Appendix L
Green Remediation Evaluation and Implementation Approach

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1 Introduction

This appendix presents the Green Remediation Evaluation and Implementation Approach for the sediment remedy for the upper reach (river mile [RM] 3.0 to RM 5.0) of the Lower Duwamish Waterway (LDW) Superfund Site in King County, Washington. The remedy is consistent with the *Remedial Design Work Plan* (RDWP; Anchor QEA and Windward 2019), as selected in the U.S. Environmental Protection Agency's (EPA's) November 2014 Record of Decision (ROD; EPA 2014). The Green Remediation Evaluation and Implementation Approach was prepared in support of the Basis of Design Report (BODR), which corresponds to the Preliminary (30%) Remedial Design (RD). This evaluation was prepared on behalf of the City of Seattle, King County, the Port of Seattle, and The Boeing Company, collectively referred to as the Lower Duwamish Waterway Group (LDWG).

The Green Remediation Evaluation and Implementation Approach builds upon previous green remediation analyses conducted for the LDW Feasibility Study (FS; AECOM 2012). The previous LDW FS analyses focused primarily on quantifying air emissions to evaluate the environmental footprint of the proposed remedial alternatives for short-term risk comparison purposes. This Green Remediation Evaluation and Implementation Approach builds on the previously developed air emissions calculations, but also presents an environmental footprint evaluation for all five core elements identified by EPA's Office of Solid Waste and Emergency Response in the *Superfund Green Remediation Strategy* (EPA 2010a).

1.1 Purpose

According to EPA's Office of Solid Waste and Emergency Response *Superfund Green Remediation Strategy* (EPA 2010a), "*…green remediation is generally recognized as a major step in maximizing the environmental outcome of a contaminated land cleanup…*" by incorporating specific strategies into remedial actions that minimize their environmental footprint to achieve greater net environmental benefits.

Therefore, and as described in the RDWP (Anchor QEA and Windward 2019), the purpose of the Green Remediation Evaluation and Implementation Approach is to:

1. Establish the project's environmental footprint for the sediment remedy presented in the BODR, through the five core elements identified in the *Superfund Green Remediation Strategy* (EPA 2010a): air, water, materials and waste, energy, and land and ecosystems (see Section 2).
2. Identify potential applicable greener construction activities, technologies, and practices that could be applied to the extent practicable during the sediment remedy implementation (e.g., dredging; sediment transloading, transportation, and disposal; material placement; habitat restoration; and structural work), in an effort to reduce the project's environmental footprint (consistent with the EPA *Region 10's Clean and Green Policy* [EPA 2009a]), while still achieving the ROD remedial action objectives and protectiveness requirements in a timely manner.

This appendix includes the following information:

- **Section 2** (Green Remediation Framework), which summarizes the available green remediation EPA guidance and policy that were considered in this evaluation
- **Section 3** (Construction Activities Required for the Sediment Remedy), which describes the primary, secondary, and ancillary construction activities that are anticipated to be required for the sediment remedy
- **Sections 4 through 8** (Green Remediation Core Elements 1 through 5), which evaluate key metrics used to assess the project's environmental footprint for each EPA core element (i.e., air emissions, use of water, use of materials and waste generation, use of energy, and protection of land and ecosystems)
- **Section 9** (Implementation Approach: Best Management Practices), which summarizes the potential most applicable best management practices (BMPs) to minimize the impacts of the sediment remedy

The development of this appendix is based on the BODR's Preliminary (30%) RD criteria, available information to date for the upper reach, and other key elements for implementing the sediment remedy, as well as engineering best professional judgment.

2 Green Remediation Framework

In August 2009, the Office of Solid Waste and Emergency Response (OSWER)[1] issued the green remediation policy, known as the *Principles for Greener Cleanups*, which focuses on evaluating the environmental footprint of cleanup activities (https://www.epa.gov/greenercleanups/epa-principles-greener-cleanups; EPA 2009b). The policy goal is to "…evaluate cleanup actions comprehensively to ensure protection of human health and the environment and to reduce the environmental footprint of cleanup activities, to the maximum extent possible.…" and identifies five core elements of a green cleanup assessment that should be used in selecting and implementing protective cleanup activities.

In hand with the OSWER *Principles for Greener Cleanups*, EPA Region 10 also issued in August 2009 the *Clean and Green Policy* (EPA 2009a) with the goal of promoting sustainable strategies in order to improve the environmental benefits of federal cleanup programs. Specific objectives of the *Clean and Green Policy* are as follows:

- "Protect human health and the environment by achieving RAOs.
- Support sustainable human use and reuse of remediated land.
- Minimize impacts to water quality and water resources.
- Reduce air toxics emissions and greenhouse gas production.
- Minimize material use and waste production.
- Conserve natural resources and energy." (EPA 2009a)

In addition, the Office of Superfund Remediation and Technology Innovation (OSRTI), through the 2010 *Superfund Green Remediation Strategy* (EPA 2010a), established a green remediation program management tool designed to help the Superfund Remedial Program in minimizing and reducing negative environmental effects that might occur during an environmental cleanup. The five core elements described in the *Superfund Green Remediation Strategy (*EPA 2010a) provide a framework for developing BMPs that can lead toward the green remediation objective; these five core elements are as follows:

- "**Air and Atmosphere:** *Many Superfund cleanups involve onsite and offsite emissions of GHGs and air pollutants from activities such as treatment processes, operation of heavy machinery, and transportation of routine vehicles and cargo trucks. These emissions may be reduced by applying the most appropriate advanced technologies and sound field practices."*
- "**Water:** *Superfund cleanups may also involve consumption of significant amounts of water for treatment processes and typically need management of surface water. Green remediation strategies focus on reducing water consumption, reusing treated water, and using efficient techniques to manage and protect surface water and groundwater."*

[1] As of December 2015, OSWER is now known as the Office of Land and Emergency Management (OLEM; https://19january2017snapshot.epa.gov/aboutepa/oswer-olem_.html).

- "**Materials and Waste:** *Site remediation may use significant amounts of raw materials and sometimes generates its own hazardous and non-hazardous wastes, including materials and debris that often are shipped offsite. Green remediation strategies offer opportunities to reduce materials consumption and waste generation, use recycled and local materials and spent products, and purchase environmentally preferred products."*
- "**Energy:** *Many Superfund cleanups involve energy intensive technologies. Green remediation strategies focus on opportunities to improve energy efficiency and use renewable energy sources."*
- "**Land and Ecosystems:** *Superfund sites often involve degraded onsite and offsite ecosystems and may have conditions that make the site unsafe for human or other use. Green remediation strategies focus on remedial actions that minimize further harm to the area, protect land resources and ecosystems at or near the site, and foster the return of sites to ecological, economic, social, or other uses."* (EPA 2010b)

Furthermore, in February 2012, OSRTI released the *Methodology for Understanding and Reducing a Project's Environmental Footprint* (EPA 2012). It provides a framework for evaluating the environmental footprint associated with any remedial action (cleanup activities), understanding the remedy components with the greatest influence, and determining key metrics for each of the green remediation core elements.

2.1 LDW ROD Requirements on Green Remediation

LDW ROD includes requirements for green remediation practices (see Section 13.2.5 of the ROD; EPA 2014) to be considered in the selected remedy, to the extent practicable. These ROD requirements included the following practices, consistent with EPA *Region 10's Clean and Green Policy* (EPA 2009b):

- "*Use renewable energy and energy conservation and efficiency approaches, including Energy Star equipment.*
- *Use cleaner fuels such as low-sulfur fuel or biodiesel, diesel emissions controls and retrofits, and emission reduction strategies.*
- *Use water conservation and efficiency approaches including Water Sense products.*
- *Use reused or recycled materials within regulatory requirements.*
- *Minimize transportation of materials and use rail rather than truck transport to the extent practicable."* (EPA 2014)

This appendix presents strategies that incorporate the above LDW ROD requirements on green remediation into the sediment remedy.

2.2 Other Related Green Remediation Guidance and Policy Documents

In addition to the key EPA policy documents described above (2009 *Region 10's Clean and Green Policy* [EPA 2009a], the 2010 *Superfund Green Remediation Strategy* [EPA 2010a], and the 2012 *Methodology for Understanding and Reducing a Project's Environmental Footprint* [EPA 2012]), the following documents were reviewed and considered to assess whether additional elements could be incorporated into the development of the Green Remediation Evaluation and Implementation Approach:

- *Green Remediation: Incorporating Sustainable Environmental Practices into Remediation of Contaminated Sites* (EPA 2008a)
- *EPA Considerations of Greener Cleanup Activities in Superfund* (EPA 2016)
- *Standard Guide for Greener Cleanups* (ASTM 2017)
- *Standard Guide for Integrating Sustainable Objectives into Cleanup* (ASTM 2020)
- *Green Remediation Best Management Practices: An Overview* (EPA 542-F-16-001, December 2015; EPA 2015a, and EPA 542-F-22-003, April 2022; EPA 2022)

Specific green remediation practices and BMPs applicable to each of the five green remediation core elements were also reviewed and considered for Section 9 of this appendix. These documents, sourced from the "*Green Remediation Best Management Practices*" factsheet series produced by EPA are available at EPA's "Contaminated Site Clean-Up Information (CLU-IN)" website (https://clu-in.org/greenremediation/) and include the following specific factsheets:

- *Clean Fuel & Emission Technologies for Site Cleanup* (EPA 542-F-10-008, August 2010; EPA 2010b)
- *Integrating Renewable Energy into Site Cleanup* (EPA 542-F-11-006, April 2011; EPA 2011a)
- *Introduction to Green Remediation* (May 2011; EPA 2011b)
- *Materials and Waste Management* (EPA 542-F-13-003, December 2013; EPA 2013a)
- *Excavation and Surface Restoration* (EPA 542-F-19-002, August 2019; EPA 2019)
- *Integrating Renewable Energy* (EPA 542-F-22-001, EPA 2022)

This Green Remediation Evaluation and Implementation Approach has been developed to be consistent, to the extent practical, with the above EPA green remediation guidance and policy documents, the outlined evaluation methodology, and the application of sustainable cleanup activities, technologies, and practices.

2.3 Methodology

As stated in Section 1.1, the purpose of the Green Remediation Evaluation and Implementation Approach is to establish the environmental footprint of the sediment remedy and evaluate potential greener construction activities, technologies, and practices. A cleanup project's environmental footprint is defined by EPA's 2012 *Methodology for Understanding and Reducing a Project's*

Environmental Footprint (EPA 2012) as the combined effect that the multiple project components may have on the environment. Doing an environmental footprint analysis brings a number of benefits to a project, including 1) estimating footprint reductions that might be achieved from making project improvements; and 2) identifying aspects of a cleanup project that dominate the footprint, allowing the project design team to more specifically target those aspects during RD and implementation.

The environmental footprint of a project can be conceptually quantified by evaluating the five green remediation core elements through defined metrics, which are designed to not only reflect parameters that a project design team has a relatively direct ability to change, but also encourage practices that would result in favorable changes to the metric values. It is important to note that the construction activities and the Preliminary (30%) RD criteria and assumptions serve as the baseline for the development of the environmental footprint of the sediment remedy in this appendix. However, the quantification of this environmental footprint for Preliminary (30%) RD is a high-level, conceptual evaluation, based on current available design information assumed contractor equipment and past engineering experience with similar projects.

Section 2 and Table 2.1 of EPA's 2012 *Methodology for Understanding and Reducing a Project's Environmental Footprint* (EPA 2012) present the typical metrics to be considered for a cleanup project; Section 3 of the same document presents the step-by-step process to quantify applicable metrics. The metrics selected for the environmental footprint of the upper reach sediment remedy in this appendix are as follows[2]:

- Total air emissions (Section 4)
- Total water use (Section 5)
- Total use of raw materials and total generated waste (Section 6)
- Total energy use (Section 7)

Quantities for the above metrics are provided in this appendix based on Preliminary (30%) RD assumptions and are intended to be used for a high-level, conceptual green remediation evaluation.

The methodology adopted from EPA's 2012 *Methodology for Understanding and Reducing a Project's Environmental Footprint* (EPA 2012) for this appendix "*…does not constitute an EPA requirement. Use of this methodology is intended to support the remedial process and to help improve the environmental outcome of cleanup efforts but not to disrupt, delay, or otherwise reduce protectiveness of a remedy….*" (EPA 2012).

[2] Quantitative metrics are not provided for the green remediation core element 5, "protection of land and ecosystems," because this core element is described using qualitative metrics, consistent with EPA's 2012 *Methodology for Understanding and Reducing a Project's Environmental Footprint* (EPA 2012).

3 Construction Activities Required for the Sediment Remedy

As stated in the 2012 *Methodology for Understanding and Reducing a Project's Environmental Footprint* (EPA 2012), construction activities associated with the upper reach sediment remedy are the baseline for determining the project's environmental footprint, to comprehensively include the work required to implement, understand the sediment remedy components with the greatest influence, and appropriately represent the environmental impacts and effects the project may potentially generate on the environment. It is important to note that the construction activities included in this appendix are based on past engineering experience with similar projects but are conceptual in nature.

Defining the construction activities is also an opportunity to implement green remediation practices, consistent with the goals of the *Superfund Green Remediation Strategy* (EPA 2010a). The anticipated construction activities needed to implement the sediment remedy can be classified as primary (major construction activities), secondary (minor construction activities), and ancillary (additional activities that are indirectly required or associated with the sediment remedy implementation). For the purposes of the Preliminary (30%) RD, all of the equipment utilized in the primary and secondary construction activities is assumed to be operated using hydrocarbon fuels. The construction activities associated with the upper reach sediment remedy are described in detail in this section.

3.1 Primary Construction Activities

The following anticipated construction activities are conceptual for Preliminary (30%) RD analysis purposes; the selected contractor will identify actual proposed equipment and disposal facility(ies) in the contractor's Remedial Action Work Plan (RAWP). These construction activities are identified as primary because they represent the major construction activities conducted within or outside of the project site and directly contribute to the project's environmental footprint:

- Sediment removal (assumed mechanical dredging, using either a barge-mounted precision excavator or barge-mounted derrick crane/bucket) under these scenarios:
  - Open-water dredging
  - Nearshore dredging
  - Restricted access dredging
  - Shoreline/bank excavation
- Identified debris removal, using an excavator, where possible, or potentially conventional derrick with clamshell, grapple, or vibratory hammer for removal of large debris
- Sediment transloading, upland transportation, and off-site disposal:
  - Transportation (via tugboat and barge) of dredged sediments to the transload facility (located within the LDW vicinity)

- Offloading of the dredge sediments at the transload facility into stockpiles, loading stockpiles into containers, and loading containers onto railcars for off-site upland landfill disposal
  - Transportation (via truck and rail) of dredged sediments for off-site upland landfill disposal (assumed to be in Arlington, Oregon)[3]
  - Water treatment of transloaded materials at the transloading facility
- Material transportation and placement of clean materials (i.e., sand, gravelly sand, gravel, or cobble that meet specified quality criteria) and amendments (assumed to be zero valent iron [ZVI], for Preliminary [30%] RD for capping at Area 18 only) to the upper reach. Materials are intended for backfill, enhanced natural recovery (ENR), residuals management cover (RMC), and caps. The materials are assumed to be placed via mechanical placement, using barge-mounted precision excavator or barge-mounted derrick crane/bucket:
  - Transportation of clean materials to the LDW, including the following:
    - Transportation (via truck) of clean materials from a local quarry to an onshore staging area (outside of the LDW upper reach)
    - Transportation (via tug and barge) of clean materials from an onshore staging area (outside of the LDW upper reach) to the LDW upper reach
    - Transportation (via rail) of ZVI from a vendor in Chicago, Illinois[4], to the upper reach
  - Placement of sand for RMC, ENR, and cap (chemical isolation layer)
  - Placement of sand/ZVI mixed material for cap chemical isolation layer
  - Placement of gravelly sand for general backfill and cap habitat layer
  - Placement of gravel and cobble for cap erosion protection/filter layer
- Structural work:
  - Pile removal and replacement
  - Relocation/reinstatement of docks/floats

3.2 Secondary Construction Activities

The following anticipated activities are identified as secondary because they represent the minor construction activities to be conducted within the project site:

- Site preparation:

[3] The assumption of a disposal facility in Oregon is only for the purposes of the Green Remediation Evaluation and Implementation Approach at Preliminary (30%) RD. The contractor will be responsible for identifying and proposing the actual disposal facility in the RAWP.

[4] The assumption of ZVI product purchase in Illinois is only for the purposes of the Green Remediation Evaluation and Implementation Approach at Preliminary (30%) RD. The contractor will be responsible for identifying and proposing the actual ZVI vendor in the RAWP.

    - Equipment mobilization
    - Shoreline/bank area site clearing
    - Upland staging area setup and staging of equipment
- Bathymetric and topographic surveying
- Environmental compliance
    - Confirmational sediment sampling and environmental monitoring
- Site closure
    - Equipment decontamination and demobilization

3.3 Ancillary Activities (Not Evaluated)

Ancillary activities, or activities indirectly required or associated with the implementation of the sediment remedy, are sourced elsewhere and not dependent on the remedy itself; therefore, they are not considered applicable activities to the project's environmental footprint. Ancillary activities may include the following:

- Import and purchase of electricity, heating/cooling, or steam, and related transmission and distribution
- Mining/quarrying/excavation from borrow pits of raw materials and aggregates required for backfill, capping, RMC, and ENR
- Manufacturing of construction equipment and materials
- Manufacturing of staging equipment and temporary/support facilities
- Extraction, production, refinement, and transportation of fuels, lubricants, etc.
- Transport/commuting of workers to/from the project site
- Landfill emissions, management, and operations

Therefore, ancillary activities are not further considered or evaluated in this Green Remediation Evaluation and Implementation Approach.

4 Green Remediation Core Element 1: Air Emissions

Conventional sediment remediation involves construction activities that consume a significant amount of gasoline, diesel, and other fuels to power heavy equipment. These fuels release air pollutants that contribute to greenhouse gas (GHG) and pollution accumulation in the atmosphere. For this appendix, the evaluation of the green remediation core element 1 was conducted using air emission metrics. Air emissions were estimated for primary and secondary construction activities (as described in Section 3) for the following air constituents:

- Hydrocarbons (HC)
- Volatile organic compounds (VOCs)
- Carbon monoxide (CO)
- Nitrogen oxides (NO_X)
- Particulate matter less than 10 microns in diameter (PM_{10})
- Particulate matter less than 2.5 microns in diameter ($PM_{2.5}$)
- Sulfur dioxide (SO_2)
- Carbon dioxide (CO_2), also a key GHG

This section discusses air emission sources and categories (Section 4.1), baseline equipment assumptions (Section 4.2), assumed fuel usage inputs for the air emission calculations based on time or mass-distance travelled (Section 4.3), associated air emission factors (EmFs; Section 4.4), and the results of the air emission calculations (Section 4.5).

4.1 Air Emissions Sources and Categories

The 2012 *Methodology for Understanding and Reducing a Project's Environmental Footprint* (EPA 2012) and relevant emissions accounting protocols (WRI/WBCSD 2004; EPA 2005) specify establishing "operational boundaries" for the emissions-generating entity under consideration (referred to as the "reporting entity," which can be a country, company, or project). For this appendix, the LDW upper reach project is defined as the "reporting entity."

The air emission calculation process involves: 1) identifying air emissions sources associated with its "operations" (in this case the anticipated construction activities associated with the implementation of the sediment remedy), and 2) categorizing the resultant air emissions as direct ("Scope 1"), indirect ("Scope 2"), or optional ("Scope 3," or other indirect), per EPA (2005, 2012) and WRI/WBCSD (2004)[5], which are defined for this project in the following subsections. The upper reach is a working waterway, and industrial activities and public use will occur simultaneously with anticipated cleanup construction activities. This air emissions inventory evaluates the incremental increase in air

[5] "Direct," "indirect," and "optional" emissions categories are designations presented in EPA's 2005 *Climate Leaders Greenhouse Gas Inventory Protocol* (EPA 2005). Scope 1, 2, and 3 are associated descriptive terms, as well as corresponding designations presented in *The Greenhouse Gas Protocol* (WRI/WBCSD 2004).

emissions related to the upper reach cleanup construction only and does not consider day-to-day air emissions within or adjacent to the upper reach associated with industrial activities or public uses.

4.1.1 *Direct Air Emissions (Due to Primary and Secondary Construction Activities)*

Direct air emissions are from sources derived from conducting remedial construction activities and owned or controlled by the "reporting entity" (the LDW upper reach project). In this case, direct air emissions sources include primary and secondary construction activities (as described in Sections 3.1 and 3.2), such as stationary, mobile, and process-related sources from owned or controlled construction equipment and vehicles used to carry out dredging, transload, upland transportation, disposal[6], material placement, structural work, surveying, and environmental compliance activities.

Direct air emissions were generally estimated for these activities based on assumptions associated with the type and number of equipment and vehicles, the duration of their use based on the specific function, the effective operation time, and the daily fuel consumption. Direct air emissions inventory has been based entirely on calculating fossil fuel consumption (primarily diesel fuel)[7]. However, the opportunities for renewable energy source use during the sediment remedy implementation are identified in Sections 7.2 and 9.4 of this appendix and, as discussed therein, could be further evaluated during RD and implemented in specific construction activities, where feasible, to help reduce the air emissions associated with the sediment remedy.

4.1.2 *Indirect Air Emissions (Not Evaluated)*

Indirect air emissions are a consequence of conducting remedial construction activities but occur at sources owned or controlled by a separate, different "reporting entity." Examples of indirect air emission sources might include importing/purchasing electricity, heating/cooling, or steam, and related transmission/distribution, extraction/quarrying/excavation of raw materials; manufacturing of construction equipment and materials; extraction, production, refinement, and transportation of purchased fuels, lubricants, etc.; employee transport and commuting; and landfill air emissions due to operations at the disposal facility. These indirect air emissions are related to the ancillary activities described in Section 3.3.

These types of air emissions have not been quantified for the project and are not evaluated because they are considered beyond the scope of this analysis; it is unknown to what extent they would be accounted for in any inventories conducted by other "reporting entities" (i.e., manufacturers, vendors,

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6 While transload and upland transportation and off-site disposal of dredge sediments may be conducted outside of the project site and may fall under the control of a another "reporting entity" (i.e., subcontractors), the air emissions resulting from these activities are of significant magnitude relative to the indirect air emissions. Therefore, these air emissions are included in this inventory in the direct emissions category because they are key components of the remedial construction activities from the upper reach project.

7 For the purposes of this Green Remediation Evaluation and Implementation Approach, sulfur content of diesel fuel is assumed to be 15 ppm (ultra-low sulfur diesel).

contractors). Therefore, indirect air emissions are not further considered or evaluated in this Green Remediation Evaluation and Implementation Approach.

4.1.3 Other Greenhouse Gas Emission Contributions (Not Evaluated)

GHGs are gases that are trapped in the atmosphere, due to the combustion of fossil fuels (coal, natural gas, and oil), solid waste, trees, and other biological materials, and as a result of livestock and other agricultural practices, land use, and the decay of organic waste in municipal solid waste landfills (https://www.epa.gov/ghgemissions/overview-greenhouse-gases[8]; EPA 2022). The largest GHG contributors are CO_2, methane (CH_4), and nitrous oxide (N_2O); other GHGs are emitted in smaller quantities. Total GHG emissions are typically reported as metric tons (tonnes) of carbon dioxide equivalents (CO_2-eq), calculated by multiplying the tonnes of each GHG emitted by that GHG's global warming potential[9] (GWP; EPA 2005) and summing the results. Therefore, CH_4 and N_2O can be typically included in the CO_2-eq total.

For all diesel fuel vehicle types tracked as part of this inventory, the emission factors (EmFs) are 0.26 grams per gallon (g/gal) for N_2O and 0.8 g/gal (or less) for CH_4, as presented in *Direct Emissions from Mobile Combustion Sources* (Table A-6; EPA 2008b). CO_2 has an EmF of 10.21 kilograms per gallon (kg/gal; EPA 2022). Although the GWPs of N_2O and CH_4 are 298 and 25, respectively[10], the contribution of CO_2 to CO_2-eq is more than 100 times greater than the collective contribution of N_2O and CH_4[11]. For this reason, GHG emissions from N_2O and CH_4 would not be discernible in a CO_2-eq total reported to two significant figures (as is typical engineering practice for this type of evaluation), and, therefore, they have not been included in this inventory due to this *de minimus* contribution. Therefore, CO_2 and CO_2-eq should be considered equivalent in the air emissions inventory of this appendix.

4.2 Baseline Conditions and Equipment Assumptions

The EPA has developed an engine classification for on-road vehicles (light and heavy duty, locomotives, motorcycles, etc.) and non-road equipment/engines (marine engines/vessel, construction equipment) called the Tier System, with the purpose of identifying air emission standards corresponding to when a specific engine was manufactured and help reduce engine emissions (https://www.epa.gov/emission-standards-reference-guide[12]; EPA 2022). The EPA emission standards for each tier are specific to the type of equipment (on-road vehicles, non-road

[8] Website accessed in May 2022.

[9] The GWP represents the effect a given GHG has on global warming in the atmosphere relative to one unit of CO_2. GWPs for all of the GHGs are listed in *Climate Leaders Greenhouse Gas Inventory Protocol - Design Principles*, Table 6-3 (EPA 2005).

[10] For every tonne of GHG emitted, the contributions to global warming associated with N_2O and CH_4 are 298 and 25 (Table 5-2; EPA 2015) times higher, respectively, than for CO_2.

[11] For each gallon of diesel fuel burned, the CO_2 contribution over the combined N_2O and CH_4 contribution is equal to 10,210 g CO_2/[(0.26 g N_2O x 298) + (0.8g CH_4 x 25)] = 105.

[12] Website accessed in May 2022.

equipment/engines), the year of manufacture, and the engine power. The following is the definition of the EPA's Tier System[13]:

- **Pre-Tier Engines.** All equipment manufactured prior to 1996; it is assumed that this equipment was produced without a requirement to meet specific air emission standards.
- **Tier 1 Engines.** All equipment manufactured between 1997 and 2005.
- **Tier 2 Engines.** All equipment manufactured between 2001 and 2010.
- **Tier 3 Engines.** All equipment manufactured between 2006 and 2011.
- **Tier 4 Engines.** All equipment manufactured in 2008 and later.

As a conservative estimate, baseline conditions and equipment assumptions for the Preliminary (30%) RD air emissions calculations are presented in this appendix based on use of equipment with Tier 2 and lower tier engines (i.e., all equipment manufactured before 2010).

Prior to conducting the Green Remediation Evaluation and Implementation Approach, a survey among local marine construction contractors was performed to identify the approximate distribution of the age of construction equipment currently in active use (as of 2022) in the Puget Sound area in Washington. Along with the baseline conditions described previously, the resulting average age range of the equipment from local market conditions will be used in Intermediate (60%) RD to inform and aid establishing specification requirements (i.e., minimum Tier level required) for the contractor to reduce air emissions during sediment remedy implementation. A summary of baseline conditions and equipment assumptions for all equipment types for the air emission calculations for this appendix is presented in Table L-1.[14]

4.3 Air Emission Calculation Inputs

Direct air emissions for primary and secondary construction activities are calculated based on estimating diesel fuel usage for each construction activity on a time basis (for construction equipment and vehicles) and on a mass-distance basis (for placement material and dredged sediment transport). Emissions were then calculated using available EmFs from various EPA sources (see Section 4.4).

Table L-2 presents the inputs for the direct air emissions calculations by construction activity, including quantities (i.e., dredged sediment and placement material volume), production rates for each construction activity (both obtained from Appendix M of the BODR), anticipated daily fuel

[13] Note that the model year range between tiers overlaps in some cases, because model year requirements vary based on the horsepower of the equipment (e.g., a 50-hp engine manufactured in 2003 was required to meet Tier 1 emission standards, while a 160-hp engine manufactured in the same year [2003] was required to meet instead Tier 2 emission standards; EPA 2022). The range in model years provided in this appendix represents the widest possible range for the specific tier.

[14] Based on local marine construction contractor survey, and for the purposes of this appendix, no equipment anticipated to be used was assumed to be considered Tier 1 or Tier 3.

usage or distance travelled, and estimated daily equipment operation rates and durations (assumed based on professional judgment and experience from similar projects).

4.3.1 Time-Based Fuel Usage Estimates

For all direct air emissions-generating activities (except for transportation of placement material and dredged sediment), the following input parameters were used to estimate total diesel fuel usage:

- Assumed construction vehicle, or equipment types and numbers
- Estimated daily vehicle operation and uptime (effective operation time)
- Estimated fuel consumption rates
- Total implementation time (defined as total quantity divided by the specific production rate for each construction activity)

Table L-3 presents a list of the assumptions for equipment and vehicles and fuel usage per piece of equipment.

4.3.2 Mass-Distance-Based Fuel Usage Estimates

For activities related to transportation of placement material and dredged sediments, a mass-distance travelled approach was used to estimate total fuel usage. The mass of placement material and dredged sediments, and the distance travelled during transportation via rail, truck, or barge, was accounted for, and available ton-mile[15]-based fuel economy factors (EPA 2022) were used to calculate total fuel usage.

Input parameters to estimate fuel usage due to transportation of placement materials (via truck and tug/barge) and dredged sediment for disposal (via rail) included the mass of materials (in tons) and distances travelled (in miles). Assumptions related to rail, truck, and barge diesel fuel consumption and transport capacity are presented in Tables L-4, L-5, and L-6, respectively.

4.4 Air Emission Factor Sources

Air EmFs for HC, VOCs, CO, NO_X, PM_{10}, $PM_{2.5}$, SO_2, and CO_2 are either provided in or are calculated using assumptions from EPA's *Exhaust and Crankcase Emission Factors for Nonroad Compression-Ignition Engines in MOVES3.0.2* (EPA 2021). Air EmFs (in grams of pollutant per horsepower-hour [g/hp-hr]) vary based on the horsepower of the equipment; the equipment and associated engine power assumed in this appendix are listed in Table L-3.

4.4.1 Air Emission Factors for HC, VOCs, CO, NO_x, and PM

Air EmFs for HC, VOCs, CO, NO_X, PM_{10}, and $PM_{2.5}$ are provided in Table A-4 in Appendix A of Motor Vehicle Emission Simulator (MOVES3.0.2; EPA 2021) on-road vehicles (light- and heavy-duty,

[15] A unit of freight transportation is equivalent to a ton of freight moved 1 mile.

locomotives, motorcycles, etc.) and non-road equipment/engines (marine engines/vessel, construction equipment). Based on an analysis of particle size distribution data of particulate matter (PM) emissions from diesel engines, all PM emissions are assumed to be smaller than 10 microns, and 97% of PM emissions are smaller than 2.5 microns (EPA 2021). Therefore, no adjustment was applied to the PM emission factor to calculate total PM_{10} emissions, and an adjustment of 0.97 was applied to the PM emission factor to calculate total $PM_{2.5}$ emissions.

Air EmFs for HC, VOCs, CO, NO_X, PM_{10}, and $PM_{2.5}$ for rail, trucks, and vessels (mass-distance-based air emission estimates) and for the various tier engines (baseline conditions and equipment assumptions described in Section 4.2) are presented in Tables L-4, L-5, and L-6, respectively. Air EFs for HC, VOCs, CO, NO_X, PM_{10}, and $PM_{2.5}$ for construction equipment and vehicles (time-based air emission estimates) and for the various tier engines (baseline conditions and equipment assumptions in Section 4.2) are presented in Table L-7.

4.4.2 Air Emission Factors for SO_2 and CO_2

Air EFs for SO_2 and CO_2 were calculated based relationships provided in MOVES3.0.2 (EPA 2021). Equations 1 and 2 utilize a brake-specific fuel consumption (BSFC) factor, which is provided in Table A-4 in Appendix A of MOVES3.0.2 (EPA 2021), to compute CO_2 and SO_2 air EmFs, respectively.

Equation 1

$$SO_2 = \left(BSFC * \frac{lb}{g} * (1 - \mathrm{soxcnv}) - \mathrm{HC}\right) * 0.01 * soxdsl * \frac{Mass\ SO_2}{Mass\ S}$$

where:

SO_2	=	Sulfur dioxide emission factor (g/hp-hr)
BSCF	=	Horsepower-specific break-specific fuel consumption (unitless)
HC	=	Hydrocarbon emission factor (g/hp-hr)
soxcnv	=	Fraction of fuel sulfur converted to direct PM (unitless)
$\frac{lb}{g}$	=	Conversion factor from pounds to grams (unitless; 453.6)
soxdsl	=	Percent of sulfur in nonroad diesel fuel by weight (%)
Mass S	=	Mass of sulfur (g)
Mass SO_2	=	Mass of sulfur dioxide (g)

Equation 2

$$CO_2 = \left(BSFC * \frac{lb}{g} - HC\right) * \frac{Mass\ C}{Mass\ Diesel} * \frac{Mass\ CO_2}{Mass\ C}$$

where:

CO_2	=	Carbon dioxide emission factor (g/hp-hr)
BSCF	=	Horsepower specific break-specific fuel consumption (unitless)
HC	=	Hydrocarbon emission factor (g/hp-hr)
$\frac{lb}{g}$	=	Conversion factor from pounds to grams (unitless; 453.6)
Mass C	=	Mass of carbon (g)
Mass Diesel	=	Mass of diesel (g)
Mass CO_2	=	Mass of carbon dioxide (g)

Air EmFs for SO_2 and CO_2 for rail, trucks, and barges (mass-distance-based air emission estimates) and for the various tier engines (baseline conditions and equipment assumptions described in Section 4.2) are presented in Tables L-4, L-5, and L-6, respectively. Air EmFs for SO_2 and CO_2 for construction equipment and vehicles (time-based air emission estimates) and for the various tier engines (baseline conditions and equipment assumptions described in Section 4.2) are presented in Table L-7.

4.5 Air Emission Results

Detailed and high-level summaries of the total direct air emissions (in metric tonnes) for each of the eight air constituents are presented in Tables L-8 and L-9, and Figure L-1, broken out by construction activity. As depicted in Figure L-1, for all air constituents evaluated, the construction activities that represent the vast majority of the total direct air emissions encompass 1) sediment transload, upland transportation, and disposal, and 2) clean material transportation and placement, followed by 3) sediment dredging.

As shown in Figure L-1, the four air constituents that contribute the most to the direct air emissions due to the sediment transload, upland transportation, and disposal activity are CO (53%), NO_x (56%), SO_2 (59%), and CO_2 (60%). The remaining four air constituents (HC, VOCs, PM_{10} and $PM_{2.5}$) account for between 40% and 49% of direct air emissions for this same construction activity. For the clean material transportation and placement activity, all air constituents contribute between 17% and 22% to the direct air emissions. For the sediment dredging activity, all air constituents contribute in a similar proportion (approximately from 13% to 22%) to the direct air emissions.

High-level summaries of the total direct air emissions (in metric tonnes) for each of the eight air constituents are presented in Tables L-10 and Figure L-2, broken out by equipment type. Among all vehicle and equipment types for each of the construction activities, The use of various vessels (including tugboats, push boats, and work boats, used to not only haul dredge sediment to the transload facility, but also to haul clean materials for placement to the site and position other marine construction equipment) accounts for the majority of the total direct air emissions for four of eight air constituents (HC, VOCs, PM_{10}, and $PM_{2.5}$) ranging from 42 to 46%. The transportation via rail of dredged sediments (for off-site disposal) and ZVI (assumed for Preliminary [30%] RD to be needed for capping purposes) accounts for the majority of the total direct air emissions for six of the eight air constituents (HC, VOCs, CO, NO_x, SO_2, and CO_2) ranging from 35% to 38%. Truck transportation (to haul dredged sediments to an intermodal facility for off-site upland landfill disposal and to haul clean placement materials from a local quarry to an onshore staging area) represents 12% to 25% of total direct air emissions for all eight air constituents, making it in general the third largest source of contaminants.

Section 9.1 presents the potential BMPs that could be applicable to the various construction activities of the upper reach sediment remedy and help reduce air emissions during remedial construction.

5 Green Remediation Core Element 2: Use of Water

As part of the 2012 *Methodology for Understanding and Reducing a Project's Environmental Footprint* (EPA 2012), use of water was evaluated as green remediation core element 2. Water use within the context of sediment remediation is assumed to be relatively minimal for most remedial technologies. The most common nonpotable water uses (outside of personnel use) identified in the implementation of the sediment remedy are water spraying for dust control purposes, water used in equipment decontamination, and additional water needs at the transload facility.

Water spraying to address dust control is expected to be limited to application at the on-site upland staging area, where equipment and materials may be staged during construction. It is assumed that water would be applied at a rate of 4,000 gallons (equivalent of one water truck) per week to limit dust production during construction in the summer months (July through September). However, the in-water work window for the LDW is from October to February, outside of the summer months, so if the work happens as scheduled, no water use is expected from water spraying.

Water use associated with equipment decontamination is expected to be low. Decontamination is only anticipated to occur during mobilization (prior to the start of construction), prior to transitioning from dredging to capping activities, and during demobilization (at the end of construction). The decontamination process is limited to only equipment that comes into contact with dredged sediments (i.e., material handling buckets) and is expected to require less than 5,000 gallons of water during the course of each construction season.

Similar to equipment decontamination, water use at the transload facility is expected to also be low; it is assumed that the transload facility would require less than 1,000 gallons of water during the course of each construction season.

Overall, the water use of the LDW upper reach sediment remedy is expected to be minimal, with water primarily being used for equipment decontamination and water use at the transload facility. It is assumed that all of the water use described in this section is nonpotable water (either rain collected water, river water, or a nonpotable public water supply; no potable water usage is considered in this appendix). The total nonpotable water consumption for two construction seasons is expected to be approximately 12,000 gallons.

Section 9.2 presents the potential BMPs that could be applicable to the various construction activities of the LDW upper reach sediment remedy and help in reusing water and reducing water consumption during implementation.

6 Green Remediation Core Element 3: Use of Materials and Waste Generation

Consistent with the 2012 *Methodology for Understanding and Reducing a Project's Environmental Footprint* (EPA 2012), the green remediation core element 3 (use of materials and waste generation) focuses on quantification of raw, recycled, and waste materials associated with the LDW upper reach sediment remedy with the intent of reducing raw material usage and waste generation and increasing material recycling, all to the extent practicable. Overall, the benefits of quantifying this core element may include the following:

- Reducing the depletion of natural resources, such as sand, gravel, and cobble
- Reducing the use of landfills for disposal
- Reducing the environmental impact of production of new materials
- Reducing the overall project cost

Table L-11 presents the quantities of raw and waste materials identified from construction activities required for the sediment remedy.

The largest use of clean raw materials for the sediment remedy is anticipated to be for material placement activities (approximately 67,800 cubic yards, including the need to import clean materials, such as sand, gravelly sand, gravel, and cobble, used for backfill, RMC, ENR, and capping) and for structural work (including the need to replace approximately 98 timber and steel piles and approximately 650 square feet of steel bulkhead); see Table L-11.

Consistent with Section 10.5.2 of the BODR, it was assumed in this appendix that all materials for placement activities will be regionally sourced from commercially available suppliers (i.e., sand and gravel quarries) that can supply materials for backfill, capping (e.g., sand, gravel, cobble) and for RMC/ENR (e.g., sand). These materials will need to meet design quantities, delivery schedules, gradations, and chemical quality criteria established in RD for each material type. As stated in the BODR (Section 10.5.2), beneficial use of clean dredged material was evaluated as a potential source of materials, but it entails significant coordination and timing complications, among other issues, and for recent cleanup projects, has been difficult to accomplish. Given the anticipated schedule for cleanup in the upper reach, beneficial use of clean dredged material has been screened from further consideration. If beneficial use opportunities are identified during subsequent design stages, consideration of these sources will be included in an updated Green Remediation Evaluation and Implementation Approach.

The largest source of waste generated is the dredge contaminated sediment, which will be approximately 117,700 cubic yards, equivalent to 179,300 tons, to be disposed in an off-site landfill facility (Table L-11). The beneficial use of dredged contaminated sediments either before or after treatment was also investigated for the LDW project (AECOM 2012). However, contaminated untreated sediment is not suitable for direct beneficial use applications and therefore, beneficial use of contaminated sediments has not been further considered. In addition to dredged sediments, approximately 93 steel and timber piles, approximately 88 piles from the stub pile timber bulkhead, and approximately 650 tons of debris will be required to be removed and will generate additional waste (Table L-11). Because of the metals contained in some of these structures, they are expected to have the greatest opportunity for reuse or recycling to reduce landfill disposal.

Section 9.3 presents the potential BMPs that could be appliable to the various construction activities of the LDW upper reach sediment remedy and help reduce raw material use and waste generation.

7 Green Remediation Core Element 4: Use of Energy

Significant amounts of energy, specifically originating from fossil fuels, are expected to be consumed to power engines and equipment, facilitate transport activities, and run operations associated with the LDW upper reach sediment remedy. As part of the 2012 *Methodology for Understanding and Reducing a Project's Environmental Footprint* (EPA 2012), use of energy based on fossil fuel consumption (gasoline, diesel, etc.) to carry out the sediment remedy was evaluated as a metric for green remediation core element 4; potential options to use renewable energy are also discussed.

7.1 Total Energy Use

Typical sediment remedies are primarily conducted with diesel-powered engines and equipment. Diesel fuel consumption is assumed to be the key metric that quantifies the total energy that is anticipated to be utilized for the upper reach remedy implementation. Table L-12 presents the approximate volume of diesel fuel consumed for each construction activity for the overall LDW project. The highest energy consumption is anticipated to occur for the upland transportation and disposal of sediment material (approximately 149,000 gallons), followed by mechanical offloading (approximately 58,200 gallons) at the transload facility and all types of dredging (approximately 39,400 gallons). Also, all types of material placement, structural work, and transportation of clean placement material to the upper reach account for an energy consumption of approximately 22,600, 23,400, and 19,200 gallons, respectively.

Consistent with Section 10.2.5 of the BODR, it is assumed that the upper reach project has commercial transload facilities in close proximity (Duwamish Reload Facility, operated by WM [formerly Waste Management], and 5400 W. Marginal Way facility, operated by Lafarge North America) that could readily be used for transloading dredged materials from barges and loading into trucks or rail cars for transportation to a disposal facility. Since a project-specific transload facility will not be further considered in RD, it is assumed that for the baseline conditions scenario, all transloading activities would occur at a commercial facility that only operates a diesel-powered crane for transloading.

Minor construction activities, such as surveying and environmental monitoring, are expected to use the least amount of diesel-based energy (less than 1,000 gallons each). Based on the Preliminary (30%) RD assumptions, the upper reach sediment remedy is anticipated to use approximately 313,300 gallons of diesel energy over two construction seasons.

7.2 Potential Renewable Energy Use

With recent advancements in electric-powered engines, manufacturers are beginning to produce electric-powered construction equipment alongside their legacy diesel equipment. According to Seattle City Light (https://www.seattle.gov/city-light/about-us/what-we-do), 91% of all electric energy generated in 2020 was from renewable sources (86% hydropower and 5% wind power) and another 6% came from low- to no-emission sources (nuclear and biogas); the remaining 3% came from unspecified sources. This means the use of electric-powered equipment can be nearly emission-free.

Knowing that one of the highest diesel energy consumption sources is derived from transloading activities, significant energy savings could be realized with an electric-powered crane. Of the approximately 58,200 gallons of diesel anticipated to be consumed in the mechanical transloading process (which includes the use of a tugboat, a 100-ton crane, and a front-end loader), the diesel-powered offloading crane represents approximately 70% of the total fuel consumption (or 40,700 gallons of diesel fuel). Therefore, using an electric-powered crane or excavator to offload dredge material would reduce the total diesel energy consumption to approximately 17,500 gallons. One of the two commercial transload facilities located in the LDW, the Duwamish Reload Facility, is currently using electric power for transloading operations off of barges. Selection of this transload facility by the contractor could eliminate fuel consumption and substantially reduce associated air emissions for the offloading portion of the transloading process (but would not affect the tugboat fuel consumption).

In addition to electrifying land-based construction equipment, contractors are also beginning to evaluate electrifying water-based dredge equipment. In 2021, the Port of Long Beach completed a 10-year long, approximately $1.5 billion, electrification project at the Long Beach Container Terminal at Middle Harbor, and is now able to conduct neatly all operations (including maintenance dredging) using electricity (https://polb.com/port-info/news-and-press/port-reaches-milestone-at-long-beach-container-terminal-08-20-2021/).[16] To supply the electrical power required by the Long Beach Container Terminal, the Port of Long Beach installed four electrical substations capable of delivering shore-power to nearby vessels. The installation of these substations took over four years and cost approximately $185 million. This has resulted in overall air emissions reductions, cheaper operating/maintenance costs, and downtime optimization (i.e., no need for refueling, less maintenance) during in-water construction activities. Currently there are no substations along the Upper Reach capable of delivering sufficient electrical power to perform electric dredging, and it is assumed at least two substations or equivalent temporary power drops would be needed to allow for electric dredging in the entire Upper Reach area.

As part of the survey among local marine construction contractors discussed in Section 4.2, each contractor was asked about the potential for the conversion of their existing diesel-powered equipment into electric-powered. A summary of challenges and concerns identified follows:

- No current availability of electric-powered dredges in Washington State, so equipment would be required to be either:
  - Retrofitted (with an estimated average cost of $200,000 per piece of equipment)
  - Shipped from southern California (with an estimated mobilization cost of $200,000 per piece of equipment)

[16] Website accessed in May 2022.

  - Purchased new (with an estimated cost of $1,000,000 per piece of equipment)
- Additional capital investment for ancillary equipment required to support electric-powered dredging would be needed:
  - Procurement of electric cable, cable reel, transformers, protective housing for cable (with a total estimated cost between $200,000 and $400,000)
  - Development of infrastructure consisting of multiple electric terminals (with an estimated cost between $100,000 and $300,000, per terminal location); costs estimated in coordination with the local electric utility (Seattle City Light)
- Specific electric equipment technical and logistical requirements and considerations limit the implementability of electric dredging and/or could delay completion of the remedial action in the upper reach:
  - Electric dredges are likely limited to a 1-mile radius around the electric terminal; ideally power sources would be located on both sides of the river to cover all potential dredging areas
  - Battery-powered equipment currently has limited reliability and does not supply enough active time to be feasible (maximum of 4 hours capacity) without multiple redundant equipment dedicated to a single task
  - Management of electric tether (i.e., electric cable connecting shorepower to the dredge):
    - May add up to 20% additional downtime on construction activities as reeling of the cable is an intensive activity, when moving from one dredging location to another, and contractors may be unfamiliar with the equipment
    - Additional barge, tugboat, and deckhands required for the additional tether-related activities
    - Electric tether would be ideally placed along the shoreline; floating cable across the LDW is an option, but would necessarily require protective housings, adding additional cost, and complexity/logistics/coordination for LDW navigation
  - Shallow water presents increased risk of damage to electric cable
  - High level of coordination required for vessel traffic and tribal fishing as all electric dredging equipment (dredge, cable, and additional vessels and equipment for the additional tether-related activities) will block or partially block navigation areas within the LDW
- Timing for implementation:
  - Local contractors and Seattle City Light identified a minimum lead time of approximately 1 year to be able to accommodate and implement electric dredges and required infrastructure in the Seattle area (including time for procurement and retrofitting of dredging equipment, electric terminal design and installation, etc.)

- Unproven technical feasibility with Pacific Northwest contractors; local contractors are unfamiliar and inexperienced with electric dredging operations

Many of the above challenges would require additional capital investment to purchase, develop, or retrofit existing equipment. Additional evaluations will continue to be carried forward during RD to assess the viability of electrification for sediment remediation in the LDW through the various construction activities. The feasibility of implementing electrical dredging also depends upon the timing when remedial action will occur. Because the upper reach design and overall anticipated implementation schedule are farther along than the middle or lower reaches, electrical dredging may be more feasible for consideration for the middle and lower reaches.

Section 9.4 presents the potential BMPs that could be appliable to the various construction activities of the LDW upper reach sediment remedy and help reduce consumption of diesel-powered energy. In addition to the BMPs listed in Section 9.4, the 2012 *Methodology for Understanding and Reducing a Project's Environmental Footprint* (EPA 2012) identifies the following renewable energy sources that can be considered in place of diesel fuel:

- Use of biodiesel in place of diesel for heavy equipment use or transportation
- Voluntary purchase of renewable electricity from an electricity provider in the form of a "green pricing" or "green marketing" product
- Voluntary purchase of renewable electricity through the purchase of renewable energy certificates

8 Green Remediation Core Element 5: Protection of Land and Ecosystems

The protection of land and the ecosystem is another important aspect of green remediation. Ecosystems have physical, biological, and chemical elements that facilitate the transfer and storage of materials and energy through the environment. The ROD describes the criteria to define the areas that are considered habitat for compliance with Section 404 of the Clean Water Act (CWA) and Section 7 of the Endangered Species Act (ESA).

Per the 2012 *Methodology for Understanding and Reducing a Project's Environmental Footprint* (EPA 2012), this green remediation core element 5 involves minimizing degradation and/or enhancing the ecology of the project (the LDW upper reach) and other affected areas, through a qualitative description of the effects of the sediment remedy on land and ecosystems. BMPs provide tools for preserving existing wildlife habitat during remediation and accelerating the beneficial reuse of previously degraded land to enhance biodiversity following remediation actions.

The LDW upper reach sediment remedy will primarily be implemented from water-based vessels, but limited excavation of intertidal areas and banks may require land-based excavation equipment, land access, and specific staging areas to manage the excavated material (see Section 10.2.1); in those cases, clearing and grubbing of existing vegetation will be needed. In addition, an on-site upland staging area may be necessary to stockpile clean placement material or as a location to move equipment from the uplands into the water. For the protection of land, selection of an upland staging area (if required) and transloading facility should be limited to areas already developed for industrial use, to avoid clearing trees and other potential habitat.

As with all in-water projects, work is restricted to specific windows designed to minimize impacts on the aquatic ecosystem. Approved in-water construction activities will occur during fish windows designated for the LDW (generally from October through February) to protect threatened or endangered species under the ESA.

Section 11.6 of the BODR presents the design measures to offset aquatic habitat modifications (areas defined as above -10 feet mean lower low water), such as placement of backfill to return the dredged area to existing elevations, which will be incorporated into the LDW upper reach sediment remedy, and for compliance with the ROD, as well as Section 404 of the CWA and Section 7 of the ESA. Section 9.5 of this appendix presents additional potential BMPs that could be applicable to the various construction activities of the upper reach sediment remedy and help in protecting land and ecosystems.

9 Implementation Approach: Best Management Practices

This section presents a comprehensive list of potential BMPs that might be applicable to the five green remediation core elements identified the *Superfund Green Remediation Strategy (*EPA 2010) in relation to the upper reach sediment remedy and its anticipated construction activities. Potential applicable BMPs, consistent with the BODR and the Preliminary (30%) RD, are described in the following sections. The listed BMPs will be further assessed in Intermediate (60%) RD for availability of more advanced technologies and materials, for feasibility and implementability of greener practices into the sediment remedy, and in consideration of procurement restrictions. To the extent that specific BMPs will be required, these BMPs will be incorporated into the project specifications, which will be developed for submittal with the Intermediate (60%) RD deliverable. The contractor will have inherent motivation to select other specific BMPs listed in this section in cases where such BMPs will increase efficiency and reduce cost, and therefore, have an appropriate return on investment that justifies their use.

9.1 BMPs for Air Pollutant Emission Reduction

The *Green Remediation Best Management Practices: Clean Fuel & Emission Technologies for Site Cleanup* (EPA 2010b) establishes the following potential BMPs to reduce emissions of air pollutants during sediment remedy implementation:

- **Selection of Appropriately Sized-Vehicles:** Selection of appropriately sized vehicles for the construction activity is key in reducing emissions of air pollutants. Using undersized equipment may result in longer construction durations, which translate into more fuel consumption and, therefore, increasing air emissions. Similarly, using oversized equipment may result in wasted fuel and associated higher air emissions.
- **Effective Operation and Maintenance:** To increase the efficiency of vehicles and construction equipment, the following BMPs are available:
  - Engine idling restrictions for construction equipment
  - Automatic shut-down devices programmed to cut an engine after a predetermined time limit (such as 3 minutes) unless engine operation is needed for intermittent activities
  - Preventive maintenance to ensure peak operating efficiency (e.g., engine tune-ups according with manufacturer recommendations, checking fuel tank for dirt/insects, keeping tight connections and moving parts well-lubricated, periodic replacement of filters in air and fuel systems, use of manufacturer's recommended grade of motor oil)
  - Changes in daily routines (e.g., selecting high-quality equipment lubricants made of biodegradable ingredients, cleaning up any spilled fuels immediately to avoid damage to vehicles or engine bodies; handling all materials used to absorb fuel spills in accordance with health and safety requirements and storing the material in

noncombustible containers; properly disposing or recycling spent materials or liquid waste such as tires, transmission or brake fluids, used oil and filters, wash-rack waste, coolant, and spent solvent; simple changes in driving techniques [such as avoiding rapid acceleration, braking, and excessive speeds, and removing unneeded items in a vehicle])

  - Effective fleet management (e.g., planning to minimize fuel consumption through efficient transportation routes, transfer of only full loads, selection of appropriately sized vehicles, and low-carbon commuting and travel by workers)
- **Advanced Diesel Technologies:** Clean diesel technologies applied to on-road and non-road (i.e., off-road) vehicles can significantly reduce diesel pollution created during remediation. As discussed in Section 4.2. the Intermediate (60%) RD will establish specification requirements (i.e., minimum Tier level required) for the contractor to diminish air emissions during sediment remedy implementation. Diesel engines tend to last longer than gasoline engines and are commonly retrofitted with a form of advanced exhaust after treatment to reduce emissions. Forms of advanced technology are diesel oxidation catalysts, diesel particulate filters, partial diesel particulate filters, and selective catalytic reduction.
- **Alternative Fuels:** The use of biofuels and biodiesel blends provides opportunities for reducing PM and sulfur dioxide (SO_2) emissions.[17]
- **Fuel Additives:** Additives can enhance fuel performance and often result in improved fuel economy and lower air emissions (e.g., emulsified diesel).
- **Fuel-Efficient or Alternative-Fuel Vehicles:** The following are options for fuel-efficient or alternative-fuel vehicles:
  - Replacement of aging vehicles with newer ones operated by more fuel-efficient engines or relying on alternative fuel can significantly reduce fossil fuel consumption and associated air emissions.
  - Deploying vehicles with higher fuel efficiency for both on-site and off-site activities should also lead to lower fuel costs for site cleanup.
  - Alternative vehicles include those using electric, hybrid gasoline/electric, or compressed natural gas fuel systems.

9.2 BMPs for Water Use

The *Green Remediation: Incorporating Sustainable Environmental Practices into Remediation of Contaminated Sites* (EPA 2008a) and *Green Remediation Best Management Practices: Excavation and*

[17] As of 2010, the use of ultra-low sulfur diesel is a requirement for all non-road and all new on-road diesel-powered vehicles and equipment with engine ratings of 50 horsepower or more, according to the *Green Remediation Best Management Practices: Clean Fuel & Emission Technologies for Site Cleanup* (EPA 2010b).

Surface Restoration (EPA 2019) establish the following potential BMPs for water use during remedy implementation:

- **Minimizing Water Consumption:** Any construction activity should minimize freshwater consumption (e.g., using native vegetation requiring little or no irrigation, using high-efficiency water fixtures, valves, and piping).
- **Maximize Water Reuse:** Any construction activity should maximize water reuse during daily operations and treatment processes.

BMPs aimed to protect water quality during dredging operational activities are described in detail in Section 11.1 of the BODR.

9.3 BMPs for Use of Materials and Waste Generation Reduction

BMPs intended to reduce the use of raw materials and waste generation will be established in consideration of procurement restrictions (i.e., the implementing entity could be a public entity). Some of the BMPs may be noncompetitive and, therefore, not acceptable for project implementation (e.g., selection of a greener supplier or specific greener products).

The *Green Remediation Best Management Practices: Materials and Waste Management* (EPA 2013a) establishes the following potential BMPs to reduce waste generation and the use of virgin materials during remedy implementation:

- **Purchase of Greener Products:** The incorporation of greener products should begin during planning stages of the cleanup, to facilitate sustainable materials management[18] during construction. The following BMPs are available:
  - Choose material suppliers with availability, production and distribution center near the site to minimize fuel consumption associated with delivery (if allowed under procurement rules).
  - Choose suppliers that will take back unused materials.
- **Promote Material Reuse and/or Recycling.** The following BMPs are available during remedy implementation to promote material reuse and recycling:
  - Use reconstituted reactive media whenever feasible (e.g., regenerated rather than virgin granular activated carbon[19]).
  - Use non-virgin and/or locally sourced backfill and cap materials (e.g., beneficial use) provided that gradation and chemical quality criteria can be ensured.

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[18] The *Green Cleanups Contracting and Administrative Toolkit* (EPA 2015b) is useful EPA guidance, which includes sample procurement and contract language and criteria for sustainable materials management.

[19] As described in Section 10.4, AC amendment is not included in ENR as part of the Preliminary (30%) RD. If AC amendment is selected as a component during a subsequent phase of the RD, prescriptive criteria established for AC will also be identified as part of the Intermediate (60%) RD.

  - Salvage and sort clean materials with potential value for on-site reuse (such as removed vegetation or armor), recycling (e.g., metal, concrete), resale, or donation.
  - Recycle routine single-use items regularly.

9.4 BMPs for Energy Use Reduction and Renewable Energy Promotion

The *Green Remediation Best Management Practices: Integrating Renewable Energy into Site Cleanup* (EPA 2011a) and *Green Remediation Best Management Practices: Integrating Renewable Energy* (EPA 2022) establishes the following potential BMPs to reduce energy use and maximize the use of renewable energy during remedy implementation:

- **Assessing and Optimizing Energy Use:** To the extent possible, replace aging equipment with newer models meeting higher energy conservation standards.
- **Maximizing Energy Efficiency and Monitoring Energy Demand:** General BMPs for energy conservation and efficiency include the following:
  - Follow equipment vendor recommendations for routine maintenance, conduct periodic inspections, and quickly repair/upgrade industrial equipment such as fans, pumps, air compressors, and others when needed.
  - Track energy consumption through tools such as plug-in meters and whole-system meter devices.
- **Purchasing Clean Energy from Off-Site Resources:** Where on-site production of renewable energy is technically or economically infeasible or cannot meet the full energy demand of cleanup, clean energy can be voluntarily purchased. In addition, selecting clean power products certified through an independent third-party program (such as the Green-e Energy Program) can be incorporated to promote the use of renewable energy.
- **Diversify the Sources of Renewable Energy:** To the extent possible, increase power generation capacity and reduce single-source reliance.

9.5 BMPs for Land Resource/Ecosystem Protection

Section 11.6 of the BODR presents some examples of design measures to offset aquatic habitat modifications (areas defined as above -10 feet mean lower low water) that may be incorporated into the LDW upper reach sediment remedy to the extent practicable, and for compliance with the ROD, Section 404 of the CWA, and Section 7 of the ESA.

The *Green Remediation Best Management Practices: Excavation and Surface Restoration* (EPA 2019) and the *Ecosystem Services at Contaminated Site Cleanups* (EPA 2017) establish the following additional BMPs for the protection of land resources and ecosystems:

- **Safeguarding Land and Ecosystems**
  - Restrict machinery, vehicle, and worker traffic to well-defined corridors that are minimally obtrusive and to minimize soil compaction and land disturbance during site activities.
  - Include design work zones, traffic plans, and construction phases to minimize or avoid habitat disruption.
  - Avoid removing trees in staging areas/uncontaminated zones.
  - Inspect equipment left on site before renewing field activities, to avoid harming animals potentially nesting in the equipment. Operation of equipment with nest debris also could cause equipment inefficiency or breakdown.
  - Reuse on-site or local clean materials (e.g., on-site stockpiled sand and gravel material) rather than importing additional material for fill.
- **Site Preparation and Land Restoration**
  - Revegetate backfilled areas as quickly as possible through use of a diverse mix of native grasses, shrubs, forbs, and trees supporting many habitat types.
  - Restore and/or maintain ecosystems in ways that mirror existing general conditions.
  - Seed or install native rather than non-native species, which typically increases the rate of plant survival and minimizes the need for irrigation and soil or plant inputs.
  - Substitute chemical fertilizers, herbicides, or pesticides with nonsynthetic inputs, integrated pest management methods, and soil solarizing techniques during vegetation planting, transplanting, or ongoing maintenance.

10 References

AECOM 2012. *Final Feasibility Study*. Submitted to the U.S. Environmental Protection Agency and the Washington State Department of Ecology. Ocotber 31, 2012.

Anchor QEA and Windward 2019. *Remedial Design Work Plan for the Lower Duwamish Waterway Upper Reach*. Submitted to the U.S. Environmental Protection Agency. December 16, 2019.

ASTM (ASTM International), 2017. Standard Guide for Greener Cleanups. West Conshohocken, Pennsylvania: ASTM International. DOI: 10.1520/E2893-16E01.

ASTM, 2020. Standard Guide for Integrating Sustainable Objectives into Cleanup. West Conshohocken, Pennsylvania: ASTM International. DOI: 10.1520/E2876-13R20.

City of Seattle, 2015. *Seattle Biological Evaluation*. Prepared for City of Seattle. May 2015

EPA (U.S. Environmental Protection Agency), 2005. Climate Leaders Greenhouse Gas Inventory Protocol - Design Principles. May 2005.

EPA, 2008a. Green Remediation: Incorporating Sustainable Environmental Practices into Remediation of Contaminated Sites. EPA 542-R-08-002. April 2008.EPA, 2008b. Direct Emissions from Mobile Combustion Sources. USEPA Office of Air and Radiation. EPA 430-K-08-004. May 2008.

EPA, 2009a. Clean and Green Policy. Prepared by Office of Environmental Cleanup, Office of Air, Waste, and Toxics, and Office of Compliance and Enforcement. August 13, 2009.

EPA, 2009b. Principles for Greener Cleanups. Prepared by Office of Land and Emergency Management. August 27, 2009.

EPA, 2010a. Superfund Green Remediation Strategy. Prepared by Office of Solid Waste and Emergency Response and Office of Superfund Remediation and Technology Innovation. September 2010.

EPA, 2010b. Green Remediation Best Management Practices: Clean Fuel & Emission Technologies for Site Cleanup. Prepared by Office of Solid Waste and Emergency Response (5102G). EPA 542-F-10-008. August 2010.

EPA, 2011a. Green Remediation Best Management Practices: Integrating Renewable Energy into Site Cleanup. Prepared by Office of Solid Waste and Emergency Response (5102G). EPA 542-F-11-006. April 2011.

EPA, 2011b. Introduction to Green Remediation. Prepared by Office of Solid Waste and Emergency Response (5102G). May 2011

EPA, 2012. Methodology for Understanding and Reducing a Project's Environmental Footprint. Prepared by Office of Solid Waste and Emergency Response and Office of Superfund Remediation and Technology Innovation. EPA 542-R-12-002. February 2012.

EPA, 2013a. Green Remediation Best Management Practices: Materials and Waste Management. U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response (5203P). EPA 542-F-13-003. December 2013.

EPA, 2013b. Control of Emissions from Idling Locomotives. Office of Transportation and Air Quality. EPA-420-F-13-050 (supersedes EPA-420-F-08-014). December 2013.

EPA, 2014. Record of Decision. Lower Duwamish Waterway Superfund Site. U.S. Environmental Protection Agency.

EPA, 2015a. Green Remediation Best Management Practices: An Overview. U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response (5203). EPA 542-F-16-001. December 2015 Update.

EPA 2015b. Green Cleanups Contracting and Administrative Toolkit. Office and Land and Emergency Management. Office of Superfund Remediation and Technology Innovation. December 2015 Update.

EPA, 2016a. Memorandum to: Regional Superfund National Program Managers, Regions 1-10 Regional Counsels, Regions 1-10. Regarding: Considerations of Greener Cleanup Activities in the Superfund Cleanup Process. August 2, 2016

EPA 2017. Ecosystem Services at Contaminated Site Cleanups. Engineering Forum Issue Paper. EPA 542-R-17-004. August 2017.

EPA, 2019. Green Remediation Best Management Practices: Excavation and Surface Restoration. Prepared by Office of Land and Emergency Management (5203). EPA 542-F-19-002. August 2019.

EPA, 2021. Exhaust and Crankcase Emission Factors for Nonroad Compression-Ignition Engines in MOVES3.0.2. Assessment and Standards Division - Office of Transportation and Air Quality. EPA-420-R-21-021. September 2021.

EPA, 2022. Emission Factors for Greenhouse Gas Inventories. GHG Emission Factor Hub. April 1, 2022.

WRI/WBCSD (World Resources Institute and World Business Council for Sustainable Development), 2004. The Greenhouse Gas Protocol. A Corporate Accounting and Reporting Standard. Revised Edition. March 2004.

Tables

Table L-1
Baseline Conditions and Equipment Assumptions for Air Emissions

Activity	Equipment type	Description	Emission Basis and Assumptions: Based on Fuel Consumption or Distance	Fuel Consumption [1] (gallons/hour)	Distance (miles)	Uptime (%)	Shift Duration (hour/day)	Production Rate	Assumed Distribution of Equipment Based on EPA's Tier System [2,3] (%): Pre-Tier	Tier 2
Site Preparation	Tug Boat (800 HP)	Mobilization of 2 derrick barges and 3 material handling barges to the site per construction season	Fuel Consumption	28	--	20%	8	N/A	100%	0%
Structural Work	Crane (150-ton)	Pulling/installation of piles and temporary dismantling of structures	Fuel Consumption	16	--	70%	10	25 piles per day/68 days of work	0%	100%
	Push Boat (800 HP)	Move barge	Fuel Consumption	28	--	70%	10	25 piles per day/68 days of work	100%	0%
	Work Boat (Two-stroke)	Transportation for crew members; also, assist with pulling/installation of piles, temporary dismantling of float, outfall work, and debris removal	Fuel Consumption	1.5	--	20%	10	25 piles per day/68 days of work	100%	0%
Sediment Dredging	Crane (150-ton)	Used for open-water, nearshore, and contingency re-dredging	Fuel Consumption	16	--	70%	10	Ranging from 800 to 1,200 cy per day	0%	100%
	Hydraulic Excavator (180 HP)	Used for restricted access dredging and shoreline/bank excavation	Fuel Consumption	20	--	70%	10	500 cy per day	0%	100%
	Push Boat (800 HP)	Move barge	Fuel Consumption	28	--	70%	10	Linked to crane/excavator	100%	0%
	Work Boat (Two-stroke)	Transportation for crew members, also assist with ancillary dredging activities	Fuel Consumption	1.5	--	20%	10	Linked to crane/excavator	100%	0%
Sediment Transloading, Upland Transportation, and Disposal	Tug Boat (3,000 HP)	Barge transport of sediment to and from transload facility (assumed 5 miles, one-way)	Distance	806 ton-mi/gal (or 40 gal/hr)	5	20%	10	N/A	100%	0%
	Offloading Crane (100-ton)	Transload sediment from barge to truck or railcar	Fuel Consumption	16	--	70%	10	1,200 cy per day	0%	100%
	Front-end Loader (Rough Terrain Forklift)	Assist in transloading of sediment to truck or railcar	Fuel Consumption	6	--	80%	10	Linked to crane	0%	100%
	Truck (20-ton Dump Truck)	Upland transport of dredged sediments to a nearby intermodal facility for loading onto a railcar	Distance	131 ton-mi/gal (or 13 gal/hr)	20	N/A	10	N/A	0%	100%
	Rail (Locomotive+Train)	Rail transport of dredged sediments from intermodal facility to a Subtitle D disposal facility in Arlington, OR (300 miles, one-way) [4]	Distance	470 ton-mi/gal	300	N/A	10	N/A	0%	100%
Material Transportation and Placement	Truck (20-ton Dump Truck)	Upland transport of capping, backfill, ENR, and RMC materials from local quarry to shore (assumed 20 miles)	Distance	131 ton-mi/gal (or 13 gal/hr)	20	N/A	10	N/A	0%	100%
	Rail (Locomotive+Train)	Rail transport of zero-valent iron from vendor in Chicago, IL (1,700 miles, one-way) [5]	Distance	470 ton-mi/gal	1,700	N/A	10	N/A	0%	100%
	Tug Boat (3,000 HP)	Barge transport of capping, backfill, ENR, and RMC materials from shore to LDW UR site (assumed 20 miles)	Distance	806 ton-mi/gal (or 40 gal/hr)	20	20%	10	N/A	100%	0%
	Crane (150-ton)	Used for open-water and nearshore material placement	Fuel Consumption	16	--	70%	10	Ranging from 700 to 1,200 cy per day	0%	100%
	Hydraulic Excavator (180 HP)	Used for restricted access and upland material placement	Fuel Consumption	20	--	70%	10	900 cy per day	0%	100%
	Push Boat (800 HP)	Move barge	Fuel Consumption	28	--	70%	10	Linked to crane/excavator	100%	0%
	Work Boat (Two-stroke)	Transportation for crew members, also assist with ancillary material placement activities	Fuel Consumption	1.5	--	20%	10	Linked to crane/excavator	100%	0%
Surveys, Confirmational Sediment Sampling, and Environmental Monitoring	Work Boat (Two-stroke)	Conduct survey and sampling activities	Fuel Consumption	1.5	--	20%	10	N/A	100%	0%

Notes:
1. The air emissions inventory for this Green Remediation Evaluation and Implementation Approach was based entirely on tracking fossil fuel consumption (primarily diesel fuel with 15 ppm sulfur content [ultra-low sulfur diesel]).
2. The EPA "Tier System" emission standards for each tier are specific to the type of equipment (on-road vehicles, non-road equipment/engines), the year of manufacture, and the engine power. Pre-Tier engines are those manufactured prior to 1996. Tier 1 engines are those manufactured between 1997 and 2005. Tier 2 engines are those manufactured between 2001 and 2010. Tier 3 are those manufactured between 2006 and 2011. Tier 4 engines are those manufactured in 2008 and later.
3. Based on local marine construction contractor survey, and for the purposes of this Green Remediation Evaluation and Implementation Approach, no equipment anticipated to be used was assumed to be considered Tier 1 nor Tier 3.
4. The assumption of a disposal facility in Oregon is only for the purposes of the Green Remediation Evaluation and Implementation Approach at 30% RD. The contractor will be responsible for identifying and proposing the actual disposal facility in the RAWP.
5. The assumption of acquiring zero-valent iron from a facility in Chicago, IL is only for the purposes of the Green Remediation Evaluation and Implementation Approach at 30% RD. The contractor will be responsible for identifying and proposing the actual source in the RAWP.
cy: cubic yard; ENR: enhanced natural recovery; EPA: U.S. Environmental Protection Agency; gal/hr: gallon/hour; HP: horsepower; LDW: Lower Duwamish Waterway; N/A: not applicable; RAWP: Remedial Action Work Plan; RD: Remedial Design; RMC: residuals management cover; ton-mi/gal: ton-mile per gallon

Table L-2
General Inputs for Air Emission Calculations

Construction Activity	Type of Vehicle/Equipment Used	SCC Description	Notes	Equipment Uptime	Equipment Quantity	Total Daily Diesel Usage (gal/day)	Shift Duration (hr)	Production Rate (quantity/day)	One-way Distance (miles)	Quantity Units	Quantity
SITE PREPARATION											
Equipment Mobilization/Demobilization (8 hours/day)											
	Tug Boat (800 HP)	Diesel Inboard/Sterndrive (800 HP)	Assume mobilization/demobilization of 2 derrick rigs and 3 material barges. Assume 8 hrs/day for 4 days per construction season.	0.2	5	225	8	1	na	construction season	2
STRUCTURAL WORK											
Timber and Steel Pile Removal and Replacement (10 hrs/day)											
	150-ton Crane	Diesel Cranes	Assume each work day contains one 10-hr shift. Assume pile removal or replacement occurs at 25 piles/day. Assume 1 dolphin is equal to 5 piles.	0.7	1	112	10	25	na	# piles	185
	Push Boat	Diesel Inboard/Sterndrive (800 HP)		0.7	1	197	10	25	na	# piles	185
	Work Boat	Two-stroke Outboard (WB)		0.2	1	3	10	25	na	# piles	185
Timber Bulkhead Removal/Replacement, Temporary Float Dismantle/Relocation/ Reinstallation, Outfall Work, and Debris Removal											
	150-ton Crane	Diesel Cranes	Assume each work day contains one 10-hr shift.Assume a total of 68 days including structural dismantle, relocation and reinstallation based of 37 days for timber bulkhead removal and replacement, 8 days for temporary float relocation, 8 days for outfall plug and abandon, temporary diversion and 10 days for outfall pipe extension and support, including apron. Assume 5 days for identified debris removal.	0.7	1	112	10	1.00	na	# of days	68
	Push Boat	Diesel Inboard/Sterndrive (800 HP)		0.7	1	197	10	1.00	na	# of days	68
	Work Boat	Two-stroke Outboard (WB)		0.2	1	3	10	1.00	na	# of days	68
SEDIMENT DREDGING											
Open-water Dredging (10 hours/day)											
	150-ton Crane	Diesel Cranes	Assume each work day contains one 10-hr shift.	0.7	1	112	10	1,200	na	cy sediment	70,058
	Push Boat	Diesel Inboard/Sterndrive (800 HP)		0.7	1	197	10	1,200	na	cy sediment	70,058
	Work Boat	Two-stroke Outboard (WB)		0.2	1	3	10	1,200	na	cy sediment	70,058
Nearshore Dredging (10 hours/day)											
	150-ton Crane	Diesel Cranes	Assume each work day contains one 10-hr shift.	0.7	1	112	10	700	na	cy sediment	16,821
	Push Boat	Diesel Inboard/Sterndrive (800 HP)		0.7	1	197	10	700	na	cy sediment	16,821
	Work Boat	Two-stroke Outboard (WB)		0.2	1	3	10	700	na	cy sediment	16,821
Restricted Access Dredging (10 hours/day)											
	Hydraulic Excavator	Diesel Excavators	Assume each work day contains one 10-hr shift.	0.7	1	140	10	500	na	cy sediment	1,442
	Push Boat	Diesel Inboard/Sterndrive (800 HP)		0.7	1	197	10	500	na	cy sediment	1,442
	Work Boat	Two-stroke Outboard (WB)		0.2	1	3	10	500	na	cy sediment	1,442
Contingency Redredging (10 hours/day)											
	150-ton Crane	Diesel Cranes	Assume each work day contains one 10-hr shift.	0.7	1	112	10	900	na	cy sediment	10,233
	Push Boat	Diesel Inboard/Sterndrive (800 HP)		0.7	1	197	10	900	na	cy sediment	10,233
	Work Boat	Two-stroke Outboard (WB)		0.2	1	3	10	900	na	cy sediment	10,233
Shoreline/ Bank Excavation (10 hours/day)											
	Hydraulic Excavator	Diesel Excavators	Assume each work day contains one 10-hr shift.	0.7	1	140	10	800	na	cy sediment	19,200
	Push Boat	Diesel Inboard/Sterndrive (800 HP)		0.7	1	197	10	800	na	cy sediment	19,200
	Work Boat	Two-stroke Outboard (WB)		0.2	1	3	10	800	na	cy sediment	19,200

Table L-2
General Inputs for Air Emission Calculations

Construction Activity	Type of Vehicle/Equipment Used	SCC Description	Notes	Equipment Uptime	Equipment Quantity	Total Daily Diesel Usage (gal/day)	Shift Duration (hr)	Production Rate (quantity/day)	One-way Distance (miles)	Quantity Units	Quantity
SEDIMENT TRANSLOADING, UPLAND TRANSPORTATION, AND DISPOSAL											
Mechanical Offloading (10 hours/day)											
	Tug Boat (3,000 HP)	Diesel Inboard/Sterndrive (3,000 HP)	Assume each work day contains one 10 hr-shift. Assume bulking factor of 5% for mechanical offloading. Assume tug boat transports dredge sediment to an offloading area 5 mi away (one-way).	0.2	1	na	10	na	5	ton	188,246
	100-ton Crane	Diesel Cranes		0.7	1	112	10	1,200	na	cy sediment	124,325
	Front-end Loader	Diesel Rough Terrain Forklifts		0.8	1	48	10	1,200	na	cy sediment	124,325
Upland Transportation and Disposal (10 hours/day)											
	Truck (20-ton Dump Truck)	Diesel Off-highway Trucks	Assume dredged sediments trucked from LDW upper reach to intermodal facility in South Seattle or Tukwila. Assume 10 miles each way (20 miles round trip).	na	1	na	10	na	20	ton	188,246
	Rail	na	Assume sediment disposal by rail to landfill in Arlington, OR for 300 mi (one-way).	na	1	na	10	na	300	ton	188,246
MATERIAL TRANSPORTATION AND PLACEMENT											
Transportation of Clean Materials to LDW Upper Reach											
	Truck (20-ton Dump Truck)	Diesel Off-highway Trucks	Assume sand, gravelly sand, gravel, and cobble are transported 20 miles from quarry to onshore staging area by truck and 20 miles to LDW upper reach by barge. Includes material placement quantity for Upper Reach and cPAH-only RAA remediation activities.	na	1	na	10	na	20	ton	107,264
	Tug Boat (3,000 HP)	Diesel Inboard/Sterndrive (3,000 HP)		0.2	1	na	10	na	20	ton	107,264
	Rail	na	Assume ZVI material is transported 1,700 miles by rail from Chicago, IL vendor the to LDW upper reach (one-way)	na	1	na	10	na	1,700	ton	137
Open-water Placement of Sand for Residuals Management Cover and Enhanced Natural Recovery (10 hours/day)											
	150-ton Crane	Diesel Cranes	Assume each work day contains one 10-hr shift.	0.7	1	112	10	1,200	na	cy sand	7,708
	Push Boat	Diesel Inboard/Sterndrive (800 HP)		0.7	1	197	10	1,200	na	cy sand	7,708
	Work Boat	Two-stroke Outboard (WB)		0.2	1	3	10	1,200	na	cy sand	7,708
Open-water Placement of Gravelly Sand for Backfill (10 hours/day)											
	150-ton Crane	Diesel Cranes	Assume each work day contains one 10-hr shift.	0.7	1	112	10	1,200	na	cy gravelly sand	27,046
	Push Boat	Diesel Inboard/Sterndrive (800 HP)		0.7	1	197	10	1,200	na	cy gravelly sand	27,046
	Work Boat	Two-stroke Outboard (WB)		0.2	1	3	10	1,200	na	cy gravelly sand	27,046
Nearshore Placement of Sand for Residuals Management Cover and Enhanced Natural Recovery (10 hours/ day)											
	150-ton Crane	Diesel Cranes	Assume each work day contains one 10-hr shift.	0.7	1	112	10	1,000	na	cy sand	405
	Push Boat	Diesel Inboard/Sterndrive (800 HP)		0.7	1	197	10	1,000	na	cy sand	405
	Work Boat	Two-stroke Outboard (WB)		0.2	1	6	10	1,000	na	cy sand	405
Nearshore Placement of Gravelly Sand for Backfill and Habitat Layer (10 hours/day)											
	150-ton Crane	Diesel Cranes	Assume each work day contains one 10-hr shift.	0.7	1	112	10	1,000	na	cy gravelly sand	10,163
	Push Boat	Diesel Inboard/Sterndrive (800 HP)		0.7	1	197	10	1,000	na	cy gravelly sand	10,163
	Work Boat	Two-stroke Outboard (WB)		0.2	1	3	10	1,000	na	cy gravelly sand	10,163
Capping (Sand/ZVI for Chemical Isolation Layer) (10 hours/day)											
	150-ton Crane	Diesel Excavators	Assume each work day contains one 10-hr shift.	0.7	1	112	10	900	na	cy sand	915
	Push Boat	Diesel Inboard/Sterndrive (800 HP)		0.7	1	197	10	900	na	cy sand	915
	Work Boat	Two-stroke Outboard (WB)		0.2	1	3	10	900	na	cy sand	915
Capping (Gravelly Sand for Habitat Layer) (10 hours/day)											
	150-ton Crane	Diesel Cranes	Assume each work day contains one 10-hr shift.	0.7	1	112	10	900	na	cy gravelly sand	686
	Push Boat	Diesel Inboard/Sterndrive (800 HP)		0.7	1	197	10	900	na	cy gravelly sand	686
	Work Boat	Two-stroke Outboard (WB)		0.2	1	3	10	900	na	cy gravelly sand	686
Capping (Cobble/Gravel for Erosion Protection/Filter Layer) (10 hours/day)											
	150-ton Crane	Diesel Cranes	Assume each work day contains one 10-hr shift.	0.7	1	112	10	700	na	cy cobble/ gravel	457
	Push Boat	Diesel Inboard/Sterndrive (800 HP)		0.7	1	197	10	700	na	cy cobble/ gravel	457
	Work Boat	Two-stroke Outboard (WB)		0.2	1	3	10	700	na	cy cobble/ gravel	457

Table L-2
General Inputs for Air Emission Calculations

Construction Activity	Type of Vehicle/Equipment Used	SCC Description	Notes	Equipment Uptime	Equipment Quantity	Total Daily Diesel Usage (gal/day)	Shift Duration (hr)	Production Rate (quantity/day)	One-way Distance (miles)	Quantity Units	Quantity
Restricted Access Placement of Sand for Enhanced Natural Recovery											
	Hydraulic Excavator	Diesel Excavators	Assume each work day contains one 10-hr shift. Includes material placement quantity for Upper Reach site and cPAH-only RAA remediation activities.	0.7	1	140	10	700	na	cy sand	975
	Push Boat	Diesel Inboard/Sterndrive (800 HP)		0.7	1	197	10	700	na	cy sand	975
	Work Boat	Two-stroke Outboard (WB)		0.2	1	3	10	700	na	cy sand	975
Restricted Access Placement of Gravelly Sand for Backfill											
	Hydraulic Excavator	Diesel Excavators	Assume each work day contains one 10-hr shift.	0.7	1	140	10	700	na	cy gravelly sand	18
	Push Boat	Diesel Inboard/Sterndrive (800 HP)		0.7	1	197	10	700	na	cy gravelly sand	18
	Work Boat	Two-stroke Outboard (WB)		0.2	1	3	10	700	na	cy gravelly sand	18
Upland Placement of Sand for Residuals Management Cover and Enhanced Natural Recovery											
	Hydraulic Excavator	Diesel Excavators	Assume each work day contains one 10-hr shift.	0.7	1	140	10	900	na	cy sand	530
	Push Boat	Diesel Inboard/Sterndrive (800 HP)		0.7	1	197	10	900	na	cy sand	530
	Work Boat	Two-stroke Outboard (WB)		0.2	1	3	10	900	na	cy sand	530
Upland Placement of Gravelly Sand for Backfill											
	Hydraulic Excavator	Diesel Excavators	Assume each work day contains one 10-hr shift.	0.7	1	140	10	900	na	cy gravelly sand	19,172
	Push Boat	Diesel Inboard/Sterndrive (800 HP)		0.7	1	197	10	900	na	cy gravelly sand	19,172
	Work Boat	Two-stroke Outboard (WB)		0.2	1	3	10	900	na	cy gravelly sand	19,172
SURVEYS											
	Work Boat	Two-stroke Outboard (WB)	Assume one survey per day and each work day contains one 10 hr-shift. Assume a total of 249 survey events based on pre-construction (bathy and topo), post- dredge, post- placement, post-construction (bathy and topo), contractor progress surveys for the construction duration, and as-built survey.	0.2	1	3	10	1.00	na	surveys	249
CONFIRMATIONAL SEDIMENT SAMPLING AND ENVIRONMENTAL MONITORING											
	Work Boat	Two-stroke Outboard (WB)	Assume one water quality monitoring event per dredge day and each work day contains one 10 hr-shift. Assume 191 water quality monitoring events. Assume 24 confirmational sediment sampling events.	0.2	1	3	10	1.00	na	monitoring events	215

Notes:
1. Quantities and production rates obtained from Appendix M (Opinion of Probable Cost).
2. Equipment and daily equipment operation rates assumed based on engineering best professional judgment and experience in similar sediment projects.

cy: cubic yard; LDW: Lower Duwamish Waterway; gal: gallon; HP: horsepower; hr: hour; na: not applicable; PB: push boat; SCC: Standard Classification Code; WB: work boat; ZVI zero valent iron

Table L-3. Equipment Type and Fuel Usage Assumptions per Equipment Type

Equipment Type	Equipment Uptime (%)	Equipment Daily Use - Work Day (hours/day)	Fuel Consumption Rate (gal/hour)	Daily Diesel Fuel Usage (gal/day)
Hydraulic Excavator	70%	10	20	140
Front-end Loader	80%	10	6	48
150-ton Crane	70%	10	16	112
100-ton Crane	70%	10	16	112
Tug Boat (3,000 HP)	20%	10	40	80
Tug Boat (800 HP)	20%	8	28	45
Push Boat	70%	10	28	197
Work Boat	20%	10	1.5	3

Notes:

1. Equipment uptimes (effective operation time) and fuel consumption rates were from local contractors in Washington State and, estimated for each equipment based on engineering best professional judgment and experience on other similar sediment projects.

2. Daily use of equipment is based on assumptions provided in Appendix M (Opinion of Probable Cost).

3. Daily diesel fuel usage is calculated as fuel consumption rate (gal/hour) x equipment uptime (%) x work day (hours/day).

4. Daily diesel fuel usage is calculated for a single piece of equipment. Assumed number pieces of equipment is presented in Table L-2.

gal: gallon; gal/day: gallon/day; gal/hour: gallon/hour; HP: horsepower

Table L-4. Rail Transportation Assumptions

Parameter	Pre Tier	Tier 2	Unit	Comments/Reference
Diesel fuel economy for train/locomotive	470		ton-mi/gal	National average fuel consumption rate of 470 ton-miles/gallon based from data collected by the Association of American Railroads (Pg. 2 of 'Freight Railroads and Climate Change").
Emission Factors				Source for Emission Factors (HC, CO, NO_x and PM_{10}): "Locomotives Exhaust Emissions Standards" (March 2016; Office of Transportation and Air Quality [OTAQ]; EPA- 420-B-16-024) Source for Conversion Factors: EPA Technical Highlights "Emission Factors for Locomotives" (April 2009; Office of Transportation and Air Quality [OTAQ]; EPA-420-F-09-025) In order to use emission factors in g/gal, as conversion factor of 20.8 bhp-hr/gal (for Large Line Haul and Passenger Locomotives) is available in Table 3. VOC emissions are 1.053 times HC emissions and $PM_{2.5}$ emissions are 0.97 times PM_{10} emissions (pg.4). SO_2 emissions are dependent upon fuel properties and not engine properties (pg.5): SO_2 (g/gal) = (fuel density) x (conversion factor) x (64 g SO_2/32 g S) x (S content of fuel) The current density of diesel fuel is 6.76 lbs/gal (3,066 g/gal) (https://www.atlasoil.com/media/documents/safety-data-sheets/Marathon/Marathon_No-2_Ultra-Low-Sulfur-Diesel-Dyed-15-PPM-Sulfur-Max.pdf). The current sulfur content of diesel fuel is 15 ppm (ultra-low-sulfur diesel fuel; https://www.epa.gov/diesel-fuel-standards/diesel-fuel-standards-and-rulemakings). The fraction of fuel sulfur converted to SO_2 is 97.8% (pg.5). Therefore, SO_2 (g/gal) = (3,066 g/gal) x (0.978) x (64 g SO_2 / 32 g S) x (15e-6) = 0.089 g/gal The CO_2 emission factor is 10.21 kg CO_2/gal, as in Table 8 - "Scope 3 Category 4: Upstream Transportation and Distribution and Category 9: Downstream Transportation and Distribution" from Emission Factors for Greenhouse Gas Inventories April 2022).
Hydrocarbons (HC)	1.0	0.3	g/bhp-hr	
	20.8	6.2	g/gal	
Volatile Organic Compounds (VOCs)	1.1	0.3	g/bhp-hr	
	21.9	6.6	g/gal	
Carbon Monoxide (CO)	5.0	1.5	g/bhp-hr	
	104.0	31.2	g/gal	
Nitrous Oxides (NO_X)	9.5	5.5	g/bhp-hr	
	197.6	114.4	g/gal	
Particulate Matter 10 µm (PM_{10})	0.2	0.1	g/bhp-hr	
	4.6	2.1	g/gal	
Particulate Matter 2.5 µm ($PM_{2.5}$)	0.2	0.1	g/bhp-hr	
	4.4	2.0	g/gal	
Sulfur Dioxide (SO_2)	0.09		g/gal	
Carbon Dioxide (CO_2)	10,210		g/gal	
Distance from intermodal facility to Subtitle D disposal landfill facility (transport of dredged sediment)	300		miles	Dredged sediment is assumed to be transferred from an intermodal facility to an off-site disposal landfill facility, assumed to be located in Arlington, OR.
Distance from zero valent iron (ZVI) vendor (Chicago,IL) to LDW upper reach	1700		miles	Zero valent iron (ZVI) is assumed to be transported from a vendor in Chicago, IL to LDW upper reach.

Notes:

1. Ton-mile is a unit of freight transportation equivalent to a ton of freight moved 1 mile.

bph: usable power; g: gram; gal: gallon; hr: hour; kg: kilogram; L: liter; mi: mile; ppm: parts per million; ZVI: zero valent iron

Table L-5. Truck Transportation Assumptions

Parameter	Pre-Tier	Tier 2	Unit	Comments/Reference
Dump Truck				Assumed truck capacity and fuel consumption based on engineering best professional judgement and experience on other similar sediment projects.
Average power	600		hp	
Capacity	20		tons	
Fuel consumption	13		gal/hr	
CO_2 emission factor for trucks	0.21		kg CO_2/ton-mile	Source: Table 8- "Scope 3 Category 4: Upstream Transportation and Distribution and Category 9: Downstream Transportation and Distribution" from Emission Factors for Greenhouse Gas Inventories April 2022
Diesel fuel economy for trucks	130		ton-mile/gallon	Calculated as 27.46 kg/gal / 0.211 kg/ton-mi ≈ 130 ton-mile/gal
Emission Factors				$PM_{2.5}$ emissions are 0.97 times PM_{10} emissions (Pg. 35) CO_2 = [BSFC (lb/hp-hr) * 453.6(g/lb) -HC (g/hp-hr)] * 0.87 * (44/12) (Pg.34) SO_2 (g/hp-hr) = [BSFC(lb/hp-hr) * 453.6(g/lb)* (1 -soxcnv) -HC(g/hp-hr)] * 0.01 * soxdsl(%) * 2 (Pg.34) BSFC = 0.408 (lb/hp-hr; 0-100 HP) and 0.367 (lb/hp-hr; >100 HP); 0.87 = carbon mass fraction of diesel; 44/12 = ratio of CO2 mass tocarbon mass; soxcnv = 0.02247 which is the fraction of fuel sulfur converted to direct PM; 0.01= conversion factor from weight percent to weight fraction and, 2 = g SO_2 /g sulfur VOC emissions are 1.053 times HC emissions Reference: EPA Technical Highlights "Emission Factors for Locomotives" (April 2009; Office of Transportation and Air Quality [OTAQ]; EPA-420-F-09-025).
Hydrocarbons (HC)	35.3	8.7	g/gal	
Volatile Organic Compounds (VOCs)	37.2	9.1	g/gal	
Carbon Monoxide (CO)	140.2	68.9	g/gal	
Nitrous Oxides (NO_X)	435.1	212.9	g/gal	
Particulate Matter 10 µm (PM_{10})	20.9	6.9	g/gal	
Particulate Matter 2.5 µm ($PM_{2.5}$)	20.2	6.6	g/gal	
Sulfur Dioxide (SO_2)	0.3	0.3	g/gal	
Carbon Dioxide (CO_2)	27,500	27,500	g/gal	
Distance from LDW upper reach to intermodal facility (transport of dredged sediment for off-site disposal)	20		miles	Upland transport of dredged sediment for off-site disposal, by truck, from offloading facility to a nearby intermodal facility is a conservative assumption for the distance required for truck transportation from the LDW upper reach to the intermodal facility.
Distance from local quarry to onshore staging area (transport fo clean materials for placement)	20		miles	Upland transport of clean material, by truck, is a conservative assumption for the distance required for truck transportation from the quarry to an onshore staging area in the LDW.

Notes:

1. Ton-mile is a unit of freight transportation equivalent to a ton of freight moved 1 mile.

2. In order to use emission factors in g/gal, the steady state factors are converted using the average horsepower of the specific equipment and the fuel consumption rate (gal/hr).

Emission factors (g/gal) = Emission Factors (g/hp-hr)*Equipment horsepower (HP)/ Fuel Consumption (gal/ hr)

BSFC: brake specific fuel consumption (lb/hp-hr); g: gram; gal: gallon; hp: horsepower; hr: hour; kg: kilogram; mi: mile

Table L-6. Barge Transportation Assumptions

Parameter	Pre-Tier	Tier 2	Unit	Comments/Reference
Tug/barge - Diesel Inboard/Sterndrive (3,000 HP)				Average fuel consumption of empty and fully loaded tug/barge: (15+85)/2 = 50, rounded down to 40 gal/hour in order to use NONROAD EPA emission factors. Empty tug/barges typically consume 15 gal/hour. Fully loaded tug/barges consume 85 gal/hour in Seattle area, derived from 1999 Puget Sound Clean Air Agency (www.pscleanair.org) document entitled "1999 TUGBOAT FUEL CONSUMPTION IN SEATTLE AREA" http://www.epa.gov/ttn/chief/conference/ei11/poster/agyei.pdf
Average power	3,000		hp	
Fuel consumption	40		gal/hr	
CO_2 emission factor for boats	0.041		kg CO_2/ton-mile	Source: Table 8- "Scope 3 Category 4: Upstream Transportation and Distribution and Category 9: Downstream Transportation and Distribution" from Emission Factors for Greenhouse Gas Inventories April 2022.
Diesel fuel economy for boats	968		ton-mile / gallon	Calculated as 33.055 kg/gal / 0.041 kg/ton-mi ≈ 806 ton-mile/gal.
Emission Factors				Source:"Exhaust and Crankcase Emission Factors for Nonroad Compression-Ignition Engines in MOVES3.0.2"(EPA-420-R-21-021, September 2021) PM2.5 emissions are 0.97 times PM10 emissions (Pg.35) CO2 = [BSFC (lb/hp-hr) * 453.6(g/lb) -HC (g/hp-hr)] * 0.87 * (44/12) (Pg.34) SO2 (g/hp-hr) = [BSFC(lb/hp-hr) * 453.6(g/lb)* (1 -soxcnv) -HC(g/hp-hr)] * 0.01 * soxdsl(%) * 2 (Pg.34) BSFC = 0.408 (lb/hp-hr; 0-100 HP) and 0.367 (lb/hp-hr; >100 HP); 0.87 = carbon mass fraction of diesel; 44/12 = ratio of CO2 mass tocarbon mass; soxcnv = 0.02247 which is the fraction of fuel sulfur converted to direct PM ; 0.01= conversion factor from weight percent to weight fraction and, 2 = g SO2 /g sulfur VOC emissions are 1.053 times HC emissions (Pg.4) (EPA Technical Highlights "Emission Factors for Locomotives" (April 2009; Office of Transportation and Air Quality [OTAQ]; EPA-420-F-09-025))
Hydrocarbons (HC)	51.0	12.5	g/gal	
Volatile Organic Compounds (VOCs)	53.7	13.2	g/gal	
Carbon Monoxide (CO)	202.5	57.3	g/gal	
Nitrous Oxides (NO_X)	628.5	307.5	g/gal	
Particulate Matter 10 µm (PM_{10})	30.2	9.9	g/gal	
Particulate Matter 2.5 µm ($PM_{2.5}$)	29.2	0.4	g/gal	
Sulfur Dioxide (SO_2)	0.4	0.4	g/gal	
Carbon Dioxide (CO_2)	39,700	39,800	g/gal	
Distance from LDW upper reach to offloading area (transport of dredge sediment)	5		miles	Dredged sediment is assumed to be transported by barge to an offloading area, which is assumed to be 5 miles from middle point of the LDW upper reach.
Distance from onshore staging area to LDW upper reach (transport of clean materials for placement)	5		miles	Sand, gravelly sand, gravel, and cobble are assumed to be transported by barge from onshore staging area to the LDW upper reach.

Notes:

1. Ton-mile is a unit of freight transportation equivalent to a ton of freight moved 1 mile.

2. In order to use emission factors in g/gal, the steady state factors are converted using the average horsepower of the specific equipment and the fuel consumption rate (gal/hr).
Emission factors (g/gal) = Emission Factors (g/hp-hr)*Equipment horsepower (HP)/ Fuel Consumption (gal/ hr)

CO: carbon monoxide; CO_2: carbon dioxide; g: gram; gal: gallon; HP: horsepower; NO_X: nitrogen oxides (NO and NO_2); $PM_{2.5}$: particulate matter less that 2.5 microns in diameter; PM_{10}: particulate matter less than 10 microns in diameter; SO_2: sulfur dioxide; VOC: volatile organic compounds

Table L-7. Air Emission Factors for Construction Equipment and Vehicles

Type of Vehicle/Equipment Used	SCC Description	HP	Fuel Consumption Rate (gal/hour)	Pre-Tier Emission Factors (g/gal)								Tier 2 Emission Factors (g/gal)							
				HC	VOCs	CO	NO_X	PM_{10}	$PM_{2.5}$	SO_2	CO_2	HC	VOCs	CO	NOX	PM_{10}	$PM_{2.5}$	SO_2	CO_2
Work Boat	Two-stroke Outboard (WB)	45	1.5	54.00	56.86	150.00	207.00	24.00	23.28	0.16	17,539	8.37	8.81	45.97	141.84	10.17	9.86	0.16	17,684
Push Boat	Two-stroke Outboard (PB)	875	28	21.17	22.30	84.07	260.94	12.52	12.14	0.15	16,438	5.20	5.48	23.79	127.67	4.11	3.99	0.15	16,519
100-ton and 150-ton Cranes	Diesel Cranes	675	16	28.69	30.21	113.91	353.53	16.96	16.45	0.21	22,312	7.05	7.42	55.98	172.97	5.57	5.40	0.21	22,381
Hydraulic Excavator	Diesel Excavators	450	20	15.30	16.11	60.75	188.55	9.05	8.77	0.11	11,900	3.76	3.96	18.97	97.54	2.97	2.88	0.11	11,936
Tug Boat (800 HP)	Diesel Inboard/Sterndrive (800 HP)	875	28	21.17	22.30	84.07	260.94	12.52	12.14	0.15	16,468	5.20	5.48	23.79	127.67	4.11	3.99	0.15	16,519
Front-end Loader	Diesel Rough Terrain Forklifts	238	6	26.92	28.34	106.88	331.71	15.91	15.44	0.19	20,935	12.23	12.88	29.61	158.33	5.23	5.07	0.19	20,981

Notes:

1. . Emission factors derived from "Exhaust and Crankcase Emission Factors for Nonroad Compression-Ignition Engines in MOVES3.0.2"(EPA-420-R-21-021, September 2021). Steady state factors derived from Table A-4 (Appendix A). Emissions factors are based on the equipment horsepower and Tier category.

2. Pre- Tier emission factors were assumed to be Tier 0. $PM_{2.5}$ emissions are assumed to 0.97 times PM_{10} emissions (see Pg. 35).
CO2 (g/hp-hr) = [BSFC (lb/hp-hr) * 453.6(g/lb) -HC (g/hp-hr)] * 0.87 * (44/12); SO2 (g/hp-hr) = [BSFC(lb/hp-hr) * 453.6(g/lb)* (1 -soxcnv) -HC(g/hp-hr)] * 0.01 * soxdsl(%) * 2 (Pg. 34). BSFC = 0.408 (lb/hp-hr; 0-100 HP) and 0.367 (lb/hp-hr; >100 HP); 0.87 = carbon mass fraction of diesel; 44/12 = ratio of CO2 mass tocarbon mass; soxcnv = 0.02247 which is the fraction of fuel sulfur converted to direct PM; 0.01= conversion factor from weight percent to weight fraction and, 2 = g SO2 /g sulfur.
VOC emissions are 1.053 times HC emissions (see Pg.4)
Reference: EPA Technical Highlights "Emission Factors for Locomotives" (April 2009; Office of Transportation and Air Quality [OTAQ]; EPA-420-F-09-025).

3. Emission factors (g/gal) = Emission Factors (g/hp-hr)*Equipment horsepower (HP)/ Fuel Consumption (gal/ hr)
HC: hydrocarbon; CO: carbon monoxide; $CO_{2:}$ carbon dioxide; g: gram; gal: gallon; HP: horsepower; $NO_{X:}$ nitrogen oxides (NO and NO_2); PB: push boat; PM: particulate matter; $PM_{2.5:}$ particulate matter less that 2.5 microns in diameter; $PM_{10:}$ particulate matter less than 10 microns in diameter; SCC: Standard Classification Code; $SO_{2:}$ sulfur dioxide; VOC: volatile organic compounds; WB: work boat; BSFC: brake-specific fuel consumption; soxcnv: 0.2447 or 0.3 (fraction of fuel sulfur converted to direct PM); soxdsl: 0.0015% (episodic weight percent of sulfur in nonroad ultra low sulfur (15 ppm) diesel fuel)

Table L-8. Detailed Summary of Direct Emissions by Construction Activity

Construction Activity	Type of Vehicle/Equipment Used	SCC Description	Notes	Pre Tier - Total Emissions (Metric Tonnes) Hydrocarbons (HC)	Volatile Organic Compounds (VOCs)	Carbon Monoxide (CO)	Nitrogen Oxides (NO_X)	Particulate Matter 10 µm (PM_{10})	Particulate Matter 2.5 µm ($PM_{2.5}$)	Sulfur Dioxide (SO_2)	Carbon Dioxide (CO_2)
SITE PREPARATION											
Equipment Mobilization/Demobilization (8 hours/day)											
	Tug Boat (800 HP)	Diesel Inboard/Sterndrive (800 HP)	Assume mobilization/demobilization of 2 derrick rigs and 3 material barges. Assume 8 hrs/day for 4 days per construction season.	0.0127	0.0134	0.0504	0.1564	0.0075	0.0073	0.0001	9.9
			SUBTOTAL EMISSIONS - SITE PREPARATION	**0.013**	**0.013**	**0.050**	**0.156**	**0.008**	**0.007**	**0.00009**	**9.9**
STRUCTURAL WORK											
Timber and Steel Pile Removal and Replacement (10 hrs/day)											
	150-ton Crane	Diesel Cranes	Assume each work day contains one 10-hr shift. Assume pile removal or replacement occurs at 25 piles/day. Assume 1 dolphin is equal to 5 piles.	0.0238	0.0250	0.0944	0.2930	0.0141	0.0136	0.0002	18.5
	Push Boat	Diesel Inboard/Sterndrive (800 HP)		0.0308	0.0325	0.1224	0.3798	0.0182	0.0177	0.0002	23.9
	Work Boat	Two-stroke Outboard (WB)		0.0012	0.0013	0.0033	0.0046	0.0005	0.0005	0.0000	0.4
Timber Bulkhead Removal/Replacement, Temporary Float Dismantle/Relocation/ Reinstallation, Outfall Work, and Debris Removal											
	150-ton Crane	Diesel Cranes	Assume each work day contains one 10-hr shift.Assume a total of 68 days including structural dismantle, relocation and reinstallation based of 37 days for timber bulkhead removal and replacement, 8 days for temporary float relocation, 8 days for outfall plug and abandon, temporary diversion and 10 days for outfall pipe extension and support, including apron. Assume 5 days for identified debris removal.	0.22	0.23	0.87	2.69	0.13	0.13	0.0016	169.9
	Push Boat	Diesel Inboard/Sterndrive (800 HP)		0.28	0.30	1.12	3.49	0.17	0.16	0.0020	219.9
	Work Boat	Two-stroke Outboard (WB)		0.0110	0.0116	0.0306	0.04	0.0049	0.0047	0.00003	3.6
			SUBTOTAL EMISSIONS - STRUCTURAL WORK	**0.012**	**0.013**	**0.048**	**0.148**	**0.007**	**0.007**	**0.0001**	**9.3**
SEDIMENT DREDGING											
Open-water Dredging (10 hours/day)											
	150-ton Crane	Diesel Cranes	Assume each work day contains one 10-hr shift.	0.1876	0.1975	0.7448	2.3116	0.1109	0.1076	0.0013	145.9
	Push Boat	Diesel Inboard/Sterndrive (800 HP)		0.2432	0.2560	0.9655	2.9966	0.1437	0.1394	0.0017	188.8
	Work Boat	Two-stroke Outboard (WB)		0.0095	0.0100	0.0263	0.0363	0.0042	0.0041	0.0000	3.1
Nearshore Dredging (10 hours/day)											
	150-ton Crane	Diesel Cranes	Assume each work day contains one 10-hr shift.	0.0772	0.0813	0.3066	0.9515	0.0456	0.0443	0.0006	60.1
	Push Boat	Diesel Inboard/Sterndrive (800 HP)		0.1001	0.1054	0.3974	1.2334	0.0592	0.0574	0.0007	77.7
	Work Boat	Two-stroke Outboard (WB)		0.0039	0.0041	0.0108	0.0149	0.0017	0.0017	0.00001	1.3
Restricted Access Dredging (10 hours/day)											
	Hydraulic Excavator	Diesel Excavators	Assume each work day contains one 10-hr shift.	0.0062	0.0065	0.0245	0.0761	0.0037	0.0035	0.0000	4.8
	Push Boat	Diesel Inboard/Sterndrive (800 HP)		0.0120	0.0126	0.0477	0.1480	0.0071	0.0069	0.0001	9.3
	Work Boat	Two-stroke Outboard (WB)		0.0005	0.0005	0.0013	0.0018	0.0002	0.0002	0.000001	0.2
Contingency Redredging (10 hours/day)											
	150-ton Crane	Diesel Cranes	Assume each work day contains one 10-hr shift.	0.0365	0.0385	0.1451	0.4502	0.0216	0.0209	0.0003	28.4
	Push Boat	Diesel Inboard/Sterndrive (800 HP)		0.0474	0.0499	0.1880	0.5836	0.0280	0.0272	0.0003	36.8
	Work Boat	Two-stroke Outboard (WB)		0.0018	0.0019	0.0051	0.0071	0.0008	0.0008	0.00001	0.6
Shoreline/ Bank Excavation (10 hours/day)											
	Hydraulic Excavator	Diesel Excavators	Assume each work day contains one 10-hr shift.	0.0514	0.0541	0.2041	0.6335	0.0304	0.0295	0.0004	40.0
	Push Boat	Diesel Inboard/Sterndrive (800 HP)		0.1000	0.1053	0.3969	1.2319	0.0591	0.0573	0.0007	77.6
	Work Boat	Two-stroke Outboard (WB)		0.0039	0.0041	0.0108	0.0149	0.0017	0.0017	0.00001	1.3
			SUBTOTAL EMISSIONS - SEDIMENT DREDGING	**0.88**	**0.93**	**3.47**	**10.69**	**0.52**	**0.50**	**0.01**	**675.6**

Table L-8. Detailed Summary of Direct Emissions by Construction Activity

Construction Activity	Type of Vehicle/Equipment Used	SCC Description	Notes	Pre Tier - Total Emissions (Metric Tonnes) Hydrocarbons (HC)	Volatile Organic Compounds (VOCs)	Carbon Monoxide (CO)	Nitrogen Oxides (NO_X)	Particulate Matter 10 µm (PM_{10})	Particulate Matter 2.5 µm ($PM_{2.5}$)	Sulfur Dioxide (SO_2)	Carbon Dioxide (CO_2)
SEDIMENT TRANSLOADING, UPLAND TRANSPORTATION, AND DISPOSAL											
Mechanical Offloading (10 hours/day)											
	Tug Boat (3,000 HP)	Diesel Inboard/Sterndrive (3,000 HP)	Assume each work day contains one 10 hr-shift. Assume bulking factor of 5% for mechanical offloading. Assume tug boat transports dredge sediment to an offloading area 5 mi away (one-way).	0.0496	0.0522	0.1968	0.6109	0.0293	0.0284	0.0004	38.6
	100-ton Crane	Diesel Cranes		0.3329	0.3505	1.3217	4.1022	0.1968	0.1909	0.0024	258.9
	Front-end Loader	Diesel Rough Terrain Forklifts		0.1339	0.1410	0.5315	1.6496	0.0791	0.0768	0.0010	104.1
Upland Transportation and Disposal (10 hours/day)											
	Truck (20-ton Dump Truck)	Diesel Off-highway Trucks	Assume dredged sediments trucked from LDW upper reach to intermodal facility in South Seattle or Tukwila. Assume 10 miles each way (20 miles round trip).	1.0199	1.0740	4.0498	12.5693	0.6030	0.5849	0.0073	794.4
	Rail	na	Assume dredged sediments railed from intermodal facility to an off-site landfill disposal facility in Arlington, OR for 300 miles (one-way).	2.4993	3.9476	18.7445	35.6146	0.8248	0.8000	0.0160	1840.2
			SUBTOTAL EMISSIONS - SEDIMENT TRANSLOADING, UPLAND TRANSPORTATION, AND DISPOSAL	**4.04**	**5.57**	**25**	**55**	**1.73**	**1.68**	**0.03**	**3036.2**

Table L-8. Detailed Summary of Direct Emissions by Construction Activity

Construction Activity	Type of Vehicle/Equipment Used	SCC Description	Notes	Pre Tier - Total Emissions (Metric Tonnes)							
				Hydrocarbons (HC)	Volatile Organic Compounds (VOCs)	Carbon Monoxide (CO)	Nitrogen Oxides (NO_X)	Particulate Matter 10 µm (PM_{10})	Particulate Matter 2.5 µm ($PM_{2.5}$)	Sulfur Dioxide (SO_2)	Carbon Dioxide (CO_2)
MATERIAL TRANSPORTATION AND PLACEMENT											
Transportation of Clean Materials to LDW Upper Reach											
	Truck (20-ton Dump Truck)	Diesel Off-highway Trucks	Assume sand, gravelly sand, gravel, and cobble are transported 20 miles from quarry to onshore staging area by truck and 20 miles to LDW upper reach by barge. Includes material placement quantity for Upper Reach and cPAH-only RAA remediation activities.	0.5812	0.6120	2.3076	7.1620	0.3436	0.3333	0.0042	452.7
	Tug Boat (3,000 HP)	Diesel Inboard/Sterndrive (3,000 HP)		0.1130	0.1190	0.4486	1.3925	0.0668	0.0648	0.0008	88.0
	Rail	na	Assume ZVI material is transported 1,700 miles by rail from Chicago, IL vendor the to LDW upper reach (one-way)	0.0103	0.0108	0.0515	0.0979	0.0023	0.0022	0.00004	5.1
Open-water Placement of Sand for Residuals Management Cover and Enhanced Natural Recovery (10 hours/day)											
	150-ton Crane	Diesel Cranes		0.0206	0.0217	0.0819	0.2543	0.0122	0.0118	0.0001	16.1
	Push Boat	Diesel Inboard/Sterndrive (800 HP)	Assume each work day contains one 10-hr shift.	0.0268	0.0282	0.1062	0.3297	0.0158	0.0153	0.0002	20.8
	Work Boat	Two-stroke Outboard (WB)		0.0010	0.0011	0.0029	0.0040	0.0005	0.0004	0.00000	0.3
Open-water Placement of Gravelly Sand for Backfill (10 hours/day)											
	150-ton Crane	Diesel Cranes		0.0724	0.0763	0.2875	0.8924	0.0428	0.0415	0.0005	56.3
	Push Boat	Diesel Inboard/Sterndrive (800 HP)	Assume each work day contains one 10-hr shift.	0.0939	0.0988	0.3727	1.1568	0.0555	0.0538	0.0007	73.0
	Work Boat	Two-stroke Outboard (WB)		0.0037	0.0038	0.0101	0.0140	0.0016	0.0016	0.00001	1.2
Nearshore Placement of Sand for Residuals Management Cover and Enhanced Natural Recovery (10 hours/ day)											
	150-ton Crane	Diesel Cranes		0.0013	0.0014	0.0052	0.0160	0.0008	0.0007	0.00001	1.0
	Push Boat	Diesel Inboard/Sterndrive (800 HP)	Assume each work day contains one 10-hr shift.	0.0017	0.0018	0.0067	0.0208	0.0010	0.0010	0.00001	1.3
	Work Boat	Two-stroke Outboard (WB)		0.0001	0.0001	0.0004	0.0005	0.0001	0.0001	0.0000004	0.0
Nearshore Placement of Gravelly Sand for Backfill and Habitat Layer (10 hours/day)											
	150-ton Crane	Diesel Cranes		0.0327	0.0344	0.1297	0.4024	0.0193	0.0187	0.0002	25.4
	Push Boat	Diesel Inboard/Sterndrive (800 HP)	Assume each work day contains one 10-hr shift.	0.0423	0.0446	0.1681	0.5217	0.0250	0.0243	0.0003	32.9
	Work Boat	Two-stroke Outboard (WB)		0.0016	0.0017	0.0046	0.0063	0.0007	0.0007	0.00000	0.5
Capping (Sand/ZVI for Chemical Isolation Layer) (10 hours/day)			.								
	150-ton Crane	Diesel Excavators		0.0033	0.0034	0.0130	0.0402	0.0019	0.0019	0.00002	2.5
	Push Boat	Diesel Inboard/Sterndrive (800 HP)	Assume each work day contains one 10-hr shift.	0.0042	0.0045	0.0168	0.0522	0.0025	0.0024	0.00003	3.3
	Work Boat	Two-stroke Outboard (WB)		0.0002	0.0002	0.0005	0.0006	0.0001	0.0001	0.0000005	0.1
Capping (Gravelly Sand for Habitat Layer) (10 hours/day)											
	150-ton Crane	Diesel Cranes		0.0024	0.0026	0.0097	0.0302	0.0014	0.0014	0.00002	1.9
	Push Boat	Diesel Inboard/Sterndrive (800 HP)	Assume each work day contains one 10-hr shift.	0.0032	0.0033	0.0126	0.0391	0.0019	0.0018	0.00002	2.5
	Work Boat	Two-stroke Outboard (WB)		0.0001	0.0001	0.0003	0.0005	0.0001	0.0001	0.0000004	0.0
Capping (Cobble/Gravel for Erosion Protection/Filter Layer) (10 hours/day)											
	150-ton Crane	Diesel Cranes		0.0021	0.0022	0.0083	0.0259	0.0012	0.0012	0.00002	1.6
	Push Boat	Diesel Inboard/Sterndrive (800 HP)	Assume each work day contains one 10-hr shift.	0.0027	0.0029	0.0108	0.0335	0.0016	0.0016	0.00002	2.1
	Work Boat	Two-stroke Outboard (WB)		0.0001	0.0001	0.0003	0.0004	0.0000	0.0000	0.0000003	0.0
Restricted Access Placement of Sand for Enhanced Natural Recovery											
	Hydraulic Excavator	Diesel Excavators	Assume each work day contains one 10-hr shift. Includes material placement quantity for Upper Reach site and cPAH-only RAA remediation activities.	0.0030	0.0031	0.0119	0.0368	0.0018	0.0017	0.00002	2.3
	Push Boat	Diesel Inboard/Sterndrive (800 HP)		0.0058	0.0061	0.0230	0.0715	0.0034	0.0033	0.00004	4.5
	Work Boat	Two-stroke Outboard (WB)		0.0002	0.0002	0.0006	0.0009	0.0001	0.0001	0.000001	0.1
Restricted Access Placement of Gravelly Sand for Backfill											
	Hydraulic Excavator	Diesel Excavators		0.0001	0.0001	0.0002	0.0007	0.00003	0.00003	0.0000004	0.0
	Push Boat	Diesel Inboard/Sterndrive (800 HP)	Assume each work day contains one 10-hr shift.	0.0001	0.0001	0.0004	0.0013	0.0001	0.0001	0.000001	0.1
	Work Boat	Two-stroke Outboard (WB)		0.00000	0.00000	0.00001	0.00002	0.000002	0.000002	0.00000001	0.0
Upland Placement of Sand for Residuals Management Cover and Enhanced Natural Recovery											
	Hydraulic Excavator	Diesel Excavators		0.0013	0.0013	0.0050	0.0155	0.0007	0.0007	0.00001	1.0
	Push Boat	Diesel Inboard/Sterndrive (800 HP)	Assume each work day contains one 10-hr shift.	0.0025	0.0026	0.0097	0.0302	0.0014	0.0014	0.00002	1.9
	Work Boat	Two-stroke Outboard (WB)		0.0001	0.0001	0.0003	0.0004	0.00004	0.00004	0.0000003	0.0
Upland Placement of Gravelly Sand for Backfill											
	Hydraulic Excavator	Diesel Excavators		0.0456	0.0480	0.1812	0.5623	0.0270	0.0262	0.0003	35.5
	Push Boat	Diesel Inboard/Sterndrive (800 HP)	Assume each work day contains one 10-hr shift.	0.0887	0.0934	0.3523	1.0934	0.0525	0.0509	0.0006	69.0
	Work Boat	Two-stroke Outboard (WB)		0.0035	0.0036	0.0096	0.0132	0.0015	0.0015	0.00001	1.1
			SUBTOTAL EMISSIONS - MATERIAL TRANSPORTATION AND PLACEMENT	**1.17**	**1.23**	**5**	**14**	**0.69**	**0.67**	**0.01**	**904.2**

Table L-8. Detailed Summary of Direct Emissions by Construction Activity

Construction Activity	Type of Vehicle/Equipment Used	SCC Description	Notes	Pre Tier - Total Emissions (Metric Tonnes)							
				Hydrocarbons (HC)	Volatile Organic Compounds (VOCs)	Carbon Monoxide (CO)	Nitrogen Oxides (NO_X)	Particulate Matter 10 µm (PM_{10})	Particulate Matter 2.5 µm ($PM_{2.5}$)	Sulfur Dioxide (SO_2)	Carbon Dioxide (CO_2)
SURVEYS											
	Work Boat	Two-stroke Outboard (WB)	Assume one survey per day and each work day contains one 10 hr-shift. Assume a total of 249 survey events based on pre-construction (bathy and topo), post- dredge, post- placement, post-construction (bathy and topo), contractor progress surveys for the construction duration, and as-built survey.	0.02	0.02	0.06	0.195	0.0094	0.0091	0.0001	12.3
			SUBTOTAL EMISSIONS - SURVEYS	**0.02**	**0.02**	**0.06**	**0.195**	**0.0094**	**0.0091**	**0.0001**	**12.3**
CONFIRMATIONAL SEDIMENT SAMPLING AND ENVIRONMENTAL MONITORING											
	Work Boat	Two-stroke Outboard (WB)	Assume one water quality monitoring event per dredge day and each work day contains one 10 hr-shift. Assume 191 water quality monitoring events. Assume 24 confirmational sediment sampling events.	0.01	0.01	0.05	0.17	0.01	0.01	0.0001	10.6
			SUBTOTAL EMISSIONS - CONFIRMATIONAL SEDIMENT SAMPLING AND ENVIRONEMENTAL MONITORING	**0.01**	**0.01**	**0.03**	**0.036**	**0.0041**	**0.0040**	**0.000025**	**2.7**
			TOTAL DIRECT AIR EMISSIONS (Metric Tonnes, rounded)	**6.7**	**8.4**	**35.0**	**87.0**	**3.3**	**3.2**	**0.05**	**5,100**

Table L-8. Detailed Summary of Direct Emissions by Construction Activity

				Tier 2 - Total Emissions (Metric Tonnes)							
Construction Activity	Type of Vehicle/Equipment Used	SCC Description	Notes	Hydrocarbons (HC)	Volatile Organic Compounds (VOCs)	Carbon Monoxide (CO)	Nitrogen Oxides (NO_X)	Particulate Matter 10 µm (PM_{10})	Particulate Matter 2.5 µm ($PM_{2.5}$)	Sulfur Dioxide (SO_2)	Carbon Dioxide (CO_2)
SITE PREPARATION											
Equipment Mobilization/Demobilization (8 hours/day)											
	Tug Boat (800 HP)	Diesel Inboard/Sterndrive (800 HP)	Assume mobilization/demobilization of 2 derrick rigs and 3 material barges. Assume 8 hrs/day for 4 days per construction season.	0.0031	0.0033	0.0143	0.077	0.00246	0.00239	0.00009	9.9
			SUBTOTAL EMISSIONS - SITE PREPARATION	**0.003**	**0.003**	**0.014**	**0.077**	**0.002**	**0.002**	**0.00009**	**9.9**
STRUCTURAL WORK											
Timber and Steel Pile Removal and Replacement (10 hrs/day)											
	150-ton Crane	Diesel Cranes	Assume each work day contains one 10-hr shift. Assume pile removal or replacement occurs at 25 piles/day. Assume 1 dolphin is equal to 5 piles.	0.0058	0.0061	0.0464	0.1434	0.0046	0.0045	0.0002	18.5
	Push Boat	Diesel Inboard/Sterndrive (800 HP)		0.0076	0.0080	0.0346	0.1858	0.0060	0.0058	0.0002	24.0
	Work Boat	Two-stroke Outboard (WB)		0.0002	0.0002	0.0010	0.0031	0.00023	0.000219	0.000004	0.4
Timber Bulkhead Removal/Replacement, Temporary Float Dismantle/Relocation/ Reinstallation, Outfall Work, and Debris Removal											
	150-ton Crane	Diesel Cranes	Assume each work day contains one 10-hr shift.Assume a total of 68 days including structural dismantle, relocation and reinstallation based of 37 days for timber bulkhead removal and replacement, 8 days for temporary float relocation, 8 days for outfall plug and abandon, temporary diversion and 10 days for outfall pipe extension and support, including apron. Assume 5 days for identified debris removal.	0.05	0.06	0.43	1.32	0.04	0.04	0.0016	170.5
	Push Boat	Diesel Inboard/Sterndrive (800 HP)		0.07	0.07	0.32	1.71	0.05	0.05	0.0020	221.0
	Work Boat	Two-stroke Outboard (WB)		0.0017	0.0018	0.009	0.03	0.0021	0.0020	0.000033	3.6
			SUBTOTAL EMISSIONS - STRUCTURAL WORK	**0.003**	**0.003**	**0.013**	**0.072**	**0.002**	**0.002**	**0.0001**	**9.4**
SEDIMENT DREDGING											
Open-water Dredging (10 hours/day)											
	150-ton Crane	Diesel Cranes	Assume each work day contains one 10-hr shift.	0.0461	0.0485	0.3661	1.1310	0.0364	0.0353	0.0013	146.3
	Push Boat	Diesel Inboard/Sterndrive (800 HP)		0.0597	0.0629	0.2732	1.4661	0.0472	0.0458	0.0017	189.7
	Work Boat	Two-stroke Outboard (WB)		0.0015	0.0015	0.0081	0.0248	0.0018	0.0017	0.0000	3.1
Nearshore Dredging (10 hours/day)											
	150-ton Crane	Diesel Cranes	Assume each work day contains one 10-hr shift.	0.0190	0.0200	0.1507	0.4655	0.0150	0.0145	0.0006	60.2
	Push Boat	Diesel Inboard/Sterndrive (800 HP)		0.0246	0.0259	0.1125	0.6035	0.0194	0.0188	0.0007	78.1
	Work Boat	Two-stroke Outboard (WB)		0.0006	0.0006	0.0033	0.0102	0.0007	0.0007	0.00001	1.3
Restricted Access Dredging (10 hours/day)											
	Hydraulic Excavator	Diesel Excavators	Assume each work day contains one 10-hr shift.	0.0015	0.0016	0.0077	0.0394	0.0012	0.0012	0.0000	4.8
	Push Boat	Diesel Inboard/Sterndrive (800 HP)		0.0030	0.0031	0.0135	0.0724	0.0023	0.0023	0.0001	9.4
	Work Boat	Two-stroke Outboard (WB)		0.0001	0.0001	0.0004	0.0012	0.0001	0.0001	0.000001	0.2
Contingency Redredging (10 hours/day)											
	150-ton Crane	Diesel Cranes	Assume each work day contains one 10-hr shift.	0.0090	0.0094	0.0713	0.2203	0.0071	0.0069	0.0003	28.5
	Push Boat	Diesel Inboard/Sterndrive (800 HP)		0.0116	0.0122	0.0532	0.2855	0.0092	0.0089	0.0003	36.9
	Work Boat	Two-stroke Outboard (WB)		0.0003	0.0003	0.0016	0.0048	0.0003	0.0003	0.00001	0.6
Shoreline/ Bank Excavation (10 hours/day)											
	Hydraulic Excavator	Diesel Excavators	Assume each work day contains one 10-hr shift.	0.0126	0.0133	0.0637	0.3277	0.0100	0.0097	0.0004	40.1
	Push Boat	Diesel Inboard/Sterndrive (800 HP)		0.0245	0.0259	0.1123	0.6027	0.0194	0.0188	0.0007	78.0
	Work Boat	Two-stroke Outboard (WB)		0.0006	0.0006	0.0033	0.0102	0.0007	0.0007	0.00001	1.3
			SUBTOTAL EMISSIONS - SEDIMENT DREDGING	**0.21**	**0.23**	**1.24**	**5.27**	**0.17**	**0.17**	**0.01**	**678.5**

Table L-8. Detailed Summary of Direct Emissions by Construction Activity

Construction Activity	Type of Vehicle/Equipment Used	SCC Description	Notes	Tier 2 - Total Emissions (Metric Tonnes) Hydrocarbons (HC)	Volatile Organic Compounds (VOCs)	Carbon Monoxide (CO)	Nitrogen Oxides (NO_X)	Particulate Matter 10 µm (PM_{10})	Particulate Matter 2.5 µm ($PM_{2.5}$)	Sulfur Dioxide (SO_2)	Carbon Dioxide (CO_2)
SEDIMENT TRANSLOADING, UPLAND TRANSPORTATION, AND DISPOSAL											
Mechanical Offloading (10 hours/day)											
	Tug Boat (3,000 HP)	Diesel Inboard/Sterndrive (3,000 HP)	Assume each work day contains one 10 hr-shift. Assume bulking factor of 5% for mechanical offloading. Assume tug boat transports dredge sediment to an offloading area 5 mi away (one-way).	0.0122	0.0128	0.0557	0.2989	0.0096	0.0004	0.0004	38.7
	100-ton Crane	Diesel Cranes		0.0818	0.0861	0.6496	2.0071	0.0646	0.0627	0.0024	259.7
	Front-end Loader	Diesel Rough Terrain Forklifts		0.0608	0.0640	0.1472	0.7874	0.0260	0.0252	0.0010	104.3
Upland Transportation and Disposal (10 hours/day)											
	Truck (20-ton Dump Truck)	Diesel Off-highway Trucks	Assume dredged sediments trucked from LDW upper reach to intermodal facility in South Seattle or Tukwila. Assume 10 miles each way (20 miles round trip).	0.2505	0.2638	1.9904	6.1496	0.1980	0.1920	0.0073	794.4
	Rail	na	Assume dredged sediments railed from intermodal facility to an off-site landfill disposal facility in Arlington, OR for 300 miles (one-way).	1.1247	1.1843	5.6234	20.6190	0.3749	0.3636	0.0160	1840.2
			SUBTOTAL EMISSIONS - SEDIMENT TRANSLOADING, UPLAND TRANSPORTATION, AND DISPOSAL	**1.53**	**1.61**	**8**	**30**	**0.67**	**0.64**	**0.03**	**3037.3**

Table L-8. Detailed Summary of Direct Emissions by Construction Activity

Construction Activity	Type of Vehicle/Equipment Used	SCC Description	Notes	Tier 2 - Total Emissions (Metric Tonnes) Hydrocarbons (HC)	Volatile Organic Compounds (VOCs)	Carbon Monoxide (CO)	Nitrogen Oxides (NO_X)	Particulate Matter 10 µm (PM_{10})	Particulate Matter 2.5 µm ($PM_{2.5}$)	Sulfur Dioxide (SO_2)	Carbon Dioxide (CO_2)
MATERIAL TRANSPORTATION AND PLACEMENT											
Transportation of Clean Materials to LDW Upper Reach											
	Truck (20-ton Dump Truck)	Diesel Off-highway Trucks	Assume sand, gravelly sand, gravel, and cobble are transported 20 miles from quarry to onshore staging area by truck and 20 miles to LDW upper reach by barge. Includes material placement quantity for Upper Reach and cPAH-only RAA remediation activities.	0.1427	0.1503	1.1341	3.5041	0.1128	0.1094	0.0042	452.7
	Tug Boat (3,000 HP)	Diesel Inboard/Sterndrive (3,000 HP)		0.0277	0.0292	0.1269	0.6813	0.0219	0.0009	0.0008	88.2
	Rail	na	Assume ZVI material is transported 1,700 miles by rail from Chicago, IL vendor the to LDW upper reach (one-way)	0.0031	0.0033	0.0155	0.0567	0.0010	0.0010	0.00004	5.1
Open-water Placement of Sand for Residuals Management Cover and Enhanced Natural Recovery (10 hours/day)											
	150-ton Crane	Diesel Cranes	Assume each work day contains one 10-hr shift.	0.0051	0.0053	0.0403	0.1244	0.0040	0.0039	0.0001	16.1
	Push Boat	Diesel Inboard/Sterndrive (800 HP)		0.0066	0.0069	0.0301	0.1613	0.0052	0.0050	0.0002	20.9
	Work Boat	Two-stroke Outboard (WB)		0.0002	0.0002	0.0009	0.0027	0.0002	0.0002	0.00000	0.3
Open-water Placement of Gravelly Sand for Backfill (10 hours/day)											
	150-ton Crane	Diesel Cranes	Assume each work day contains one 10-hr shift.	0.0178	0.0187	0.1413	0.4366	0.0141	0.0136	0.0005	56.5
	Push Boat	Diesel Inboard/Sterndrive (800 HP)		0.0231	0.0243	0.1055	0.5660	0.0182	0.0177	0.0007	73.2
	Work Boat	Two-stroke Outboard (WB)		0.0006	0.0006	0.0031	0.0096	0.0007	0.0007	0.000011	1.2
Nearshore Placement of Sand for Residuals Management Cover and Enhanced Natural Recovery (10 hours/ day)											
	150-ton Crane	Diesel Cranes	Assume each work day contains one 10-hr shift.	0.0003	0.0003	0.0025	0.0078	0.0003	0.0002	0.000009	1.0
	Push Boat	Diesel Inboard/Sterndrive (800 HP)		0.0004	0.0004	0.0019	0.0102	0.0003	0.0003	0.000012	1.3
	Work Boat	Two-stroke Outboard (WB)		0.00002	0.00002	0.0001	0.0003	0.0000	0.000024	0.0000004	0.0
Nearshore Placement of Gravelly Sand for Backfill and Habitat Layer (10 hours/day)											
	150-ton Crane	Diesel Cranes	Assume each work day contains one 10-hr shift.	0.0080	0.0084	0.0637	0.1969	0.0063	0.0061	0.0002	25.5
	Push Boat	Diesel Inboard/Sterndrive (800 HP)		0.0104	0.0109	0.0476	0.2552	0.0082	0.0080	0.0003	33.0
	Work Boat	Two-stroke Outboard (WB)		0.0003	0.0003	0.0014	0.0043	0.0003	0.0003	0.00000	0.5
Capping (Sand/ZVI for Chemical Isolation Layer) (10 hours/day)			.								
	150-ton Crane	Diesel Excavators	Assume each work day contains one 10-hr shift.	0.0008	0.0008	0.0064	0.0197	0.0006	0.0006	0.00002	2.5
	Push Boat	Diesel Inboard/Sterndrive (800 HP)		0.0010	0.0011	0.0048	0.0255	0.0008	0.0008	0.00003	3.3
	Work Boat	Two-stroke Outboard (WB)		0.00003	0.00003	0.0001	0.0004	0.00003	0.00003	0.0000005	0.1
Capping (Gravelly Sand for Habitat Layer) (10 hours/day)											
	150-ton Crane	Diesel Cranes	Assume each work day contains one 10-hr shift.	0.0006	0.0006	0.0048	0.0148	0.0005	0.0005	0.00002	1.9
	Push Boat	Diesel Inboard/Sterndrive (800 HP)		0.0008	0.0008	0.0036	0.0191	0.0006	0.0006	0.00002	2.5
	Work Boat	Two-stroke Outboard (WB)		0.00002	0.00002	0.0001	0.0003	0.00002	0.00002	0.0000004	0.0
Capping (Cobble/Gravel for Erosion Protection/Filter Layer) (10 hours/day)											
	150-ton Crane	Diesel Cranes	Assume each work day contains one 10-hr shift.	0.0005	0.0005	0.0041	0.0127	0.0004	0.0004	0.00002	1.6
	Push Boat	Diesel Inboard/Sterndrive (800 HP)		0.0007	0.0007	0.0031	0.0164	0.0005	0.0005	0.00002	2.1
	Work Boat	Two-stroke Outboard (WB)		0.00002	0.00002	0.0001	0.0003	0.00002	0.00002	0.0000003	0.0
Restricted Access Placement of Sand for Enhanced Natural Recovery											
	Hydraulic Excavator	Diesel Excavators	Assume each work day contains one 10-hr shift. Includes material placement quantity for Upper Reach site and cPAH-only RAA remediation activities.	0.0007	0.0008	0.0037	0.0190	0.0006	0.0006	0.00002	2.3
	Push Boat	Diesel Inboard/Sterndrive (800 HP)		0.0014	0.0015	0.0065	0.0350	0.0011	0.0011	0.00004	4.5
	Work Boat	Two-stroke Outboard (WB)		0.0000	0.0000	0.0002	0.0006	0.0000	0.0000	0.000001	0.1
Restricted Access Placement of Gravelly Sand for Backfill											
	Hydraulic Excavator	Diesel Excavators	Assume each work day contains one 10-hr shift.	0.00001	0.00001	0.0001	0.0004	0.00001	0.00001	0.0000004	0.0
	Push Boat	Diesel Inboard/Sterndrive (800 HP)		0.00003	0.00003	0.0001	0.0007	0.00002	0.00002	0.000001	0.1
	Work Boat	Two-stroke Outboard (WB)		0.000001	0.000001	0.00000	0.00001	0.000001	0.000001	0.00000001	0.0
Upland Placement of Sand for Residuals Management Cover and Enhanced Natural Recovery											
	Hydraulic Excavator	Diesel Excavators	Assume each work day contains one 10-hr shift.	0.0003	0.0003	0.0016	0.0080	0.0002	0.0002	0.00001	1.0
	Push Boat	Diesel Inboard/Sterndrive (800 HP)		0.0006	0.0006	0.0028	0.0148	0.0005	0.0005	0.00002	1.9
	Work Boat	Two-stroke Outboard (WB)		0.00001	0.00002	0.0001	0.0003	0.00002	0.00002	0.0000003	0.0
Upland Placement of Gravelly Sand for Backfill											
	Hydraulic Excavator	Diesel Excavators	Assume each work day contains one 10-hr shift.	0.0112	0.0118	0.0566	0.2909	0.0089	0.0086	0.0003	35.6
	Push Boat	Diesel Inboard/Sterndrive (800 HP)		0.0218	0.0229	0.0997	0.5350	0.0172	0.0167	0.0006	69.2
	Work Boat	Two-stroke Outboard (WB)		0.0005	0.0006	0.0029	0.0091	0.0006	0.0006	0.00001	1.1
			SUBTOTAL EMISSIONS - MATERIAL TRANSPORTATION AND PLACEMENT	**0.29**	**0.30**	**2**	**7**	**0.23**	**0.20**	**0.01**	**905.6**

Table L-8. Detailed Summary of Direct Emissions by Construction Activity

Construction Activity	Type of Vehicle/Equipment Used	SCC Description	Notes	Tier 2 - Total Emissions (Metric Tonnes) Hydrocarbons (HC)	Volatile Organic Compounds (VOCs)	Carbon Monoxide (CO)	Nitrogen Oxides (NO_X)	Particulate Matter 10 µm (PM_{10})	Particulate Matter 2.5 µm ($PM_{2.5}$)	Sulfur Dioxide (SO_2)	Carbon Dioxide (CO_2)
SURVEYS											
	Work Boat	Two-stroke Outboard (WB)	Assume one survey per day and each work day contains one 10 hr-shift. Assume a total of 249 survey events based on pre-construction (bathy and topo), post- dredge, post- placement, post-construction (bathy and topo), contractor progress surveys for the construction duration, and as-built survey.	0.004	0.00	0.02	0.095	0.0031	0.0030	0.0001	12.3
			SUBTOTAL EMISSIONS - SURVEYS	**0.004**	**0.00**	**0.02**	**0.095**	**0.0031**	**0.0030**	**0.0001**	**12.3**
CONFIRMATIONAL SEDIMENT SAMPLING AND ENVIRONMENTAL MONITORING											
	Work Boat	Two-stroke Outboard (WB)	Assume one water quality monitoring event per dredge day and each work day contains one 10 hr-shift. Assume 191 water quality monitoring events. Assume 24 confirmational sediment sampling events.	0.003	0.004	0.02	0.08	0.003	0.003	0.0001	10.7
			SUBTOTAL EMISSIONS - CONFIRMATIONAL SEDIMENT SAMPLING AND ENVIRONEMENTAL MONITORING	**0.001**	**0.002**	**0.01**	**0.024**	**0.0018**	**0.0017**	**0.000025**	**2.7**
			TOTAL DIRECT AIR EMISSIONS (Metric Tonnes, rounded)	**2.2**	**2.3**	**13.0**	**46.0**	**1.2**	**1.1**	**0.05**	**5,100**

Notes:

1. Total emissions for construction equipment/vehicle are calculated as total daily diesel usage (gal/day) / production rate (units/day) x units x emission factor (g/gal) x (1E-6 metric ton/g).
2. Total emissions for rail transportation are calculated as total diesel usage (gal) x emission factor (g/gal) x (1E-6 metric ton/g).
   2a. Total diesel usage for train (gal) is calculated as total tonnage-distance covered (ton-mi) / train fuel economy (ton-mi/gal).
   2b. Total tonnage-distance covered (ton-mi) is calculated as tonnage transported (metric ton) x one-way distance.
3. Total emissions for truck transportation are calculated as total diesel usage (gal) x emission factor (g/gal) x (1E-6 metric ton/g).
   3a. Total diesel usage for trucks (gal) is calculated as total tonnage-distance covered (ton-mi) / truck fuel economy (ton-mi/gal).
   3b. Total tonnage-distance covered (ton-mi) is calculated as tonnage transported (metric ton) x one-way distance.
4. Total emissions for barge transportation are calculated as total diesel usage (gal) x emission factor (g/gal) x (1E-6 metric ton/g).
   4a. Total diesel usage for boats (gal) is calculated as total tonnage-distance covered (ton-mi) / barge fuel economy (ton-mi/gal).
   4b. Total tonnage-distance covered (ton-mi) is calculated as tonnage transported (metric ton) x one-way distance.

CO: carbon monoxide; $CO_{2:}$ carbon dioxide; cy: cubic yard; gal: gallon; HP: horsepower; na: not applicable; $NO_{X:}$ nitrogen oxides (NO and NO_2); PB: push boat; $PM_{2.5:}$ particulate matter less that 2.5 microns in diameter; $PM_{10:}$ particulate matter less than 10 microns in diameter; SCC: Standard Classification Code; $SO_{2:}$ sulfur dioxide; VOC: volatile organic compounds; WB: work boat; ZVI: Zero Valent Iron

Table L-9. High-Level Summary of Direct Emissions by Construction Activity

Construction Activity	Total Emissions (Metric Tonnes)							
	Hydrocarbons (HC)	Volatile Organic Compounds (VOCs)	Carbon Monoxide (CO)	Nitrous Oxides (NO_X)	Particulate Matter 10 µm (PM_{10})	Particulate Matter 2.5 µm ($PM_{2.5}$)	Sulfur Dioxide (SO_2)	Carbon Dioxide (CO_2)
Site Preparation	0.01	0.01	0.05	0.16	0.01	0.01	0.00	10
Structural Work	0.39	0.41	1.75	5.38	0.24	0.23	0.00	437
Sediment Dredging	0.61	0.64	2.71	8.45	0.38	0.36	0.01	677
Sediment Transloading, Upland Transportation, and Disposal	1.57	1.65	8.61	30.17	0.69	0.67	0.03	3,037
Material Transportation and Placement	0.59	0.63	3.02	9.43	0.38	0.37	0.01	900
Surveys	0.02	0.02	0.06	0.19	0.01	0.01	0.00	12
Confirmational Sediment Sampling and Environmental Monitoring	0.01	0.01	0.05	0.17	0.01	0.01	0.00	11

Table L-10. High-Level Summary of Direct Emissions by Equipment Type

Vehicle or Equipment Type	Total Emissions (Metric Tonnes)							
	Hydrocarbons (HC)	Volatile Organic Compounds (VOCs)	Carbon Monoxide (CO)	Nitrous Oxides (NO_X)	Particulate Matter 10 µm (PM_{10})	Particulate Matter 2.5 µm ($PM_{2.5}$)	Sulfur Dioxide (SO_2)	Carbon Dioxide (CO_2)
Dredging/Material Placement Crane	0.17	0.18	1.32	4.09	0.13	0.13	0.00	529
Transload/Disposal Crane	0.08	0.09	0.65	2.01	0.06	0.06	0.00	260
Hydraulic Excavator	0.03	0.03	0.13	0.69	0.02	0.02	0.00	84
Front-end Loader	0.06	0.06	0.15	0.79	0.03	0.03	0.00	104
Vessels (Tug Boat, Push Boat, and Work Boat)	1.34	1.41	5.25	16.10	0.78	0.76	0.01	1018
Rail Transportation	1.13	1.19	5.64	20.68	0.38	0.36	0.02	1845
Truck Transportation	0.39	0.41	3.12	9.65	0.31	0.30	0.01	1247

Notes:

1. See Table L-1 for baseline conditions and equipment assumptions for direct air emissions inventory.

HC: hydrocarbon; CO: carbon monoxide; CO_2: carbon dioxide; HP: horsepower; NO_X: nitrogen oxides (NO and NO_2); PM2.5: particulate matter less that 2.5 microns in diameter; PM_{10}: particulate matter less than 10 microns in diameter; SO_2: sulfur dioxide; VOC: volatile organic compounds

Table L-11. Material Use and Waste Generation Summary

Material Use and Waste Generation	Activity Type	Activity	Quantity
Raw Materials	**Material Placement[1]**	Clean Raw Materials (sand, gravelly sand, gravel, cobble) Volume (cy)	67,800
	Structural Work	Replaced Number of Timber Piles	96
		Replaced Number of Steel Piles	2
		Replaced Steel Bulkhead Area (sf)	650
Waste Generated	**Sediment Dredging**	Disposed Dredge Contaminated Sediment Volume (cy)	117,700
	Debris Removal	Debris Removed (ton)	650
	Structural Work	Removed Number of Timber Piles	91
		Removed Number of Steel Piles	2
		Removed Stub Piles (Bulkhead)	88

Notes:

1. Includes all material placement quantities required for the Upper Reach and cPAH-Only RAA remediation activities.

2. Volumes are rounded to the nearest hundred.

cy: cubic yard

sf: square foot

Table L-12. Diesel Energy Consumption Summary

Activity	Task	Quantity of Material (cy)	Number of Work Days	Total Daily Diesel Usage (gal/day)	Volume of Diesel Consumed (gal)
Structural Work	Timber and Steel Pile Removal and Replacement	--	7	312	2,182
	Timber Bulkhead Removal/Replacement, Temporary Float Dismantle/Relocation/ Reinstallation, Outfall Work, and Debris Removal	--	68	312	21,196
Sediment Removal	Open-Water Dredging	70,058	59	312	18,390
	Nearshore Dredging	16,821	25	312	7,793
	Restricted Access Dredging	1,442	3	340	1,019
	Contingency Re-Dredging	10,233	12	312	3,740
	Shoreline/Bank Excavation	19,200	25	340	8,493
Sediment Offloading, Transloading, Upland Transportation, and Disposal	Mechanical Offloading	124,325	104	560	58,240
	Upland Transportation and Disposal	124,325	--	-	149,044
Material Transportation and Placement	Transportation of Clean Raw Materials (sand, gravelly sand, gravel, cobble) to LDW Upper Reach	68,075	--	--	19,171
	Open-water Placement	34,754	29	312	9,039
	Nearshore Material Placement	10,568	11	315	3,462
	Capping	2,058	3	312	935
	Restricted Access Placement	994	5	340	1,699
	Upland Material Placement	19,702	22	340	7,473
Other Construction Activities	Surveys	--	249	3	747
	Confirmational Sediment Sampling and Environmental Monitoring	--	215	3	645
			Total Diesel Consumed (gal)		**313,268**

Notes:

1. The volume of diesel consumed for upland transportation and disposal and transporatation of clean raw materials is based on the quantity of material, distance travelled, and the fuel economy by the equipment used.

cy: cubic yard

gal/day: gallon/day

gal: gallon

Figures

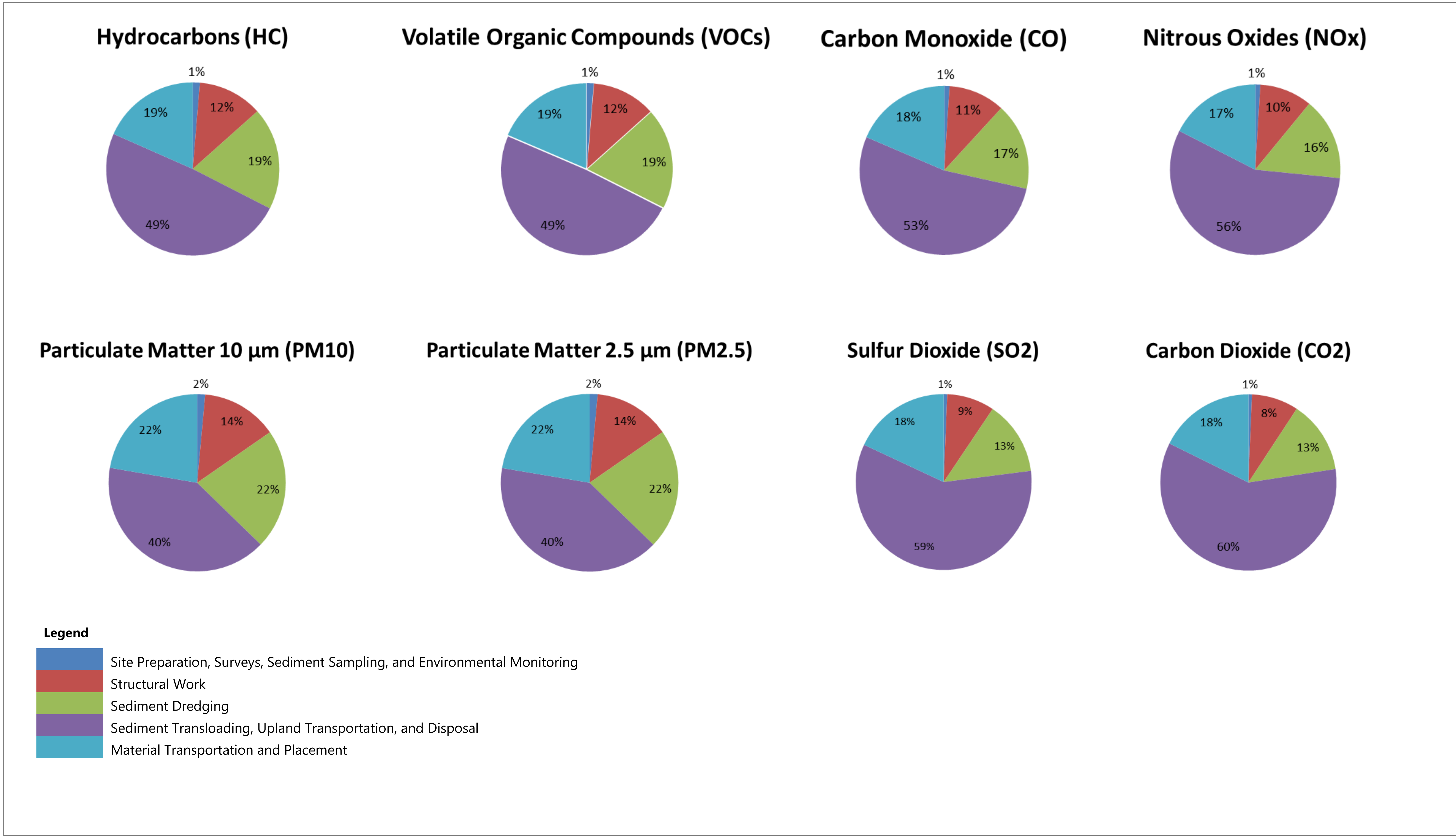

Figure L-1
High-Level Summary of Direct Emissions by Construction Activity

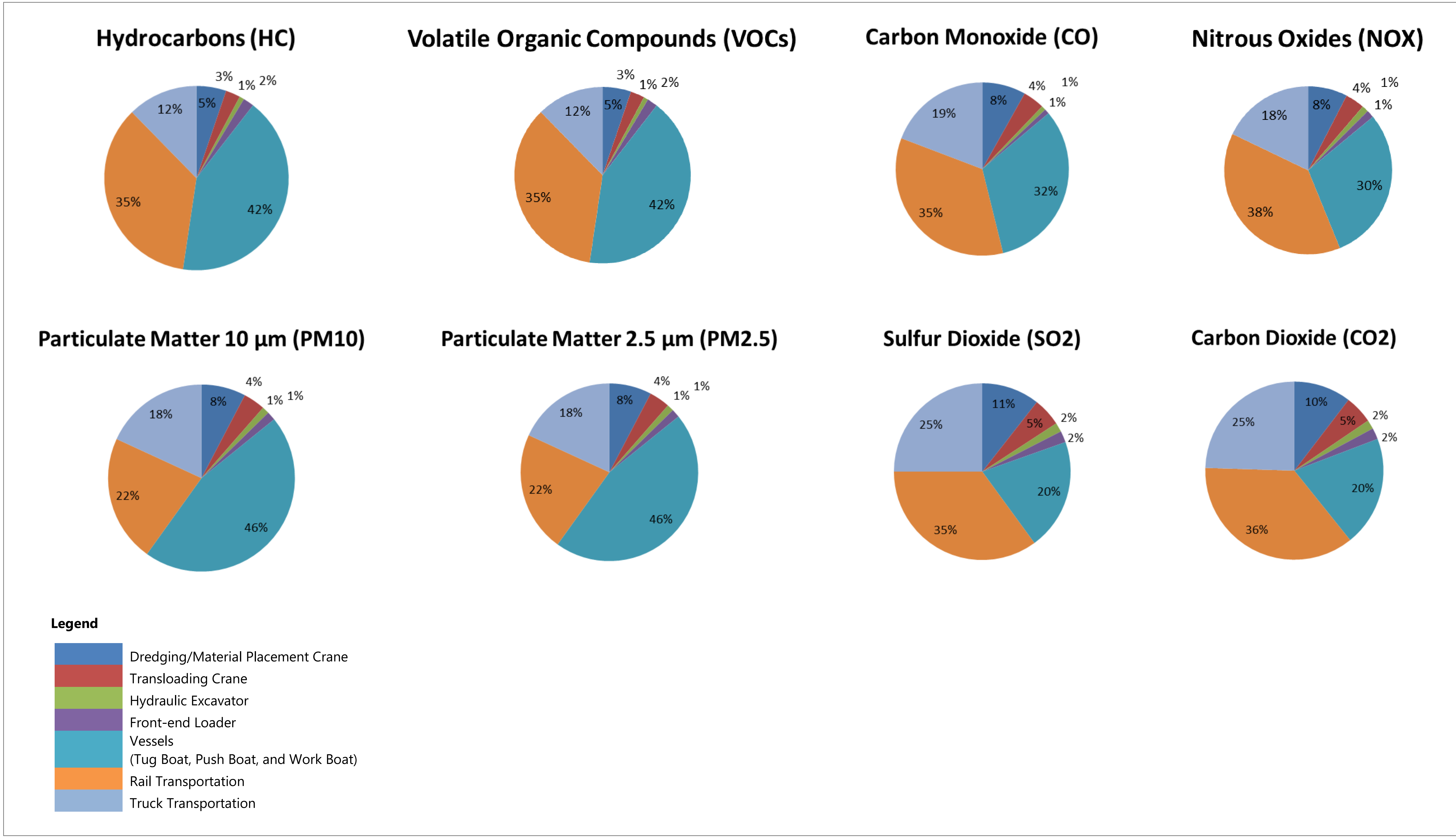

Figure L-2
High-Level Summary of Direct Emissions by Equipment Type