water Vadose Fresh Water (Eq. 747-1) from Cleanup Levels and Risk Calculation (CLARC) tables (Accessed July 2021).

Preliminary Practical Quantitation Limit (PQL) based on values provided in one of the following: (1) Ecology's Guidance for Remediation of Petroleum Contaminated Sites. Toxics Cleanup Program. Publication No. 10-09-057. Revised June 2016. (2) Ecology Memorandum "Wishram Cleanup Site: Preliminary Cleanup Levels and Contaminants of Potential Concern for Groundwater, Surface Water and Upland Soils" dated 28 May 2021; or (3) Method reporting limits (MRLs) provided by Pace Analytical for Pace Analytical National in Mount Juliet, TN (provided 4/27/2022) and Pace Analytical in Minneapolis, MN (provided 5/9/2022).

PROPOSED SATURATED ZONE SOIL CLEANUP LEVELS
BNSF Wishram Railyard, Wishram, Washington

												Off-Railyard Property					BNSF Wishram Railyard Property				
Chemical	CAS Rn	Units	Soil Method A Industrial Properties (Table 745-1) (mg/kg)	Soil Method B Lowest Cancer & Noncancer (mg/kg)	Soil Method C Lowest Cancer & Noncancer (mg/kg)	Empirical Determination - Soil Protective of GW and GW to SW Pathways	3-Phase Model Soil Protective of GW Saturated (Eq. 747-1) (mg/kg)	3-Phase Model Soil Protective of GW to SW Saturated Fresh Water (Eq. 747-1) (mg/kg)	Natural Background (mg/kg)	Preliminary Practical Quantitation Limit (PQL) (mg/kg)	PQL Source	Proposed CUL Saturated Soil (mg/kg)	Source Proposed CUL Saturated Soil (10-15 feet bgs)	Maximum Detection (mg/kg)	Saturated Soil Sample(s) with Maximum Concentration (10-15 feet bgs)	Maximum Detection Above Proposed Unrestricted Saturated Soil CUL = COC (Yes / No)	Proposed CUL Saturated Soil (mg/kg)	Source Proposed CUL Saturated Soil (Railyard 10-15 feet bgs)	Maximum Detection (mg/kg)	Saturated Soil Sample(s) with Maximum Concentration (Railyard 10-15 feet bgs)	Maximum Detection Above Proposed Restricted / Industrial Saturated Soil CUL = COC (Yes / No)
NWTPH-Gx																					
Gasoline-Range Organics	unavailable25	mg/kg	30	--	--	Not applicable	--	--	--	5	(1)	30	Method A	210	T-4-13.5	Yes	30	Method A	1,300	B-12-3-13	Yes
NWTPH-Dx - without silica gel cleanup																					
Diesel-Range Organics	unavailable09	mg/kg	2,000	--	--	Not applicable	--	--	--	25	(1)	2,000	Method A	ND	--	No	2,000	Method A	9,070	B-18-24(13.5-14.0)	Yes
Oil-Range Organics	unavailable10	mg/kg	2,000	--	--	Not applicable	--	--	--	100	(1)	2,000	Method A	ND	--	No	2,000	Method A		--	No
Total TPH-Dx (HalfDL_WA)	unavailable09	mg/kg	2,000	--	--	Not applicable	--	--	--	25	(1)	2,000	Method A	ND	--	No	2,000	Method A	9,710	B-18-24(13.5-14.0)	Yes
NWTPH-Dx - with silica gel cleanup																					
Diesel-Range Organics	unavailable09	mg/kg	2,000	--	--	Not applicable	--	--	--	25	(1)	2,000	Method A	60,600	E-15-14.5	Yes	2,000	Method A	43,000	TG-D1-12	Yes
Oil-Range Organics	unavailable10	mg/kg	2,000	--	--	Not applicable	--	--	--	100	(1)	2,000	Method A	60,000	W-5-14.5	Yes	2,000	Method A	71,000	B-12-2-12	Yes
Total TPH-Dx (HalfDL_WA)	unavailable09	mg/kg	2,000	--	--	Not applicable	--	--	--	25	(1)	2,000	Method A	105,000	E-15-14.5	Yes	2,000	Method A	109,000	B-12-2-12	Yes
BTEX																					
Benzene	71-43-2	mg/kg	0.03	18	2,400	Empirical - ND in wells	Empirical	Empirical	--	0.005	(1)	18	Method B C	ND	--	No	2,400	Method C C	0.089	B-12-2-12	No
Ethylbenzene	100-41-4	mg/kg	6	8,000	350,000	Empirical - ND in wells	Empirical	Empirical	--	0.005	(1)	8,000	Method B NC	ND	--	No	350,000	Method C NC	1.31	B-18-24(13.5-14.0)	No
Toluene	108-88-3	mg/kg	7	6,400	280,000	Empirical Below GW&SW CUL	Empirical	Empirical	--	0.005	(1)	6,400	Method B NC	ND	--	No	280,000	Method C NC	0.16	B-12-2-12	No
Xylene, m,p-	108-38-3	mg/kg	--	16,000	700,000	Empirical - ND in wells	Empirical	Empirical	--	0.0065	(3)	16,000	Method B NC	--	--	No	700,000	Method C NC	1.26	B-18-24(13.5-14.0)	No
Xylene, o-	95-47-6	mg/kg	--	16,000	700,000	Empirical - ND in wells	Empirical	Empirical	--	0.0065	(3)	16,000	Method B NC	--	--	No	700,000	Method C NC	0.34	B-12-2-12	No
Total Xylenes (HalfDL_WA)	1330-20-7	mg/kg	9	16,000	700,000	Empirical - ND in wells	Empirical	Empirical	--	0.0065	(3)	16,000	Method B NC	--	--	No	700,000	Method C NC	1.29	B-18-24(13.5-14.0)	No
Xylene, total	1330-20-7	mg/kg	9	16,000	700,000	Empirical - ND in wells	Empirical	Empirical	--	0.0065	(3)	16,000	Method B NC	ND	--	No	700,000	Method C NC	0.81	B-12-2-12	No
Polycyclic Aromatic Hydrocarbons																					
1-Methylnaphthalene	90-12-0	mg/kg	--	34	4,500	Empirical - Data Based	Empirical	Empirical	--	0.5	(1)	34	Method B Cancer	ND	--	No	4,500	Method C C	260	TG-D1-12	No
2-Methylnaphthalene	91-57-6	mg/kg	--	320	14,000	Empirical Below GW&SW CUL	Empirical	Empirical	--	0.5	(1)	320	Method B NC	ND	--	No	14,000	Method C NC	410	TG-D1-12	No
Naphthalene	91-20-3	mg/kg	5	1,600	70,000	Empirical Below GW&SW CUL	Empirical	Empirical	--	0.5	(1)	1,600	Method B NC	ND	--	No	70,000	Method C NC	19.1	B-18-24(13.5-14.0)	No
Total Naphthalenes (HalfDL_WA)	91-20-3	mg/kg	5	1,600	70,000	Empirical Below GW&SW CUL	Empirical	Empirical	--	0.5	(1)	1,600	Method B NC	ND	--	No	70,000	Method C NC	679	TG-D1-12	No
Benzo(a)anthracene	56-55-3	mg/kg	--	--	--	--	--	--	--	0.05	(1)	--	--	ND	--	No	--	--	4.3	TG-D0-12	No
Benzo(a)pyrene	50-32-8	mg/kg	--	--	--	--	--	--	--	0.05	(1)	--	--	ND	--	No	--	--	2.6	TG-D0-12	No
Benzo(b)Fluoranthene	205-99-2	mg/kg	--	--	--	--	--	--	--	0.05	(1)	--	--	ND	--	No	--	--	1.9	TG-D0-12	No
Benzo(k)Fluoranthene	207-08-9	mg/kg	--	--	--	--	--	--	--	0.05	(1)	--	--	ND	--	No	--	--	0.0312	B-18-18(14.0-14.5)	No
Chrysene	218-01-9	mg/kg	--	--	--	--	--	--	--	0.05	(1)	--	--	ND	--	No	--	--	10	TG-D0-12	No
Dibenz(a,h)Anthracene	53-70-3	mg/kg	--	--	--	--	--	--	--	0.05	(1)	--	--	ND	--	No	--	--	0.0179	B-18-18(14.0-14.5)	No
Indeno(1,2,3-c,d)Pyrene	193-39-5	mg/kg	--	--	--	--	--	--	--	0.05	(1)	--	--	ND	--	No	--	--	0.0559	B-18-18(14.0-14.5)	No
Total cPAH TEQ (HalfDL_WA)	50-32-8	mg/kg	2	0.19	130	Empirical - ND in berm wells	Empirical	Empirical	--	0.05	(1)	0.19	Method B C	ND	--	No	130	Method C C	3.42	TG-D0-12	No
Acenaphthene	83-32-9	mg/kg	--	4,800	210,000	Empirical Below GW&SW CUL	Empirical	Empirical	--	0.0435	(2)	4,800	Method B NC	ND	--	No	210,000	Method C NC	18	TG-D1-12	No
Acenaphthylene	208-96-8	mg/kg	--		--	Empirical No CUL	Empirical	Empirical	--	0.05	(1)	--	--	ND	--	No	--	--	3.8	TG-D1-12	No
Anthracene	120-12-7	mg/kg	--	24,000	1,100,000	Empirical Below GW&SW CUL	Empirical	Empirical	--	0.0435	(2)	24,000	Method B NC	ND	--	No	1,100,000	Method C NC	8.1	TG-D0-12	No
Benzo(g,h,i)Perylene	191-24-2	mg/kg	--	--	--	Empirical No CUL	Empirical	Empirical	--	0.05	(1)	--	--	ND	--	No	--	--	1.1	TG-D0-12	No
Fluoranthene	206-44-0	mg/kg	--	3,200	140,000	Empirical - ND in wells	Empirical	Empirical	--	0.05	(1)	3,200	Method B NC	ND	--	No	140,000	Method C NC	4	TG-D0-12	No
Fluorene	86-73-7	mg/kg	--	3,200	140,000	Empirical Below GW&SW CUL	Empirical	Empirical	--	0.02	(2)	3,200	Method B NC	ND	--	No	140,000	Method C NC	24	TG-D1-12	No
Phenanthrene	85-01-8	mg/kg	--		--	Empirical No CUL	Empirical	Empirical	--	0.05	(1)	--	--	ND		No	--	--	41	TG-D0-12,TG-D1-12	No
Pyrene	129-00-0	mg/kg	--	2,400	110,000	Empirical Below GW&SW CUL	Empirical	Empirical	--	0.05	(1)	2,400	Method B NC	ND	--	No	110,000	Method C NC	19	TG-D0-12	No
Volatile Organic Compounds																					
1,2,3-Trimethylbenzene	526-73-8	mg/kg	--	800	35,000	Empirical - ND in wells	Empirical	Empirical	--	0.005	(3)	800	Method B NC	--	--	No	35,000	Method C NC	8.52	B-18-24(13.5-14.0)	No
1,2,4-Trimethylbenzene	95-63-6	mg/kg	--	800	35,000	Empirical - ND in wells	Empirical	Empirical	--	0.005	(3)	800	Method B NC	--	--	No	35,000	Method C NC	19	B-18-24(13.5-14.0)	No
1,3,5-Trimethylbenzene	108-67-8	mg/kg	--	800	35,000	Empirical - ND in wells	Empirical	Empirical	--	0.005	(3)	800	Method B NC	--	--	No	35,000	Method C NC	0.942	B-18-24(13.5-14.0)	No
Cymene (p-Isopropyltoluene)	99-87-6	mg/kg	--	--	--	Empirical No CUL	Empirical	Empirical	--	0.005	(3)	--	--	--	--	No	--	--	2.82	B-18-24(13.5-14.0)	No
Isopropylbenzene	98-82-8	mg/kg	--	8,000	350,000	Empirical	Empirical	Empirical	--	0.0025	(3)	8,000	Method B NC	--	--	No	350,000	Method C NC	1.11	B-18-24(13.5-14.0)	No
Naphthalene	91-20-3	mg/kg	5	1,600	70,000	Empirical Below GW&SW CUL	Empirical	Empirical	--	0.5	(1)	1,600	Method B NC	--	--	No	70,000	Method C NC	19.7	B-18-24(13.5-14.0)	No
n-Butylbenzene	104-51-8	mg/kg	--	4,000	180,000	Empirical - ND in wells	Empirical	Empirical	--	0.0125	(3)	4,000	Method B NC	--	--	No	180,000	Method C NC	2.68	B-18-24(13.5-14.0)	No
n-Propylbenzene	103-65-1	mg/kg	--	8,000	350,000	Empirical - ND in wells	Empirical	Empirical	--	0.005	(3)	8,000	Method B NC	--	--	No	350,000	Method C NC	2.39	B-18-24(13.5-14.0)	No
Sec-Butylbenzene	135-98-8	mg/kg	--	8,000	350,000	Empirical - ND in wells	Empirical	Empirical	--	0.0125	(3)	8,000	Method B NC	--	--	No	350,000	Method C NC	1.82	B-18-24(13.5-14.0)	No
Metals																					
Arsenic	7440-38-2	mg/kg	20	0.67	88	Above GW&SW CUL	0.15	0.15	20	4.5	(2)	20	Background	--	--	No	20	Background	2.6	B-16-09-15	No
Barium	7440-39-3	mg/kg	--	16,000	700,000	Empirical - Data Based	Empirical	Empirical	--	0.5	(3)	16,000	Method B NC	--	--	No	700,000	Method C NC	120	B-16-24-12	No
Chromium, total (Cr III for soil)	7440-47-3	mg/kg	2,000	120,000	5,300,000	Empirical Below GW&SW CUL	Empirical	Empirical	42	0.5	(1)	120,000	Method B NC	--	--	No	5,300,000	Method C NC	18.2	B-16-19-12FT	No
Lead	7439-92-1	mg/kg	1,000	--	--	Above SW CUL	150	25	17	0.5	(3)	150	Protective Soil-GW	--	--	No	25	Protective GW-SW	19.6	B-18-18(14.0-14.5)	No

Table presents proposed cleanup levels (CULs) and CUL sources for constituents detected in one or soil samples collected between 2002 and 2018. Results include samples collected from unsaturated vadose soil.

Diesel-Range Organics — Detected constituents above the proposed CUL are shaded blue. These constituents are identified as Constituents of Concern (COCs) for saturated soil between 10 and 15 feet below ground surface.

Abbreviations and Symbols

" - -" denotes not measured, not available, or not applicable.

mg/kg = milligrams per kilogram

Where "Empirical" is listed in the row, it has been assumed that an empirical demonstration indicates that the contaminant is not reaching groundwater/surface water at values above what is considered protective; based on groundwater samples collected between November 2016 and August 2020.

Empirical Below CUL = constituent not reported above the proposed groundwater (GW) and/or surface water (SW) CUL in groundwater samples. Above CUL = constituent reported above the proposed groundwater CUL in one or more groundwater samples collected between November 2016 and August 2020. ND = constituent not detected in groundwater. No CUL = no CUL for constituent.

There are no known or potential sources of hexavalent chromium at the site; therefore, it is assumed that all of the chromium is trivalent and the Method A number for total chromium is 100 µg/L in accordance with WAC 246-290-310.

Total cPAHs = Possible total cPAHs are based on the relative toxicity of each cPAH to benzo(a)pyrene and were calculated by multiplying the individual cPAH concentrations by a toxicity equivalency factor (TEF) and summing the adjusted concentrations. Non-detects were included as noted.

Total Naphthalenes = Total Naphthalenes concentrations were calculated by summing 1-Methylnaphthalene, 2-Methylnaphthalene, and Naphthalene concentrations. Non-detects were included as noted.

Total Xylenes = Total Xylenes concentrations were calculated by summing Xylene, m,p- and Xylene, o- concentrations. Non-detects were included as noted.

(HalfDL_WA) = If an individual chemical was not detected, a value of one half the method reporting limit was used as the concentration in the calculation, except when all chemicals used in the calculation were not detected then one half the lowest method reporting limit was used as the total concentration.

Cleanup Levels

Cleanup level values based on Washington State Department of Ecology (Ecology) Model Toxics Control Act (MTCA) Method C values (Method C C = Cancer or Method C NC = Non Cancer) and MTCA Method A values for soil (Table 745-1) based on Washington State Administrative Code (WAC) 173-340-745 and 3-Phase Model Soil Protective of Groundwater Saturated (Eq. 747-1) and 3-Phase Model Soil Protective of Groundwater to Surface Water Saturated Fresh Water (Eq. 747-1) from Cleanup Levels and Risk Calculation (CLARC) tables (Accessed July 2021).

Preliminary Practical Quantitation Limit (PQL) based on values provided in one of the following: (1) Ecology's Guidance for Remediation of Petroleum Contaminated Sites. Toxics Cleanup Program. Publication No. 10-09-057. Revised June 2016. (2) Ecology Memorandum "Wishram Cleanup Site: Preliminary Cleanup Levels and Contaminants of Potential Concern for Groundwater, Surface Water and Upland Soils" dated 28 May 2021; or (3) Method reporting limits (MRLs) provided by Pace Analytical for Pace Analytical National in Mount Juliet, TN (provided 4/27/2022) and Pace Analytical in Minneapolis, MN (provided 5/9/2022).

SUMMARY OF CONSTITUENTS OF CONCERN (COCs) AND PROPOSED CLEANUP LEVELS (CULs)
BNSF Wishram Railyard, Wishram, Washington

Media / COCs	Units	Proposed CUL	Proposed CUL Source
Groundwater			
Diesel-Range Organics	µg/L	500	Method A
Oil-Range Organics	µg/L	500	Method A
Total TPH-Dx	µg/L	500	Method A
1-Methylnaphthalene	µg/L	1.5	Method B Cancer
Arsenic, total	µg/L	5	Background
Barium, total	µg/L	2,000	Maximum Contaminant Level (WA State and Federal)
Iron, dissolved	µg/L	11,000	Method B Noncancer
Manganese, dissolved	µg/L	750	Method B Noncancer
Surface Water			
Diesel-Range Organics	µg/L	500 / 3,000	Method A / Environmental effects-based concentration
Oil-Range Organics	µg/L	500 / 3,000	Method A / Environmental effects-based concentration
Total TPH-Dx	µg/L	500 / 3,000	Method A / Environmental effects-based concentration
1-Methylnaphthalene	µg/L	2.1	Risk Assessment Information System (RAIS)
Arsenic, total	µg/L	5	Background
Lead, total	µg/L	2.5	Aquatic Life Water Quality Criteria (173-201A / CWA §304)
Iron, dissolved	µg/L	1,000	Aquatic Life Water Quality Criteria (CWA §304)
Manganese, dissolved	µg/L	50	Human Health Water Quality Criteria (CWA §304)
Soil - Vadose Zone (On- and Off-Railyard Property)			
Diesel-Range Organics	mg/kg	2,000	Method A
Oil-Range Organics	mg/kg	2,000	Method A
Total TPH-Dx	mg/kg	2,000	Method A
Soil - Saturated Zone (On- and Off-Railyard Property)			
Gasoline-Range Organics	mg/kg	30	Method A
Diesel-Range Organics	mg/kg	2,000	Method A
Oil-Range Organics	mg/kg	2,000	Method A
Total TPH-Dx	mg/kg	2,000	Method A

Notes:

COC = Constituents of concern

CUL = Cleanup level. Refer to Appendix B to the Draft Feasibility Study Report for more information.

"µg/L" = micrograms per liter

"mg/kg" = milligrams per liter

Total TPH-Dx = Total TPH-Dx concentrations calculated by summing diesel-range organics (DRO) and oil-range organics (ORO) concentrations.

Cleanup Levels:

Groundwater: Cleanup level values based on Model Toxics Control Act (MTCA) Method B values (B Cancer or B Non Cancer) and MTCA Method A values for groundwater (Table 720-1) based on Washington State Administrative Code (WAC) 173-340-720 from Cleanup Levels and Risk Calculation (CLARC) tables (Accessed July 2021), and Washington State (246-290 WAC) and Federal (40 CFR 141) Maximum Contaminant Levels (MCLs).

Surface Water: Cleanup level values based on Ecology MTCA Method B values (B Cancer or B Non Cancer), MTCA Method A values and other applicable, relevant, and appropriate requirements (ARARs) under applicable state (173-201A-240 WAC) and federal laws [Section 304 of the Clean Water Act (CWA); 40 CFR Subpart D 131.45] for surface water based on WAC 173-340-730 from CLARC tables (Accessed July 2021).

Risk Assessment Information System (RAIS) (https://rais.ornl.gov/tools/eco_search.php),

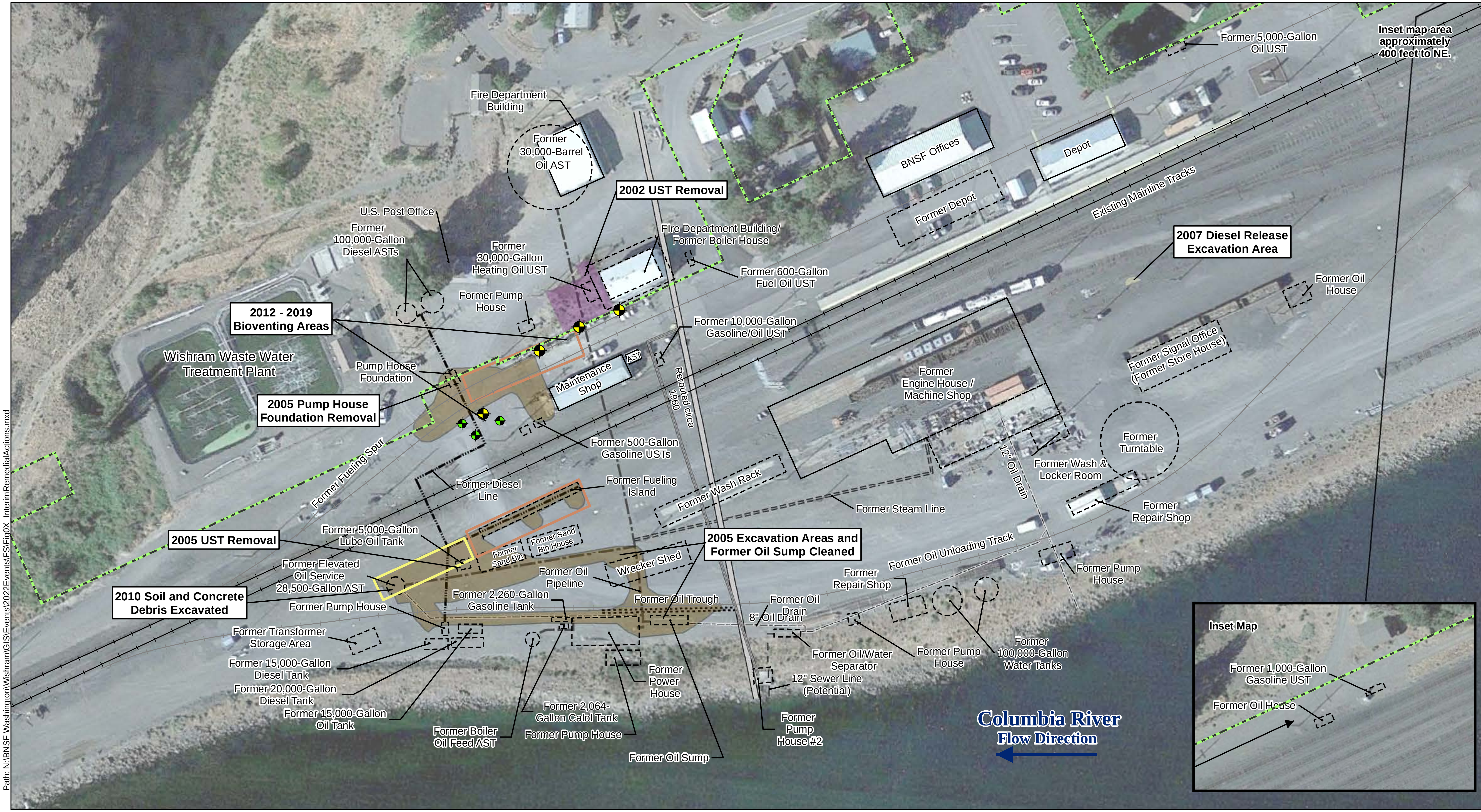
Environmental Effects-Based Concentrations (EEBC), from Concentrations of Gasoline and Diesel Range Organics Predicted to be Protective of Aquatic Receptors in Surface Waters, Implementation Memorandum No. 23 (Ecology, August 25, 2021).

Proposed Restricted / Industrial CULs for soil On BNSF Railyard Property

Soil: Cleanup level values based on Ecology MTCA Method C values (Cancer and Noncancer) and MTCA Method A (Table 745-1) values for soil based on WAC 173-340-745 and 3-Phase Model Soil Protective of Groundwater Vadose (Eq. 747-1) and 3-Phase Model Soil Protective of Groundwater to Surface Water Vadose Fresh Water (Eq. 747-1). from CLARC tables (Accessed July 2021).

Proposed Unrestricted CULs for soil in non-industrial use (zoned or otherwise) areas Off BNSF Railyard Property.

Soil: Cleanup level values based on Ecology MTCA Method B values (Cancer and Noncancer) and MTCA Method A (Table 740-1) values for soil based on WAC 173-340-740 and 3-Phase Model Soil Protective of Groundwater Vadose (Eq. 747-1) and 3-Phase Model Soil Protective of Groundwater to Surface Water Vadose Fresh Water (Eq. 747-1). from CLARC tables (Accessed July 2021).



Coordinate System: NAD 1983 StatePlane Washington South FIPS 4602 Feet

Legend

- Bioventing Injection Well
- Air Sparge (AS) Well
- Approximate BNSF Property Line
- Former Bunker Fuel / Oil Pipeline
- Former Oil Drain
- Former Oil Trough
- Former Sewer Line (Potential)
- Stormwater Underdrain (A portion removed from service circa 1960)
- Stormwater Underdrain (Rerouted portion circa 1960)
- Former Diesel Line
- Former Steam Line
- Suspected Diesel Fueling Area
- Suspected Oil Fueling Area
- Approximate Previous Excavation Area
- Approximate Previous Excavation Area
- Approximate Previous Excavation Area
- Existing Site Feature
- Former Site Feature

Note:
1. Locations are approximate.

N

0 50 100

Scale: Feet

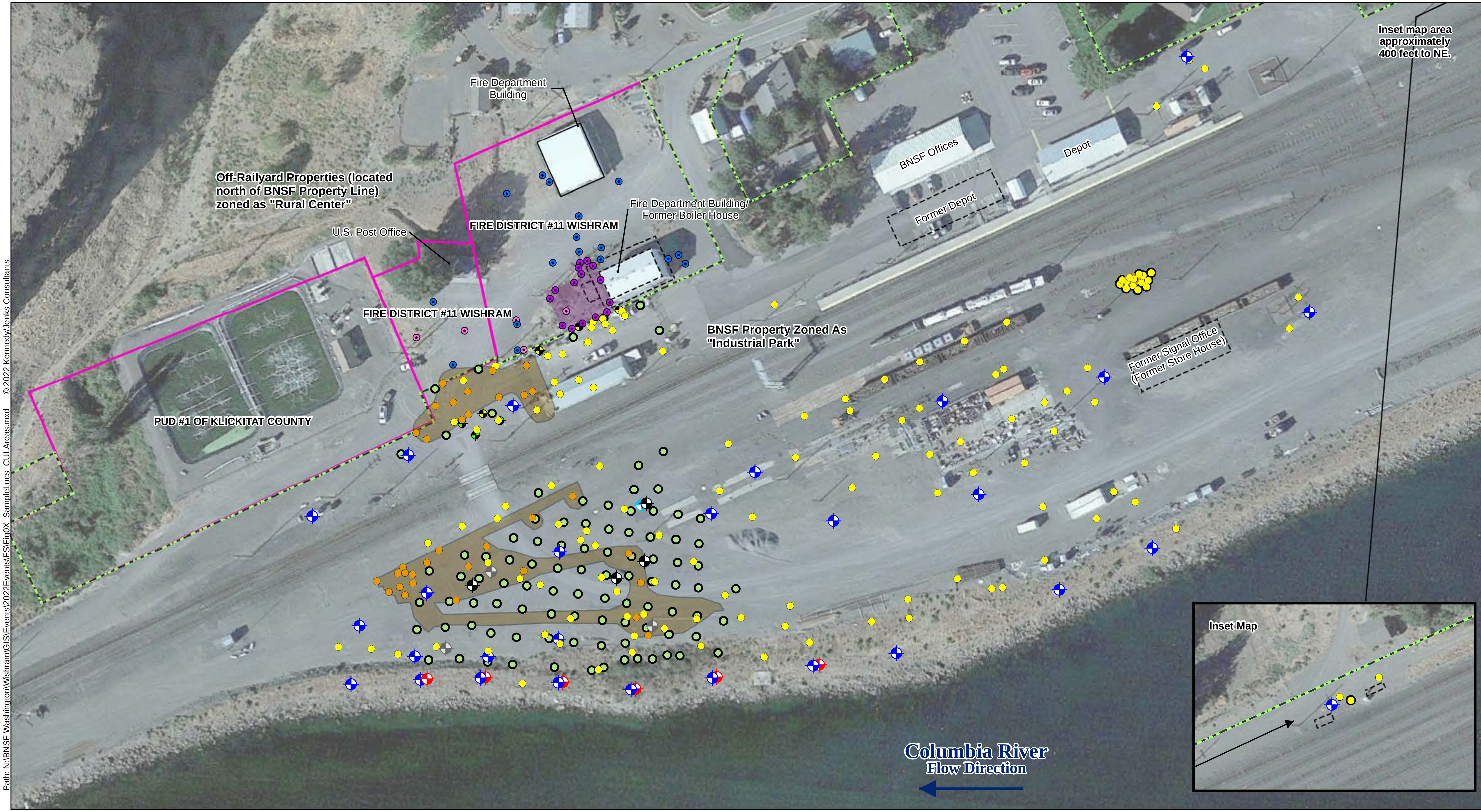
Kennedy/Jenks Consultants

BNSF Wishram Railyard
Wishram, Washington

Current and Historical Site Features and Previous Interim Remedial Actions

2196120*06
May 2022

Figure B-1



Path: N:\BNSF Washington\Wishram\GIS\Events\2022Events\FS\Fig0X_SampleLocs_CULAreas.mxd © 2022 Kennedy/Jenks Consultants

Coordinate System: NAD 1983 StatePlane Washington South FIPS 4602 Feet

Legend

- Approximate BNSF Property Line
- LIF Location - Within BNSF Property Boundary
- LIF Location - North of BNSF Property Boundary

Location North of BNSF Property Boundary

- Excavation Soil Sample
- Soil Boring Location
- Off-Railyard Parcel Boundaries
- Approximate 2002 Excavation
- Approximate 2005/2010 Excavation

Location Within BNSF Property Boundary

- Abandoned Monitoring Well
- Air Sparge
- Soil Vapor Extraction
- Excavation Soil Sample
- OHM-3R
- OHM Well
- Shallow Monitoring Well
- Deep Monitoring Well
- Soil Boring Location

Notes:
1. Selected parcel boundaries and property owners (shown) based on review of Klickitat County zoning maps through Interactive Mapping Program, accessed 27 April 2022.

N

0 50 100
Scale: Feet

Kennedy/Jenks Consultants

BNSF Wishram Railyard
Wishram, Washington

Zoning Designations and Sample Locations (2002-2018) - Main Area

2296120*00
May 2022

Figure B-2

Appendix C

LNAPL Recoverability Estimate

Appendix C: LNAPL Recoverability Estimate

Introduction

This Appendix to the Uplands Feasibility Study Report (FS Report) presents an estimate of the recoverability of submerged light non-aqueous phase liquids (LNAPL) from beneath the BNSF Wishram Railyard (Ecology Site Name: BNSF Track Switching Facility) (site) in Wishram, Washington.

LNAPL with properties consistent with both diesel and Bunker-C oil is present south of the mainline tracks near the former underground oil pipelines and the former Power House (see Figures 7, 8, and 20 in the FS Report). As shown on Figure 20 in the FS Report, eastern and western LNAPL areas have been defined based on the variations of depth and apparent LNAPL thickness, as well as depths to bedrock. The LNAPL recoverability estimate focuses on the eastern LNAPL area, which is characterized by primarily Bunker-C oil LNAPL submerged at depths from approximately 10 feet below ground surface (bgs) to 85 feet bgs. Submerged LNAPL observed south of the mainline is classified as potentially recoverable, as evidenced by apparent LNAPL thicknesses measurements of 12 feet or more in three of the four oil head monitoring (OHM) wells (OHM-1, OHM-2, and OHM-3) and by laboratory measurements of LNAPL physical properties.

LNAPL Recoverability Estimate Procedures

American Petroleum Institute's LNAPL Distribution and Recovery Model (LDRM) (API 2007) was used to estimate the percentages of recoverable LNAPL and total LNAPL that could potentially be removed from the subsurface in the eastern LNAPL area, and the amount of residual LNAPL that would remain. The LDRM was populated using laboratory-analyzed physical properties for LNAPL and water samples collected from wells OHM-1, OHM-2, and OHM-3 and soil properties for soil cores collected from the three OHM well borings. The LNAPL and soil property data used in the LDRM runs are summarized in Table C-1 [previously reported in Tables 24 and 25 of the *Uplands Remedial Investigation Report BNSF Wishram Railyard* (Kennedy Jenks 2020)].

The LDRM was used to estimate the removal of LNAPL from wells OHM-1, OHM-2, and OHM-3 under various conditions. The results were then applied to a representative number of wells with similar LNAPL conditions that would be needed to capture LNAPL from the entire submerged LNAPL body. The LDRM was run for three separate subsurface temperature scenarios and corresponding laboratory analyzed LNAPL density and viscosity measurements (Table C-1):

(1) LNAPL removal under a temperature of 70 degrees Fahrenheit (°F) [21 degrees Celsius (°C)] and LNAPL viscosity ranging from 696 to 1989 centipoise (cp) for the three wells.

(2) LNAPL removal at a heated subsurface temperature of 100 °F (38 °C) and reduced LNAPL viscosity ranging from 188 to 421 cp for the three wells.

(3) LNAPL removal at a heated subsurface temperature of 130 °F (55 °C) and lowest measured LNAPL viscosities ranging from 70 to 133 cp for the three wells.

The scenarios were modeled for 1, 10, and/or 1,000 years of LNAPL skimmer recovery well operation as shown in Table C-2. Inputs for the skimmer recovery model included a well radius of 0.25 foot and a radius of capture of 20 feet. The only LDRM input parameters changed between the three scenarios were the LNAPL viscosity and LNAPL density, which decrease with increasing temperature. The estimated total recoverable LNAPL for each temperature scenario by well was based on a skimming operating time of 1,000 years (with one exception) to achieve a minimum of 99 percent recovery of the recoverable LNAPL. For well OHM-2 under scenario (1) at 70 °F, the model was run for the maximum model allowable time (9,999 years) to achieve greater than 99 percent recovery.

The lowest temperature (70 °F) scenario (1) was run for a duration of 10 years. Scenario (1) is representative of FS Alternatives 1 and 4, which include 10 years of LNAPL skimmer operation with no subsurface heating. [Note that 70 °F is slightly higher than ambient groundwater temperatures (between 56 and 66 °F) measured between March 2019 and August 2021 in five monitoring wells]. The LDRM estimate for 1 year of skimmer operation is shown in Table C-2 for comparison to scenarios (2) and (3).

The highest temperature (lowest viscosity) scenario (3) was run for a duration of 1 year. Scenario (3) provides an estimate for FS Alternative 5, which includes 1 year of LNAPL removal operation with subsurface heating at temperatures between 122 and 158 °F. The 100 °F temperature scenario (2) was also modeled for 1 year of LNAPL removal to evaluate the differences between low and moderate temperature heating scenarios.

LDRM Results

Based on the selected LNAPL and soil physical properties, estimates of the percent of recoverable LNAPL removed and the percent of total LNAPL removed were derived from the LDRM. The LDRM results also provided an estimate of the recoverable LNAPL as a percent of the total LNAPL mass modeled. LDRM results are summarized in Table C-2.

For the simulated conditions of each well, reductions in the LNAPL viscosity resulted in increases in LNAPL recoverability; LNAPL density values had less impacts on LNAPL removal estimates. As shown in Table C-2, the estimates of LNAPL removed compared to total recoverable LNAPL and total LNAPL mass modeled varied significantly between the three OHM wells. The estimated LNAPL removed as a percent of total LNAPL mass modeled was highest for well OHM-2 (42 to 55 percent); achievable after 1,000 years of operation or more. However, for the tested scenarios and durations applicable to FS Alternatives (e.g., 1 or 10 years), the percent of recoverable LNAPL removed and the percent of total LNAPL removed were consistently higher for well OHM-1 than wells OHM-2 and OHM-3.

Alternatives 1, 4, and 5 in the FS include operation of 18 LNAPL removal wells to address the submerged LNAPL impacts. The estimated percent of the recoverable LNAPL removed from the eastern LNAPL area of the site was based on skimmer operation of six of each OHM well (with applicable LNAPL and soil conditions), for a total of 18 LNAPL removal wells.

As shown in Table C-2, the estimated percentages of recoverable LNAPL removed were similar for the low temperature scenario (1) after 10 years (20 percent) and high temperature scenario (3) after 1 year (21 percent). The percent recovery for scenario (2) was roughly half (or less) of that of scenarios (1) and (3) (10 percent). The percent of total LNAPL removed was similar for scenarios (1) and (3), with results of 4.5 and 6.7 percent, respectively.

Discussion

The LDRM is limited in its ability to evaluate oil removal, based on the conceptual site model. The LNAPL at the site is submerged (trapped) below the water table, not floating on top of it. One of the assumptions made in the LDRM is that the water, oil, and air phases are in vertical equilibrium – i.e., the intermediate fluid (oil) sits on top of the denser fluid (water) and below the less dense air. The LDRM uses the observed LNAPL thickness in the well to define the capillary pressure as a function of elevation above the LNAPL/water interface. The capillary properties control the associated saturations of water, LNAPL, and air (API 2007). In cases where vertical equilibrium does not exist, the model can only generally represent the distribution of the various phases, as the LDRM formulation is not able to accurately account for residual LNAPL trapped beneath the water table.

The higher viscosity and molecular weight of the LNAPL, compared to groundwater, result in the LNAPL being trapped in the pore spaces below the water table. An example in the API LDRM guidance (API 2007) illustrated the inverse relationship between LNAPL viscosity on LNAPL recovery: increasing viscosity 10-fold from 0.5 cp to 5 cp resulted in initial LNAPL recovery rates decreasing by 90 percent.

Based on their review of documented LNAPL remediation examples, the authors of the API LDRM guidance (API 2007) indicated that for most environmental remediation cases, hydraulic recovery of more than 30 percent of the LNAPL in-place would be the exception rather than the rule. For finer grained materials, the authors state that recovery of more than 15 percent of the LNAPL volume in-place would be unusual. Factoring in the higher viscosity (up to 1,989 cp at 70°F) of the site Bunker-C oil LNAPL, which is approximately 400- to 4,000-times higher than the LDRM guidance example data range (0.5 to 5 cp, representative of liquids including gasoline, water, and jet fuel) and the fine sands lithology in OHM-2 and OHM-3 soil cores, the low LNAPL recovery percentages estimated by the LDRM for the site appear reasonable.

References

American Petroleum Institute (API). 2007. LNAPL Distribution and Recovery Model (LDRM) Volume 2: User and Parameter Selection Guide. API Publication 4760. January 2007.

Kennedy/Jenks Consultants. 2020. Uplands Remedial Investigation Report BNSF Wishram Railyard (Ecology Site Name BNSF Track Switching Facility) Wishram, Washington. Prepared by Kennedy/Jenks Consultants for BNSF Railway Company. 20 October 2020.

Attachments

Table C-1 Summary of LNAPL Distribution and Recovery Model (LDRM) Inputs
Table C-2 Summary of Recoverable LNAPL Estimates

SUMMARY OF LNAPL DISTRIBUTION AND RECOVERY MODEL (LDRM) INPUTS
BNSF Wishram Railyard

Modeled Well	OHM-1			OHM-2			OHM-3			Data Source
Input Parameters										
Temperature degrees F	70	100	130	70	100	130	70	100	130	
LNAPL Density, ρ_o (g/cm^3)	0.949	0.940	0.929	0.962	0.954	0.941	0.960	0.951	0.941	Lab, varies by temperature
LNAPL Viscosity (cp)	696	188	70	1580	396	122	1989	421	133	Lab, varies by temperature
Maximum LNAPL Thickness (ft)	21.54			11.98			12.17			Measured between 12/2016 and 11/2018
Maximum LNAPL Thickness Date	8/21/2018			8/21/2018			8/21/2018			
Ground Surface Elevation (ft)	172.68			172.73			172.82			
Water Table Elevation (ft)	162.35			162.19			162.04			
Air/Water Surface Tension, σ_{aw} (dyne/cm)	58.2			58.7			59.2			Lab
Air/LNAPL Surface Tension, σ_{ao} (dyne/cm)	31.4			31.8			32			Lab
LNAPL/Water Surface Tension, σ_{ow} (dyne/cm)	12.9			16.7			14.5			Lab
Total soil core depth interval	52.5' - 55'			38' - 40'			28.5' - 31'			
Lithology of soil core	Gravel with silt and sand			Fine Sand			Fine Sand			
Porosity, n (ratio pore volume)	0.204			0.488			0.502			Lab
Hydraulic Conductivity (ft/day)	10			10			10			
van Genuchten "N," N (dimensionless)	1.5			1.9			1.7			Lab
van Genuchten "α," α (ft^{-1})	0.22			0.64			0.09			Lab
Irreducible Water Saturation, S_{wr} (ratio pore volume)	0.138			0.056			0.248			Lab
Residual LNAPL Saturation, Saturated Zone, S_{ors} (ratio pore volume)	0.191			0.138			0.282			Lab

Notes:

Lab = Analyses for fluid properties performed by PTS Laboratories, Inc. of Santa Fe Springs, California in 2017 (OHM-2 data), and PTS Laboratories, Inc. of Houston, Texas, in 2019 (OHM-1 and OHM-3 data).

LNAPL = light non-aqueous phase liquid

Maximum LNAPL thickness between December 2016 and November 2018 was measured on 21 August 2018 for all three wells.

ft^{-1} = 1/feet

g/cm^3 = grams per cubic centimeter

dyne/cm = dyne per centimeter

ft^3/ft^2 = cubic feet per square foot

ft = feet

LIF = Laser Induced Fluorescence

cp = centipoise

SUMMARY OF RECOVERABLE LNAPL ESTIMATES
BNSF Wishram Railyard

				Model Time Elapsed (years)	1 YR	10 YR	1,000 YR			
	Dynamic Viscosity (cP)	Density (g/cc)	Lithology	Total Porosity (% Vb)	Percent of Recoverable LNAPL Removed	Percent of Recoverable LNAPL Removed	Percent of Recoverable LNAPL Removed	Percent of Recoverable LNAPL Removed after 10 yrs (no heat) or 1 yr (with heat)	Percent of Total LNAPL Removed after 10 yrs (no heat) or 1 yr (with heat)	Recoverable LNAPL Percent of Total LNAPL
OHM-1 70 °F (21 °C)	696	0.949	Gravel with silt and sand	20%	*7.6%*	50%	100%	50%	14%	28%
OHM-1 Heat 100 °F (38 °C)	188	0.940			26%		100%	26%	8%	31%
OHM-1 Heat 130 °F (54 °C)	70	0.929			55%		100%	55%	19%	34%
OHM-2 70 °F (21 °C)	1,580	0.962	Fine Sand	49%	*0.3%*	3%	100%	2.9%	1.2%	42%
OHM-2 Heat 100 °F (38 °C)	396	0.954			1.4%		99%	1.4%	0.7%	49%
OHM-2 Heat 130 °F (54 °C)	122	0.941			5.6%		100%	5.6%	3.1%	55%
OHM-3 70 °F (21 °C)	1,989	0.960	Fine Sand	50%	*0.8%*	9%	99%*	8.8%	0.1%	1.6%
OHM-3 Heat 100 °F (38 °C)	421	0.951			4.6%		100%	4.6%	0.1%	2.0%
OHM-3 Heat 130 °F (54 °C)	133	0.941			15%		100%	15%	0.4%	2.9%
Eastern LNAPL Area Estimates										
18 wells 70 °F (21 °C)	Assumes 6 of each OHM well				*2.9%*	20%		20%	4.5%	12%
18 wells Heat 100 °F (38 °C)	Assumes 6 of each OHM well				10%			10%	2.6%	14%
18 wells Heat 130 °F (54 °C)	Assumes 6 of each OHM well				21%			21%	6.7%	18%

Notes:

Dynamic viscosities: 2016 data for OHM-2, 2019 data for OHM-1 and OHM-3. Light non-aqueous phase liquid (LNAPL) not collected in 2019 from OHM-2 for analysis.

Run LDRM recovery for Skimmer recovery system, variable recovery times (1, 10, 1000 years), Radius of well = 0.25 foot,
Radius of Capture = 20 feet (based on wells on 40-foot spacing)

1 year is estimated time for low-temperature thermal removal (LTTR) operation (50-70 °C) [estimated time LTTR system would run]; FS Alternative 5.

10 years is estimated time for physical LNAPL removal without heating (70 °F); FS Alternatives 1 and 4.

1,000 years is used as the end point for achieving extent practicable LNAPL Removal of the Recoverable LNAPL (targeting minimum of 99% recovery).

* = For OHM-2 at 70 °F, the model was run for 9,999 years to achieve 99% removal of the recoverable LNAPL.

YR - Year

% - Percentage

18 wells options assume 6 wells of each of OHM-1, OHM-2, and OHM-3 to calculate totals.

OHM-1, 70°F, 10 years

VARIABLE	INITIAL CONDITIONS FOR RUN	FINAL FOR RUN
LNAPL Thickness [ft]	21.54	15.31
Total LNAPL [ft]	1.33	1.14
Mobile LNAPL [ft]	1.33	0.87
Recoverable LNAPL [ft]	0.37	0.18
Residual LNAPL [ft]	0.00	0.69
LNAPL Transmissivity [ft2/d]	0.06	0.03
LNAPL Discharge [gpd]	0.75	0.29

Percent Recovery (Total) =	13.8
Percent Recovery (Recoverable) =	50.3
Average Drawdown (within ROC) (ft) =	0.000
Air (vacuum) discharge (scfm) =	0.000
Final LNAPL Recovered Volume (gal) =	1732.
Simulation Time (years) =	10.0

OHM-1, 70°F, 1000 years

VARIABLE	INITIAL CONDITIONS FOR RUN	FINAL FOR RUN
LNAPL Thickness [ft]	21.54	0.17
Total LNAPL [ft]	1.33	0.97
Mobile LNAPL [ft]	1.33	0.01
Recoverable LNAPL [ft]	0.37	0.00
Residual LNAPL [ft]	0.00	0.01
LNAPL Transmissivity [ft2/d]	0.06	0.00
LNAPL Discharge [gpd]	0.75	0.00

Percent Recovery (Total) =	27.5
Percent Recovery (Recoverable) =	99.9
Average Drawdown (within ROC) (ft) =	0.000
Air (vacuum) discharge (scfm) =	0.000
Final LNAPL Recovered Volume (gal) =	3436.
Simulation Time (years) =	1000.0

OHM-2, 70°F, 9999 years

VARIABLE	INITIAL CONDITIONS FOR RUN	FINAL FOR RUN
LNAPL Thickness [ft]	11.98	0.54
Total LNAPL [ft]	1.50	0.87
Mobile LNAPL [ft]	1.50	0.04
Recoverable LNAPL [ft]	0.63	0.00
Residual LNAPL [ft]	0.00	0.04
LNAPL Transmissivity [ft2/d]	0.01	0.00
LNAPL Discharge [gpd]	0.05	0.00
Percent Recovery (Total) =		41.8
Percent Recovery (Recoverable) =		99.5
Average Drawdown (within ROC) (ft) =		0.000
Air (vacuum) discharge (scfm) =		0.000
Final LNAPL Recovered Volume (gal) =		5916.
Simulation Time (years) =		9999.0

OHM-1, 70°F, 1 year

VARIABLE	INITIAL CONDITIONS FOR RUN	FINAL FOR RUN
LNAPL Thickness [ft]	21.54	20.64
Total LNAPL [ft]	1.33	1.30
Mobile LNAPL [ft]	1.33	1.26
Recoverable LNAPL [ft]	0.37	0.34
Residual LNAPL [ft]	0.00	0.93
LNAPL Transmissivity [ft2/d]	0.06	0.06
LNAPL Discharge [gpd]	0.75	0.67
Percent Recovery (Total) =		2.1
Percent Recovery (Recoverable) =		7.6
Average Drawdown (within ROC) (ft) =		0.000
Air (vacuum) discharge (scfm) =		0.000
Final LNAPL Recovered Volume (gal) =		260.
Simulation Time (years) =		1.0

OHM-2, 70°F, 10 years

VARIABLE	INITIAL CONDITIONS FOR RUN	FINAL FOR RUN
LNAPL Thickness [ft]	11.98	11.81
Total LNAPL [ft]	1.50	1.48
Mobile LNAPL [ft]	1.50	1.47
Recoverable LNAPL [ft]	0.63	0.61
Residual LNAPL [ft]	0.00	0.86
LNAPL Transmissivity [ft2/d]	0.01	0.01
LNAPL Discharge [gpd]	0.05	0.05
Percent Recovery (Total) =		1.2
Percent Recovery (Recoverable) =		2.9
Average Drawdown (within ROC) [ft] =		0.000
Air (vacuum) discharge (scfm) =		0.000
Final LNAPL Recovered Volume (gal) =		171.
Simulation Time (years) =		10.0

OHM-2, 70°F, 1000 years

VARIABLE	INITIAL CONDITIONS FOR RUN	FINAL FOR RUN
LNAPL Thickness [ft]	11.98	5.63
Total LNAPL [ft]	1.50	0.97
Mobile LNAPL [ft]	1.50	0.50
Recoverable LNAPL [ft]	0.63	0.09
Residual LNAPL [ft]	0.00	0.41
LNAPL Transmissivity [ft2/d]	0.01	0.00
LNAPL Discharge [gpd]	0.05	0.00
Percent Recovery (Total) =		35.5
Percent Recovery (Recoverable) =		84.4
Average Drawdown (within ROC) [ft] =		0.000
Air (vacuum) discharge (scfm) =		0.000
Final LNAPL Recovered Volume (gal) =		5016.
Simulation Time (years) =		1000.0

OHM-3, 70°F, 1000 years

VARIABLE	INITIAL CONDITIONS FOR RUN	FINAL FOR RUN
LNAPL Thickness [ft]	12.17	1.61
Total LNAPL [ft]	1.92	1.90
Mobile LNAPL [ft]	1.92	0.25
Recoverable LNAPL [ft]	0.03	0.00
Residual LNAPL [ft]	0.00	0.25
LNAPL Transmissivity [ft2/d]	0.00	0.00
LNAPL Discharge [gpd]	0.01	0.00

Percent Recovery (Total) =	1.4
Percent Recovery (Recoverable) =	98.7
Average Drawdown (within ROC) (ft) =	0.000
Air (vacuum) discharge (scfm) =	0.000
Final LNAPL Recovered Volume (gal) =	250.
Simulation Time (years) =	1000.0

OHM-2, 70°F, 1 year

VARIABLE	INITIAL CONDITIONS FOR RUN	FINAL FOR RUN
LNAPL Thickness [ft]	11.98	11.96
Total LNAPL [ft]	1.50	1.50
Mobile LNAPL [ft]	1.50	1.50
Recoverable LNAPL [ft]	0.63	0.63
Residual LNAPL [ft]	0.00	0.87
LNAPL Transmissivity [ft2/d]	0.01	0.01
LNAPL Discharge [gpd]	0.05	0.05

Percent Recovery (Total) =	0.1
Percent Recovery (Recoverable) =	0.3
Average Drawdown (within ROC) (ft) =	0.000
Air (vacuum) discharge (scfm) =	0.000
Final LNAPL Recovered Volume (gal) =	17.
Simulation Time (years) =	1.0

OHM-3, 70°F, 1 year

VARIABLE	INITIAL CONDITIONS FOR RUN	FINAL FOR RUN
LNAPL Thickness [ft]	12.17	12.12
Total LNAPL [ft]	1.92	1.92
Mobile LNAPL [ft]	1.92	1.92
Recoverable LNAPL [ft]	0.03	0.03
Residual LNAPL [ft]	0.00	1.89
LNAPL Transmissivity [ft2/d]	0.00	0.00
LNAPL Discharge [gpd]	0.01	0.01

Percent Recovery (Total) =	0.0
Percent Recovery (Recoverable) =	0.9
Average Drawdown (within ROC) (ft) =	0.000
Air (vacuum) discharge (scfm) =	0.000
Final LNAPL Recovered Volume (gal) =	2.
Simulation Time (years) =	1.0

OHM-3, 70°F, 10 years

VARIABLE	INITIAL CONDITIONS FOR RUN	FINAL FOR RUN
LNAPL Thickness [ft]	12.17	11.68
Total LNAPL [ft]	1.92	1.92
Mobile LNAPL [ft]	1.92	1.85
Recoverable LNAPL [ft]	0.03	0.02
Residual LNAPL [ft]	0.00	1.82
LNAPL Transmissivity [ft2/d]	0.00	0.00
LNAPL Discharge [gpd]	0.01	0.01

Percent Recovery (Total) =	0.1
Percent Recovery (Recoverable) =	8.6
Average Drawdown (within ROC) (ft) =	0.000
Air (vacuum) discharge (scfm) =	0.000
Final LNAPL Recovered Volume (gal) =	22.
Simulation Time (years) =	10.0

OHM-1, 100°F, 1 year

VARIABLE	INITIAL CONDITIONS FOR RUN	FINAL FOR RUN
LNAPL Thickness [ft]	21.54	18.34
Total LNAPL [ft]	1.44	1.32
Mobile LNAPL [ft]	1.44	1.17
Recoverable LNAPL [ft]	0.44	0.32
Residual LNAPL [ft]	0.00	0.85
LNAPL Transmissivity [ft2/d]	0.27	0.20
LNAPL Discharge [gpd]	3.71	2.40

Percent Recovery (Total) =	8.1
Percent Recovery (Recoverable) =	26.2
Average Drawdown (within ROC) (ft) =	0.000
Air (vacuum) discharge (scfm) =	0.000
Final LNAPL Recovered Volume (gal) =	1094.
Simulation Time (years) =	1.0

OHM-1, 100°F, 1000 years

VARIABLE	INITIAL CONDITIONS FOR RUN	FINAL FOR RUN
LNAPL Thickness [ft]	21.54	0.04
Total LNAPL [ft]	1.44	0.99
Mobile LNAPL [ft]	1.44	0.00
Recoverable LNAPL [ft]	0.44	0.00
Residual LNAPL [ft]	0.00	0.00
LNAPL Transmissivity [ft2/d]	0.27	0.00
LNAPL Discharge [gpd]	3.71	0.00

Percent Recovery (Total) =	30.9
Percent Recovery (Recoverable) =	100.0
Average Drawdown (within ROC) (ft) =	0.000
Air (vacuum) discharge (scfm) =	0.000
Final LNAPL Recovered Volume (gal) =	4170.
Simulation Time (years) =	1000.0

OHM-2, 100°F, 1 year

VARIABLE	INITIAL CONDITIONS FOR RUN	FINAL FOR RUN
LNAPL Thickness [ft]	11.98	11.89
Total LNAPL [ft]	1.71	1.70
Mobile LNAPL [ft]	1.71	1.69
Recoverable LNAPL [ft]	0.83	0.81
Residual LNAPL [ft]	0.00	0.88
LNAPL Transmissivity [ft2/d]	0.05	0.05
LNAPL Discharge [gpd]	0.30	0.30
Percent Recovery (Total) =		0.7
Percent Recovery (Recoverable) =		1.4
Average Drawdown (within ROC) (ft) =		0.000
Air (vacuum) discharge (scfm) =		0.000
Final LNAPL Recovered Volume (gal) =		109.
Simulation Time (years) =		1.0

OHM-2, 100°F, 1000 years

VARIABLE	INITIAL CONDITIONS FOR RUN	FINAL FOR RUN
LNAPL Thickness [ft]	11.98	1.40
Total LNAPL [ft]	1.71	0.89
Mobile LNAPL [ft]	1.71	0.11
Recoverable LNAPL [ft]	0.83	0.00
Residual LNAPL [ft]	0.00	0.10
LNAPL Transmissivity [ft2/d]	0.05	0.00
LNAPL Discharge [gpd]	0.30	0.00
Percent Recovery (Total) =		47.5
Percent Recovery (Recoverable) =		98.7
Average Drawdown (within ROC) (ft) =		0.000
Air (vacuum) discharge (scfm) =		0.000
Final LNAPL Recovered Volume (gal) =		7654.
Simulation Time (years) =		1000.0

OHM-3, 100°F, 1 years

VARIABLE	INITIAL CONDITIONS FOR RUN	FINAL FOR RUN
LNAPL Thickness [ft]	12.17	11.90
Total LNAPL [ft]	1.98	1.98
Mobile LNAPL [ft]	1.98	1.94
Recoverable LNAPL [ft]	0.04	0.04
Residual LNAPL [ft]	0.00	1.90
LNAPL Transmissivity [ft2/d]	0.01	0.01
LNAPL Discharge [gpd]	0.05	0.05

Percent Recovery (Total) =	0.1
Percent Recovery (Recoverable) =	4.7
Average Drawdown (within ROC) (ft) =	0.000
Air (vacuum) discharge (scfm) =	0.000
Final LNAPL Recovered Volume (gal) =	17.
Simulation Time (years) =	1.0

OHM-3, 100°F, 1000 years

VARIABLE	INITIAL CONDITIONS FOR RUN	FINAL FOR RUN
LNAPL Thickness [ft]	12.17	0.18
Total LNAPL [ft]	1.98	1.94
Mobile LNAPL [ft]	1.98	0.03
Recoverable LNAPL [ft]	0.04	0.00
Residual LNAPL [ft]	0.00	0.03
LNAPL Transmissivity [ft2/d]	0.01	0.00
LNAPL Discharge [gpd]	0.05	0.00

Percent Recovery (Total) =	2.0
Percent Recovery (Recoverable) =	99.9
Average Drawdown (within ROC) (ft) =	0.000
Air (vacuum) discharge (scfm) =	0.000
Final LNAPL Recovered Volume (gal) =	368.
Simulation Time (years) =	1000.0

OHM-1, 130°F, 1 year

VARIABLE	INITIAL CONDITIONS FOR RUN	FINAL FOR RUN
LNAPL Thickness [ft]	21.54	14.14
Total LNAPL [ft]	1.57	1.27
Mobile LNAPL [ft]	1.57	0.91
Recoverable LNAPL [ft]	0.54	0.23
Residual LNAPL [ft]	0.00	0.68
LNAPL Transmissivity [ft2/d]	0.80	0.39
LNAPL Discharge [gpd]	13.18	4.22

Percent Recovery (Total) = 18.9

Percent Recovery (Recoverable) = 55.1

Average Drawdown (within ROC) (ft) = 0.000

Air (vacuum) discharge (scfm) = 0.000

Final LNAPL Recovered Volume (gal) = 2780.

Simulation Time (years) = 1.0

OHM-1, 130°F, 1000 years

VARIABLE	INITIAL CONDITIONS FOR RUN	FINAL FOR RUN
LNAPL Thickness [ft]	21.54	0.02
Total LNAPL [ft]	1.57	1.03
Mobile LNAPL [ft]	1.57	0.00
Recoverable LNAPL [ft]	0.54	0.00
Residual LNAPL [ft]	0.00	0.00
LNAPL Transmissivity [ft2/d]	0.80	0.00
LNAPL Discharge [gpd]	13.18	0.00

Percent Recovery (Total) = 34.2

Percent Recovery (Recoverable) = 100.0

Average Drawdown (within ROC) (ft) = 0.000

Air (vacuum) discharge (scfm) = 0.000

Final LNAPL Recovered Volume (gal) = 5048.

Simulation Time (years) = 1000.0

OHM-2, 130°F, 1 year

VARIABLE	INITIAL CONDITIONS FOR RUN	FINAL FOR RUN
LNAPL Thickness [ft]	11.98	11.61
Total LNAPL [ft]	2.04	1.97
Mobile LNAPL [ft]	2.04	1.95
Recoverable LNAPL [ft]	1.13	1.06
Residual LNAPL [ft]	0.00	0.89
LNAPL Transmissivity [ft2/d]	0.23	0.21
LNAPL Discharge [gpd]	1.71	1.56

Percent Recovery (Total) =	3.1
Percent Recovery (Recoverable) =	5.6
Average Drawdown (within ROC) (ft) =	0.000
Air (vacuum) discharge (scfm) =	0.000
Final LNAPL Recovered Volume (gal) =	596.
Simulation Time (years) =	1.0

OHM-2, 130°F, 1000 years

VARIABLE	INITIAL CONDITIONS FOR RUN	FINAL FOR RUN
LNAPL Thickness [ft]	11.98	0.26
Total LNAPL [ft]	2.04	0.92
Mobile LNAPL [ft]	2.04	0.02
Recoverable LNAPL [ft]	1.13	0.00
Residual LNAPL [ft]	0.00	0.02
LNAPL Transmissivity [ft2/d]	0.23	0.00
LNAPL Discharge [gpd]	1.71	0.00

Percent Recovery (Total) =	55.0
Percent Recovery (Recoverable) =	99.7
Average Drawdown (within ROC) (ft) =	0.000
Air (vacuum) discharge (scfm) =	0.000
Final LNAPL Recovered Volume (gal) =	10575.
Simulation Time (years) =	1000.0

OHM-3, 130°F, 1 years

VARIABLE	INITIAL CONDITIONS FOR RUN	FINAL FOR RUN
LNAPL Thickness [ft]	12.17	11.31
Total LNAPL [ft]	2.05	2.05
Mobile LNAPL [ft]	2.05	1.90
Recoverable LNAPL [ft]	0.06	0.05
Residual LNAPL [ft]	0.00	1.86
LNAPL Transmissivity [ft2/d]	0.03	0.03
LNAPL Discharge [gpd]	0.24	0.19

Percent Recovery [Total] =	0.4
Percent Recovery [Recoverable] =	15.0
Average Drawdown [within ROC] [ft] =	0.000
Air [vacuum] discharge [scfm] =	0.000
Final LNAPL Recovered Volume [gal] =	78.
Simulation Time [years] =	1.0

OHM-3, 130°F, 1000 years

VARIABLE	INITIAL CONDITIONS FOR RUN	FINAL FOR RUN
LNAPL Thickness [ft]	12.17	0.05
Total LNAPL [ft]	2.05	2.00
Mobile LNAPL [ft]	2.05	0.01
Recoverable LNAPL [ft]	0.06	0.00
Residual LNAPL [ft]	0.00	0.01
LNAPL Transmissivity [ft2/d]	0.03	0.00
LNAPL Discharge [gpd]	0.24	0.00

Percent Recovery [Total] =	2.7
Percent Recovery [Recoverable] =	100.0
Average Drawdown [within ROC] [ft] =	0.000
Air [vacuum] discharge [scfm] =	0.000
Final LNAPL Recovered Volume [gal] =	521.
Simulation Time [years] =	1000.0

Appendix D

Summary of Remedial Alternatives Cost Estimates

TABLE D1
ALTERNATIVE 1 - PHYSICAL LNAPL REMOVAL, FOCUSED BIOSPARGE, MNA, AND TARGETED EXCAVATION
BNSF Wishram Railyard

Item Description	Quantity	Unit	Unit Cost	Extension	Assumptions
A. Preliminary Activities					
Cleanup Action Plan (CAP)	1	Unit Cost	$30,000	$30,000	
Permitting					
General Demolition/Grading/Construction	1	Unit Cost	$10,000	$10,000	
JARPA/Shoreline - construction close to Columbia River	1	Unit Cost	$100,000	$100,000	
DAHP	1	Unit Cost	$10,000	$10,000	
Health and Safety Plan	1	Unit Cost	$5,000	$5,000	
Deed Restriction/Soil Management Plan	1	Unit Cost	$20,000	$20,000	
Item A. Estimated Cost				**$175,000**	
B. Physical LNAPL Removal (B1 and B2)					
B1. Recovery Well Construction					
Mobilization/Demobilization	1	Unit Cost	$10,000	$10,000	
Private Utility Locate	1	Unit Cost	$5,000	$5,000	
Extraction Well Installation	15	well	$27,000	$405,000	15 stainless steel (316) 6-inch dia. Muni-pak wells (due to heaving sands). Sonic with 10-inch borehole. 30-day estimate.
Investigation-Derived Waste (IDW) Water Transport and Disposal	30	Unit Cost	$250	$7,500	Decontamination and development water; 2 drums per well (30 total); $250 per drum T&D
Investigation-Derived Waste (IDW) Soil Transport and Disposal	120	Unit Cost	$250	$30,000	8 drums per well (120 total); $250 per drum T&D.
Waste Disposal (soil, water, and NAPL from system installation)	1	Unit Cost	$30,000	$30,000	
Cultural Resource Monitoring	30	day	$2,000	$60,000	CRM during well installations (30 days)
Oversight Labor	65	day	$2,000	$130,000	Pre-drilling/construction preparations (5 days), 2 staff field oversight for well install (30 days), H&S, daily records, field equipment,
Washington State Sales Tax	1	Unit Cost	$48,000	$48,000	10.1 percent of construction capital cost (Item B).
Item B1. Estimated Cost				**$726,000**	
B2. LNAPL Removal Vacuum Extraction					
Vacuum Extraction Oversight	30	events	$4,500	$135,000	One person, 32 hours per event, assumes quarterly to annual recovery over a 10 year period.
Vacuum Extraction Subcontractor	30	events	$12,000	$360,000	3 days per event, vacuum extraction subcontractor $4000/day
Investigation-Derived Waste (IDW) LNAPL/Water Transport and Disposal	30	events	$9,000	$270,000	60 gallons/well average, 15 wells, $10/gallon
Decommission (P&A) LNAPL removal wells	1	Unit Cost	$62,000	$62,000	Decommission 18 LNAPL removal wells - Includes P&A - backfill monitoring well casings with bentonite chips, cement monument in-place. Utility locate (GPR, conductive). Includes oversight
Item B2. Estimated Cost				**$827,000**	
Total Item B (B1+B2). Estimated Cost				**$1,553,000**	
C. Biosparge Systems Installations - One System - (LNAPL Western LNAPL)					
Design and Topo Survey	1	Unit Cost	$55,000	$55,000	8 to 10 design sheets plus specifications (one system, one site area).
Biosparging System Construction	1	Unit Cost	$574,050	$574,050	Installation of One System: (1) 5 shallow and 3 paired shallow/deep biosparge wells (11 total wells) in western LNAPL area. Construct a treatment pad/shed and furnish air compressor, PLC, distribution manifold, electrical/mechanical connections, trenching, install piping to each biosparge well, install shallow/deep biosparge wells. Includes cultural resource monitoring during well and trench install (4 weeks) and CM and EOR oversight and system startup (6 weeks)
Biosparge System O&M	5	years	$30,000	$150,000	Quarterly system checks, replacement equipment and annual system testing (check valves, compressor, components)
Other - Construction Completion Report, O&M Plan, WA Sales Tax	1	Unit Cost	$76,000	$76,000	
Decommission (P&A) biosparge wells and remove one biosparge system	1	Unit Cost	$44,100	$44,100	Decommission 11 biosparge wells total [systems (1) - Includes P&A - backfill monitoring well casings with bentonite chips, cement monument in-place. Utility locate (GPR, conductive). Remove system equipment and grout piping in-place (1 biosparge system). Includes oversight
Item C. Estimated Cost				**$900,000**	
D. Berm Soil Excavation					
Design and Topo Survey	1	Unit Cost	$17,000	$17,000	
Excavation and Disposal	1	Unit Cost	$74,000	$74,000	
Construction Completion Report, Regulatory Oversight	1	Unit Cost	$13,000	$13,000	
Item D. Estimated Cost				**$104,000**	
E. Groundwater Monitoring During Alternative Implementation					Duration/frequency: 10 years (5 semiannual (SA), 5 annual during active remediation, followed by 30 years (3 years MNA SA, 19 years annual, 8 years biennial)
Groundwater Sampling and Chemical Analyses - During Biosparge Remediation (Semiannual for 5 years, 25 wells)	250	well samples	$800	$200,000	Groundwater monitoring of 25 wells for TPH-Dx, 4 wells for PAHs & TPH-Gx, plus 5 QC samples (duplicates, trip blanks, field blank). Site-wide liquid levels. 2 staff, 3 field days. Data validation / reporting to Ecology (EIM, lab reports, table).
Groundwater Sampling and Chemical Analyses - During Physical LNAPL Removal (Annual for 5 years, 25 wells)	125	well samples	$800	$100,000	Groundwater monitoring of 25 wells for TPH-Dx, 25 wells Total&Diss Arsenic, 4 wells for PAHs & TPH-Gx, plus 5 QC samples (duplicates, trip blanks, field blank). Site-wide liquid levels. 2 staff, 3 field days. Data validation / reporting to Ecology (EIM, lab reports, table).
Groundwater Sampling and Chemical Analyses - MNA Evaluation (Semiannual for 3 years, 37 wells)	222	well samples	$950	$210,900	Groundwater monitoring of 37 wells for TPH-Dx, 25 wells MNA parameters, 4 wells for PAHs & TPH-Gx, plus 5 QC samples (duplicates, trip blanks, field blank). Site-wide liquid levels. 2 staff, 3 field days. Data validation / reporting to Ecology (EIM, lab reports, table).
Groundwater Sampling and Chemical Analyses - Compliance Monitoring (Annual for 19 years, 25 wells)	475	well samples	$800	$380,000	Groundwater monitoring of 25 wells for TPH-Dx, 25 wells Total&Diss Arsenic, 4 wells for PAHs & TPH-Gx, plus 5 QC samples (duplicates, trip blanks, field blank). Site-wide liquid levels. 2 staff, 3 field days. Data validation / reporting to Ecology (EIM, lab reports, table).
Groundwater Sampling and Chemical Analyses - Compliance Monitoring (Biennial for 8 years (4 events total), 25 wells)	100	well samples	$800	$80,000	Groundwater monitoring of 25 wells for TPH-Dx, 25 wells Total&Diss Arsenic, 4 wells for PAHs & TPH-Gx, plus 5 QC samples (duplicates, trip blanks, field blank). Site-wide liquid levels. 2 staff, 3 field days. Data validation / reporting to Ecology (EIM, lab reports, table).
Investigation-Derived Waste Water Handling/Disposal	26	years	$4,000	$104,000	IDW management during sampling years after completion of active LNAPL removal
Item E. Estimated Cost				**$1,075,000**	
F. Other					
Project Coordination, Annual Monitoring Report to Ecology	36	year	$25,000	$900,000	During active years (remediation and/or compliance monitoring)
Regulatory Oversight	36	year	$10,000	$360,000	Includes periodic review once every 5 years.
Item F. Estimated Cost				**$1,260,000**	
Total Estimated Cost				**$5,067,000**	

Notes:
1. Estimated cost was prepared at -30/+50% for relative comparison amongst alternatives. The prepared cost estimate is not intended for budgetary purposes.
2. An engineering cost estimate will be prepared in conjunction with CAP preparation and design (technical specifications and drawings).

TABLE D2
ALTERNATIVE 2 - INSTITUTIONAL CONTROLS AND ENVIRONMENTAL CONVENANTS WITH COMPLIANCE GROUNDWATER MONITORING
BNSF Wishram Railyard

Item Description	Quantity	Unit	Unit Cost	Extension	Assumptions
A. Preliminary Activities					
Deed Restriction/Soil Management Plan	1	Unit	$25,000	$25,000	
Item A. Estimated Cost				**$25,000**	
B. Groundwater Monitoring During Alternative Implementation					Duration/frequency: Annual for 30 years
Groundwater Sampling and Chemical Analyses - Compliance Monitoring (Annual for 30 years, 25 wells)	750	well samples	$800	$600,000	Groundwater monitoring of 25 wells for TPH-Dx, 25 wells Total&Diss Arsenic, 4 wells for PAHs and TPH-Gx, plus 5 QC samples (duplicates, trip blanks, field blank). Site-wide liquid levels. 2 staff, 3 field days. Data validation / reporting to Ecology (EIM, lab reports, table).
Investigation-Derived Waste Water Handling/Disposal	30	years	$4,000	$120,000	
Item B. Estimated Cost				**$720,000**	
C. Other - Annual Reporting and Regulatory Oversight					
Project Coordination, Annual Monitoring Report to Ecology	30	year	$15,000	$450,000	
Regulatory Oversight	30	year	$7,500	$225,000	Includes periodic review once every 5 years.
Item C. Estimated Cost				**$675,000**	
Total Estimated Cost				**$1,420,000**	

Notes:
1. Estimated cost was prepared at -30/+50% for relative comparison amongst alternatives. The prepared cost estimate is not intended for budgetary purposes.
2. An engineering cost estimate will be prepared in conjunction with CAP preparation and design (technical specifications and drawings).

TABLE D3
ALTERNATIVE 3 - LNAPL CONTAINMENT, BIOSPARGE, MNA, AND TARGETED EXCAVATION
BNSF Wishram Railyard

Item Description	Quantity	Unit	Unit Cost	Extension	Assumptions
A. Preliminary Activities					
Cleanup Action Plan (CAP)	1	Unit Cost	$30,000	$30,000	
Permitting					
General Demolition/Grading/Construction	1	Unit Cost	$10,000	$10,000	
JARPA/Shoreline - construction close to Columbia River	1	Unit Cost	$100,000	$100,000	
DAHP	1	Unit Cost	$10,000	$10,000	
Health and Safety Plan	1	Unit Cost	$5,000	$5,000	
Deed Restriction/Soil Management Plan	1	Unit Cost	$20,000	$20,000	
Item A. Estimated Cost				**$175,000**	
B. Sheet Pile Wall Installation					
Design (plans and specifications)	1	Unit Cost	$80,000	$80,000	Geotech investigation/evaluation and sheet pile wall design
Topographical Survey	1	Unit Cost	$10,000	$10,000	
Mobilization/Demobilization	1	Unit Cost	$116,500	$116,500	5 percent of construction cost (Item C, excluding construction management).
Private Utility Locate	1	Unit Cost	$5,000	$5,000	
Site Security	1	Unit Cost	$5,000	$5,000	Temporary fencing, signage, etc.
Erosion Control	1	Unit Cost	$5,000	$5,000	Construction entrance, silt fence, catch basin protection, stockpile management, etc.
Traffic Control	10	day	$500	$5,000	Traffic control for dump trucks entering and leaving site.
Sawcut Existing Pavement	100	linear feet	$5	$500	Foundations of former buildings along alignment
Demo and Remove Existing Pavement	1	Unit Cost	$5,000	$5,000	
Steel Sheet Pile Materials	25,500	SF	$50	$1,275,000	Estimated area from depth to bedrock along alignment of sheet pile wall
Steel Sheet Pile Installation	25,500	SF	$40	$1,020,000	Estimate half is >60' deep, other half <60' deep
Utility Restoration	1	Unit Cost	$5,000	$5,000	
Construction Management	1	Unit Cost	$250,000	$250,000	Project management, oversight, direct expenses, etc.
Sheet Pile Wall Construction Completion Report	1	Unit Cost	$15,000	$15,000	includes as-built drawings
Item B. Estimated Cost				**$2,782,000**	
C. Biosparge Systems Installation - Two Systems (Mainline and Engine House)					
Design and Topo Survey	1	Unit Cost	$85,000	$85,000	Common design for both systems with additional layout sheets for second system. 16 to 20 design sheets plus specifications (two systems)
Biosparging System Construction	1	Unit Cost	$995,750	$995,750	Installation of Two Systems: (1) 20 shallow AS wells around the mainline tracks; (2) 25 shallow AS wells beneath the former Engine House. For each system construct a treatment pad/shed and furnish air compressor, PLC, distribution manifold, electrical/mechanical connections, trenching, install piping to each biosparge well, install shallow/deep AS wells. Includes cultural resource monitoring during well and trench install (6 weeks) and CM and EOR oversight well and system install and system startup (12 weeks)
Biosparge System O&M	5	years	$40,000	$200,000	Quarterly system checks, replacement equipment and annual system testing (check valves, compressor, components)
Other - Construction Completion Report, O&M Plan, WA Sales Tax	1	Unit Cost	$100,000	$100,000	
Decommission (P&A) biosparge wells and remove two biosparge systems	1	Unit Cost	$100,500	$100,500	Decommission 45 biosparge wells total [systems (1), (2)] - Includes P&A - backfill monitoring well casings with bentonite chips, cement monument in-place. Utility locate (GPR, conductive). Remove system equipment and grout piping in-place (2 biosparge systems). Includes oversight.
Item C. Estimated Cost				**$1,482,000**	
D. Berm Soil Excavation					
Design and Topo Survey	1	Unit Cost	$17,000	$17,000	
Excavation and Disposal	1	Unit Cost	$74,000	$74,000	Excavate 560 CY; off-site disposal of 170 CY
Construction Completion Report, Regulatory Oversight	1	Unit Cost	$13,000	$13,000	
Item D. Estimated Cost				**$104,000**	
E. Groundwater Monitoring During Alternative Implementation					Duration/frequency: 5 years (5 semiannual (SA)) during active remediation, followed by 30 years (3 years MNA SA, 21 years annual, 6 years biennial)
Groundwater Sampling and Chemical Analyses - During Biosparge Remediation (Semiannual for 5 years, 25 wells)	250	well samples	$800	$200,000	Groundwater monitoring of 25 wells for TPH-Dx, 4 wells for PAHs & TPH-Gx, plus 5 QC samples (duplicates, trip blanks, field blank). Site-wide liquid levels. 2 staff, 3 field days. Data validation / reporting to Ecology (EIM, lab reports, table).
Groundwater Sampling and Chemical Analyses - MNA Evaluation (Semiannual for 3 years, 37 wells)	222	well samples	$950	$210,900	Groundwater monitoring of 37 wells for TPH-Dx, 25 wells MNA parameters, 4 wells for PAHs & TPH-Gx, plus 5 QC samples (duplicates, trip blanks, field blank). Site-wide liquid levels. 2 staff, 3 field days. Data validation / reporting to Ecology (EIM, lab reports, table).
Groundwater Sampling and Chemical Analyses - Compliance Monitoring (Annual for 21 years, 25 wells)	525	well samples	$800	$420,000	Groundwater monitoring of 25 wells for TPH-Dx, 25 wells Total&Diss Arsenic, 4 wells for PAHs & TPH-Gx, plus 5 QC samples (duplicates, trip blanks, field blank). Site-wide liquid levels. 2 staff, 3 field days. Data validation / reporting to Ecology (EIM, lab reports, table).
Groundwater Sampling and Chemical Analyses - Compliance Monitoring [Biennial for 6 years (3 events total), 25 wells]	75	well samples	$800	$60,000	Groundwater monitoring of 25 wells for TPH-Dx, 25 wells Total&Diss Arsenic, 4 wells for PAHs & TPH-Gx, plus 5 QC samples (duplicates, trip blanks, field blank). Site-wide liquid levels. 2 staff, 3 field days. Data validation / reporting to Ecology (EIM, lab reports, table).
Investigation-Derived Waste Water Handling/Disposal	32	years	$4,000	$128,000	IDW management for sampling years during and after completion of active biosparge
Item E. Estimated Cost				**$1,019,000**	
F. Other - Annual Reporting and Regulatory Oversight					
Project Coordination, Annual Monitoring Report to Ecology	32	year	$25,000	$800,000	During active years (remediation and/or compliance monitoring)
Regulatory Oversight	32	year	$10,000	$320,000	Includes periodic review once every 5 years.
Item F. Estimated Cost				**$1,120,000**	
Total Estimated Cost				**$6,682,000**	

Notes:
1. Estimated cost was prepared at -30/+50% for relative comparison amongst alternatives. The prepared cost estimate is not intended for budgetary purposes.
2. An engineering cost estimate will be prepared in conjunction with CAP preparation and design (technical specifications and drawings).

TABLE D4

ALTERNATIVE 4 - PHYSICAL LNAPL REMOVAL, BIOSPARGE, MNA, AND TARGETED EXCAVATION

BNSF Wishram Railyard

Item Description	Quantity	Unit	Unit Cost	Extension	Assumptions
A. Preliminary Activities					
Cleanup Action Plan (CAP)	1	Unit Cost	$30,000	$30,000	
Permitting					
General Demolition/Grading/Construction	1	Unit Cost	$10,000	$10,000	
JARPA/Shoreline - construction close to Columbia River	1	Unit Cost	$100,000	$100,000	
DAHP	1	Unit Cost	$10,000	$10,000	
Health and Safety Plan	1	Unit Cost	$5,000	$5,000	
Deed Restriction/Soil Management Plan	1	Unit Cost	$20,000	$20,000	
Item A. Estimated Cost				**$175,000**	
B. Physical LNAPL Removal (B1 and B2) and Biosparge (after Physical LNAPL Removal) (B3)					Implementation of biosparge after Physical LNAPL Removal contingent on NSZD Assessment
B1. Recovery Well Construction					
Mobilization/Demobilization	1	Unit Cost	$10,000	$10,000	
Private Utility Locate	1	Unit Cost	$5,000	$5,000	
Extraction Well Installation	15	well	$27,000	$405,000	15 stainless steel (316) 6-inch dia. Muni-pak wells (due to heaving sands). Sonic with 10-inch borehole. 30-day estimate.
Investigation-Derived Waste (IDW) Water Transport and Disposal	30	Unit Cost	$250	$7,500	Decontamination and development water; 2 drums per well (30 total); $250 per drum T&D
Investigation-Derived Waste (IDW) Soil Transport and Disposal	120	Unit Cost	$250	$30,000	8 drums per well (120 total); $250 per drum T&D.
Waste Disposal (soil, water, and NAPL from system installation)	1	Unit Cost	$30,000	$30,000	
Cultural Resource Monitoring	30	day	$2,000	$60,000	CRM during well installations (30 days)
Oversight Labor	65	day	$2,000	$130,000	Pre-drilling/construction preparations (5 days), 2 staff field oversight for well install (30 days), H&S, daily records, field equipment,
Washington State Sales Tax	1	Unit Cost	$48,000	$48,000	10.1 percent of construction capital cost (Item B).
Item B1. Estimated Cost				**$726,000**	
B2. LNAPL Removal Vacuum Extraction					
Vacuum Extraction Oversight	30	events	$4,500	$135,000	One person, 32 hours per event, assumes quarterly to annual recovery over a 10 year period.
Vacuum Extraction Subcontractor	30	events	$12,000	$360,000	3 days per event, vacuum extraction subcontractor $4000/day
Investigation-Derived Waste (IDW) LNAPL/Water Transport and Disposal	30	events	$9,000	$270,000	60 gallons/well average, 15 wells, $10/gallon
Item B2. Estimated Cost				**$765,000**	
B3. Biosparge System Installation After Physical LNAPL Removal					Contingent on NSZD Assessment After Physical LNAPL Removal
Biosparge System Installation - Eastern LNAPL Area (Post Physical LNAPL Removal)	1	Unit Cost	$279,500	$279,500	Expand from Western LNAPL Area biosparge system (reuse remediation shed, air compressor, PLC, modify distribution manifold and install piping, convert 18 MPE wells into biosparge wells (shallow and deep drop tube and packers plus labor to install). Includes separate mobilization to construct after completion of Physical LNAPL Removal
Biosparge System Operation - Eastern LNAPL Area	5	Year	$30,000	$150,000	Quarterly System Checks, Annual system performance testing. Operate biosparge system in Eastern LNAPL Area for 5 years after completion of Physical LNAPL Removal. O&M conducted separately from other biosparge systems in Part C.
Decommission (P&A) LNAPL removal / biosparge wells and remove one biosparge system	1	Unit Cost	$102,500	$102,500	Decommission 18 converted LNAPL removal / biosparge wells and one system - Includes P&A - backfill monitoring well casings with bentonite chips, cement monument in-place. Utility locate (GPR, conductive). Remove system equipment and grout piping in-place (1 biosparge systems). Includes oversight
Item B3. Estimated Cost				**$532,000**	
Total Item B (B1+B2). Estimated Cost				*$1,491,000*	*Without biosparging in eastern LNAPL area after physical LNAPL removal*
Total Item B (B1+B2+B3). Estimated Cost				**$2,023,000**	Includes biosparging in eastern LNAPL area after physical LNAPL removal
C. Biosparge Systems Installations - Three Systems - (Mainline Tracks, Engine House, and LNAPL (Western and South End of Eastern LNAPL))					
Design and Topo Survey	1	Unit Cost	$100,000	$100,000	Common design for the three systems with additional layout sheets for second/third systems. 20 to 24 design sheets plus specifications
Biosparging System Construction	1	Unit Cost	$1,436,800	$1,436,800	Installation of Three Systems: (1) 20 shallow biosparge wells in mainline track area; (2) 25 shallow biosparge wells beneath former Engine House; (3) 5 shallow and 13 paired shallow/deep biosparge wells (31 total wells) in LNAPL areas (western plus south end of eastern LNAPL). For each system construct a treatment pad/shed and furnish air compressor, PLC, distribution manifold, electrical/mechanical connections, trenching, install piping to each biosparge well, install shallow/deep biosparge wells. Includes cultural resource monitoring during well and trench install (8 weeks) and CM and EOR oversight and system startup (15 weeks)
Biosparge System O&M	5	years	$50,000	$250,000	Quarterly system checks, replacement equipment and annual system testing (check valves, compressor, components)
Other - Construction Completion Report, O&M Plan, WA Sales Tax	1	Unit Cost	$149,000	$149,000	
Decommission (P&A) biosparge wells and remove three biosparge systems	1	Unit Cost	$155,100	$155,100	Decommission 76 biosparge wells total [systems (1), (2), (3)] - Includes P&A - backfill monitoring well casings with bentonite chips, cement monument in-place. Utility locate (GPR, conductive). Remove system equipment and grout piping in-place (3 biosparge systems). Includes oversight
Item C. Estimated Cost				**$2,091,000**	
D. Berm Soil Excavation					
Design and Topo Survey	1	Unit Cost	$17,000	$17,000	
Excavation and Disposal	1	Unit Cost	$74,000	$74,000	
Construction Completion Report, Regulatory Oversight	1	Unit Cost	$13,000	$13,000	
Item D. Estimated Cost				**$104,000**	
E. Groundwater Monitoring During Alternative Implementation					Duration/frequency: 15 years (5 semiannual (SA), 10 annual) during active remediation, followed by 30 years (3 years MNA SA, 15 years annual, 12 years biennial)
Groundwater Sampling and Chemical Analyses - During Biosparge Remediation (Semiannual for 5 years, 25 wells)	250	well samples	$800	$200,000	Groundwater monitoring of 25 wells for TPH-Dx, 4 wells for PAHs & TPH-Gx, plus 5 QC samples (duplicates, trip blanks, field blank). Site-wide liquid levels. 2 staff, 3 field days. Data validation / reporting to Ecology (EIM, lab reports, table).
Groundwater Sampling and Chemical Analyses - During Physical LNAPL Removal followed by Biosparge in Eastern LNAPL Area (Annual for 10 years, 25 wells)	250	well samples	$800	$200,000	Groundwater monitoring of 25 wells for TPH-Dx, 25 wells Total&Diss Arsenic, 4 wells for PAHs & TPH-Gx, plus 5 QC samples (duplicates, trip blanks, field blank). Site-wide liquid levels. 2 staff, 3 field days. Data validation / reporting to Ecology (EIM, lab reports, table).
Groundwater Sampling and Chemical Analyses - MNA Evaluation (Semiannual for 3 years, 37 wells)	222	well samples	$950	$210,900	Groundwater monitoring of 37 wells for TPH-Dx, 25 wells MNA parameters, 4 wells for PAHs & TPH-Gx, plus 5 QC samples (duplicates, trip blanks, field blank). Site-wide liquid levels. 2 staff, 3 field days. Data validation / reporting to Ecology (EIM, lab reports, table).
Groundwater Sampling and Chemical Analyses - Compliance Monitoring (Annual for 15 years, 25 wells)	375	well samples	$800	$300,000	Groundwater monitoring of 25 wells for TPH-Dx, 25 wells Total&Diss Arsenic, 4 wells for PAHs & TPH-Gx, plus 5 QC samples (duplicates, trip blanks, field blank). Site-wide liquid levels. 2 staff, 3 field days. Data validation / reporting to Ecology (EIM, lab reports, table).
Groundwater Sampling and Chemical Analyses - Compliance Monitoring [Biennial for 12 years (6 events total), 25 wells]	150	well samples	$800	$120,000	Groundwater monitoring of 25 wells for TPH-Dx, 25 wells Total&Diss Arsenic, 4 wells for PAHs & TPH-Gx, plus 5 QC samples (duplicates, trip blanks, field blank). Site-wide liquid levels. 2 staff, 3 field days. Data validation / reporting to Ecology (EIM, lab reports, table).
Investigation-Derived Waste Water Handling/Disposal	31	years	$4,000	$124,000	IDW management during sampling years after completion of active LNAPL removal
Item E. Estimated Cost				**$1,155,000**	
F. Other					
Project Coordination, Annual Monitoring Report to Ecology	41	year	$25,000	$1,025,000	During active years (remediation and/or compliance monitoring)
Regulatory Oversight	41	year	$10,000	$410,000	Includes periodic review once every 5 years.
Item F. Estimated Cost				**$1,435,000**	
Total Estimated Cost				**$6,983,000**	Includes biosparging in eastern LNAPL zone after physical LNAPL removal

Notes:

1. Estimated cost was prepared at -30/+50% for relative comparison amongst alternatives. The prepared cost estimate is not intended for budgetary purposes.
2. An engineering cost estimate will be prepared in conjunction with CAP preparation and design (technical specifications and drawings).

TABLE D5
ALTERNATIVE 5 - LOW-TEMPERATURE THERMAL REMOVAL (LTTR), BIOSPARGE, MNA, AND TARGETED EXCAVATION
BNSF Wishram Railyard

Item Description	Quantity	Unit	Unit Cost	Extension	Assumptions
A. Preliminary Activities					
Cleanup Action Plan (CAP)	1	Unit Cost	$30,000	$30,000	
Permitting					
General Demolition/Grading/Construction	1	Unit Cost	$10,000	$10,000	
JARPA/Shoreline - construction close to Columbia River	1	Unit Cost	$100,000	$100,000	
Air Quality Permit	1	Unit Cost	$10,000	$10,000	
DAHP	1	Unit Cost	$10,000	$10,000	
Health and Safety Plan	1	Unit Cost	$5,000	$5,000	
Deed Restriction/Soil Management Plan	1	Unit Cost	$20,000	$20,000	
Item A. Estimated Cost				**$185,000**	
B. LNAPL Removal - Low-Temperature Thermal Removal (LTTR) and Biosparge (LTTR and Biosparge)					
Design (preliminary plans)	1	Unit Cost	$20,000	$20,000	Thermal design by subcontractor
System Installation and Operation	1	Unit Cost	$3,580,600	$3,580,600	Thermal Specialty Subcontractor Cost Estimate: Heat Enhanced NAPL Recovery - Electrical Resistive Heating (ERH) to target temperature of 50-70°C with multiphase extraction (MPE) of LNAPL and groundwater. Assume 54 heater borings. Total operating time of 20 months. Estimate includes design, procurement, mobilization, installation, water / LNAPL treatment/separation, electrical power, operation and decommisionnng/demobilization. Also includes decommissioning of PVC monitoring wells in the eastern LNAPL area. Addresses eastern LNAPL area.
Basis of Design Report (BODR)	1	Unit Cost	$25,000	$25,000	Preparation of system design, including site visit and meeting, thermal modeling and refinement of treatment, evaluation of data gaps, risk/uncertainty evaluation
Private Utility Locate	1	Unit Cost	$10,000	$10,000	
Site Security	1	Unit Cost	$5,000	$5,000	Fencing
Erosion Control	1	Unit Cost	$5,000	$5,000	
Traffic Control	10	day	$500	$5,000	
Investigation-Derived Waste (IDW) Soil Transport and Disposal	1	Unit Cost	$40,000	$40,000	heater borings, MPE wells and temp points
Recovered LNAPL Transport and Disposal	40,000	gal	$10	$400,000	
Sewer Connection for Water Disposal	1	Unit Cost	$30,000	$30,000	
Cultural Resource Monitoring	40	day	$2,000	$80,000	
Construction Management	1	Unit Cost	$400,000	$400,000	Project management, oversight, direct expenses, etc.
Biosparge System Installation - Eastern LNAPL Area (Post LTTR)	1	Unit Cost	$339,900	$339,900	Assumes reusing treatment pad/shed from LTTR, and furnishing an air compressor, PLC, distribution manifold and piping, convert 18 MPE wells into biosparge wells (shallow and deep drop tube and packers plus labor to install). Includes separate mobilization to construct after completion of LTTR.
Biosparge System Operation - Eastern LNAPL Area	3	Year	$15,000	$45,000	Quarterly System Checks, Annual system performance testing. Operate biosparge system in Eastern LNAPL Area for 3 years after completion of LTTR. Assumes concurrent O&M with other biosparge systems in Part C.
Decommission (P&A) LNAPL removal / biosparge wells and remove one biosparge system	1	Unit Cost	$102,500	$102,500	Decommission 18 converted LNAPL removal / biosparge wells and one system - Includes P&A - backfill monitoring well casings with bentonite chips, cement monument in-place. Utility locate (GPR, conductive). Remove system equipment and grout piping in-place (1 biosparge systems). Includes oversight
Item B. Estimated Cost				**$5,088,000**	
C. Biosparge Systems Installations - Three Systems - (Mainline Tracks, Engine House, and LNAPL (Western and South End of Eastern LNAPL))					
Design and Topo Survey	1	Unit Cost	$100,000	$100,000	Common design for the three systems with additional layout sheets for second/third systems. 20 to 24 design sheets plus specifications
Biosparging System Construction	1	Unit Cost	$1,436,800	$1,436,800	Installation of Three Systems: (1) 20 shallow biosparge wells in mainline track area; (2) 25 shallow biosparge wells beneath former Engine House; (3) 5 shallow and 13 paired shallow/deep biosparge wells (31 total wells) in LNAPL areas (western plus south end of eastern LNAPL). For each system construct a treatment pad/shed and furnish air compressor, PLC, distribution manifold, electrical/mechanical connections, trenching, install piping to each biosparge well, install shallow/deep biosparge wells. Includes cultural resource monitoring during well and trench install (8 weeks) and CM and EOR oversight and system startup (15 weeks)
Biosparge System O&M	5	years	$50,000	$250,000	Quarterly system checks, replacement equipment and annual system testing (check valves, compressor, components)
Other - Construction Completion Report, O&M Plan, WA Sales Tax	1	Unit Cost	$149,000	$149,000	
Decommission (P&A) biosparge wells and remove three biosparge systems	1	Unit Cost	$155,100	$155,100	Decommission 76 biosparge wells total [systems (1), (2), (3)] - Includes P&A - backfill monitoring well casings with bentonite chips, cement monument in-place. Utility locate (GPR, conductive). Remove system equipment and grout piping in-place (3 biosparge systems). Includes oversigh
Item C. Estimated Cost				**$2,091,000**	
D. Berm Soil Excavation					
Design and Topo Survey	1	Unit Cost	$17,000	$17,000	
Excavation and Disposal	1	Unit Cost	$74,000	$74,000	
Construction Completion Report, Regulatory Oversight	1	Unit Cost	$13,000	$13,000	
Item D. Estimated Cost				**$104,000**	
E. Groundwater Monitoring During Alternative Implementation					Duration/frequency: 5 years (5 semiannual (SA)) during active remediation, followed by 30 years (3 years MNA SA, 15 years annual, 12 years biennial)
Groundwater Sampling and Chemical Analyses - During Biosparge Remediation (Semiannual for 5 years, 25 wells)	250	well samples	$800	$200,000	Groundwater monitoring of 25 wells for TPH-Dx, 4 wells for PAHs & TPH-Gx, plus 5 QC samples (duplicates, trip blanks, field blank). Site-wide liquid levels. 2 staff, 3 field days. Data validation / reporting to Ecology (EIM, lab reports, table).
Groundwater Sampling and Chemical Analyses - MNA Evaluation (Semiannual for 3 years, 37 wells)	222	well samples	$950	$210,900	Groundwater monitoring of 37 wells for TPH-Dx, 25 wells MNA parameters, 4 wells for PAHs & TPH-Gx, plus 5 QC samples (duplicates, trip blanks, field blank). Site-wide liquid levels. 2 staff, 3 field days. Data validation / reporting to Ecology (EIM, lab reports, table).
Groundwater Sampling and Chemical Analyses - Compliance Monitoring (Annual for 15 years, 25 wells)	375	well samples	$800	$300,000	Groundwater monitoring of 25 wells for TPH-Dx, 25 wells Total&Diss Arsenic, 4 wells for PAHs & TPH-Gx, plus 5 QC samples (duplicates, trip blanks, field blank). Site-wide liquid levels. 2 staff, 3 field days. Data validation / reporting to Ecology (EIM, lab reports, table).
Groundwater Sampling and Chemical Analyses - Compliance Monitoring [Biennial for 12 years (6 events total), 25 wells]	150	well samples	$800	$120,000	Groundwater monitoring of 25 wells for TPH-Dx, 25 wells Total&Diss Arsenic, 4 wells for PAHs & TPH-Gx, plus 5 QC samples (duplicates, trip blanks, field blank). Site-wide liquid levels. 2 staff, 3 field days. Data validation / reporting to Ecology (EIM, lab reports, table).
Investigation-Derived Waste Water Handling/Disposal	24	years	$4,000	$96,000	IDW management during sampling years after completion of active LNAPL removal
Item E. Estimated Cost				**$927,000**	
F. Other - Annual Reporting and Regulatory Oversight					
Project Coordination, Annual Monitoring Report to Ecology	29	year	$25,000	$725,000	During active years (remediation and/or compliance monitoring)
Regulatory Oversight	29	year	$10,000	$290,000	Includes periodic review once every five years.
Item F. Estimated Cost				**$1,015,000**	
Total Estimated Cost				**$9,410,000**	

Notes:
1. Estimated cost was prepared at -30/+50% for relative comparison amongst alternatives. The prepared cost estimate is not intended for budgetary purposes.
2. An engineering cost estimate will be prepared in conjunction with CAP preparation and design (technical specifications and drawings).

TABLE D6
COST SUMMARY
BNSF Wishram Railyard

Cost Summary							
Alternative	Planning / Permitting	LNAPL Remedy	Biosparging	Shallow Berm Excavation	Groundwater Monitoring	Annual Reporting	Total
Alternative 1 - Physical LNAPL Removal, Focused Biosparge, MNA, and Targeted Excavation	$ 175,000	$ 1,553,000	$ 900,000	$ 104,000	$ 1,075,000	$ 1,260,000	$ 5,067,000
Alternative 2 - Institutional Controls and Environmental Covenants with Compliance Monitoring	$ 25,000	$ -	$ -	$ -	$ 720,000	$ 675,000	$ 1,420,000
Alternative 3 - LNAPL Containment, Biosparge, MNA, and Targeted Excavation	$ 175,000	$ 2,782,000	$ 1,482,000	$ 104,000	$ 1,019,000	$ 1,120,000	$ 6,682,000
Alternative 4 - Physical LNAPL Removal, Biosparge, MNA, and Targeted Excavation	$ 175,000	$ 2,023,000	$ 2,091,000	$ 104,000	$ 1,155,000	$ 1,435,000	$ 6,983,000
Alternative 5 - Low-Temperature Thermal Removal (LTTR), Biosparge, MNA, and Targeted Excavation	$ 185,000	$ 5,088,000	$ 2,091,000	$ 104,000	$ 927,000	$ 1,015,000	$ 9,410,000